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UNITED STATES OF AMERICA
BEFORE THE NUCLEAR REGULATORY COMMISSION

In the Matter of	)	
Proposed Rule: Waste Confidence – Continued Storage of Spent Nuclear Fuel 10 C.F.R. Part 51	)	Docket No. 2012-0246
Draft Waste Confidence Generic Environmental Impact Statement	)	

DECLARATION OF DR. ARJUN MAKHIJANI
REGARDING THE WASTE CONFIDENCE PROPOSED RULE
AND DRAFT GENERIC ENVIRONMENTAL IMPACT STATEMENT

Under penalty of perjury, I, Dr. Arjun Makhijani, declare as follows:

1.0 STATEMENT OF QUALIFICATIONS

1.1. I am President of the Institute for Energy and Environmental Research (IEER), an independent non-profit organization located in Takoma Park, Maryland. Under my direction, IEER produces technical studies on a wide range of energy and environmental issues to provide advocacy groups and policymakers with sound scientific information and analyses as applied to environmental and health protection and for the purpose of promoting the understanding and the democratization of science. IEER has been doing nuclear-related studies for about 26 years.

1.2. As demonstrated in my attached curriculum vitae (CV), and as summarized below, I am qualified by training and extensive professional experience to render my professional opinion regarding technical, economic, and public health issues related to radioactive waste management and disposal.

1.3. I have a Ph.D. (Engineering), granted by the Department of Electrical Engineering and Computer Sciences of the University of California, Berkeley, where I specialized in the application of plasma physics to controlled nuclear fusion. I also have a master's degree in electrical engineering from Washington State University and a bachelor's degree in electrical engineering from the University of Bombay.

1.4. In addition, over a period of more than 25 years, I have developed extensive experience in evaluating nuclear fuel cycle-related issues, including proposed classification and strategies for radioactive waste storage and disposal, accountability with respect to measurement of radioactive effluents from nuclear facilities, health and environmental effects of nuclear testing and nuclear facility operation, strategies for disposition of fissile materials, energy efficiency, and comparative costs of energy sources including nuclear power. I have authored or co-authored many publications on these subjects. I have testified before Congress on several occasions regarding issues related to nuclear waste, reprocessing, environmental releases of radioactivity, and regulation of nuclear weapons plants.

1.5. An extensive part of my work has been to analyze various issues related to radioactive waste management, classification, and disposal. This work includes studies on low-level waste characteristics, high-level waste characteristics, methods of spent fuel disposal, characteristics of geologic repositories, and research related to geologic repositories. I have studied radioactive waste in both the commercial and military sectors. On two occasions, I was the director of teams that analyzed ANDRA's research plans for a geological repository for high level radioactive waste in France on behalf of a French government-sponsored stakeholder committee (2004, 2011). I am the principal author of a book on nuclear waste, *High-Level Dollars Low-Level Sense: A Critique of Present Policy for the Management of Long-Lived Radioactive Waste and Discussion of An Alternative Approach* (Apex Press 1992). This book included an analysis of U.S. waste classification regulations. I am the principal author of an assessment of the costs of managing and disposing of depleted uranium from the National Enrichment Facility (2004 and 2005).

1.6. I also have served on a number of oversight and advisory committees and boards with respect to my areas of expertise. Between 1997 and 2002, I was on the expert team monitoring independent audits of the Los Alamos National Laboratory's compliance with the radiation release portion of the Clean Air Act (40 CFR 61 Subpart H). The monitoring program was conducted under a Consent Decree that resulted from a federal court finding that Los Alamos was out of compliance with Subpart H. In that capacity, I reviewed extensive records, models, facilities, procedures, measurements, and other aspects of the Los Alamos National Laboratory air emissions control and measurement program in order to determine whether the audits were being properly conducted and whether they were thoroughly done. I also served as a member of the Radiation Advisory Committee of the U.S. Environmental Protection Agency's (EPA's) Science Advisory Board from 1992 to 1994 and the EPA's Advisory Subcommittee on cleanup standards of the National Advisory Committee on Environmental Policy and Technology during part of the 1990s. In addition, I have served as an expert consultant to numerous organizations regarding technical, economic, and public health issues related to radioactive waste management. I have also been a consultant on energy issues to several U.N. agencies, the Tennessee Valley Authority, the Lower Colorado River Authority, the Lawrence Berkeley Laboratory, Edison Electric Institute, and the Congressional Office of Technology Assessment. I was elected a Fellow of the American Physical Society (APS) in 2007, an honor granted to at most one-half of one percent of APS members.

1.7. I have written or co-authored a number of books and other publications analyzing the safety, economics, and efficiency of various energy sources, including nuclear power and sustainable energy sources such as wind and solar energy. I was the principal author of the first evaluation of energy end-uses and energy efficiency potential in the U.S. economy (published by the Electronics Research Laboratory, University of California at Berkeley in 1971). I was also the principal author of the first overview study of the relationship between energy and agriculture, *Energy and Agriculture in the Third World* (Ballinger 1975). This study included consideration of both traditional and modern energy sources. I was one of the principal technical staff persons of the Ford Foundation Energy Policy Project and a co-author of its final report, *A Time to Choose*, which helped shape U.S. energy policy during the mid-to-late 1970s. I am a co-author of *Investment Planning in the Energy Sector*, which is an economic model published by the Lawrence Berkeley Laboratory in 1976. I am also the principal author of *Nuclear Power Deception* (Apex Books 1999), an analysis of nuclear power policy, safety, and the promises of energy "too cheap to meter" in the United States. On behalf of the SEED Coalition, I assessed the capital costs of proposed nuclear power reactors in South Texas (2008). In addition, I am the author of *Carbon-Free and Nuclear-Free* (RDR Books and IEER Press 2007, reprinted in 2008 and 2010). To the best of my knowledge, *Carbon-Free and Nuclear-Free* is the first detailed analysis of a transition to a U.S. economy based completely on renewable energy, without any use of fossil fuels or nuclear power.

1.8. I have also done extensive work with respect to the health and environmental effects of nuclear weapons production. I am the principal author of the first independent assessment of radioactivity emissions from a nuclear weapons plant (1989) and co-author of the first audit of the cost of the U.S. nuclear weapons program (*Atomic Audit* 1998). I am also the principal editor and a co-author of the first global assessment of the health and environmental effects of nuclear weapons production (*Nuclear Wastelands* 1995 and 2000), which was nominated for a Pulitzer Prize by MIT Press.

1.9. I am co-author (with Yves Marignac) of an analysis of the post-Fukushima complementary safety assessments (including waste management and storage) prepared by the French nuclear power plant and reprocessing plant operators. The report in French is entitled *Sûreté nucléaire en France post-Fukushima: Analyse critique des Évaluations complémentaires de sûreté (ECS) menées sur les installations nucléaires françaises après Fukushima* (Post-Fukushima Nuclear Safety in France: Analysis of the Complementary Safety Assessments (CSAs)). A summary is available in English.

2.0 PURPOSE OF DECLARATION AND SUMMARY OF EXPERT OPINION

2.1. The purpose of this declaration is to provide the Nuclear Regulatory Commission (NRC) with my expert opinion regarding the environmental analysis supporting the NRC's proposed Waste Confidence rule as well as the proposed rule itself.[1] This environmental analysis is presented in the NRC's Draft Waste Confidence Generic Environmental Impact Statement[2] (Draft GEIS). In conducting my review of these documents, I focused on the NRC's discussion of environmental impacts of long-term spent fuel storage and spent fuel disposal.

[1] 78 Fed. Reg., pp. 56621-56622 (Sept. 13, 2013), NRC 2013a, NRC 2013b
[2] NRC 2013a

2.2. In addition to reviewing the proposed rule and the Draft GEIS, I have also reviewed a number of other relevant documents. These documents include the relevant reference documents cited in the Draft GEIS and the NRC's final license renewal rule.[3] I have also reviewed the proposed and final versions of the 2010 Waste Confidence Decision Update[4] and prepared comments on the earlier proposed version.[5] In addition, I am familiar with the proposed and final versions of the 2010 Temporary Storage Rule,[6] and I reviewed and commented on the NRC's 2013 scoping proposal for the Draft GEIS.[7] Further, I am familiar with the NRC's uranium fuel cycle rule and relevant associated reference documents. And I am familiar with the NRC's now-suspended Long-Term Waste Confidence Project and related documents.[8] Finally, I am familiar with relevant aspects of governing law and guidance, including the National Environmental Policy Act (NEPA) and relevant NRC implementing regulations. My comments on the scope of the Draft GEIS are incorporated here by reference.[9]

2.3. In the Draft GEIS, NRC seeks to support three findings that are presented in proposed 10 CFR 51.23(a)(2) and Table B-1: (a) that it is feasible to store spent fuel safely and without significant adverse environmental impacts for an indefinite period, (b) that it is feasible to have a mined geologic repository within 60 years following the life of a licensed reactor, and (c) that spent fuel disposal will not have impacts on the environment that are significant enough to foreclose extended operation for any nuclear power plant.[10] In my professional opinion, the Draft GEIS is extremely inadequate to support these proposed findings. Significant evidence exists to show that the environmental impacts of long-term or indefinite storage of spent fuel will likely be significant and could cause significant risks to human health. In the case of indefinite storage, they are likely to be catastrophic; among other things it is likely that institutional control will be lost. For purposes of this declaration, I use the same definitions of "long-term" and "indefinite" as those used in the Draft GEIS.[11]

2.4. The NRC's first proposed findings are that spent fuel can be safely stored for an indefinite time period (10 CFR 51.23(a)(2)) and that it can be stored indefinitely without significant adverse environmental impacts (Table B-1).[12] These findings have scant technical support; the available analysis generally points in the opposite direction. The Draft GEIS fails to provide a detailed quantitative analysis of the impacts to public health and the environment that would occur in the event of an accidental release of radiation during spent fuel storage or transfer. Given the high level of radioactivity in spent fuel, the high burnup of much of the spent fuel, and the very long half-lives of certain radioactive materials (including plutonium-239 and long-lived

[3] 78 Fed. Reg., p. 37282 (June 20, 2013)
[4] NRC 2008a and NRC 2010a
[5] Makhijani 2009
[6] NRC 2008b and NRC 2010b
[7] NRC 2012c and Makhijani 2013
[8] *See, e.g.,* NRC 2010a, p. 81040 and Borchardt 2012
[9] Makhijani 2013
[10] NRC 2013b, p. 56804-56805
[11] NRC 2013a, p. 1-12
[12] NRC 2013b, p. 56804-56805

fission products with half-lives that range from 30 years to millions of years), these impacts could be substantial.

2.5. In addition, the Draft GEIS contains almost no information about spent fuel characteristics that could cause adverse safety risks and environmental impacts during long-term or indefinite storage. That is perhaps due to the fact that, in other contexts, the NRC itself has acknowledged that it currently lacks sufficient information to reach informed conclusions about the behavior of spent fuel in storage over the long term. Little-understood factors affecting the safety of spent fuel storage include the degree to which spent fuel and its host containers corrode and degrade over a prolonged period of time, the phenomenon of "failed fuel," and the effect of high burnup fuel on the integrity of cladding and storage containers. For instance, although high burnup fuel now makes up a significant portion of spent fuel inventories, there is no explicit consideration of long-term dry storage and disposal of failed high-burnup fuel. The cladding of such fuel degrades much more during reactor operation than low burnup fuel; continued degradation appears likely during prolonged storage. The NRC currently has little or no empirical data regarding its behavior under extended dry storage conditions. The NRC itself identified the data gaps in a Draft Study of Technical Needs in 2012[13] but failed to note these gaps in the Draft GEIS. The NRC's amnesia regarding its own study undermines the credibility and integrity of the Draft GEIS. The Draft GEIS contains no analysis of how high burnup spent fuel characteristics may contribute to the risk of an accidental release of radioactivity from spent fuel that has been stored for a long period in dry casks, preceded by prolonged (60 to 120 years) of storage in spent fuel pools; or how degradation may contribute to accidental releases and radiation exposure risks during the many transfers that would take place in case of long-term or indefinite storage. The NRC should factor in its own prior acknowledgement of the potential for degradation of high burnup spent fuel and the low state of knowledge of a number of critical factors prior to declaring its confidence in the safety of long-term or indefinite spent fuel storage.[14]

2.6. My second major criticism of these first findings is that they depend on the unsupported assumption that institutional controls will remain effective indefinitely. Instead of addressing the risk of accidental radioactivity releases posed by the poorly understood behavior of spent fuel in long-term storage, the NRC simply assumes that current regulations and institutional measures for managing spent fuel will remain in place indefinitely, and that any new problems that arise will be resolved, such that spent fuel storage will never pose a significant health or environmental problem. In my opinion, this assumption of active institutional control for an indefinite period of time lacks any factual, historical, or financial foundation and even common sense when it extends to very long time periods. First, it is fundamentally inconsistent with

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[13] NRC 2012a

[14] The Draft GEIS makes just one explicit substantive statement about degradation of high burnup fuel and that related to the "short-term" time frame: "This [reduced ductility] phenomenon could influence the approach used for repackaging spent fuel but the NRC is not aware of information that would require it to conclude that high-burnup fuel would need to be repackaged during the short-term timeframe defined in the draft GEIS. Should spent fuel cladding be more brittle, greater care could be required during handling operations, regardless of when repackaging would occur, to limit the potential for damage to spent fuel assemblies that could affect easy retrievability of the spent fuel and complicate repackaging operations." (NRC 2013a, p. B-13)

federal law and policy (including NRC's own regulations) that institutional controls should only be relied on for a period of decades, not hundreds of years. Second, it is contradicted by the experience of history that governments tend to fail or change substantially over time. To assume that the federal government will exist for tens of millennia and each year appropriate significant sums of money to manage spent fuel at sites that produce no revenue flies in the face of current facts and U.S. history, including a dozen federal government shut downs since 1980, not to speak of the Civil War, when the United States did not have a single government, budget, or currency. In this century, the White House had received a number of petitions, some with thousands of signatures, for secession from the United States as of November 12, 2012.[15]

2.7. Finally, even under the assumption of institutional controls for an indefinite period, the Draft GEIS fails to address the expense of those measures, the risk that they may fail, and how such costs and risks may impact reactor licensing and license extension decisions.

2.8. The question of feasibility of spent fuel disposal cannot be evaluated without considering the probability that a repository will safely contain radioactivity for the hundreds of thousands of years required. And, in order to evaluate that probability, it is necessary to evaluate the environmental impacts of disposing of spent fuel in a range of geologic media. NRC cannot simply presume that a repository is feasible. Disposal impacts are relevant because they are part of the waste confidence finding that a mined geologic repository is feasible. By definition of such feasibility, such a repository must meet reasonable health and safety standards. Moreover, we note that Table S-3 at 10 CFR 51.51 is invalid for estimating high-level waste disposal impacts. Among other things, its underlying assumption of disposal in a bedded salt repository for spent fuel disposal was repudiated by the NRC itself in 2008.[16] Therefore, the NRC must prepare a new disposal impact analysis in the context of its waste confidence decision. Further, *sufficient capacity* at one or more such sites meeting safety criteria must be available to accommodate spent fuel from any and all commercial light water reactors that may be built. The Draft GEIS sets no upper limit on the amount of spent fuel to be disposed of. By failing to evaluate spent fuel disposal impacts, the NRC has excluded a major part of the picture regarding the feasibility of spent fuel disposal. The concept of feasibility also includes cost. What will it cost to isolate spent fuel for many thousands of years? Is the cost affordable when compared with the profit that a nuclear reactor will yield? These questions must be evaluated in order to assess the feasibility of spent fuel disposal. As part of this analysis, the NRC should also evaluate the probability that sufficient repository capacity will be available in a timely manner so as to avoid excessive storage risks and costs. Of course, by doing so it would also be calculating the probability that sufficient repository capacity will *not* be available. In the proposed rule, the NRC fails to even address the question of repository capacity. And it only refers to "a" mined geologic repository, as if one were enough. This is a significant deficiency. As we will show, persuasive arguments can be made that two repositories may be needed if there is a resurgence of nuclear power. Appeals to repository programs in Sweden and Finland do not resolve this issue – their nuclear power programs are very small compared to the United States and therefore involve a small amount of spent fuel.

[15] Weiner 2012
[16] NRC 2008a, p. 59555

2.9. Further, the NRC has no valid environmental analysis on which it can rely for an evaluation of spent fuel disposal impacts. Table B-1 depends on the EPA standard for Yucca Mountain.[17] The proposed rule simply asserts that because the Yucca Mountain rule limits radiation doses in principle, "that the impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR part 54 should be eliminated."[18] This is like saying that the existence of a law against drunken driving allows society to conclude that the impacts of drunken driving would in fact not be large enough to worry about. In addition, the licensing proceeding for Yucca Mountain is far from complete (if it is ever completed); so it is not clear that Yucca Mountain would meet the required performance specified in 40 CFR 197.

2.10. In view of the above, it is my conclusion that the NRC lacks a factual and scientific basis for a finding of confidence that spent fuel can be safely stored for the long-term, much less indefinitely. The NRC also lacks a factual and scientific basis for a finding of confidence that spent fuel can be disposed of safely within acceptable, legally binding health and safety standards. In fact, the available evidence suggests that both long-term storage and disposal of spent fuel could pose significant safety and environmental risks. Further, the costs of long-term storage and disposal could run into hundreds of billions of dollars. The NRC should prepare a new Draft GEIS that meaningfully examines these risks.

2.11. My declaration is organized as follows:

- In Section 3, I will provide background information regarding past environmental studies and regulations and the Draft GEIS.
- In Section 4, I will discuss the basis for my expert opinion that the NRC's proposed finding that spent fuel can be stored for a long-term or indefinite period safely and without significant environmental impacts is not supported by adequate data or analysis.
- In Section 5, I will address criticality risks and high burnup fuel.
- In Section 6, I will address the unreasonableness of the NRC's critical assumption of perpetual institutional control and continued funding of spent fuel storage and management for millennia, tens of millennia, or longer.
- In Section 7, I will address the potential consequences of indefinite storage that have been ignored or treated very inadequately in the Draft GEIS, notably in case of a loss of institutional control.
- In Section 8, I will discuss the basis for my expert opinion that the NRC's proposed findings regarding the feasibility and safety of spent fuel disposal are unsupported.
- In Section 9, I will discuss site-specific issues that are not amenable to resolution in a generic manner.
- Section 10 contains a summary of the main points of my declaration.
- Section 11 provides a list of references. Electronic copies of these documents are also being provided.

[17] The Yucca Mountain standard at 40 CFR 197.
[18] NRC 2013b

3.0 PROPOSED RULE AND ASSOCIATED DRAFT GEIS

A. Proposed Rule

3.1. Proposed Section 51.23(a)(2) makes the following predictions:

> i. It is "feasible to safely store spent nuclear fuel following the licensed life for operation of a reactor" and
> ii. It is "feasible to have a mined geologic repository within 60 years following the licensed life for operation of a reactor."[19]

And it states that these conclusions are consequent upon preparation of the Draft GEIS.[20] No time limit is placed on the feasibility of storage safety in paragraph i above.

3.2. The proposed finding regarding the feasibility of having a mined repository in 60 years does not include a finding that the capacity of the repository will be sufficient. This is a change from the 2010 Waste Confidence Decision, which included a finding that "sufficient mined geologic repository capacity will be available . . . when necessary."[21] It appears the NRC thinks the sufficiency of repository capacity is no longer an issue, because spent fuel can be stored safely for an indefinite period:

> Based on the preceding discussion, the NRC believes that for the storage timeframes considered in the draft GEIS, regulatory oversight will continue in a manner consistent with NRC's regulatory actions and oversight in place today to provide for continued storage of spent fuel in a safe manner until sufficient repository capacity is available for the safe disposal of all spent fuel.[22]

3.3. Proposed Table B-1 categorizes spent fuel storage impacts as "SMALL."[23] It also makes the following finding regarding the safety and environmental impacts of spent fuel storage:

> The expected increase in the volume of spent fuel from an additional 20 years of operation can be safely accommodated onsite with small environmental effects through dry or pool storage at all plants, if a permanent repository or monitored retrievable storage is not available.[24]

3.4. With respect to impacts of disposing of spent reactor fuel, proposed Table B-1 states:

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[19] NRC 2013b, p. 56804
[20] NRC 2013b, p. 56804
[21] NRC 2010a, p. 81067
[22] NRC 2013a, p. B-20
[23] NRC 2013b, p. 56805
[24] NRC 2013b, p. 56805

> For the high-level waste and spent-fuel disposal component of the fuel cycle, the EPA established a dose limit of 15 millirem (0.15 mSv) per year for the first 10,000 years and 100 millirem (1.0 mSv) per year between 10,000 years and 1 million years for offsite releases of radionuclides at the proposed repository at Yucca Mountain, Nevada.
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> The Commission concludes that the impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR Part 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the impacts of spent fuel and high level waste disposal, this issue is considered Category 1.[25]

3.5. Proposed Table B-1 is inconsistent with another regulation that also makes a finding on the same subject: Table S-3 in 10 CFR 51.51.[26] Table S-3 summarizes the NRC's conclusion that the impacts of spent fuel disposal will be zero, based on the assumption that spent fuel will be disposed of in a bedded salt repository. Proposed Table B-1 contradicts Table S-3 by concluding that long-term doses could be as high as 100 millirem per year. But the NRC does not attempt to reconcile proposed Table B-1 and Table S-3; nor does it address the fact that in the 2008 Draft Waste Confidence Update, it repudiated bedded salt as a geologic medium for a repository.[27] Nothing in the NRC's response to public comments on this point negated this repudiation of the unsuitability of bedded salt for spent fuel disposal.[28]

B. Waste Confidence Draft GEIS

3.6. The Draft GEIS considers three different time periods for spent fuel storage: short-term (60 years), long-term (160 years), and indefinite storage. As described in the Draft GEIS:

> The first, most likely, timeframe is the short-term timeframe, which analyzes 60 years of continued storage after the end of a reactor's licensed life for operation. The NRC acknowledges, however, that the short-term timeframe, although the most likely, is not certain. Accordingly, the draft GEIS also analyzed two additional timeframes. The long-term timeframe considers the environmental impacts of continued storage for a total of 160 years after the end of a reactor's licensed life for operation. Finally, although the NRC considers it highly unlikely, the draft GEIS includes an analysis of an indefinite timeframe, which assumes that a repository does not become available.[29]

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[25] NRC 2013b, p. 56805

[26] The Draft GEIS acknowledges that "[t]he environmental impacts of portions of the uranium fuel cycle that occur before new fuel is delivered to the plant and after spent fuel is sent to a disposal site have been evaluated and are codified" in 10 CFR 51.51 and Table S-3. (NRC 2013a, p. 1-22)

[27] NRC 2008a, p. 59555

[28] NRC 2010a, pp. 81043 and 81044

[29] NRC 2013a, p. xxvii

3.7. The Draft GEIS addresses spent fuel storage impacts in Appendix B. Issues regarding spent fuel storage integrity are divided into pool storage (Section B.3.1.1) and dry storage (Section B.3.2.1). With respect to the integrity of spent fuel stored in pools, the NRC cites several studies done between 1977 and 2006 for the conclusion that "[d]egradation of the spent fuel [stored in pools] should be minimal over the short-term storage timeframe."[30] The Draft GEIS also states that: "the NRC is not aware of any information that would call into question the technical feasibility of continued safe storage of spent fuel in spent fuel pools beyond the short-term storage timeframe."[31]

3.8. With respect to the integrity of fuel in dry storage, the Draft GEIS asserts that "spent fuel has been safely stored in dry casks for more than 25 years."[32] The Draft GEIS cites four "[r]ecent studies" that "have confirmed dry cask storage reliability:" Bare et al. 2001, Einziger et al. 2003, IAEA 2006, and EPRI 1998."[33] The Draft GEIS also states:

> Although the current record for dry cask storage supports the technical feasibility of continued safe storage, the NRC constantly works to investigate and monitor the behavior of spent fuel storage systems to identify any unexpected and deleterious safety conditions before there are adverse impacts.[34]

The 2013 NRC guidance on the state of knowledge of high burnup fuel (HBF) states the following:

> The experimental confirmatory basis that low burnup fuel (≤45 GWd/MTU) will maintain its integrity in dry cask storage over extended time periods was provided in NUREG/CR-6745 (Ref. 1), "Dry Cask Storage Characterization Project—Phase 1; CASTOR V/21 Cask Opening and Examination" and NUREG/CR-6831 (Ref. 2), "Examination of Spent PWR Fuel Rods after Years in Dry Storage."
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> A confirmatory basis, which includes information over a similar length of the time available for low burnup fuel, does not exists for HBF (>45 GWd/MTU). Certification and licensing HBF for storage was permitted for an initial 20-year-term using the guidance contained in ISG-11, Rev. 3, (Ref. 3) which was based on short term laboratory tests and analysis that may not be applicable to the storage of HBF beyond 20 years, particularly with the current state of knowledge regarding HBF cladding properties. (Ref. 4)[35]

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[30] NRC 2013a, p. B-9
[31] NRC 2013a, p. B-9
[32] NRC 2013a, p. B-12
[33] NRC 2013a, p. B-12
[34] NRC 2013a, pp. B-12 – B-13 (citing Interim Staff Guidance-24, *Use of a Demonstration Program as Confirmation of Integrity for Continued Storage of High Burnup Fuel Beyond 20 Years,* Accession No. ML13056A516)
[35] NRC Interim Staff Guidance 24 (2013), p. 1

3.9. But, the NRC acknowledges in the Draft GEIS that it is "aware of concerns regarding potential detrimental effects of hydride reorientation on cladding behavior (e.g., reduced ductility)."[36] As described in the Draft GEIS:

> Reduced ductility, which makes the cladding more brittle, increases the difficulty of keeping spent fuel assemblies intact during handling and transportation. Research performed in Japan and the United States (Billone et al. 2013) indicated that: (1) hydrides could reorient at a significantly lower stress than previously believed and (2) high-burnup fuel could exhibit a higher ductile-to-brittle transition temperature due to the presence of radial hydrides. This phenomenon could influence the approach used for repackaging spent fuel but the NRC is not aware of information that would require it to conclude that high-burnup fuel would need to be repackaged during the short-term timeframe defined in the draft GEIS. Should spent fuel cladding be more brittle, greater care could be required during handling operations, regardless of when repackaging would occur, to limit the potential for damage to spent fuel assemblies that could affect easy retrievability of the spent fuel and complicate repackaging operations.[37]

3.10. With respect to dry storage of spent fuel during the "short term," *i.e.,* 60 years, the Draft GEIS concludes that:

> Based on available information and operational experience, degradation of the spent fuel should be minimal over the short-term storage timeframe if conditions inside the canister are appropriately maintained (e.g., consistent with the technical specifications for storage). Thus, it is expected that only routine maintenance will be needed over the short-term storage timeframe.[38]

3.11. With respect to long-term (160 years) and indefinite dry storage of spent fuel, the Draft GEIS concludes:

> Repackaging of spent fuel may be needed if storage continues beyond the short-term storage timeframe. In the draft GEIS, the NRC conservatively assumes that the dry casks would need to be replaced if storage continues beyond the short-term storage timeframe. The NRC assumes replacement of dry casks after 100 years of service life, even though studies and experience to date do not preclude a longer service life.[39]

In addition, the NRC asserts that it "continues to evaluate aging management programs and to monitor dry cask storage so that it can update its service life assumptions as necessary and consider any circumstances that might require repackaging spent fuel earlier than anticipated."[40]

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[36] NRC 2013a, p. B-13
[37] NRC 2013a, p. B-13
[38] NRC 2013a, p. B-13
[39] NRC 2013a, p. B-13
[40] NRC 2013a, p. B-13

3.12. The Draft GEIS asserts that "[a]ccidents associated with repackaging spent fuel are evaluated in Section 4.18 and the environmental impacts are SMALL because the accident consequences would not exceed the NRC accident dose standard contained in 10 CFR 72.106."[41] However, the discussions of accidents in Section 4.18.1.2 (regarding design-basis dry storage accidents) and Section 4.18.2.2 (regarding severe dry storage accidents) do not indicate whether NRC considered the contribution to accident risk by spent fuel deterioration during long-term and indefinite storage. Further, the purpose of the study cited was "solely" to show the method of the calculation as it should be applied to specific situations. "Thus, no inferences or conclusions should be drawn with regard to the study's regulatory implications."[42] Yet the Draft GEIS has applied its results to a generic regulatory situation.

3.13. The Draft GEIS does not address the environmental impacts of spent fuel disposal. Instead, it states that: "The environmental impacts addressed in this draft GEIS are limited to the environmental impacts of continued storage."[43] As clarified in the Scoping Process Summary Report:

> Spent nuclear fuel disposal is outside the scope of the Waste Confidence analysis, which will consider the environmental impacts of continued storage prior to ultimate disposal. The development of a national repository, the licensing of Yucca Mountain or another repository site, environmental impacts associated with disposal in a repository, funding issues, recycling, and other waste disposal strategies are outside the scope of this GEIS.[44]

4.0 THE NRC'S PROPOSED FINDING THAT SPENT FUEL CAN BE STORED FOR A LONG-TERM OR INDEFINITE PERIOD SAFELY AND WITHOUT SIGNIFICANT ENVIRONMENTAL IMPACTS IS NOT SUPPORTED BY ADEQUATE DATA OR ANALYSIS.

4.1. The NRC's first proposed findings are that spent fuel can be safely stored for an indefinite time period (10 CFR 51.23(a)(2)(i)) without significant adverse environmental impacts (Table B-1). These findings are almost devoid of valid technical support so far as long-term and indefinite storage is concerned.

A. Environmental Impacts of Storage

4.2. The Draft GEIS should comprehensively analyze all aspects of accidents involving dry cask storage and inter-cask fuel transfers based on sound scientific information. When the information is incomplete or has significant uncertainties, these should be stated. If there are methodological studies that provide a guide to how calculations should be done, the guidance should be used to

41 NRC 2013a, p. B-13
42 NRC Pilot 2007, p. v
43 NRC 2013a, p. 1-4
44 NRC Scoping 2013, p. 42

develop estimates. In some cases, the data gaps are so large, that a realistic calculation of uncertainties can be operationally meaningless in the sense of its usefulness for choosing among alternative courses of action. The Draft GEIS should have assessed data gaps in this manner. Instead of such a procedure, the Draft GEIS has improperly used a pilot study (hereafter Pilot Study) intended to demonstrate a method to declare that public health impacts due to an accident during spent fuel storage transfer would be SMALL[45] for the purpose of the waste confidence regulation, when the study explicitly states that it should not be used for regulatory purposes:

> The methodology developed in this study can be used as a guide for performing other similar PRAs [probabilistic risk assessments]. Moreover, the results of this study can be used in conjunction with the methodology selected to determine the need for other PRAs, improvements in data gathering and analysis, and additional engineering design analysis. It should be noted that the focus of this pilot study *was solely on the methodology* and its limited (i.e., case-specific) application. Thus*, no inferences or conclusions should be drawn with regard to the study's regulatory implications*.[46]

4.3. There are a number of reasons that the Pilot Study should not be used in a generic, regulatory context, especially in a situation where the impacts of indefinitely long periods of storage and repeated transfers are being assessed, as is the case in the Draft GEIS. First, it was a pilot study done to develop methodology; it was not designed for general use. For instance, the study considered high burnup Boiling Water Reactor (BWR) spent fuel.[47] Most U.S. reactors are pressurized water reactors (PWR). The space between the fuel pellet and the fuel rod decreases with burnup. However, the gap between the fuel pellet and the fuel rod is reduced much more in a PWR than a BWR.[48] As the Nuclear Waste Technical Review Board (NWTRB) has pointed out, "[h]igh-burnup fuels tend to swell and close the pellet-cladding gap, which increases the cladding stresses and can lead to creep and stress corrosion cracking of cladding in extended storage."[49] This shows that the difference in the fuel pellet cladding gap between PWRs and BWRs is of material importance for high burnup fuel; it needs to be taken into account in the analysis of impacts of spent fuel storage and transport.

4.4. The Pilot Study listed a number of uncertainties but did not consider them in its quantitative analysis:

> The changes that occur in the properties of the fuel and the cladding while in-reactor may introduce *large errors* into the determination of the release factors, because of the uncertainty of the database....*No attempt has been made to quantify the degree of the uncertainties* or to determine if they are significant to the risk.[50]

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[45] NRC 2013a, pp. 4-82 and 4-83
[46] NRC Pilot 2007, p. v, italics added
[47] NRC Pilot 2007, p. 1-2
[48] NRC Pilot 2007, Table D-2, p. D-8
[49] NWTRB 2010, p. 11
[50] NRC Pilot 2007, p. D-19, italics added

By implication, the estimate of health impact cited in the Draft GEIS has not considered a substantial number of uncertainties. We will discuss areas where data are lacking or poor in paragraphs 4.9 to 4.11.

4.5. The study cited by the NRC for public health impact only considered spent fuel stored in a pool for 10 years followed by dry storage for 20 years.[51] The experiments of Billone et al. on high burnup fuel – the only study cited in the Draft GEIS regarding damage to spent fuel as a result of high burnup – showed significant damage to high burnup fuel upon drying:

> Pre-storage drying-transfer operations and early stage storage subject cladding to higher temperatures and much higher pressure-induced tensile hoop stresses relative to in-reactor operation and pool storage. Under these conditions, radial hydrides may precipitate during slow cooling and provide an additional embrittlement mechanism as the cladding temperature decreases below the ductile-to-brittle transition temperature (DBTT).[52]

Photographs in Billone et al. show clear damage, including significant cracks in the cladding. The Draft GEIS statement that this "could influence the approach used for repackaging spent fuel" is so limited in scope as to provide almost no insight into the environmental impacts during accidents, further degradation during prolonged storage, and during handling and transfer operations. Repackaging is far from the only or even the most important issue from the environmental point of view. We note that the NRC has yet to demonstrate how it will transfer damaged spent fuel from one cask to another (see paragraph 4.27 below).

Figure 1 shows the trends in burnup for PWRs and BWRs. It shows that high burnup fuel (more than 45 GWd per metric ton) started being discharged from reactors only around the turn of the century. Most of this is still in spent fuel pools. Examination of high burnup spent fuel after dry storage of 15 years, as was done for low burnup Surry fuel,[53] is not yet possible, though some experimental work with high burnup fuel cladding has been done.[54]

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[52] Billone et al. 2013, p. 431
[53] Einziger et al. 2003
[54] Billone et al. 2013

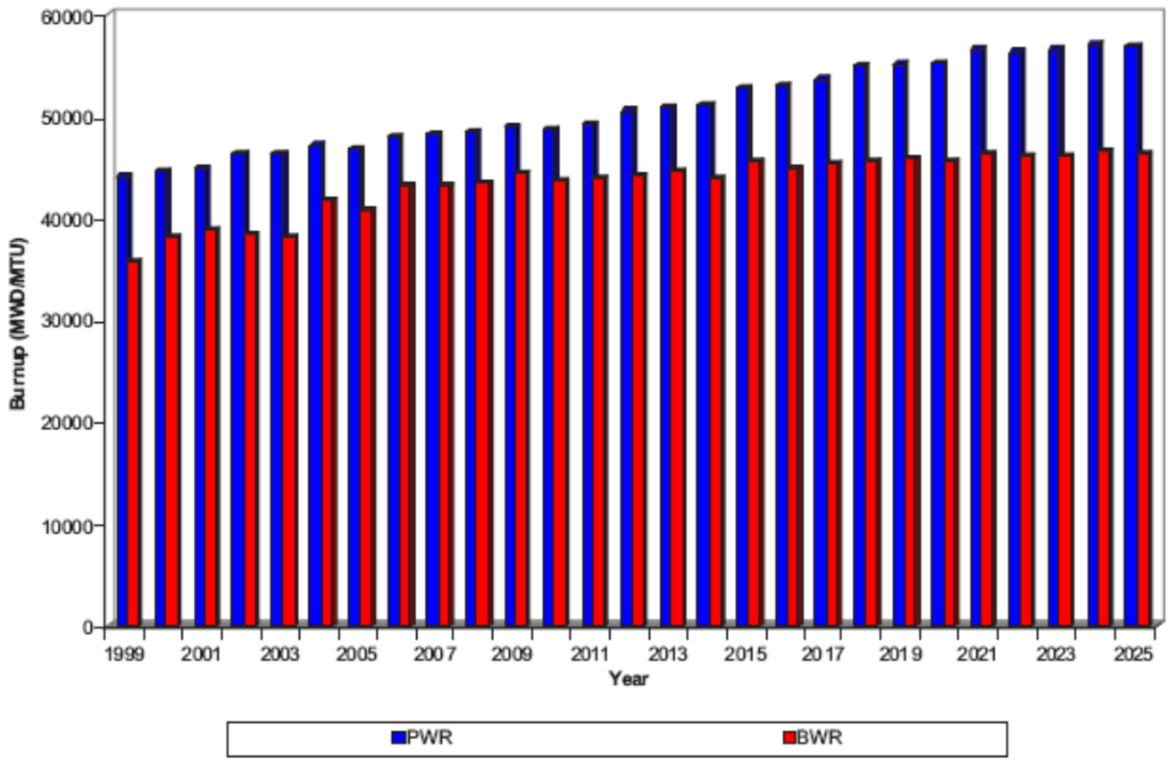

Figure 1. Burnup trends for PWR and BWR reactors in the United States (Reproduced from IAEA 2011, Fig. 6 (p. 9), with note: Courtesy of Energy Resources International)

B. NRC's Previously Raised Concerns about Spent Fuel Characteristics

4.6. The Draft GEIS assumes that spent fuel bundles can be stored for millennia and repeatedly transferred hundreds of times from one cask to another without large releases of radioactivity. But the Draft GEIS contains almost no information about spent fuel characteristics that could cause adverse safety risks and environmental impacts in case of long-term or indefinite storage, both during storage and during the many transfers that must take place. As noted in paragraph 4.5 above, even drying upon removal from the spent fuel pool and early dry cask storage drying induce significant embrittlement in high burnup spent fuel. Further, Billone et al. also found that the degradation is dependent upon the specific zirconium alloy used in the cladding material. Specifically, there was a significant difference in radial hydriding and the ductile-to-brittle transition temperature between ZIRLO and zircaloy-4 cladding subjected to high burnup.[55] The Draft GEIS says nothing about the significance of these findings for accident impacts, inter-cask transfer operations, or transportation risks. Further, little-understood factors affecting the safety of spent fuel storage include the degree to which spent fuel and its host containers corrode and degrade over a prolonged period of time, the phenomenon of "failed fuel," and the effect of high

[55] Billone et al. 2013, p. 446

burnup fuel on the integrity of cladding and storage containers. The Draft GEIS contains no analysis of how spent fuel characteristics may contribute to the risk of an accidental release of radioactivity during extended storage of dry casks; or how these factors may contribute to accident risks during the many transfers that would take place over an extended period of time, *i.e.,* transfers between pools and casks, transfers between storage casks, transfers between storage and transportation casks, and transfers between transportation casks and casks used for ultimate disposal of spent fuel.

4.7. The NRC has cited just one study (Billone et al. 2013) that has evidence about the deterioration of high burnup spent fuel during drying and subsequent storage.[56] Even so, the lessons contained in this study, such as the implications of degradation for accident consequences or the differences between risks of various zirconium alloys used as cladding material are not discussed in the Draft GEIS. However, the NRC has acknowledged elsewhere that it has a serious lack of information about the behavior of spent fuel stored for long periods. In May 2012, the NRC published a *Draft Report for Comment: Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel* (Draft Report on Technical Information Needs).[57] This report catalogs what is known, as well as the gaps in knowledge, of spent fuel degradation mechanisms. Some of the gaps will require extensive new data and a considerable amount of time to fill.

4.8. The Draft Report on Technical Information Needs was based on a number of prior reports, data from physical examination of some "lower burnup" spent fuel, and extrapolation from this data to 80 years. Based on this data, the Draft Report concluded as follows:

> ….The current regulatory framework supports at least the first 80 years of dry cask storage (i.e., a 40-year initial licensing term, followed by a license renewal for a term of up to 40 years, although many of the existing facilities were licensed for an initial term of 20 years under the regulations in place at the time).
>
> The technical basis for the initial licensing and renewal period is supported by the results of a cask demonstration project *that examined a cask loaded with lower burnup fuel* (approximately 30 GWd/MTU [gigawatt-days per metric ton

[56] NRC 2013a, p. B-13. Two of the four other studies cited, Bare et al. 2001 and Einziger et al. 2003, deal with low burnup fuel that has been stored – in fact, they relate to an examination of the same low burnup fuel from the Surry plant in Virginia. The third, IAEA 2006, makes a general assertion that international experience indicates that dry storage is satisfactory and only "a few" rod failures have been detected by sampling of cover gases. The study also refers to the same Surry cask examination as the other two as evidence of storage (IAEA 2006, p. 21). It does not deal explicitly with safety issues that might arise with high burnup fuel, though it notes that there is "a strong interest in extending the technical basis to license storage of power reactor fuel assemblies with burnups above 45 000 MW·d/MTU." (IAEA 2006, p. 21). The fourth, EPRI 1998, was prepared early in the high burnup era. Even so it flagged concerns about high burnup spent fuel at several points, including at the very start: "As the utilities push to higher and higher burnups, eventually the behavior of the fuel in storage of any duration will need to be considered." The document goes on to identify a number of concerns (EPRI 1998, p. iv). The EPRI study notes that high burnup spent fuel had not been studied "to date." (EPRI 1998, p. 6-7).
[57] NRC 2012a

uranium] average; all fuel burnup in this paper is given as peak rod average value). Following 15 years of storage, the cask internals and fuel did not show any significant degradation (Einziger et al., 2003). The data from this study can be extrapolated to maintain a licensing safety finding that *low burnup SNF* can be safely stored in a dry storage mode for at least 80 years with an appropriate aging management program that considers the effects of aging on systems, structures, and components (SSCs).[58]

Note that the existing licensing and license extension procedures are based on examination of a single cask of relatively low burnup uranium dioxide spent fuel that had been in dry storage for only 15 years. The paper lists data requirements for extending this analysis to:

- high burnup spent fuel that would be stored from 120 years to 300 years[59] – that is from about six times to about 16 times longer than the total 19-year storage time (15 years of dry storage plus four years of wet storage) of the spent fuel that was examined in Einziger et al. 2003;[60]
- spent fuel burnups up to about 62.5 GWd/MTU,[61] about double the irradiation of the spent fuel that was examined;
- mixed oxide (MOX) spent fuel (which has plutonium-239 instead of uranium-235 as the fissile material that sustains the chain reaction), even though there are hardly any data on MOX fuel degradation after dry storage; MOX fuel may be "more susceptible" to some forms of degradation, according to the Nuclear Waste Technical Review Board;[62]
- "new cladding, fuel compositions, and assembly designs that have been and will continue to be put into use."[63]

4.9. The data requirements are extensive even by the NRC staff's own accounting. According to Table 6-1 in the Draft Report on Technical Information Needs, there are 23 different degradation phenomena that have a ranking of "high" in terms of "the need for further research"[64] in addition to the data available from the lower burnup/short storage time evaluations. Table 6-1 below shows the list of those items; it is reproduced from NRC 2012a (Table 6-1 (pp. 6-2 to 6-4)). Of these 23 degradation phenomena (grouped into 19 regulatory categories), 10 had the highest (#1) priority and the rest had the second highest priority.

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[58] NRC 2012a, p. 1-1, italics added
[59] NRC 2012a, p. 1-2
[60] The wet storage time was about 3.7 years (Einziger et al. 2003, p. 6); it has been rounded to four years for this calculation.
[61] NRC 2012a, p. 3-1
[62] NRC 2012a, p. A2-2, A2-4, and A4-3, for instance
[63] NRC 2012a, p. 3-1
[64] NRC 2012a, p. 6-1 and Table 6-1

Table 6-1. Summary of Regulatory Research Areas

Component	Degradation Phenomena	Regulatory Significance	Level of Knowledge	Overall Ranking	Reason for Ranking High	Research Priority
Cladding	Galvanic corrosion	CO, RE, SR	L	H*†	This is only high if the drying task indicates that sufficient water remains in the canister. This may revert to low if sufficient water is not present. The level of knowledge is low.	2
	Stress corrosion cracking (SCC)		L	H§‡	All three mechanisms depend on a source of stress that would come from pellet swelling. If the stress is not present, the mechanisms become benign. If operative, these mechanisms could increase the source term and increase cladding stress. The latter could affect containment, especially if other degradation processes have compromised the canister.	2
	Delayed hydride cracking	CO, RE, SR	M	H§‡		2
	Low temperature creep	CO, CR, RE, SR	L	H‡		2
	Propagation of existing flaws	CO, RE, SR	L	H	There is little current knowledge of the initial flaw size distribution in high burnup cladding, and as a result, it currently cannot be determined whether the cladding will fail in the long term. Breached cladding affects the containment source term.	2
Fuel-cladding interactions	Fission gas release during accident	CO	L	H	Both of these mechanisms will result in an increased pressure in the canister and potential containment issues. The level of knowledge is low.	1
	Helium release					
	Pellet swelling	CO	L	H§	The level of knowledge is low, and swelling of the pellets would be the only source of stress for long duration cladding failure.	1
	Additional fuel fragmentation	CO	L	H	Additional fuel fragmentation will release fission gas to pressurize the rod and result in an increased source term for containment.	1
Fuel assembly hardware and damaged-fuel cans	Metal fatigue caused by temperature fluctuations	CR, RE, SR	M	H¦	Loss of assembly hardware would put the fuel in an unanalyzed state for criticality. The extent of the fatigue will depend on the size of the temperature fluctuations determined from the thermal crosscutting task.	2
	Wet corrosion and SCC	CR, RE, SR	M	H*†	This is only high if the drying task indicates that sufficient water remains in the canister. This may revert to low if sufficient water is not present	2

Table 6-1. Summary of Regulatory Research Areas (continued)

Component	Degradation Phenomena	Regulatory Significance	Level of Knowledge	Overall Ranking	Reason for Ranking High	Research Priority
Fuel baskets	Weld embrittlement	CR, SH	L	H	The knowledge of this mechanism is low and failure of the basket will leave the fuel in an unanalyzed condition for criticality.	2
	Metal fatigue due to temperature fluctuations	CR, SH	M	H	The knowledge of this failure mechanism is medium, and failure will place the fuel in an unanalyzed condition.	2
Stainless steel (SS) canister body and weld	Atmospheric SCC	CO, CR, RE, SH, TH	L	H	The canister is the primary containment vessel in storage and may be needed for moderator exclusion of high burnup fuel in transportation. It may also be the primary means of retrieval. It is currently not known whether conditions are applicable for the mechanism to be active or in what timeframe it will occur.	1
	Pitting and crevice corrosion					
SS, steel, and cast iron body, welds lids and seals	Microbiologically influenced corrosion	CO, CR, RE, SH, TH	L	H	Under the correct conditions, this mechanism could corrode seals and/or the cask body that affect containment. Little is known about whether the conditions are ripe for this mechanism to be operative.	2
Cask bolts	Corrosion, SCC, and embrittlement	CO, CR, SH, SR	L	H	While the level of knowledge is medium, failing or loosening bolts can, in the long term, compromise containment and the inert atmosphere in the canister These cladding degradation mechanisms are inoperative only if the inert atmosphere is maintained.	1
	Thermal-mechanical degradation					
Neutron absorber	Thermal aging effects	CR	L	H#	Displacement of absorbers from their original positions can impact criticality safety in the event of canister breach and water ingress. Absorbers in welded canisters cannot currently be monitored or replaced.	2

Table 6-1. Summary of Regulatory Research Areas (continued)

Component	Degradation Phenomena	Regulatory Significance	Level of Knowledge	Overall Ranking	Reason for Ranking High	Research Priority
Concrete Overpack	Multiple mechanisms	SH, SR	H	H	Concrete is the primary shielding for storage and transportation in most systems. Knowledge of the various degradation mechanisms is variable, but overall has been rated high assuming that monitoring can identify early signs of degradation. If analysis of monitoring methods shows that early degradation cannot be reliably detected, then evaluation of individual degradation mechanisms will have higher priority.	2
Crosscutting for multiple components	Drying	CO, CR, RE, SR	L	H	These crosscutting issues affect many components and mechanisms. Many of the other degradation mechanisms, listed previously, can be eliminated if the canister is dry, there is a good knowledge of the temperatures, and adequate monitoring is conducted. The monitoring task is to gain knowledge of the necessary monitoring intervals and adequacy of monitoring.	1
	Thermal calculations	CO, CR, RE, SR, TH	L	H		1
	Monitoring	CO, CR, RE, SR, TH	L	H		2

H=High
M=Medium
L=Low
CO=Confinement
CR=Criticality
RE=Retrievability
SH=Shielding
SR=Structural
[TH=Thermal]
*Rated high because it can indirectly affect criticality.
†High only if there is residual moisture after drying, otherwise low. Drying is being evaluated in a separate task.
‡Will only be high if stress generated from helium swelling of the fuel is shown to be operative.
§These rankings may change based on the results of work on pellet swelling.
¦While the level of knowledge is now medium, this is assigned high priority because it may impact criticality safety.
#Structural absorbers only

Source: NRC 2012a, Table 6-1 (pp. 6-2 to 6-4)

4.10. In Table 6-1, above, the level of knowledge of 23 degradation phenomena in the top two priorities was deemed by the NRC staff to be "low" in 18 cases, "medium" in four cases, and "high" in only one case.

4.11. The NRC Staff proposed to undertake a seven-year study of the phenomena identified in the *Draft Report on Technical Information Needs* (NRC 2012a). But funding previously designated for this research was redirected to preparation of this Draft GEIS.[65]

4.12. The NRC's failure to mention in the Draft GEIS the agency's own previously expressed concerns about the data gaps essential to understanding high burnup and MOX spent fuel and spent fuel with new cladding materials is an egregious technical omission. The missing data are critical to assessing the health and environmental impacts of spent fuel; gathering the data will need extensive additional research, which appears essential for a credible impact analysis, including placing operationally meaningful uncertainty bounds on impacts. Without this basic information, the NRC has an inadequate foundation for scientifically sound predictive safety findings regarding the behavior of high burnup spent fuel in long-term storage conditions. The Draft GEIS made no attempt to place uncertainty bounds on impacts. On the contrary, as noted in paragraph 4.4 above, the one study that the NRC cited to justify its conclusion that impact accident consequences would be low explicitly did *not* consider uncertainties. The explicit reason cited in that study for not estimating uncertainties was that "the uncertainty of the database" was such that it "may introduce large errors…" in the analysis.[66] The data gaps relevant to long-term storage of high burnup fuel are much greater than those considered in the Pilot Study. The problem of putting bounds on the impacts is therefore much more serious, in light of the issues listed in Table 6-1 above. The NRC's failure to mention its own documented concerns about spent fuel characteristics seriously compromises the scientific integrity of the Draft GEIS.

C. NWTRB on High Burnup Spent Fuel

4.13. The NRC's failure to acknowledge the amount of information that is lacking regarding spent fuel behavior over the long-term is all the more disturbing in light of the fact that the Nuclear Waste Technical Review Board (NWTRB) has expressly acknowledged the dearth of information. In 2010, NWTRB reported with respect to spent fuel integrity and degradation:

> Only limited references were found on the inspection and characterization of fuel in dry storage, and they all were performed on low-burnup fuel after only 15 years or less of dry storage. *Insufficient information is available on high-burnup fuels to allow reliable predictions of degradation processes during extended dry storage, and no information was found on inspections conducted on high-burnup fuels to confirm the predictions that have been made*.[67]

[65] Vietti-Cook 2012
[66] NRC Pilot 2007, p. D-19, italics added
[67] NWTRB 2010, p. 11, italics added

Thus, NWTRB confirms that at present no U.S. data are available for high burnups (up to 62.5 GWd/MTU) for any of the NRC's storage scenarios, or for periods of storage anywhere comparable to the long time frame of hundreds of years that the NRC will have to consider in its waste confidence GEIS in one or more scenarios. Predictions, estimates or projections that the NRC may make of the effects of high burnup spent fuel storage, particularly over long-term periods, in its waste confidence GEIS cannot be validated with scientific data or observations with presently available information. Such validation is essential for reliable and scientifically acceptable estimates of environmental and health impact of long-term storage and transportation.

4.14. The NWTRB also commented on the lack of information about interactions between different degradation mechanisms as well as the possible effect of high burnup on those interactions:

> These [degradation] mechanisms and their interactions are not well understood. New research suggests that the effects of hydrogen absorption and migration, hydride precipitation and reorientation, and delayed hydride cracking may degrade the fuel cladding over long periods at low temperatures, affecting its ductility, strength, and fracture toughness. *High-burnup fuels tend to swell and close the pellet-cladding gap, which increases the cladding stresses and can lead to creep and stress corrosion cracking of cladding in extended storage.* Fuel temperatures will decrease in extended storage, and cladding can become brittle at low temperatures.[68]

Hence, high burnup could possibly combine with other factors to create conditions that would result in severe, if not catastrophic, releases of radioactivity. This possibility must be studied.

4.15. Besides the NRC staff's 2012 proposal, the NWRTB has also proposed an extended research program to address the problem of the lack of data. The NWTRB research and development recommendations include:[69]

- Understanding the ultimate mechanical cladding behavior and fuel-cladding degradation mechanisms potentially active during extended dry storage, including those that will act on the materials introduced in the last few years for fabrication of high-burnup fuels
- Understanding and modeling the time-dependent conditions that affect aging and degradation processes, such as temperature profiles, in situ material stresses, quantity of residual water, and quantity of helium gas
- Modeling of age-related degradation of metal canisters, casks, and internal components during extended dry storage

[68] NWTRB 2010, p. 11, italics added
[69] The bullet points are quoted from NWTRB 2010, p. 14

- Inspection and monitoring of fuel and dry-storage systems to verify the actual conditions and degradation behavior over time, including techniques for ensuring the presence of helium cover gas
- Verification of the predicted mechanical performance of fuel after extended dry storage during cask and container handling, normal transportation operations, fuel removal from casks and containers, off-normal occurrences, and accident events
- Design and demonstration of dry-transfer fuel systems for removing fuel from casks and canisters following extended dry storage

As discussed above, a valid impact analysis requires collection of this information at least to a sufficient extent to make a central estimate of impacts and to put meaningful uncertainty bounds on those impacts.

D. View of Other Institutions on High Burnup Spent Fuel

4.16. Other institutions have also analyzed the critical data gaps regarding high burnup degradation and its implications for storage, transport and disposal. For instance, a 2012 paper published by the National Academy of Engineering noted the following:

> Based on its assessment, the study board concluded that the technical basis for the spent fuel currently being discharged (high utilization, burnup fuels) is not well established and that the possibility of degradation mechanisms, such as hydriding, will require more study. The NWTRB recommended periodic examinations of representative amounts of spent fuel to ensure that degradation mechanisms are not in evidence.[70]

As concerning as the serious data gaps is the fact that as recently as 2012 neither the NRC nor the nuclear power industry had implemented the periodic examinations of spent fuel recommended by the NWTRB in 2010.

4.17. We are aware that an agency preparing an environmental impact statement (EIS) can proceed even when important information is missing. But it is obliged to at least specify the important information and data gaps in any EIS and provide a discussion of the available evidence of the importance of the missing data. This is not only legally required under 40 CFR 1502.22, it is a basic element of scientific integrity and a part of the meaningful assessment of uncertainties. In case the data gaps are in critical areas and are so large that meaningful uncertainty bounds cannot be put on the impacts, the NRC should make that finding in its assessment of the problem. In this case, the NRC and other agencies know the data gaps well. Moreover, the NRC itself was on a path to remedy them at least to some extent over the coming years. But the Draft GEIS fails to discuss the consequences of a failure to include that information in its environmental impact analysis and on its conclusions.

[70] Kadak 2012, p. 30

E. Effect of Degradation of Storage Impacts

4.18. In Table 6-1 above (reproduced in paragraph 4.9 from the NRC Draft Report on Technical Information Needs (NRC 2012a)), all of the categories of "regulatory significance" of the 23 degradation phenomena – confinement, criticality, retrievability, shielding, structural, and thermal – are relevant to estimating environmental impacts, some of which could be serious. Such impacts could arise because some of the spent fuel could be degraded badly enough to result in (i) environmental releases during spent fuel inter-cask transfer and (ii) more severe impacts in cases of accidents.

4.19. For instance, in the case of microbiologically induced corrosion, Table 6-1 states that "little is known" about the conditions under which it "could corrode seals and/or the cask body that affect containment." Laboratory work and examination of spent fuel of different levels of burnup stored for long periods in spent fuel pools followed by long-term storage in dry casks is needed. It is only on this basis that models to extrapolate the environmental impacts of storage, followed by transportation (and in all but one scenario) disposal can be evaluated and extrapolated in a manner that can be scientifically validated.

4.20. As another example, consider phenomena listed near the top of Table 6-1: stress corrosion cracking, delayed hydride cracking, and low temperature creep. The NRC Draft Report on Technical Information Needs notes that "[a]ll three mechanisms depend on a source of stress that would come from pellet swelling. If the stress is not present, the mechanisms become benign. If operative, these mechanisms could increase the source term and increase cladding stress. The latter could affect containment, especially if other degradation processes have compromised the canister."[71] In other words, the NRC does not know at present whether corrosion of seals or the canister body may occur to an extent that compromises containment. Damage to canisters could set the stage for severe releases either during inter-cask transfer or because the canister itself degrades. This is an example of a case where the present state of knowledge is so low that the uncertainties appear to be so large as to be operationally meaningless.

4.21. High burnup fuels also tend to build up much thicker levels of oxide during the in-reactor period as well as much higher levels of hydrogen in the cladding. Figure 2 below shows that the typical increase in outer oxide layer thickness increases from about 20 microns at 30 GWd/MTU to about 100 microns at about 62 or 63 GWd/MTU at discharge from the reactor.[72] Moreover, the spread in the oxide layer thickness increases with burnup, indicating that some fraction of fuel rods may be at a much greater risk of failure.

4.22. Figure 3 shows that the maximum wall thickness hydrogen content increases from 200 ppm to 800 ppm at discharge over approximately the same burnup range as in Figure 2. In both cases the variability is also much greater at the higher burnup. For instance, Figure 3 shows oxide layer thicknesses for a burnup of 30 GWd/metric ton ranging from roughly 12 microns to (at most) 35 microns – a spread of 23 microns. At 63 GWd per metric ton the thickness range from

[71] NRC 2012a, p. 6-2
[72] The range of blue data points at about 63 GWd/MTU is from about 70 microns to about 130 microns. (NWTRB 2010, Figure 20 (p.56))

about 70 microns to 130 microns, a spread of 60 microns. In fact these data show that the *variability* in oxide layer thickness at 63 GWd/MT burnup is almost *twice as large as the maximum* thickness at 30 GWd/MT. The oxidation and hydriding in-reactor data point to (i) a higher probability of failure and (ii) more severe failures in some fraction of the rods in cases when failures occur upon prolonged spent fuel pool and dry storage for high burnup spent fuel. High oxide and hydrogen levels in cladding create a host of vulnerabilities in spent fuel, including increased brittleness upon drying, high hoop stresses, and other phenomena that could cause fuel to fail – that is, to develop cracks and fissures that are significant enough to cause release of fission products. Reasonable confidence in the integrity of spent fuel after long periods of storage would not only require examination of typical high burnup fuel rods but also the ones at the higher levels of initial degradation that are clearly indicated by currently available information of in-reactor performance.

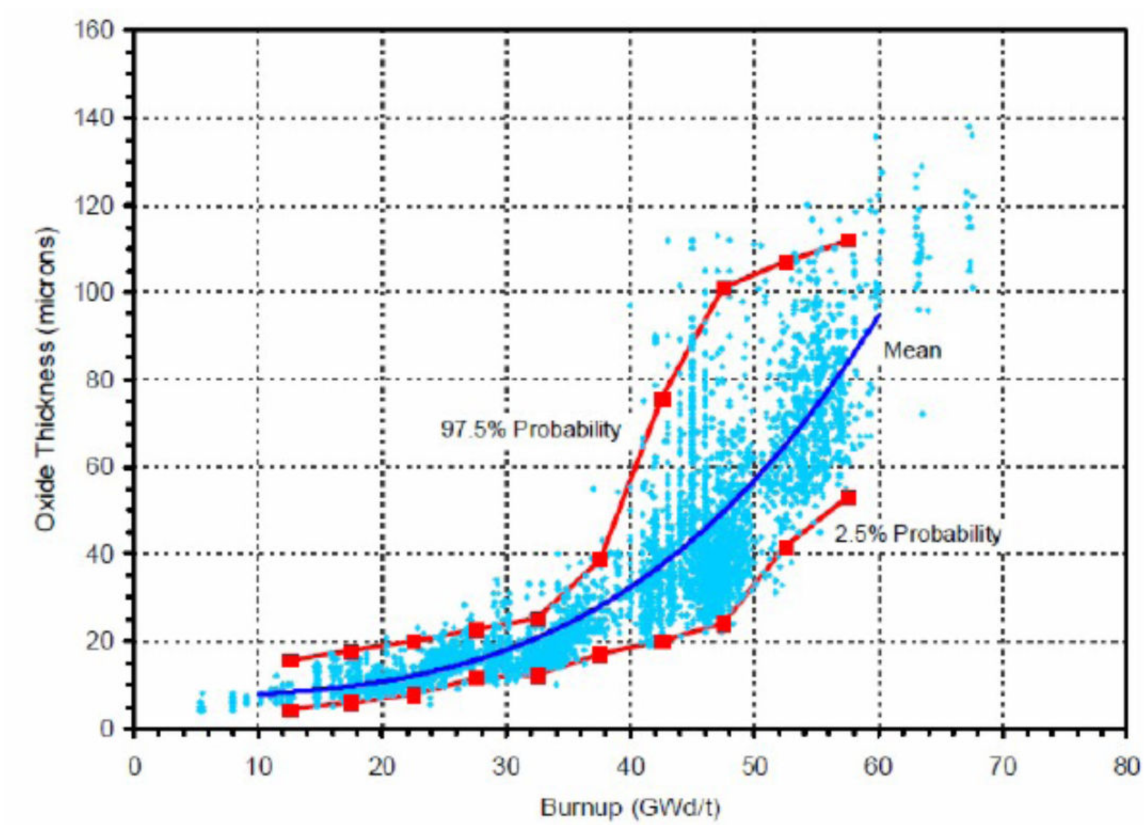

Figure 2. Cladding outer surface oxide thickness layer versus rod average burnup (Reproduced from NWTRB 2010, Figure 20 (p.56))

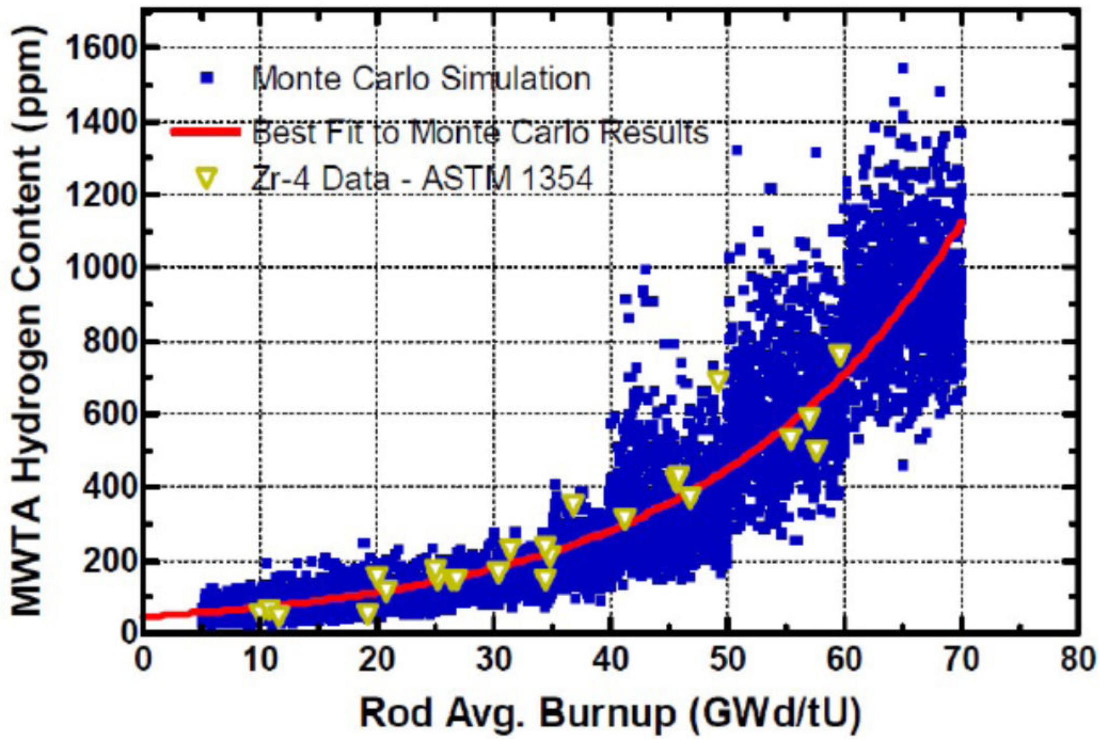

Figure 3. Maximum Wall Thickness Average Hydrogen Content in Low-Tin Zircaloy-4 Cladding (Reproduced from NWTRB 2010, Figure 21 (p.56))

4.23. The Draft GEIS cites an at-reactor dry storage facility at Surry as a successful example of dry storage.[73] The spent fuel from Surry that was examined after about 15 years of dry storage was found upon inspection to be functionally undamaged.[74] Hence one can safely assume that the spent fuel was also functionally undamaged at the time of transfer from wet to dry storage. The results of the Surry study are unlikely to be applicable to fuel that has developed some damage during irradiation, for instance, due to higher burnup, or during spent fuel pool storage. Lack of damage during much more prolonged dry storage of high burnup fuel also cannot be assumed based on the Surry study. The NWTRB has issued the following caution about prolonged spent fuel pool storage:

> Cladding may already have some small defects like tiny holes or hairline cracks, internal and external corrosion that has decreased the original metal wall-thickness, absorbed hydrogen, and hydride precipitation; however, it is very rare that new defects are detected while in the pool. Significant cladding defects can be detected during wet storage by monitoring stack off-gas for fission product gas leaks; if leaks are found, then assemblies are further inspected and breached fuel-rods are canned if necessary. Generally, a visual inspection is made of assemblies to identify fuel assemblies that may need to be classified as damaged and require

[73] NRC 2013a, p. B-12
[74] Einziger et al. 2003, p. ix

> special handling. If the cladding is functionally undamaged, there is an insignificant risk of expected fuel oxidation [at the time of transfer to dry storage]. Given undamaged cladding and the visible transfer of assemblies into and out of wet storage, the fuel-assembly containment criterion is deemed satisfied. Thus, during wet pool storage, used fuel is not expected to experience significant deterioration before dry storage. *If pool storage of fuel is continued for an extended period, it will be necessary to assess and evaluate the effects on intact or damaged fuel*.[75]

Though Draft GEIS assumes that pool storage could continue for periods approaching 140 years (the first spent fuel discharged during 80 years of total licensed operation, plus 60 years of post-operating license storage), it has not included any uncertainty analysis relating to impacts of damage that may occur in some fraction of the spent fuel during such prolonged storage.

F. Failed Fuel

4.24. Fuel failure occurs when there is a rupture in the fuel cladding, allowing fuel pellets direct contact with the environment around the fuel, the reactor coolant, spent fuel pool water, the canister environment, or the general environment during inter-cask transfer of failed fuel. If detected during cask loading, failed fuel is normally put in a "can," which is a special sleeve, prior to loading into the cask. But if failure occurs after dry storage commences, some fuel pellets could be exposed to the environment during transfer. The NRC has refused to state how it would transfer failed spent fuel. It plans to figure it out then, as noted in paragraph 4.27 below.

4.25. In the NWTRB study described above, NWTRB identified hydriding, creep, and stress corrosion cracking to be "[t]he most significant potential degradation mechanisms affecting the fuel cladding during extended storage."[76] These phenomena can lead to "failed fuel" under certain conditions.[77] The Draft GEIS concludes that these phenomena are unlikely to cause significant problems in the "short-term."[78] With respect to long-term storage, the NRC claims to be ignorant of any studies "that would cause it to question the technical feasibility of continued safe storage of spent fuel in dry casks."[79] But Table 6-1 of the Draft Study of Technical Needs admits that the level of knowledge regarding galvanic corrosion, stress corrosion cracking, low-temperature creep, and propagation of existing flaws is "low"; and that knowledge of delayed hydride cracking is only "medium." The NRC's amnesia regarding its own study undermines the credibility and integrity of the Draft GEIS.

4.26. The only explicit mention of failed fuel in the Draft GEIS is in the context of spent fuel pool leaks:

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[75] NWTRB 2010, p. 60, italics in the original
[76] NWTRB 2010, p. 10
[77] NRC 2012a, pp. A1-6 and A1-7
[78] NRC 2013a, p. B-13
[79] NRC 2013a, p. B-13

> Impacts from spent fuel pool leakage occur from radionuclide contaminants present in spent fuel pool water. The sources of radionuclide contaminants in spent fuel pool water are activation products and fission products. Activation products are elements formed from the neutron bombardment of a stable element and fission products are elements formed as a byproduct of a nuclear reaction and radioactive decay of other fission products. *The sources of activation products are corrosion and wear deposits (including corrosion films on the fuel bundle surfaces)*. Fission products come from bundles with rods that failed in-reactor or from intact bundles that adsorbed circulating fission products.[80]

This is grossly insufficient, since the principal long-term risks are likely to arise after prolonged storage has resulted in serious fuel degradation of some fraction of the fuel rods, notably in the case of high burnup spent fuel.

4.27. The NRC's failure to address the effects of failed fuel on safety and environmental risk is all the more remarkable in the context of the NRC's own admission that it does not yet know how it will transfer such failed spent fuel. The NRC has no experience in transferring failed fuel from one cask to another. By NRC's own admission, it has not even developed the procedures to do so, as illustrated by the following 2001 decision by the NRC's technical staff:

> *The NRC staff believes that the petitioner has identified a valid concern regarding the potential recovery of fuel assemblies that unexpectedly degrade during storage***.** However, in this unlikely event, the NRC staff has concluded that there is reasonable assurance that a licensee can safely unload degraded fuel or address other problems. This conclusion is based on the NRC's defense-in-depth approach to safety that includes requirements to design and operate spent fuel storage systems that minimize the possibility of degradation; requirements to establish competent organizations staffed with experienced, trained, and qualified personnel; and NRC inspections to confirm safety and compliance with requirements. The NRC staff finds acceptable these procedures for detecting degraded fuel through sampling and, on the basis of the sample results, the implementation of appropriate recovery provisions that reflect the ALARA (as low as is reasonably achievable) requirements. The NRC staff's acceptance of this approach is based on the fact that the spent fuel storage cask can be maintained in a safe condition *during the time needed to develop the necessary procedures and to assemble the appropriate equipment before proceeding with cask unloading.* The NRC staff also relies on the considerable radiological safety experience available in the nuclear industry in its assessment that appropriately detailed procedures can be prepared for the specific circumstances in a timely manner.[81]

While this "kicking the can down the road" may have been a legally valid response to the petition, it can no longer be sustained in the context of the waste confidence GEIS. The issue is material to environmental impacts, which the NRC is obliged to estimate.

[80] NRC 2013a, p. E-10, italics added
[81] NRC 2001, p. 9058, italics added

4.28. The NRC also has no basis in data or experience in estimating how much additional damage could be done to failed fuel by transferring it between casks. This would apply even to damaged medium burnup fuel stored for short or moderate periods of time (up to two or three decades) in dry casks. It is *a fortiori* true of high burnup spent fuel that has been stored for many decades or even a few hundred years, given the considerations about such spent fuel discussed in the rest of this section.

4.29. Indeed, it should be noted in this context, that no spent fuel bundle, damaged or not, has ever been transferred from one dry cask to another. Further, while the Draft GEIS postulates a Dry Transfer System for fuel inspection, repackaging and transfer, such a facility has never been built in the United States. And as discussed in paragraph 4.27, the NRC even refuses to say how it would handle and repackage failed fuel. This makes the lack of discussion of the impacts of the transfer of failed spent fuel bundles even more problematic since the NRC lacks sufficient empirical basis for estimating the probabilities and consequences of the spread of radioactivity during transfers in the normal case.

4.30. In failing to address the issue of failed spent fuel inter-cask transfers, the NRC has ignored the fact that failed spent fuel bundles are already stored in dry casks, but have never had to undergo inter-cask transfers. For instance, there are 95 failed spent fuel bundles stored in 15 dry casks at San Onofre Nuclear Generating Station alone.[82]

4.31. As discussed above, NWTRB has proposed an extended research program to address the lack of data regarding spent fuel characteristics. It is also important to have dry storage performance data on the newer cladding materials that have been developed to enable high fuel burnup, which is a relatively recent practice (since about the turn of the century[83]). There are practically no such data. Indeed, even the research has been focused mainly on in-reactor behavior of high burnup fuels rather than on degradation during prolonged storage:

> Because of the more severe conditions created by burning fuel to higher levels, new cladding materials have been developed for in-reactor service and employed by vendors such as Areva's M5 alloy, Westinghouse's optimized ZIRLO, Siemen's Duplex, and Mitsubishi's M-MDA material. Currently there is much more behavioral data available on Zircaloy-2 and -4 cladding, but work is ongoing to study the new cladding materials (mostly proprietary). From the limited information reviewed it appears new cladding research is focused primarily on in-reactor behavior and not behavior during extended storage.[84]

[82] NRC 2011b, p. 11
[83] NWTRB 2010, p. 72
[84] NWRTB 2010, p. 52

G. Other Forms of Spent Fuel – MOX Spent Fuel and Stainless Steel Spent Fuel

4.32. The United States is building a MOX plant to convert weapons-grade plutonium into commercial reactor fuel. There is no significant experience with irradiation of such MOX fuel in a commercial reactor in the United States. Only lead test assemblies have been irradiated. There is essentially no experience with storage of commercial MOX spent fuel in the United States in wet or dry storage for any length of time. France, which has the most experience with MOX spent fuel, stores it in pools and has no dry storage. The Draft GEIS simply assumes away the problem of MOX spent fuel with the following statement:

> Because the MOX fuel that would be generated at the Mixed Oxide Fuel Fabrication Facility is substantially similar to existing light water reactor fuel and is, in fact, intended for use in existing light water reactors in the United States, MOX fuel from this project is within the scope of this draft GEIS.[85]

Contrary to the claim in the Draft GEIS, MOX fuel is decidedly *not* "substantially similar to existing light water reactor fuel." In the former the fissile material is plutonium, which has different nuclear characteristics (a smaller delayed neutron fraction, for instance) than current low-enriched uranium reactor fuel. Even more importantly for the present purposes, the characteristics of the spent fuel will be different. For instance, uranium spent fuel from a PWR with initial 4.25 percent enrichment and burnup of 50 GWd per metric ton would have about 1 percent plutonium isotopes in it at discharge, including about half-a-percent plutonium-239. For the same burnup MOX fuel would typically have 8.46 percent total plutonium to start with. The spent fuel from a PWR would have about five times as much total plutonium and about three-and-half-times as much plutonium-239.[86]

4.33. In the example provided (50 GWd per metric ton burnup in a PWR), the MOX spent fuel would have about six-and-half-times the amount of plutonium-241 as the uranium spent fuel. Plutonium-241 decays into americium-241 relatively rapidly with a half-life of just 14.4 years. Amercium-241 has a half-life of 432 years.[87] Unlike plutonium-239 and plutonium-241, americium-241 is a powerful gamma radiation emitter; it would pose special problems during spent fuel transfer, long after the main gamma-emitting fission product, cesium-137 (half-life about 30 years), would have decayed away. These problems associated with americium-241 gamma radiation dose would extend to post-accident recovery in case of release of radionuclides from the spent fuel.

4.34. It stretches credulity that the NRC staff is not aware of these critical differences that would make a significant difference between impacts of MOX spent fuel and uranium spent fuel. In

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[85] NRC 2013a, p. 2-8

[86] IAEA 2007, Tables 18 and 25, pp. 65 and 70 respectively. The MOX fuel in this case started with reactor-grade plutonium. MOX fuel made with weapon-grade plutonium would have a somewhat different mixture of plutonium isotopes in the spent fuel, but it would, in any case, be much higher than the total plutonium in uranium dioxide spent fuel.

[87] Properties of radionuclides, including half-lives and dose conversion factors can be found in FGR 13 CD 2002.

any case, the Draft GEIS assertion that the two are substantially similar is wrong. A specific impact analysis is needed for MOX spent fuel.

4.35. Stainless steel fuel cladding was used as fuel cladding early in the history[88] of U.S. commercial reactors. By 1994, only one reactor had any stainless steel clad fuel in its core.[89] By 1992, a total of 679 metric tons spent fuel (uranium heavy metal content) had been generated from the stainless steel clad fuel.[90] Further, the use of stainless steel cladding was discontinued partly because in-reactor degradation of stainless steel cladding. For instance, the stainless steel cladding in the Connecticut Yankee reactor "experienced a number of fuel element failures" between 1977 and 1980, even though it had performed well in this regard prior to that time.[91] The degradation characteristics of stainless steel fuel are different than zircaloy fuel and needed to be explicitly considered in the Draft GEIS. The Draft GEIS catalogs the amount of stainless steel spent fuel but does not discuss the failed fuel or its transfer from one dry cask to another. It does not discuss whether accidents involving such failed fuel would have more or less severe consequences than failed zircaloy-clad fuel.

5.0 CRITICALITY RISKS AND HIGH BURNUP SPENT FUEL

5.1. The Draft GEIS has considered only criticality accidents in spent fuel pools.[92] However criticality is an issue for dry cask storage and transport, notably for high burnup fuel as noted in NUREG/CR-6835.

> Irradiation of nuclear fuel to high-burnup values increases the potential for fuel failure during normal and accident conditions involving transport and storage. The objective of this work is to investigate the consequences of potential fuel failure on criticality safety and external dose rates for spent nuclear fuel (SNF) storage and transport casks, with emphasis on high-burnup SNF. Analyses were performed to assess the impact of several damaged/failed fuel scenarios on the effective neutron multiplication factor (k_{eff}) and external dose rates. The damage or failure was assumed to occur during use in storage or transport, particularly in an accident. Although several of the scenarios go beyond credible conditions, they represent a theoretical limit on the effects of severe accident conditions. Further, the results provide a basis for decision making with regard to failure potential and a foundation to direct future investigations in this area.[93]

5.2. As the abstract quoted above in paragraph 5.1 notes, the study explored the theoretical limit of criticality risks for high burnup fuel. The fuel was assumed to have been in storage for 20 years. The Draft GEIS could have used these calculations to provide bounding calculations on

[88] EIA 1994, p. 23
[89] EIA 1994, p. 23
[90] EIA 1994, Table 9 (p. 27) and Table 10 (p. 28)
[91] Rivera and Meyer 1980, p. 1
[92] NRC 2013a, pp. 4-69 - 4-70
[93] NUREG/CR-6835 (2003), p. iii

doses to the public and to workers in the event of an accident approaching the limits described. But it did not consider criticality risks associated with dry storage at all.

5.3. NUREG/CR-6835 considered risks only from uranium spent fuel with various enrichment levels up to 5 percent.[94] It did not consider MOX spent fuel. As noted in paragraph 4.32 and 4.33, MOX spent fuel contains several times more plutonium-239 than uranium spent fuel with the same burnup. Since the Draft GEIS includes MOX spent fuel in its scope, it should address criticality risks of such spent fuel in dry storage and during transportation as well.

6.0 THE DRAFT GEIS FLIES IN THE FACE OF FACTS, HISTORY, AND COMMON SENSE BECAUSE IT ASSUMES INDEFINITE RELIABILITY OF INSTITUTIONAL CONTROLS

6.1. One of the Draft GEIS's greatest defects is its assumption that institutional controls of the most active sort will persist essentially forever, which in the context of spent fuel is tens or hundreds of thousands of years:

> Institutional controls, i.e., the continued regulation of spent nuclear fuel, will continue. This assumption avoids *unreasonable speculation regarding what might happen in the future regarding Federal actions* to provide for the safe storage of spent fuel. Although government agencies and regulatory safety approaches can be expected to change over long periods of time into the future, the history of radiation protection has generally been towards ensuring increased safety as knowledge of radiation and effectiveness of safety measures has improved. For the purpose of the analyses in this draft GEIS, the NRC assumes that regulatory control of radiation safety will remain at the same level of regulatory control as currently exists today.[95]

6.2**.** The Draft GEIS goes so far as to say that it is "remote and speculative" to assume that the U.S. government and its agencies will not maintain control indefinitely. This is because "a dry storage facility is typically a visible surface structure requiring active maintenance and security, making loss of institutional control so unlikely that it is a remote and speculative occurrence."[96]

6.3. Specifically the following are implicit or explicit in the NRC's assumption of institutional control for the indefinite future:

- The NRC will continue to regulate its licensees for tens of thousands of years.
- Corporations holding reactor licenses today and post-closure nuclear material possession licenses after the expiry of reactor operation licenses would continue to exist for tens of thousands of years.

[94] NUREG/CR-6835 (2003), p. 3
[95] NRC 2013a, pp. 1-14 - 1-15, italics added
[96] NRC 2013a, footnote 2, p. 1-15

- Congress will appropriate funds each year for site security and every hundred years for new casks and cask transfer facilities essentially forever.
- Congress will increase appropriations for site security after a couple of hundred years when the radiation barrier is mostly decayed away and spent fuel is more vulnerable to theft.
- Congress will appropriate funds even though there may be no more revenues flowing from reactor operation.
- State emergency planning structures will remain in place.
- Major upheavals will not disrupt society so as to make appropriations impossible even if the U.S. Government continues to exist.

6.4. The NRC may intend to use the phrase "remote and speculative" to avoid its legal obligation to analyze the impacts of the loss of institutional control. But the Draft GEIS has failed to recognize that simply throwing the phrase at the problem does not make loss of institutional control "remote and speculative" in legal or physical reality. On the contrary, it is the Draft GEIS's contention that institutional control will be maintained essentially forever to the required degree that is remote and speculative.

6.5. Given U.S. and world history, it is not unreasonable to assume that the endurance of institutions to the degree required in paragraph 6.3 will persist for a 100 years. This is a common assumption about institutional control that is factually defensible, though even that is not without caveats (see paragraph 6.7 below).

6.6. For example, empires usually fade in a few centuries. During such periods governments and societies often suffer tremendous upheavals and internal institutional changes. The NRC's assumption of institutional control is so sweeping that it not only requires the U.S. government to endure for tens of thousands of years but that its functions and institutions remain operative and vigilant.

6.7. Consider some elementary facts close to home. The half-life of plutonium-239 is more than 24,000 years. The U.S. government has existed for less than one percent of that time. In that period of time, the United States has suffered a Civil War during which it did not have a unified government. Indeed, it had two governments, with two budgets, two armies, two navies, and two currencies. The United States has also been in two world wars in less than 100 years. It has suffered a devastating terrorist attack just over a decade ago on September 11, 2001, that could have targeted a nuclear power plant. Even closer in time was the federal government shutdown in the first half of October 2013; there was a near-default on the U.S. sovereign debt in the same month. There have been a dozen federal government shutdowns since about 1981.[97] During the October 2013 federal government shutdown, most of the NRC was shut down. Some waste management functions, even for "visible" facilities almost came to a halt. For instance, the Fernald Preserve, which includes a large visible mound of radioactive waste from the Fernald uranium plant that was part of the nuclear weapons complex was closed. Had the government shutdown lasted much longer, the pump and treat operations that are a mandated part of water

[97] As cataloged in Wikipedia at http://en.wikipedia.org/wiki/Government_shutdown_in_the_United_States.

quality objectives would have come to a halt.[98] The NRC, without any analysis of these facts, has ruled it remote and speculative that the necessary degree of institutional controls will exist for many half-lives of plutonium-239. In fact, the Draft GEIS puts no upper bound on the time for which such controls will exist.

6.8. It is to be noted that there were no federal government shutdowns before 1981. There have been a dozen since then.[99] This points to the need for a serious analysis of the reliability of federal government funding even over much shorter periods than the funding for millennia assumed in the Draft GEIS. Specifically, the short-term time frame of 60 years beyond the operating license life of "a" reactor needs to be considered, especially as it could be any reactor past, present, or future. It is also important to consider the "long-term" timeframe of 100 years beyond the "short-term." The federal government will have to continue to appropriate funds each year to compensate for its failure to fulfill its contracts with nuclear utilities to begin taking spent fuel from them starting on January 31, 1998. The discontinuities in the federal government's functioning and the uncertainties surrounding budgetary processes require specific analysis in the Draft GEIS in the context of its assumptions about institutional longevity.

6.9. In view of the above-mentioned historical facts and current events, the attempt of the Draft GEIS to use the legalism of the phrase "remote and speculative" to avoid considering the consequences of the loss of institutional control is ridiculous, bizarre, and even surreal. Given the fact, an assumption of institutional control extending to millennia with the stringent set of controls required for spent fuel management, such as those listed in paragraph 6.3 above, is entirely remote, unreasonable, and speculative.

6.10. Many existing authorities, including the National Research Council, have concluded that long-term waste and remediation policy should be based on the assumption that institutional controls will eventually fail. In reviewing Department of Energy cleanup plans the National Research Council stated the following:

> The Committee on Remediation of Buried and Tank Wastes finds that much regarding DOE's intended reliance on long-term stewardship is at this point problematic….
> […]
> Other things being equal, **contaminant reduction is preferred to contaminant isolation and imposition of stewardship measures whose risk of failure is high.**
> […]

[98] Crawford 2013. Personal email communication from Lisa Crawford, Fernald Residents for Environmental Safety and Health, October 7, 2013. "Folks, the Fernald Preserve is CLOSED due to the Gov. Shut Down -- no big deal really except -- if this goes on much longer it will then begin to affect the pump and treat of the aquifer which is mandated by the OEPA & USEPA and DOE. The site is telling me that it can go about a month and then it's down to little or nothing or shut off. That could be a disaster. Since most of the site is contracted out to Stoller Co. -- those folks are still on the job, but the site is closed. Crazy if you ask me. Lc"

[99] Wikipedia: http://en.wikipedia.org/wiki/Government_shutdown_in_the_United_States. Accessed on November 8, 2013.

The committee believes that the working assumption of DOE planners must be that many contamination isolation barriers and stewardship measures at sites where wastes are left in place will eventually fail, and that much of our current knowledge of the long-term behavior of wastes in environmental media may eventually be proven wrong. Planning and implementation at these sites must proceed in ways that are cognizant of this potential fallibility and uncertainty.[100]

6.11. Indeed, even the NRC itself put a time limit on institutional controls in its low-level waste disposal regulations at 10 CFR 61.7(b)(4) and (b)(5). These regulations effectively assume that active controls (as defined in 10 CFR 61.2) will fail after 100 years. Intruder barriers, which are passive controls, are assumed in the rule to last at most 500 years. NRC's low-level waste regulations are consistent with EPA regulations for managing and disposing of high-level waste and transuranic waste. [101] The Draft GEIS has not taken account of the technical basis for these regulations.

6.12. It is to be noted that Department of Energy's (DOE) Yucca Mountain Final EIS "No-Action Scenario 1" examined the case of continued institutional control assumed for 10,000 years as well as an alternative "Scenario 2" in which that control was lost after 100 years.[102] Similarly, EPA regulations for "Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" at 40 CFR 191.14 mandate that "active institutional controls" be limited to 100 years after disposal. Since dry storage can be licensed after reactor closure, the 100 years may start after expiry of the dry storage license. EPA's regulation relating to uranium mill tailings, 40 CFR 192.02, requires active management measures for 200 years and, if feasible, up to 1,000 years. But, unlike the Draft GEIS, active measures are not assumed to be feasible beyond 1,000 years.

6.13. The Draft GEIS notes that the EPA allows for "permanent" institutional control under some Superfund scenarios and that DOE has also assumed perpetual control of portions of the Savannah River Site.[103] However, just because these agencies assume perpetual control does not relieve the NRC from its obligation under NEPA to examine the environmental impacts of an eventuality that is reasonably foreseeable in case a repository is not developed. For instance, the DOE has assumed perpetual control under a variety of circumstances. However, the DOE also did consider loss of institutional control in its Yucca Mountain EIS, as noted below in paragraph 6.14. Similarly, the DOE considered and evaluated the loss of institutional controls in its EIS relating to the Waste Isolation Pilot Plant (WIPP),[104] which is cited in the Draft GEIS.[105]

6.14. The Yucca Mountain EIS recognized that "[h]istory is marked by periods of great social upheaval and anarchy followed by periods of relative stability and peace.

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[100] NAS-NRC 2000, pp. 3 and 5, original italics; bold added.
[101] 40 CFR 191.14(a), 2011
[102] DOE 2002, Vol. I, pp. 2-70 – 2-72
[103] NRC 2013a, footnote 2, pp. 1-14 and 1-15
[104] DOE 1997, p. 4-33
[105] NRC 2013a, footnote 2, pp. 1-14 and 1-15

Throughout history, governments have ended abruptly, resulting in social instability, including some level of lawlessness and anarchy."[106]

6.15. The main barrier preventing theft of spent fuel in case of a loss of institutional control is external radiation from cesium-137. This radiation barrier decays with a half-life of about 30 years and is therefore less and less effective after one to two centuries. After time of that order of magnitude, the obstacles to theft of spent fuel bundles extracted from the casks would be far lower – low enough to present a real proliferation problem. Every metric ton of spent fuel (heavy metal content) contains more than enough plutonium to make a nuclear weapon. Extracting the plutonium from the spent fuel would also be greatly simplified due the loss of almost all of the radiation barrier. It is therefore essential for the GEIS to evaluate the potential for theft of spent fuel in case of a loss of institutional control and the potential impacts of the possible resultant proliferation.

6.16. I am not arguing here that the NRC should not evaluate a case where institutional control would be maintained for a prolonged period. If the NRC wants to examine a remote and speculative case, it is free to do so. But that cannot be the basis for scientifically valid conclusions about environmental impacts. The NRC is obligated under NEPA to consider the environmental impacts in case of a loss of institutional control because, contrary to the assertion in the Draft GEIS, such an eventuality is not "remote and speculative" for the extremely long periods in question. Rather, it is reasonably foreseeable, given the facts of history, though the exact process is not and though one might wish otherwise.

7.0. ESTIMATION OF IMPACTS OF INDEFINITE STORAGE IN THE ABSENCE OF INSTITUTIONAL CONTROLS.

7.1. As discussed in Section 6 above, it is essential for the NRC to evaluate the environmental impacts of indefinite storage in case of a loss of institutional control. These impacts are likely to be catastrophic under a variety of circumstances.

7.2. The NRC has cited the catastrophic impacts in case of loss of institutional control that were found in the Yucca Mountain EIS:

> DOE's approach to the loss of institutional controls at a dry cask storage facility was provided in its Yucca Mountain EIS (DOE 2008). In its analysis, DOE found that the loss of institutional controls resulted in catastrophic impacts for several resource areas.[107]

[106] DOE 2002, Vol. II, Appendix K, p. K-35
[107] NRC 2013a, footnote 2, pp. 1-14 and 1-15

7.3. The 2008 Yucca Mountain EIS, which is a supplement to the DOE's 2002 Yucca Mountain EIS (DOE 2002), estimates that in case of loss of institutional control there would be 1,000 "latent" cancer fatalities in the first 10,000 years and a hundred times more in the period up to a million years after that – though it considers the latter figure to be very uncertain. The impact in the longer time frame is estimated to be the result of "the unchecked deterioration and dissolution of the materials." The document describes these impacts as "catastrophic."[108]

7.4. While I agree with DOE 2008 that the impacts of the loss of institutional control in case of indefinite onsite storage would be catastrophic, I also note that the DOE *deliberately underestimated the impacts in this scenario*. It did so because it did not want to overstate the relative environmental benefits of deep geologic disposal at Yucca Mountain, its preferred alternative, compared to the no-action alternative. Without any implications as to the overall merits of the Yucca Mountain EIS or the DOE's license application, DOE's approach to the loss of institutional control was reasonable. If the underestimated impacts of the no action alternative are much greater than those of the preferred action, it allows a technical case to be made for the preferred action, which was, after all, the goal of that EIS. However, for the waste confidence GEIS, such an underestimation is not permissible, since the court has explicitly asked it to estimate the impacts in case a repository never becomes available. This requires as full and complete estimation of impacts as reasonably as possible.

7.5. I provide some examples of impacts that were ignored in the Yucca Mountain EIS loss of institutional control scenario that must be included in the waste confidence GEIS.

7.6. The DOE "did not attempt to quantify adverse health impacts from chemical toxicity of the waste forms (principally uranium dioxide and *borosilicate glass*) that could occur within the exposed population."[109]

7.7. The DOE did not quantify some of the most critical ecosystem and economic impacts of the deterioration of containers in storage after institutional control is lost, but noted the following:

> Under Scenario 2 [no institutional control after 100 years], more than 20 major waterways of the United States (for example, the Great Lakes, the Mississippi, Ohio, and Columbia rivers, and many smaller rivers along the Eastern Seaboard) that currently supply domestic water to 30.5 million people would be contaminated with radioactive material. The shorelines of these waterways would be contaminated with long-lived radioactive materials (plutonium, uranium, americium, etc.) that would result in exposures to individuals who came into contact with the sediments, potentially increasing the number of latent cancer fatalities.[110]

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[108] DOE 2008, p. S-51. We note here that in the 2002 EIS to which DOE 2008 is a supplement, the DOE estimated latent cancer fatalities in the first 10,000 years as 3,300. (DOE 2002, Vol. II, Appendix K, p. K-28)

[109] DOE 2002, Vol. I, p. 7-35, emphasis in original

[110] DOE 2002, Vol. II, Appendix K, p. K-29

7.8. When food pathways other than drinking water are considered, the DOE estimated that the radiation doses and, hence, fatalities would triple.[111] The impact of dispersed waste on vast aquifers, areas of land, and the country's most important rivers that could not be used again because of contamination was not explored in detail. The Fukushima accident that began on March 11, 2011 has shown that the economic, social, and ecological impacts of the spread of radiation contamination are far larger than indicated by a narrow view of latent cancer fatalities alone.

7.9. The Yucca Mountain EIS was completed before any physical evaluation of high burnup fuel that had been in dry storage for any length of time. This aspect needs to be included in the waste confidence GEIS.

7.10. Climate change uncertainties were not evaluated in the Yucca Mountain EIS No-Action Alternative.

7.11. In conclusion, the impacts from a failure of institutional controls are likely to be catastrophic – much more so than estimated in the Yucca Mountain EIS. Since a failure of institutional controls over millennia is reasonably foreseeable, given the facts of world and U.S. history, the NRC must realistically analyze those impacts.

8.0 THE DRAFT GEIS DOES NOT SUPPORT THE NRC'S PROPOSED FINDINGS REGARDING THE FEASIBILITY AND SAFETY OF DEEP GEOLOGIC DISPOSAL OF SPENT FUEL.

8.1. In proposed 10 CFR 51.32(a)(2)(ii), the NRC proposes to make the following finding:

> (2) The analysis in NUREG-2157 supports the Commission's determinations that it is feasible to:
> …
> (ii) have *a* mined geologic repository within 60 years following the licensed life for operation of *a* reactor.[112]

8.2. The NRC's proposed finding that it is feasible to "have *a* mined geologic repository within 60 years following the licensed life for operation of *a* reactor"[113] is so vague and incomplete that it is essentially meaningless. It is also unsupported in a number of respects. Specifically, the proposed finding is about "a mined repository" – the indefinite article is used. Will it have enough capacity to accommodate all spent fuel from all reactors? Could it safely accommodate all types of spent fuel, including failed high burnup spent fuel? The proposed rule does not say.

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[111] DOE 2002, Vol. II, Appendix K, p. K-29 and K-32
[112] NRC 2013b, p. 56804; italics to the indefinite article "a" added in two places
[113] NRC 2013b, p. 56776, italics added to both indefinite articles

8.3. The failure of the proposed rule to assure that sufficient repository capacity will be available is contrary to the prior waste confidence assertion in the 2008 version of 10 CFR 51.23, which stated:

> Further, the Commission believes there is *reasonable assurance* that *at least one* mined geologic repository will be available within the first quarter of the twenty-first century, and *sufficient repository capacity* will be available within 30 years beyond the licensed life for operation of any reactor to dispose of the commercial high level waste and spent fuel originating in such reactor and generated up to that time.[114]

8.4. The proposed rule's assertion of the feasibility of a repository does not guarantee that there will be a repository with sufficient capacity to accommodate all the spent fuel envisioned. Moreover, the Draft GEIS proposes no upper limit to spent fuel. On the contrary, it includes reactors beyond the existing ones, including new reactor designs such as small modular reactors. The NRC's conclusion that "a" repository is feasible does not provide any assurance that spent fuel from all reactors covered by the Draft GEIS will find space in it.

8.5. Every geologic location would have some limit to the amount of spent fuel it can hold due to considerations such as the faults running through the site, natural resources availability, etc. Yucca Mountain, for instance, had a legal limit of 70,000 metric tons (equivalent) of commercial and military waste. Proponents of disposal there argued that the technical limits could be much greater. But no one, so far as I am aware, has asserted that there was no technical limit. Such a limit was considered, for instance, in a paper by Professor Per Peterson of the University of California at Berkeley in the context of a prospective increase in nuclear reactor orders in 2003. He argued that the technical capacity of Yucca Mountain could be increased.

> This [analysis] suggests a minimum "technical" site capacity of approximately 75 x 2,000 = 150,000 MT of spent fuel, with a maximum site capacity greater by perhaps a factor of two or three. *Thus any substantial construction of new U.S. nuclear power infrastructure in the coming decades will almost certainly create a technical requirement (perhaps as soon as 2030 to 2050) either for additional repositories or for the construction of infrastructure for recycling spent fuel*.[115]

Thus, one of the most prominent authorities on nuclear power and nuclear waste in the United States,[116] has opined that, in the absence of reprocessing, a second repository may be needed in the United States – and would "almost certainly" be needed in the event of a nuclear power resurgence. In this context, it is important to note that this entire exercise is part of the process of licensing new reactors or extending the licenses of existing reactors. Cost is therefore a very material consideration. Long-term storage (or longer) followed by disposal in one repository could add up to between $214 billion and $351 billion. A second repository could add $34

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[114] 10 CFR 51 2008, at 51.23(a); italics added
[115] Peterson 2003, italics added
[116] Professor Peterson was a member of the Blue Ribbon Commission on America's Nuclear Future which delved into the problem of spent fuel at the behest of then Energy Secretary Steven Chu.

billion to $171 billion.[117] These are huge sums of money. The NRC must take these into account when assessing the reasonableness of its assumptions regarding long-term storage followed by disposal – or indefinite storage, which would be even more expensive.

8.6. The proposed rule neither puts limits on spent fuel nor assures that there will be sufficient room to dispose of all spent fuel that may arise, including as a result of the government's own actions to promote nuclear energy. Unless there is a specific and reasonable assurance in this regard based on technical and social reality, then spent fuel may well be stranded at reactor sites essentially forever. It is also possible to envisage a case where there is one repository that is insufficient. In that case, there would be impacts both from disposal as well as impacts from indefinite storage at reactors of a part of the spent fuel inventory.

8.7. The Draft GEIS has a section on the issue of repository technical feasibility (Section B.2.1) and one entitled "Availability of Repository Capacity" (Section B.2.2).[118] These sections appeal to the international consensus that repositories are feasible, to the Waste Isolation Pilot Plant (WIPP) in New Mexico, where transuranic wastes generated by the nuclear weapons program of the Department of Energy are being disposed of, and to the Swedish and Finnish Programs. We consider each of these in turn to show that they are, singly or together, insufficient to establish feasibility in the sense that there will be a repository that will meet specified safety standards and that it will have sufficient capacity.

8.8. We note first of all that Yucca Mountain has not been licensed. The State of Nevada raised a host of technical issues[119] before the DOE informed the NRC that it was withdrawing its application. Yucca Mountain therefore cannot be used to assert repository feasibility, in the sense of meeting the standard that the EPA set forth in 40 CFR 197.

8.9. The proposed changes to 10 CFR 51, Table B-1, make reference to the Yucca Mountain standards as follows:

> For the high-level waste and spent-fuel disposal component of the fuel cycle, the EPA established a dose limit of 15 millirem (0.15 mSv) per year for the first 10,000 years and 100 millirem (1.0 mSv) per year between 10,000 years and 1 million years for offsite releases of radionuclides at the proposed repository at Yucca Mountain, Nevada.
>
> The Commission concludes that the impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR part 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the impacts of spent fuel and high level waste disposal, this issue is considered Category 1.

[117] Cooper 2013. Exhibit MNC-4, p. 25
[118] NRC 2013a, p. B-2 and p. B-4
[119] See *U.S. Department of Energy (High-Level Waste Repository)*, LBP-09-06, 69 NRC 367, aff'd in part and rev'd in part, CLI-09-14, 69 NRC 580 (NRC 2009).

8.10. The second paragraph in the quote from Table B-1 above does not follow the first. The existence of a standard does not provide any assurance or even any indication of the actual performance of the site. Indeed, it is a *non sequitur*.

8.11. The appeal to WIPP does not provide much assurance. As noted, in paragraph 3.5, the NRC itself has repudiated a salt repository for spent fuel.

8.12. The Finnish and Swedish repository programs are more advanced than those in other countries. However, it should be noted that both these counties have very small amounts of spent fuel compared to the United States. Sweden has just ten reactors, with nuclear energy production at about eight percent of the United States. Finland has just four with production, about three percent of the United States.[120] As noted in paragraph 8.5 above, even one very large repository, accommodating hundreds of thousands of tons of spent fuel may not be sufficient under a nuclear power resurgence scenario. Moreover, size matters, because the larger the repository that is needed, the more constrained the choices for locating it are likely to be. A smaller capacity at a particular site could well mean two repositories.

8.13. Showing feasibility in the context of the U.S. power program that may expand considerably beyond the present level means showing that sufficient capacity will exist for all reactors that may be built. It is not enough to say that there will be "a" repository 60 years after the license expiry of "a" reactor. The NRC must specify the amount of spent fuel to be disposed of and show that there will be sufficient capacity to dispose of all of the spent fuel in a manner that would comply with reasonable safety standards. The Draft GEIS has not done that.

8.14. The Draft GEIS has considered questions of technical feasibility without actually examining the impact of spent fuel disposal in a repository. This is essential for a waste confidence finding. For instance, the original waste confidence finding in 1978 was connected to Table S-3 in 10 CFR51.51. The latter assumed zero impact after repository closure because the former assumed disposal in bedded salt.[121] We show below, in paragraph 8.22 that the NRC itself now acknowledges that radiation doses would, or at least could, be well above zero and even above the Yucca Mountain EPA standard of 100 millirem per year in 40 CFR 197. It is essential that a new waste confidence finding in regard to the feasibility of a repository be based on a contemporary understanding and actual scientifically valid estimates of radiation doses that might be expected at different sites in the United States.

8.15. The NRC was explicit about the exclusion of repository impacts in its response to public comments on the scope of the GEIS:

> The NRC received comments related to spent nuclear fuel disposal. Spent nuclear fuel disposal is outside the scope of the Waste Confidence analysis, which will consider the environmental impacts of continued storage prior to ultimate disposal. The development of a national repository, the licensing of Yucca

[120] NRC Information Digest 2013, Appendix T

[121] We note below in paragraph 8.21 that this was shown to be incorrect five years later in 1983, but it was the NRC's understanding in 1978 when the waste confidence rule was issued. The NRC's understanding today is that radiation doses to the public could be well above the zero exposure assumed in Table S-3.

> Mountain or another repository site*, environmental impacts associated with disposal in a repository*, funding issues, recycling, and other waste disposal strategies *are outside the scope of this GEIS*.[122]

8.16. Two of the three scenarios in the Draft GEIS involve repository disposal. It is essential at least for the NRC to demonstrate in the GEIS that one or more sites with sufficient capacity exist in the United States that would likely meet reasonable health and safety rules.

8.17. The NRC itself has recognized the interrelated nature of spent fuel storage and disposal impacts in the recent License Renewal Rule.[123] In Table B-1, the NRC declared that the impacts of spent fuel disposal are "uncertain" and that "[t]he generic conclusion of offsite radiological impacts of spent nuclear fuel and high-level waste is not being finalized pending the completion of a generic environmental impact statement on waste confidence."[124] In a footnote, the NRC explained:

> As a result of the decision of United States Court of Appeals in *New York* v. *NRC,* 681 F.3d 471 (DC Cir. 2012), the NRC cannot rely upon its Waste Confidence Decision and Rule until it has taken those actions that will address the deficiencies identified by the D.C. Circuit. *Although the Waste Confidence Decision and Rule did not assess the impacts associated with disposal of spent nuclear fuel and high-level waste in a repository, it did reflect the Commission's confidence, at the time, in the technical feasibility of a repository and when that repository could have been expected to become available.* Without the analysis in the Waste Confidence Decision and Rule regarding the technical feasibility and availability of a repository, the NRC cannot assess how long the spent fuel will need to be stored onsite.[125]

As the Commission acknowledges, the question of feasibility of spent fuel disposal is integrally related with the question of what are the environmental impacts of spent fuel storage for an indeterminate period of time. By evaluating only spent fuel storage impacts, the NRC excludes a major part of the picture regarding the environmental impacts of the back end of the nuclear fuel cycle. Specifically, if a repository becomes available, some spent fuel storage impacts will be avoided, and there will be some repository impacts. Similarly, if there is no repository, the spent fuel storage impacts will increase considerably, for a variety of reasons, including the potential loss of institutional control.

8.18. Before discussing the inadequacy of Table S-3 to support an environmental analysis of spent fuel disposal impacts, I will provide some background information. Table S-3 is based on WASH-1248, Environmental Survey of the Uranium Fuel Cycle (1974).[126] The NRC also published a narrative explanation of the table in 1981. Table S-3 contains no numerical entry for an estimate of radiation releases from a geologic repository. Instead, the table makes two key assumptions: (i) that disposal of high-level waste resulting from reprocessing and/or of spent fuel

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[122] NRC Scoping 2013, p. 42; italics added
[123] 78 Fed. Reg., p. 37282 (June 20, 2013)
[124] 78 Fed. Reg., p. 37322 (June 20, 2013)
[125] 78 Fed. Reg., p. 37323 (June 20, 2013); italics added
[126] WASH-1248

will be in a bedded salt repository[127] and (ii) that post-closure releases from such a repository will be essentially zero. Footnote 1 in Table S-3 explains that "where no entry appears . . . the Table should be as if a specific zero entry had been made." Footnote 2 also refers to WASH-1248, which contains a more detailed version of Table S-3 stating that 0.005 curies per year of releases from the repository have been included in total for transuranic and fission product gaseous releases. WASH-1248 also contains further narrative explanation of the assumptions in Table S-3. According to WASH-1248:

> The most significant solid radiological waste consists of the fission products separated from the spent fuel of an annual fuel requirement in the reprocessing operation. These high level wastes will be stored onsite for a maximum of 10 yrs., and will ultimately be shipped, probably by rail, to a Retrievable Surface Storage Facility (RSSF). The RSSF will be established to store and manage high level solid wastes under constant surveillance for up to 100 years, or until such time as a more permanent Federal repository can be established. The facility will be designed to prevent the release of significant amounts of radioactive material to the environment under all credible environmental conditions and human actions. *Therefore, such waste will not be released as effluents to the environment.*[128]

8.19. The same assumption of essentially zero release and zero impact has evidently been applied to spent fuel as well. The NRC's 1981 background information on Table S-3 affirms this:

> It has been assumed that spent fuel or high-level wastes will be disposed of in a geologic, bedded salt repository. Operation of repository facilities is similar for both spent fuel and high level waste, and *it has been assumed that a repository in bedded salt will be designed and operated so as to retain the solid radioactive waste indefinitely*. However, the radiological impacts related to the geologic disposal of spent fuel are based on the assumption that all gaseous and volatile and [sic] radionuclides in spent fuel are released before the geologic repository is sealed. Since the gaseous and volatile radionuclides are the principal contributors to environmental dose commitments, this assumption umbrellas the upper bounds of the dose commitments that may be associated with the disposal of spent fuel.[129]

8.20. Table S-3 is inadequate, incorrect, or obsolete in a number of respects. First, it assumes disposal in bedded salt; this assumption is obsolete. The NRC itself has ruled out disposal of spent fuel in salt formations on grounds of possible instability during repository operation:

> Although there are relative strengths to the capabilities of each of these potential host media [i.e., crystalline rock, clay, and salt], no geologic media previously identified as a candidate host, **with the exception of salt formations for SNF, has been ruled out based on technical or scientific information**. Salt formations are being considered as hosts only for reprocessed nuclear materials

[127] Table S-3 does not explicitly mention salt; that is in the background information, as noted in paragraph 8.19.
[128] WASH-1248, p. S-23, italics added
[129] 46 Fed. Reg., p. 15154 (March 4, 1981) Section II.1, italics added

> because heat generating waste, like SNF, exacerbates a process by which salt can rapidly deform. This process could cause problems with keeping drifts stable and open during the operating period of a repository.[130]

8.21. Second, Table S-3's assumption that disposal of spent fuel or high-level waste in bedded salt will result in zero releases (and hence zero radiation doses to the public after repository closure) has been shown to be incorrect as a generic conclusion. The most comprehensive review of radiation releases and radiation doses to the public from deep geologic disposal in a variety of geologic settings was done following the passage of the Nuclear Waste Policy Act (NWPA) in a 1983 study by the National Research Council of the National Academies.[131] This study was commissioned by the Department of Energy. It shows that there is a risk of significant radiation doses[132] in all geologic media that were quantitatively examined, *including bedded salt*.[133] More recent assessments have confirmed that there is a risk of significant radiation releases and doses from a variety of geologic media. The NRC's assumption of zero releases and radiation doses from deep geologic disposal is therefore incorrect for both high-level waste and spent fuel even for bedded salt repositories.

8.22. The NRC itself has conceded for well over a decade that the assumption of zero releases and zero doses for geologic disposal in Table S-3 is incorrect. It has not done so in so many words, but it has admitted in other regulatory contexts that radiation doses to the public would not be zero. In 1996, in the first license renewal GEIS (NUREG-1437), the NRC abandoned the zero-release, zero-dose assumption of Table S-3:

> For the high-level-waste and spent-fuel disposal component of the fuel cycle, there are no current regulatory limits for off-site releases of radionuclides for the candidate repository site at Yucca Mountain. If we assume that limits are developed along the lines of the 1995 National Academy of Sciences (NAS) report, *Technical Bases for Yucca Mountain Standards*, and that, in accordance with the Commission's Waste Confidence Decision, 10 CFR 51.23, a repository can and likely will be developed at some site that will comply with such limits, peak doses to virtually all individuals will be 100 mrem/year or less. While the Commission has reasonable confidence that these assumptions will prove correct, there is considerable uncertainty because the limits are yet to be developed, no repository application has been completed or reviewed, and uncertainty is inherent in the models used to evaluate possible pathways to the human environment. The National Academy report indicates that 100 mrem/year should be considered as a starting point for limits for individual doses, but notes that some measure of consensus exists among national and international bodies that the limits should be a fraction of the 100 mrem/year. The lifetime individual risk from 100-mrem/year dose limit is about $3x10^{-3}$.

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130 NRC 2010a, p. 81059, emphasis added

131 NAS-NRC 1983, Chapter 9. Bedded salt radiation dose estimates are shown in Figure 9-5 (p. 262).

132 I define "significant" doses in this context as being comparable to or greater than those defined in 40 CFR 190.10(a), which limits doses to the public from uranium nuclear fuel cycle operations.

133 See Chapter 9 of NAS-NRC 1983. Bedded salt radiation dose estimates are shown in Figure 9-5 (p. 262).

> Estimating cumulative doses to populations over thousands of years is more problematic.[134]

8.23. As the above quote in paragraph 8.22 shows, the NRC cannot even assure that doses will remain limited to 100 millirem per year, the current annual limit in 10 CFR 20, much less any more stringent limit that is recommended by "national and international bodies."

8.24. In addition, Table S-3 does not cover MOX fuel use, though the waste confidence rule purports to cover it.[135] It is clear that Table S-3 does not give the NRC the basis for a waste confidence statement that includes MOX spent fuel.

9.0 THE DRAFT GEIS SHOULD ACKNOWLEDGE THAT CERTAIN IMPACTS CANNOT BE ANALYZED IN A GENERIC MANNER.

9.1. The Draft GEIS claims to have considered site specific issues sufficiently to draw generally applicable conclusions regarding waste confidence so that such issues could not be brought up during reactor or specific storage facility licensing cases.[136]

9.2. I would agree that some impacts are generic and can, given adequate data, be bounded on that basis. This is the case, for instance, with the on-site impacts of transferring spent fuel from one cask to another. But other issues cannot be analyzed in a generic manner. This is because different kinds of impacts are incommensurate with each other. Therefore, it is necessary to have a bounding analysis for each major type of impact. I provide several examples in the following paragraphs.

9.3. Consider, for instance the Draft GEIS claim that a generic analysis would suffice for environmental justice issues:

> In the present case, however, the NRC has determined that it can provide an assessment of the environmental justice impacts during continued storage compared to environmental justice impacts of storage during reactor operations. …[T]his draft GEIS and the Waste Confidence rule are not licensing actions and do not authorize the continued storage of spent fuel. The environmental analysis in this draft GEIS fulfills a small part of the NRC's NEPA obligation with respect to the licensing or relicensing of a nuclear reactor or spent fuel storage facility. Further, the site-specific NEPA analysis that is required prior to an NRC licensing action will include a discussion of the impacts on minority and low income populations, and will appropriately focus on the NRC decision directly related to specific licensing actions. As with all other resource areas, this site-specific analysis will allow the NRC to make an impact determination with respect to

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[134] NUREG-1437 (1996), p.6-19
[135] NRC 2013a, p. xxix
[136] NRC 2013a, p. xxiv

> environmental justice for each NRC licensing action. *A generic determination of the human health and environmental effects impacts during continued storage is possible because the NRC understands* how the environmental impacts change when a nuclear power plant site transitions from reactor operations to continued storage. Based on this knowledge, the NRC can provide an assessment of the potential human health and environmental effects during continued storage. As discussed in the following sections, the NRC has determined that the human health and environmental effects from continued storage would be small compared to the impacts that are normally experienced during reactor operations.[137]

But once a determination is made that spent fuel storage impacts are small even for indefinite storage, they cannot be raised in a site-specific licensing process even if they were not considered in the waste confidence GEIS.

9.4. Take the example of the storage of spent fuel at the Columbia Generating Station in Washington State. A realistic analysis, including loss of institutional control, indicates that there would likely be catastrophic impacts that would contaminate Columbia River and its fish, including salmon. Indefinite storage would have devastating cultural and environmental justice impacts that could no longer be brought up for that site once a generic determination is made regarding the safety of indefinite storage. The tribes who have Columbia River-related rights would be precluded from bringing up the issue for any future new reactor or storage licenses or license extensions. The Draft GEIS does mention plants of special significance in the vicinity of the Prairie Island reactors, but provides no specific impact analysis in case of indefinite storage and dispersal of radioactivity or in case of severe accidents with high burnup failed spent fuel bundles.

9.5. The NRC's statement quoted above is an attempt to foreclose any consideration of radiation-related environmental justice site-specific issues, especially those associated with long-term or indefinite storage of spent fuel, notably in case of a failure to site a repository and indefinite on-site storage.

9.6. Health and property damage impacts provide another example. The Draft GEIS acknowledges that population densities are highly variable and that the environs of the Indian Point nuclear plant has the highest density of all. Yet, the consequences of a spent fuel pool fire are considered for the Surry plant, where the density is much lower. Moreover, the analyses cited are all more than a decade old and cannot therefore reflect the impact of growing amount of high burnup fuel in spent fuel pools.[138] It is possible to bound impacts of such accidents by focusing on high density population sites with high property value concentrations. But the Draft GEIS has not done this.

9.7. Impacts on river systems may be bounded by sites that are quite different in character. For instance, large scale dispersal of radioactivity from spent fuel storage at Prairie Island could

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[137] NRC 2013a, p. 4-11, italics added

[138] NRC 2013a, Appendix F, Table F-2 (p. F-8). The most recent document cited in the notes to this table dates from 2002.

create long-term damage to the entire Mississippi River system, including agricultural lands around it, cities that are vulnerable to flooding on its shores, barge traffic that is a major artery of commerce, and so on. Agricultural impacts alone may be bounded by sites like Fort Calhoun in Nebraska or Duane Arnold in Iowa. Such impacts would be especially important to evaluate in the case of long-term storage and indefinite storage accompanied by loss of institutional control.

9.8. It is impossible to bound critical ecological impacts in a generic manner. They will require site specific discussion. For instance, the Calvert Cliffs reactors in Maryland are situated in one of the most sensitive and unique ecosystems of the United States – the Chesapeake Bay. The impacts of a major radioactivity release into the Chesapeake Bay ecosystem are likely to be quite different than those of a similar release at Turkey Point in Florida, which has barrier islands and Biscayne National Park a few miles away or Diablo Canyon, in California, where a major release could severely impact oceanic ecosystems. It is important to remember in this context that the inventory of long-lived radioactivity in spent fuel pools in the United States is generally far larger than that in Chernobyl Unit 4, which had a severe accident and radioactivity releases in 1986. It is essential for the waste confidence GEIS to analyze critical ecosystem impacts on a site specific basis unless it can classify sites based on types of ecosystems and address bounding impacts for similar sites.

9.9. From the above examples, it is clear that the NRC should create a list of site-specific issues that are excluded from the purview of the GEIS and therefore could be brought up in individual licensing cases. In the alternative, it must show that it has bounded the impacts in a generic manner for each type of impact. This is especially important for long-term storage and indefinite storage with loss of institutional control. A GEIS must include bounding estimates for (i) the number of cancers attributable in case of a worst case release of radionuclides; (ii) the worst case damage to riverine ecosystems, such as the Mississippi River or the Columbia River; (iii) the worst case loss of agricultural land and production; (iv) the ecosystem damage to each unique ecosystem, including the Chesapeake Bay, the Mississippi River Delta, the Columbia River, and oceanic ecosystems, and (v) the worst case property damage. These evaluations should include not just today's source terms but the projected source terms based on the dates of the expiry of the licenses and the total accumulated spent fuel at that time.

10.0 SUMMARY AND CONCLUSIONS

10.1. The Draft GEIS fails to provide a detailed quantitative analysis of the impacts to public health and the environment that would occur in the event of an accidental release of radiation during spent fuel storage or transfer. Given the high level of radioactivity in spent fuel, the very long half-lives of certain radioactive materials (including plutonium-239 and long-lived fission products with half-lives that range from 30 years to millions of years), and the high burnup of much of the spent fuel, these impacts could be substantial.

10.2. The Draft GEIS contains almost no information about spent fuel characteristics that could cause adverse safety risks and environmental impacts during long-term or indefinite storage. In other contexts, the NRC itself has acknowledged that it currently lacks sufficient information to reach informed conclusions about the behavior of spent fuel in storage over the long term. Yet, it failed to note the data gaps identified as recently as 2012 in its Draft GEIS. The NRC's amnesia regarding its own study undermines the credibility and integrity of the Draft GEIS. Little-understood factors affecting the safety of spent fuel storage include the degree to which spent fuel and its host canisters corrode and degrade over a prolonged period of time and the effect of high burnup fuel on the integrity of cladding and storage canisters. For instance, although high burnup fuel now makes up a significant portion of spent fuel inventories, there is no explicit consideration of long-term dry storage and disposal of failed high-burnup fuel. The NRC currently has little or no empirical data regarding its behavior under extended dry storage conditions. The Draft GEIS contains no analysis of how high burnup spent fuel characteristics may contribute to the risk of an accidental release of radioactivity during extended storage in pools, followed by long-term storage in dry casks. The one study of high burnup spent fuel degradation that the Draft GEIS cites (Billone et al. 2013) found that different high burnup fuel cladding material degrade at markedly different rates. The Draft GEIS took no account of this finding, which indicates that a generic analysis may not be sufficient to estimate impacts unless it is designed to be bounding, having taken such differences explicitly into account.

10.3. The Draft GEIS has made an unsupported assumption that institutional controls will remain effective indefinitely on the ground. An assumption that the federal government will be there to protect health and safety even thousands of years from the present is remote and speculative. On the contrary, global and U.S. history shows that it is highly remote and speculative to assume institutional control for an indefinite period. It is also fundamentally inconsistent with federal law and policy (including NRC's own regulations) to assume that institutional controls will last forever. For instance, the NRC's low-level waste regulations assume that institutional controls will last no more than 100 years and that physical barriers to intruders will last no more than 500 years. To assume that the federal government will exist for tens of millennia and each year appropriate significant sums of money to manage spent fuel at sites that produce no revenue flies in the face of current facts and U.S. history, including a dozen federal government shut downs since 1980, not to speak of the Civil War, when the United States did not have a single government, budget, or currency.

10.4. Even under the assumption of institutional controls for an indefinite period, the Draft GEIS fails to address the expense of those measures, the risk that they may fail, and how such costs and risks may impact reactor licensing and license extension decisions.

10.5. The question of feasibility of spent fuel disposal is integrally related with the questions of the health and safety standards for disposal and whether any specific repository can comply with them. The Draft GEIS did not evaluate disposal impacts. By excluding them from its scope, the NRC has excluded a major part of the picture regarding the environmental impacts of the back end of the nuclear fuel cycle.

10.6. The Draft GEIS has failed to demonstrate the feasibility of a repository in the sense of showing that there is a site in the United States that will meet safety standards with reasonable assurance. Nor has it demonstrated that there will be sufficient repository capacity, especially given that the Draft GEIS puts no quantitative limits on how much spent fuel can be produced under the proposed waste confidence rule. Persuasive arguments can be made that two repositories may be needed if there is a resurgence of nuclear power. Appeals to repository programs in Sweden and Finland do not resolve this issue – their nuclear power programs are very small compared to the United States and therefore involve a small amount of spent fuel. Costs of long-term storage and disposal could run into hundreds of billions of dollars.

10.7. The NRC has no valid environmental analysis on which it can rely for an evaluation of spent fuel disposal impacts. Table B-1 cites the EPA Yucca Mountain standard, which does not apply to any other repository. Moreover, since the licensing proceeding for Yucca Mountain is far from complete (if it is ever completed); so it is not clear that Yucca Mountain would meet the required performance specified in 40 CFR 197. The proposed rule simply refers to the rule and asserts "that the impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR part 54 should be eliminated."[139] This is a non sequitur. It is much like saying that the existence of a law against drunken driving allows one to conclude that the impacts of drunken driving would in fact not be large enough to worry about.

10.8. The other regulation that covers high-level waste disposal impacts is Table S-3 at 10 CFR 51.51. But this table is invalid for estimating high-level waste disposal impacts. Among other things, its underlying assumption of disposal in a bedded salt repository was repudiated by the NRC itself. Therefore, the NRC must prepare a new analysis in the context of its waste confidence decision.

10.9. While some storage impacts can reasonably be addressed on a generic basis, there are many that cannot. At the very least, it is essential for the NRC to group incommensurate site-specific impacts by category, such as high population density areas, reactors on rivers that could affect large populations living along those rivers, and so on.

10.10. In view of the above, it is my conclusion that the NRC lacks a factual and scientific basis for a finding of confidence that spent fuel can be safely stored for the long-term, much less indefinitely. The NRC also lacks a factual and scientific basis for a finding of confidence that spent fuel can be disposed of safely within acceptable, legally binding health and safety standards. In fact, the available evidence suggests that both long-term storage and disposal of spent fuel could pose significant safety and environmental risks. The NRC should prepare a new Draft GEIS that meaningfully examines these risks.

10.11. The Draft GEIS should have a no-action alternative of not issuing any further licenses or license extensions for reactors or for spent fuel storage at least until the basis to do a scientifically valid GEIS exists in the area of high burnup fuel. At present the NRC lacks the factual and analytical basis to do so in a number of areas. This should be the preferred alternative.

10.12. The Draft GEIS should be redone to remedy a number of fundamental defects. Among other things, it is necessary to include a scenario that posits indefinite storage and loss of institutional control 100 years after the end of reactor operating licenses.

[139] NRC 2013b, p. 56805

10.13. The Draft GEIS must evaluate the increasing likelihood of theft after loss of institutional control and a decay of the cesium-137 radiation barrier after 200 to 300 years. It must also evaluate the environmental and proliferation consequences of such theft.

10.14. In view of the lack of factual and analytical basis for assessing the impacts of long-term or indefinite storage of high burnup spent fuel, the NRC should not permit the further production of high burnup spent fuel until such a time that it is able to evaluate the long-term spent fuel management issues related to that fuel.

10.15. I have also concluded that it will be necessary to carve out a number of issues for site specific consideration unless the NRC considers groups of sites and specific types of impacts in this GEIS. No single generic analysis can cover the issues presented by indefinite storage onsite.

The facts presented above are true to the best of my knowledge and the opinions contained herein represent my best professional judgment.

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Dr. Arjun Makhijani
Originally Submitted: December 20, 2013
Corrected Declaration Submitted: January 7, 2014

11.0 REFERENCES

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INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

6935 Laurel Avenue, Suite 201
Takoma Park, MD 20912

Phone: (301) 270-5500
FAX: (301) 270-3029
e-mail: ieer@ieer.org
http://www.ieer.org

Curriculum Vita of Arjun Makhijani

Address and Phone:
Institute for Energy and Environmental Research
6935 Laurel Ave., Suite 201
Takoma Park, MD 20912
Phone: 301-270-5500
e-mail: arjun@ieer.org
Website: www.ieer.org

A recognized authority on energy issues, Dr. Makhijani is the author and co-author of numerous reports and books on energy and environment related issues, including two published by MIT Press. He was the principal author of the first study of the energy efficiency potential of the US economy published in 1971. He is the author of *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy* (2007).

In 2007, he was elected Fellow of the American Physical Society. He was named a Ploughshares Hero, by the Ploughshares Fund (2006); was awarded the Jane Bagley Lehman Award of the Tides Foundation in 2008 and the Josephine Butler Nuclear Free Future Award in 2001; and in 1989 he received The John Bartlow Martin Award for Public Interest Magazine Journalism of the Medill School of Journalism, Northwestern University, with Robert Alvarez. He has many published articles in journals and magazines as varied as *The Bulletin of the Atomic Scientists, Environment*, *The Physics of Fluids*, *The Journal of the American Medical Association*, and *The Progressive*, as well as in newspapers, including the *Washington Post*.

Dr. Makhijani has testified before Congress, and has appeared on ABC World News Tonight, the CBS Evening News, CBS 60 Minutes, NPR, CNN, and BBC, among others. He has served as a consultant on energy issues to utilities, including the Tennessee Valley Authority, the Edison Electric Institute, the Lawrence Berkeley Laboratory, and several agencies of the United Nations.

Education:

- Ph.D. University of California, Berkeley, 1972, from the Department of Electrical Engineering. Area of specialization: plasma physics as applied to controlled nuclear fusion. Dissertation topic: multiple mirror confinement of plasmas. Minor fields of doctoral study: statistics and physics.
- M.S. (Electrical Engineering) Washington State University, Pullman, Washington, 1967. Thesis topic: electromagnetic wave propagation in the ionosphere.

- Bachelor of Engineering (Electrical), University of Bombay, Bombay, India, 1965.

Current Employment:

- 1987-present: President and Senior Engineer, Institute for Energy and Environmental Research, Takoma Park, Maryland. (part-time in 1987).
- February 3, 2004-present, Associate, SC&A, Inc., one of the principal investigators in the audit of the reconstruction of worker radiation doses under the Energy Employees Occupational Illness Compensation Program Act under contract to the Centers for Disease Control and Prevention, U.S. Department of Health and Human Services.

Other Long-term Employment

- 1984-88: Associate Professor, Capitol College, Laurel, Maryland (part-time in 1988).
- 1983-84: Assistant Professor, Capitol College, Laurel, Maryland.
- 1977-79: Visiting Professor, National Institute of Bank Management, Bombay, India. Principal responsibility: evaluation of the Institute's extensive pilot rural development program.
- 1975-87: Independent consultant (see page 3 for details)
- 1972-74: Project Specialist, Ford Foundation Energy Policy Project. Responsibilities included research and writing on the technical and economic aspects of energy conservation and supply in the U.S.; analysis of Third World rural energy problems; preparation of requests for proposals; evaluation of proposals; and the management of grants made by the Project to other institutions.
- 1969-70: Assistant Electrical Engineer, Kaiser Engineers, Oakland California. Responsibilities included the design and checking of the electrical aspects of mineral industries such as cement plants, and plants for processing mineral ores such as lead and uranium ores. Pioneered the use of the desk-top computer at Kaiser Engineers for performing electrical design calculations.

Professional Societies:

- Institute of Electrical and Electronics Engineers and its Power Engineering Society
- American Physical Society (Fellow)
- Health Physics Society
- American Association for the Advancement of Science

Awards and Honors:

- The John Bartlow Martin Award for Public Interest Magazine Journalism of the Medill School of Journalism, Northwestern University, 1989, with Robert Alvarez
- The Josephine Butler Nuclear Free Future Award, 2001
- Ploughshares Hero, Ploughshares Fund, 2006
- Elected a Fellow of the American Physical Society, 2007, "*For his tireless efforts to provide the public with accurate and understandable information on energy and environmental issues*"
- Jane Bagley Lehman Award of the Tides Foundation, 2007/2008

Advisory Council, Maryland Clean Energy Center, 2013

***Committee Member, Radiation Advisory Committee, Science Advisory Board, U.S. Environmental Protection Agency,* 1992-1994**

Invited Faculty Member, Center for Health and the Global Environment, Harvard Medical School: Annual Congressional Course, *Environmental Change: The Science and Human Health Impacts*, April 18-19, 2006, Lecture Topic: An Update on Nuclear Power - Is it Safe?

Consulting Experience, 1975-1987
Consultant on a wide variety of issues relating to technical and economic analyses of alternative energy sources; electric utility rates and investment planning; energy conservation; analysis of energy use in agriculture; US energy policy; energy policy for the Third World; evaluations of portions of the nuclear fuel cycle.

Partial list of institutions to which I was a consultant in the 1975-87 period:

- Tennessee Valley Authority
- Lower Colorado River Authority
- Federation of Rocky Mountain States
- Environmental Policy Institute
- Lawrence Berkeley Laboratory
- Food and Agriculture Organization of the United Nations
- International Labour Office of the United Nations
- United Nations Environment Programme
- United Nations Center on Transnational Corporations
- The Ford Foundation
- Economic and Social Commission for Asia and the Pacific
- United Nations Development Programme

Languages: English, French, Hindi, Sindhi, and Marathi.

Reports, Books, and Articles (Partial list)

(Newsletter, newspaper articles, excerpts from publications reprinted in books and magazines or adapted therein, and other similar publications are not listed below)

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