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

Declaration of Dr. Arjun Makhijani Regarding the Scope of Proposed Waste Confidence 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 has been doing nuclear-related studies for about twenty-five years and is 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.

1.2. 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.

1.3. As demonstrated in my attached curriculum vitae (CV), I am qualified by training and experience as an expert in the fields of plasma physics, electrical engineering, nuclear engineering, and energy-related technology and policy issues. I have extensive professional experience and am qualified as an expert in radioactive waste disposal, standards for protection of human health from radiation, and the relative costs and benefits of nuclear energy and other energy sources. I have served as an expert witness in numerous lawsuits and testified on a variety of issues including releases of radioactivity from nuclear facilities. In addition to my CV, the following paragraphs provide information regarding my qualifications to address the issues regarding the environmental impacts of spent fuel storage and disposal.

1.3. Over more than 25 years, I have developed extensive experience with nuclear fuel cycle-related issues, including standards 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 other energy-related issues. 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.

1.4. An extensive part of my work has been to analyze various issues related to radioactive waste management, classification, and disposal. This includes studies on low-level waste, high-level waste, spent fuel disposal, geologic repositories, and research related to geologic repositories. I have studied radioactive waste in both the commercial and military sectors. I was the director of a team 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). 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 included an analysis of U.S. waste classification regulations. I am the principal author of an assessment of the radioactive waste management and disposal costs of depleted uranium from the National Enrichment Facility (2004 and 2005).

1.5. Between 1997 and 2002, I was on the expert team monitoring independent audits of the compliance of Los Alamos National Laboratory 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 have 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 have 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 on the EPA's Advisory Subcommittee on cleanup standards, which was part of the National Advisory Committee on Environmental Policy and Technology. In addition, I have served as an expert consultant to numerous organizations.

1.6. 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 on *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 have 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), which is, to the best of my knowledge, 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. I have 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 in 2007, an honor granted to at most one-half of one percent of APS members.

1.7. 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.

1.8. 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.

1.9. I have reviewed the NRC's 2010 "Waste Confidence Decision Update"[1] and prepared expert comments on the NRC's 2008 Proposed Waste Confidence Decision Update.[2] I have also reviewed the NRC's 2010 final rule: "Consideration of Environmental Impacts of Temporary Storage of Spent Fuel After Cessation of Reactor Operation."[3] In addition, I am familiar with the NRC's uranium fuel cycle rule and relevant associated reference documents. And I am familiar with relevant aspects of governing law and guidance, including the National Environmental Policy Act and relevant NRC implementing regulations.

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 scope of the Environmental Impact Statement (EIS) it has proposed to prepare in response to the June 8, 2012, decision of the United States Court of Appeals for the District of Columbia in *State of New York v. NRC*.[4] In response to the NRC's Federal Register notice seeking comments on the scope of the EIS (Scoping Notice), my declaration provides my expert opinion regarding the scope of the EIS that is necessary to address the environmental impacts of long-term and perhaps indefinite storage of spent reactor

[1] NRC 2010a
[2] NRC 2008, Makhijani 2009
[3] NRC 2010b
[4] U.S. Court of Appeals 2012 pp. 6, 7, and 21

fuel.[5] To briefly summarize my declaration, I believe the scope of the EIS should include two major issues that are not addressed in the Scoping Notice: (i) the impacts of storing spent fuel for a total period of 300 years followed by transportation to a repository location and (ii) the impacts of disposing of spent fuel in a deep geologic repository. It is also my expert opinion that the NRC currently lacks sufficient information to reach scientifically well-founded conclusions about either of these issues or about the effects of storage of high burnup spent fuel for prolonged periods, and that the NRC will not be able to gather it within the two-year time frame the NRC has provided for study of the environmental impacts of extended spent fuel storage. Finally, in my expert opinion there are a number of site-specific issues related to the long-term storage of spent fuel that are not susceptible to resolution in a generic analysis. Therefore, it is my conclusion that the NRC lacks a factual basis for a finding of confidence that spent fuel can be safely stored for an extended period or disposed of safely. Under the circumstances, it is imperative for the scope of the EIS to include consideration of the alternative of not re-issuing the Waste Confidence Rule and suspending all future licensing. This no-action alternative should also be the preferred alternative since it is the only technically supportable one given the scope of the information that is lacking for assessing environmental impacts of prolonged storage and of deep geologic disposal of spent fuel.

2.2. My declaration is organized as follows. In Section 3, I will discuss the major scenarios that should be addressed in the EIS. These include the environmental impacts of storing spent fuel for up to 300 years followed by disposal in a deep geologic repository. I will also identify the principal impacts of concern for a 300-year storage period: spent fuel degradation during prolonged storage; risks of transportation, handling, and storage of spent reactor fuel at a repository site; and loss of institutional controls. In Sections 4, 5, and 6, I will discuss the necessary scope of the EIS with respect to each of these principal impacts. In Section 7, I will discuss the need to evaluate the environmental impacts of spent fuel disposal in a repository. In Section 8, I will discuss the current availability of information to address the environmental impacts of extended spent fuel storage and disposal of spent fuel in a repository. In Section 9, I will discuss site-specific issues that are not amenable to resolution in a generic manner. Finally, in Section 10 I will discuss why it is my opinion that the NRC currently lacks a sufficient basis for a waste confidence finding or finding of no significant impact and therefore should suspend licensing and re-licensing of reactors until it has collected the necessary information. Section 11 contains a summary of the main points.

3.0 The EIS should analyze, in depth, various spent fuel storage scenarios, including the scenario that a repository does not become available until the middle of the 23rd century.

3.1. In the Scoping Notice, the NRC has stated that it would consider three scenarios for storage – one in which a repository is available in the middle of this century, one in which it is available at the end of this century, and one in which "no repository is made available by the end of this century."[6] It amplified this during the public meeting held on the scope of the EIS on

[5] NRC 2012d, pp. 65137, 65138.
[6] NRC 2012d, p. 65138.

November 14, 2012. Specifically, the NRC slides prepared for that meeting show the following "potential scenarios" in the EIS:

– Storage until a repository becomes available at the *middle* of the century
– Storage until a repository becomes available at the *end* of the century
– Continued storage in the event a repository is *not available*[7]

3.2. I concur that these three scenarios should be prepared, but with due attention to the technical details and constraints discussed in the rest of this declaration. Specifically, the first two of them will require that the NRC evaluate the impacts of transportation of spent fuel to a geologic repository, the impacts of handling and storage at that location, and the post-closure impacts of repository disposal, as discussed in Sections 5 and 7. Further, in the third scenario as specified in the scoping notice and in the November 14, 2012 slides should be taken to mean that no repository ever becomes available. This problem statement would be roughly similar to the No-Action Alternative in the DOE's Yucca Mountain EIS (DOE 2002) in which the DOE considered the problem of storage for up to 10,000 years in the absence of a geologic disposal option. However, would be scientifically incorrect to use the analysis and conclusions of the No-Action Alternative in the DOE's Yucca Mountain EIS for a variety of reasons, including those discussed in Sections 6 and 8 below.

3.3. It will not be sufficient to develop the three scenarios above. It is also essential to include one additional scenario in the scope of the proposed EIS, as discussed in the rest of this section.

3.4. In view of its admission that it could not estimate the date when a repository might become available, the NRC, in its Final Waste Confidence Rule, NRC raised the possibility that storage beyond sixty years may become necessary. In the Final Rule the NRC had expressed confidence in the safety of storage for up to sixty years.[8] As a result the NRC directed its staff to prepare an EIS for longer term storage. It is not clear from the NRC scenarios cited in Section 3.1 above that the NRC plans to evaluate the full range of scenarios for storage and (implicitly) for the timing of repository availability that it has itself considered credible enough for an EIS analysis in the recent past. The staff made a preliminary assessment (in a draft report) that the NRC should evaluate the environmental impacts of storage for 200 years beyond the middle of the present century, in other words, spent fuel storage up to the year 2250. This means almost 300 years of storage in all, a fact noted by the NRC staff:

> The staff selected a 200-year span for the EIS because that is approximately when this oldest fuel will approach 300 years of storage. The 300-year period is the timeframe being used by NRC and others in technical analyses to identify spent fuel aging issues.[9]

3.5. An examination of prolonged storage well beyond sixty years past license expiration, is necessary because the NRC, in its Final Waste Confidence Decision Update admitted that it could not estimate when a repository might become available. The reason provided was the

---

[7] NRC 2012c, Slide 20, italics in the original
[8] NRC 2010a, p. 81040
[9] NRC 2011, p. 6

NRC "cannot have confidence in a target date because it cannot predict when the societal and political obstacles to a successful repository program will be overcome."[10] Consideration of prolonged storage well beyond 120 years (sixty years of licensed reactor operation followed by sixty years of storage) prior to transport to a repository is needed because many of the problems of very long term storage are likely to be much more severe than those that might be experienced to the end of this century. For instance, the extent of degradation, transportation risks, risks of handling and storage at the repository site, risks of loss of institutional control, and risks of inter-cask transfer, would be considerably different and in most cases much higher for storage that extends to 300 years from initial reactor discharge. These issues are discussed in more detail in Sections 4, 5, and 6 below. For these reasons, the NRC staff issued a draft report outlining the data requirements for storage periods up to 300 years because it is "a reasonably long performance period" to evaluate for an EIS.[11] I agree. No one can foresee whether 300 years of total storage will be required prior to transportation, but it is prudent to evaluate it. Such a scenario is also broadly compatible with institutional control considerations discussed in Section 6 below.

3.6. Other impacts also become more extreme over an extended period of time. For instance, the Nuclear Waste Technical Review Board has found that the radiation barrier declines rapidly after about 100 years. By about 300 years, the original cesium-137 inventory, which presents the main long-term radiation barrier, would have declined by a factor of about 1,000. In such a situation the risk of theft of spent fuel would increase qualitatively. As the NWTRB put it, after sufficiently prolonged storage (well over 100 years) the spent fuel "may no longer pose a deterrent to individuals approaching CSNF [commercial spent nuclear fuel]."[12] Another example is that the probability of natural phenomena such as flooding, hurricanes, and tornadoes, and earthquakes, of a given level of intensity increases as the period of time increases. Another way of putting it is that "The longer the expected period of dry storage, generally, the more severe the natural event loading will be that should be employed in analysis."[13] When climate change is added to this picture, a scenario that extends out to 300 years prior to transport to a repository would likely have much greater environmental impacts at the site (or, for that matter, at an offsite location for spent fuel storage).

3.7. In view of the NRC's own preparations to analyze storage for up to 300 years, the scope of the EIS should include a scenario of 300 years of onsite storage followed by transportation and repository disposal. This scenario should include at least one inter-cask transfer in this period, followed by transfer to a multipurpose or transportation cask at 300 years. Of course, transportation risks and repository site and disposal risks should be included in this scenario as also in every scenario that includes an assumption of deep geologic disposal and/or an assumption of transfer of spent fuel to an offsite storage location.

[10] NRC 2010a, p.81041
[11] NRC 2012a, p. 1-2.
[12] NWTRB 2010, p. 82
[13] NWTRB 2010, p. 80

4.0 The EIS should analyze, in depth, the environmental impacts of spent fuel degradation.

4.1. The EIS should analyze, in depth, the environmental impacts of uranium spent fuel degradation. After a total storage period of up to 300 years (i.e. out to the year 2250), there is a far greater likelihood of casks deteriorating to an extent that transfers from one cask to another of much, most, or all of the spent fuel would be required. This could pose major problems in case the spent fuel has degraded to the point of leaking radioactivity, especially since the NRC has no experience in unloading damaged commercial spent fuel bundles or in regulating the means and processes needed to do so. By its 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.[14]

The NRC also at present has no basis in data or experience in estimating how much additional damage such procedures might create. This would apply even to damaged medium burnup fuel stored for short or moderate periods of 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.

4.2. The NRC 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*.[15] This report catalogs what is known, as

[14] NRC 2001, emphasis added
[15] NRC 2012a

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.

4.3. NRC 2012a 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:

> ….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 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).[16]

Note that the existing licensing and license extension procedures are based on examination of single cask of relatively low burnup uranium dioxide fuel 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[17] – 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;[18]
- spent fuel burnups up to 62.5 GWd/MTU,[19] 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.[20]

---

[16] NRC 2012a, p. 1-1; italics added
[17] NRC 2012a, p. 1-2
[18] The wet storage time was about 3.7 years (Einziger et al. 2003, p. 1989); it has been rounded to four years for this calculation.
[19] NRC 2012a, p. 3-1
[20] NRC 2012a, p. A2-2, A2-4, and A4-3, for instance

- "new cladding, fuel compositions, and assembly designs that have been and will continue to be put into use."[21]

4.4. According to a 2010 report by the Nuclear Waste Technical Review Board, of spent fuel integrity and degradation, "[o]nly 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*."[22] Hence, there are no U.S. data available at present 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 EIS 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 EIS cannot be validated with scientific data or observations with presently available information. Such validation is essential for reliable and scientifically valid estimates of environmental and health impact of long-term storage and transportation.

4.5. The data requirements are extensive even by the NRC staff's own accounting. According to Table 6-1 in NRC 2012a, there are 23 different degradation phenomena that have a ranking of "high" in terms of "the need for further research"[23] in addition to the data available from the lower burnup/short storage time evaluations. The table 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.

[21] NRC 2012a, p. 3-1
[22] NWTRB 2010, p. 11, italics added
[23] 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 Pitting and crevice corrosion	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
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 Thermal-mechanical degradation	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
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)

4.6. 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.

4.7. All of the categories of "regulatory significance" of these 23 degradation phenomena – confinement, criticality, retrievability, shielding, structural, and thermal – listed in the NRC table reproduced above are relevant to estimating environmental impacts, some of which could be severe. Others could contribute to severe degradation outcomes.

4.8. For instance, in the case of microbiologically induced corrosion the table 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.

4.9. As another example, consider phenomena listed near the top of the table: stress corrosion cracking, delayed hydride cracking, and low temperature creep. The NRC draft report notes that "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."[24] In other words, the NRC does not know at present whether corrosion of seals or the canister body may or may not 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 cask itself degrades. If data indicate little likelihood of corrosion or creep for high burnup fuel storage for decades or centuries, the impacts would be materially different and lower that if these two mechanisms produce significant degradation. At present, any impact calculation for high burnup spent fuel would be based on speculation rather than data.

4.10. Consider the state of knowledge for the interactions between different degradation mechanisms as well as the possible effect of high burnup, according to the Nuclear Waste Technical Review Board:

> 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.[25]

[24] NRC 2012a, p. 6-2
[25] NWTRB 2010, p. 11, italics added

Hence high burnup could well combine with other factors to create conditions that would result in severe, if not catastrophic, releases of radioactivity. Further, the NWTRB considers the three phenomena discussed above -- hydriding, creep, and stress corrosion cracking – to be "[t]he most significant potential degradation mechanisms affecting the fuel cladding during extended storage."[26]

4.11. 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 1 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.[27] Similarly Figure 2 shows that the maximum wall thickness hydrogen content increases from 200 ppm to 800 ppm at discharge over approximately the same burnup range. In both cases the variability is also much greater at the higher burnup. High 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 degradation that is to be expected based on currently available information of in-reactor performance.

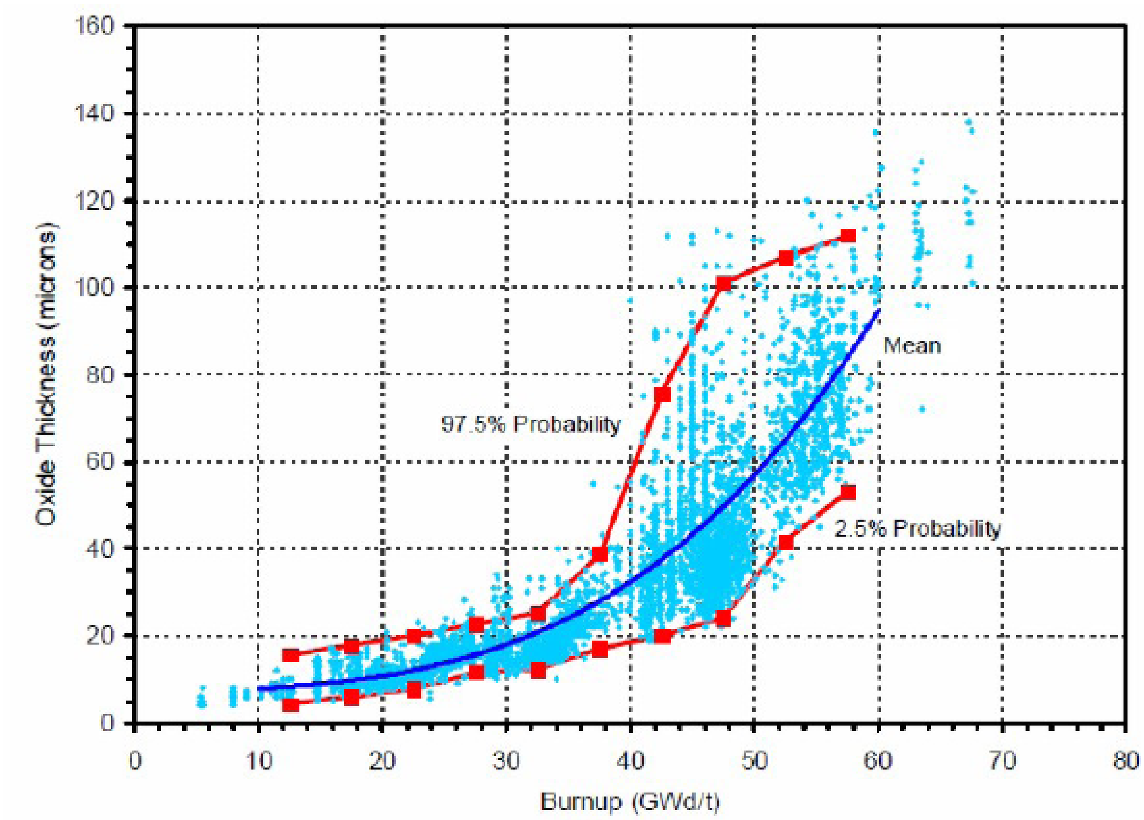

Figure 1. Cladding outer surface oxide thickness layer versus rod average burnup (Reproduced from NWTRB 2010, Figure 20 (p.56))

[26] NWTRB 2010, p. 10. Visual extrapolation of the line showing the mean.

[27] The range of blue data points at about 63 GWd/MTU is from about 70 microns to about 130 microns.

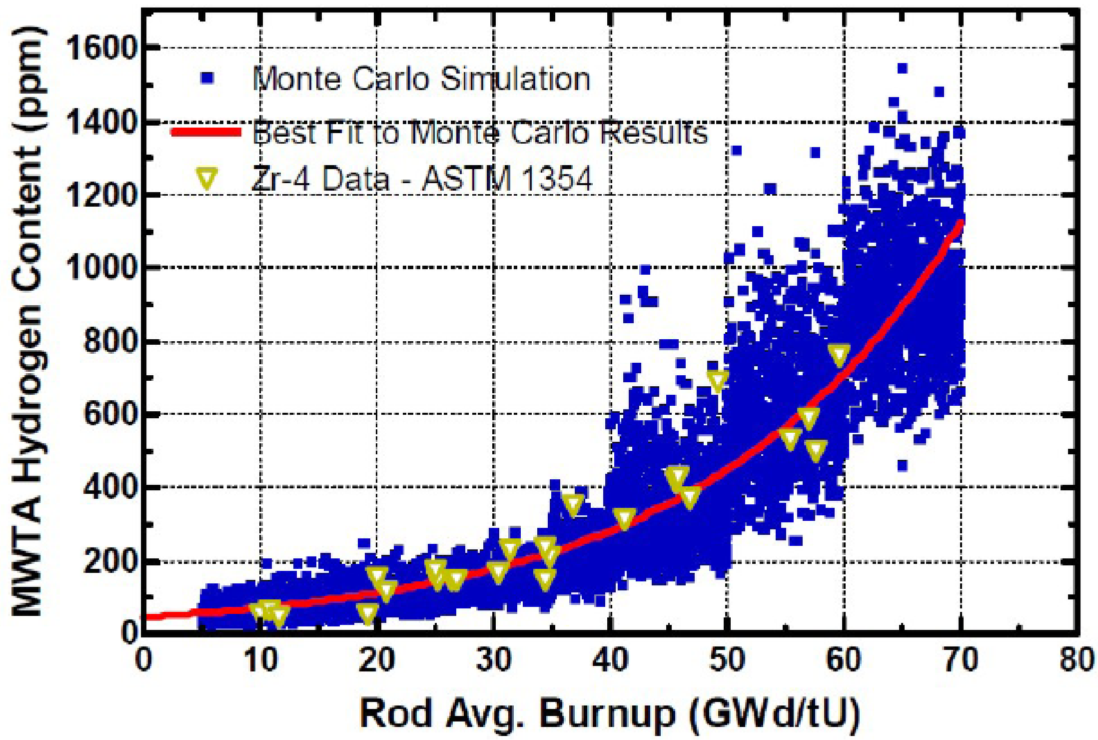

Figure 2. Maximum Wall Thickness Average Hydrogen Content in Low-Tin Zircaloy-4 Cladding (Reproduced from NWTRB 2010, Figure 21 p.56))

4.12. It is also important to have 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[28]). There are practically no such data. Indeed, even the research has been focused mainly on in-reactor behavior of high burnup fuels:

> 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.[29]

4.13. The spent fuel from Surry that was examined after about 15 years of dry storage was found upon inspection to be functionally undamaged.[30] 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 burnups, or during spent fuel pool storage. Lack of

[28] NWTRB 2010, p. 72
[29] NWRTB 2010, p. 52
[30] Einziger et al. 2003, p. 186

damage during much more prolonged dry storage of high burnup fuel also cannot be assumed based on the Surry study:

> 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 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*.[31]

4.14. The extent and types of degradation during storage can have profound consequences for health and environmental impacts in a number of ways. They affect the probability of releases as a result of aging. They will affect the extent of environmental impacts during transfer from one cask to another. They will affect the impacts of transportation accidents. They will affect radiation doses to workers who are handling the spent fuel on site. If the spent fuel is transported to a repository location (in the relevant scenarios), it will affect environmental impacts and offsite and worker radiation dose estimates at that location prior to disposal. These and other issues are discussed at length in NWRTB 2010, which sets forth an extended research program to address the problem of the lack of data. While the intent of those recommendations was to "prevent problems" by conducting the R&D, the same recommendations are also relevant for estimating impacts since the data to do so are currently largely unavailable. The NWTRB research and development recommendations include:[32]

- 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

[31] NWTRB 2010, p. 60, italics in the original
[32] 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

4.15. In sum at present the NRC lacks a realistic basis to assess degradation of high burnup spent fuel storage over long periods, the onsite and offsite radiological impacts of unloading damaged spent fuel, repackaging it as needed, and reloading it into a new cask.

4.16. The research outlined in the table in Section 4.5 above was part of the plan for the long-term storage EIS, which was supposed to be completed in the year 2019.[33] The research and modeling specified by the NWTRB in the list in paragraph 4.14 above are likely to take considerably longer to complete. The Commission's September 2012 decision to complete a waste confidence related EIS in just two years[34] leaves no time to pursue, let alone complete the work for making a scientifically valid assessment of the impacts of long term storage or of indefinite storage even for fuel from existing reactors.

4.17. The considerations in the paragraphs above in this section also apply to various designs of small modular reactors that are being proposed if their fuel designs and burnup are similar to presently licensed commercial reactors. If not, the considerations in the paragraphs below in this section would apply.

4.18. The above analysis and conclusions apply mainly to uranium spent fuel, for which there are at least some data for relatively low burnup spent fuel in dry storage for 15 years.[35] The problem of the lack of adequate data is even larger in terms of the needed research for mixed oxide (MOX) spent fuel and for spent fuel from Generation IV reactors.

4.19. 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 NRC staff will have to gather and develop data for extended storage of MOX spent fuel and extrapolate from reactor-grade MOX spent fuel to that resulting from irradiation of MOX fuel made with weapons grade plutonium. Inclusion of MOX spent fuel in the scope of the EIS may necessitate an even longer period of data gathering before a scientifically valid evaluation of environmental impacts, accident probabilities, and consequences of possible malevolent acts can be made.

[33] Borchardt 2012, p. 3
[34] Vietti-Cook 2012
[35] NRC 2012a and Einziger 2003

4.20. The NRC scoping notice also includes spent fuel from Generation IV reactors. This covers a wide range of possible reactor types with very different kinds of spent fuel. For instance, the pebble bed reactor, which has been considered from time to time, has fuel elements that have a graphite outer coating.[36] The risks arising from storage of such fuel, the accident scenarios, and the design of the storage facilities would likely be fundamentally different than those associated with zircaloy fuel rods used in light water reactors. Sodium-cooled reactors present a completely different set of issues, as would liquid thorium fuel reactors, where the fuel is a molten salt. Pilot or demonstration machines of various reactors have been built. But there is as yet no relevant analysis of extended storage of spent fuel generated under commercial reactor operating conditions (high burnup at or near rated power levels). Inclusion of Generation IV spent fuel in the scope of the EIS will necessitate an even longer period of data gathering before a scientifically valid evaluation of environmental impacts, accident probabilities, and consequences of possible malevolent acts can be made.

4.21. Stainless steel fuel cladding was used as fuel cladding early in the history[37] of U.S. commercial reactors. By 1994, only one reactor had any stainless steel clad fuel in its core.[38] By 1992, a total of 679 metric tons spent fuel (uranium heavy metal content) had been generated from the stainless steel clad fuel.[39] 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.[40] The degradation characteristics of stainless steel fuel are different than zircaloy fuel and need to be explicitly included in the scope of the EIS. All scenarios need to explicitly consider the impacts of stainless steel cladding, including the cladding that was known to be degraded during irradiation.

4.22. New cladding materials, such as silicon carbide, are being researched in part due to the desire to reduce fuel costs and increase fuel burnup. The long term performance of such cladding in storage and after repository disposal also needs to be addressed within the scope of the EIS.

4.23. Without extensive additional data on degradation mechanisms and their interactions, central and critical aspects of the EIS will be based largely on speculation and would have little or no valid scientific foundation, notably for high burnup spent fuel that has been stored for several decades or centuries, not to speak of indefinitely, for small modular reactors, for MOX spent fuel (notably MOX fuel made from weapons grade plutonium) and for spent fuel from Generation IV reactor designs.

---

[36] DOE 2010, p. 18
[37] EIA 1994, p. 23
[38] EIA 1994, p. 23
[39] EIA 1994, Table 9 (p. 27) and Table 10 (p. 28)
[40] Rivera and Meyer 1980, p. 1

5.0 The EIS should analyze, in depth, the impacts of transporting and handling spent fuel, and of storing it at repository sites.

5.1. The EIS should analyze, in depth, the impacts of transporting and handling spent fuel, and of storing it at repository sites. Spent fuel that has been stored onsite or at an offsite location for prolonged periods is subject to degradation, some of which could be severe enough to breach both the cladding and the canister. Transfer of such spent fuel to transportation casks could therefore pose risks that have not yet been encountered in practice. Similarly the impacts of transfer to disposal containers, storage at the repository location, and handling during placement of degraded spent fuel need to be evaluated. Likewise, the consequences of transportation accidents that involved degraded high burnup fuel or degraded canisters could be significantly higher than indicated by present understanding of accidents with intact fuel and canisters.

5.2. The considerations in Section 4, notably in paragraphs 4.1 to 4.14, indicate that degradation of high burnup spent fuel stored for prolonged periods (several decades to a few hundred years) needs to be taken into account during transportation. Specifically, the consequences of transportation accidents and any malevolent acts during transportation that breach the cask are may be much more severe than with lower burnup spent fuel stored for modest periods of time. For instance, if the cladding and canister are not intact, then a material breach of a transportation cask would result in releases of radioactivity. Releases due to an accident involving a fire could be severe to catastrophic. In contrast, if a canister is not degraded, then an additional barrier to radioactivity releases is available even if the transportation cask is breached.

5.3. The NWTRB has evaluated the issue of fuel degradation and its potential impact on transportation risks. Specifically, it has pointed out the need for additional analysis and modeling will be needed to analyze aging issues:

> Currently, if used fuel is stored in a dual-purpose storage system, transportation certification requires that the applicant show that the stored fuel and container is safe for transport. Given that fuel may be stored for decades before it is transported, and the possibility of degradation of fuel and corrosive deterioration of canisters over this time, applicants for transportation certificates will need to rigorously analyze such "aging" problems, which they have not needed to do in the past. It is possible that either the dual-purpose canister or the transportation overpack will have aged over its life. If so, the former numerical analysis and scale modeling of such transport packages may not reflect the actual behavior of aged fuel and packages.[41]

5.4. The aging analysis recommended by the NWTRB cannot be reliably carried out unless the degradation studies for high burnup fuel stored for several decades have been completed.

---

[41] NWTRB 2010, pp. 43-44

5.5. The NWTRB has also pointed out the inadequacies of current regulations and assumptions made by the NRC in addressing the problem of the integrity of spent fuel that has been stored for long periods:

> The NRC transportation requirements, as described above, appear to have been written for transportation of CSNF after a relatively short storage period because degradation of fuel rods and fuel assemblies is not clearly accounted for. Meeting the current specified packaging requirements after a period of extended dry storage involves satisfaction of four objectives of safe radioactive material transport: containment, shielding, criticality safety, and heat management. The focus of the regulations in 10 CFR 71 is largely on the integrity of the shipping cask and avoiding criticality, and not necessarily on the condition of the used fuel inside, provided certain performance requirements are met. However, current certification practice of transport packages requires applications to show that most fuel rods cannot be classified as damaged after transport. Consequently, it is important that at the time of transport, and after extended dry storage, (1) the initial condition and mechanical properties of the fuel and fuel-assembly structural elements are sufficiently characterized and (2) the behavior of fuel rods and fuel assemblies during normal and accident transport conditions can be sufficiently modeled to know whether transport requirements will be met.[42]

Both the requirements in the last part of this paragraph necessitate detailed knowledge of degradation phenomena before the analysis of normal transport and accident consequences can be carried out. Subsequent to those studies, transportation accident tests can be designed to examine whether proposed transports would comply with regulations for normal transport and under accident conditions.

5.6. The scope of the EIS should include impacts of transportation of high burnup fuel that has been stored for the periods of time relevant for each scenario prior to transportation to a repository location. The times for the two scenarios planned by the NRC are: transfer starting in 2050 and transfer starting in 2100. The start of the transfer for the additional scenario recommended here would be in about the year 2250.

5.7. Considerations similar to handling and inter-cask transfer of spent fuel after prolonged storage at the reactor site also apply to the handling of spent fuel once it is at the repository site. The impacts of handling, transfer, storage, and disposal during repository operation need to be examined in detail for high burnup spent fuel that has been stored for prolonged periods.

---

[42] NWTRB 2010 p. 44

6.0 The EIS should analyze, in depth, the reliability of institutional controls.

6.1. The EIS should analyze, in depth, the reliability of institutional controls, because there is extensive evidence that it is not prudent to rely on active institutional controls for more than 100 years after a facility ceases functioning for its principal purpose. Most consideration of institutional controls has been in the context of radioactive waste disposal in shallow or deep disposal facilities. We take a brief look at the relevant literature in this area first.

6.2. Many authorities, including the National Research Council, have concluded that 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.**
> […]
> *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.*[43]

6.3. The EIS should take account of the technical basis for NRC's 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 regulations are also consistent with EPA regulations for managing and disposing of high-level waste and transuranic waste. [44] For instance, scenarios could assume that the ability to do inter-cask transfers would lapse 100 years after reactor operation ceases. This assumption would be the same as that in the Department of Energy's Yucca Mountain Final EIS "no-action" alternative "Scenario 2"[45] Similarly, regulations of the Environmental Protection Agency for "Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" at 40 CFR 191 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.

---

[43] NAS-NRC 2000, pp. 3 and 5. Original italics; bold added.
[44] 40 CFR 191.14(a), 2011
[45] DOE 2002, Vol. I, p. 2-70

6.4. The problem is more complex in the case of commercial nuclear reactors partly because of the considerable uncertainty about the future of nuclear energy; this uncertainty therefore extends to any specific assumption about the end date for institutional control. For instance, new reactors have recently been licensed; they may operate to close to the end of this century. Hence, the 100-year assumption of lapse of controls in 10 CFR 61 and 40 CFR 191 would extend the date of control out to about the middle of the 23rd century when operational and licensed storage are considered for sixty years each.[46] In this scenario, transportation to a repository site would follow after 2250. Hence, this would require an extension of a storage license for the period over which transportation would take place. If more reactors are licensed in this century, that would extend the date when controls might be assumed to lapse out even farther, using the same 100-year criterion as in 10 CFR 61 and 40 CFR 191. For the purposes of the waste confidence EIS, an exact date of a lapse of institutional controls is not as critical as two other institutional control issues. First, it is unreasonable and technically and historically unsupportable to assume institutional control for thousands of years, as the DOE did in Scenario 1 of the Yucca Mountain EIS, for instance (see Section 8 below). Any assumption about institutional controls should respect the depth and breadth of historical evidence about the vulnerability of human institutions to upheaval and collapse over the decades and centuries. In other words, uncertainties about the future cannot be a license for arbitrary or ahistorical assumptions. Second, scenarios involving prolonged storage over many decades or hundreds of years must account for the reality that the worst case incidents and events (whether natural or malevolent) would increase in severity as the assumed storage period is lengthened. For instance, a hundred-year flood is worse than a ten-year flood; this reality must be taken into account in the analysis of impacts in the various scenarios in which storage periods are different. For the purposes of the waste confidence EIS my recommendation is to assume storage up to about the year 2250 followed by the time needed for transportation of spent fuel to and its disposal in a geologic repository location as the longest period for the duration of institutional controls. This should also be the guide for the assumption about the lapse of institutional controls for the scenario in which a repository is never available. History and science should provide a guide as to the severity of events to be considered over such a period of time.[47]

6.5. At least one scenario (indefinitely long periods of storage in the event of a repository never becoming available) requires consideration of times longer than those for which institutional control can reasonably be assumed. Therefore it is essential that the EIS consider storage design alternatives that would mitigate the impacts in the event that institutional control is lost. Loss of such control would significantly increase the risks of risks of malevolent acts, dispersal of radioactivity, public radiation exposure due to inadvertent intrusion on to the site, theft of nuclear materials, etc.

---

[46] End of reactor operation for newly licensed reactors is assumed to be about 2080; sixty years after that extends the institutional control date to about 2140. Adding 100 years of control after lapse of the last license takes us to the middle of the 23rd century.

[47] See also Thompson 2013.

7.0 The EIS should analyze, in depth, impacts of deep geologic disposal of spent fuel.

7.1. Two of the three scenarios identified in the NRC scoping notice and during the public meeting (see paragraph 3.1 above) involve disposal of spent fuel in a deep geologic repository – *i.e.,* disposal in the middle of this century or at the end of it. The additional scenario that should be added to the list discussed above also involves an assumption of disposal in a deep geologic repository after prolonged onsite storage up to about the year 2250. In order to fully evaluate each scenario, the EIS should include consideration of (a) the reasonableness of NRC's prediction that a repository will become available in any of those three time frames and (b) the environmental impacts of disposing of spent fuel once it is placed in a repository.

7.2. There is at present no designated deep geologic disposal location that is either being investigated or considered for licensing. The Department of Energy has withdrawn its license application for Yucca Mountain. While the matter is still in litigation, Congress has not appropriated any funds to pursue the licensing process. The EIS cannot reasonably assume that Yucca Mountain will be the designated repository.

7.3. The NRC also cannot assume that the impacts of deep disposal of high level waste as specified in Table S-3 in 10 CFR 51.51 would be a reasonable estimate of the impacts of deep disposal of spent fuel. For one thing, Table S-3 assumes disposal in bedded salt and the NRC 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 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.[48]

7.4. Since both Yucca Mountain and disposal in salt (assumed in Table S-3) are ruled out for spent fuel disposal (though for different reasons), the EIS scope must include a process that is scientifically reasonable for estimating the impacts of deep geologic disposal of spent fuel in a generic manner.

7.5. For each scenario that includes disposal in a deep geologic repository, the NRC must estimate the radiation doses to workers, the onsite and offsite environmental impacts during the period of operation as well as the post-closure environmental impacts up to and including the time of peak radiation dose.

[48] NRC 2010a, p. 81059, emphasis added

7.6. Since the analysis of disposal impacts will necessarily be generic, a process for bounding the dose will have to be developed. A bounding dose is a scientifically well-founded upper limit of exposure to individuals (workers, residents near the repository, a farming family far into the future that goes to live on the site after loss of institutional controls). This process will depend at least in part on the condition of the spent fuel to be disposed of and on the nature of the disposal casks and engineered barriers. The research described in Sections 4.1 to 4.14 will be important to making scientifically valid estimates of post-closure impacts and of peak radiation dose from uranium spent fuel. Additional work will be needed to estimate the impact of MOX spent fuel, for which a source term will also have to be developed. The NRC does not at present have the data needed to estimate the condition of the spent fuel that would be disposed of in a repository.

7.7. Deep geologic disposal impacts depend on the combined performance of the spent fuel and the disposal cask, the engineered barriers, the repository sealing system, and the near-field and far-field geologic, seismic, and hydrogeologic features of the site. In addition, assumptions are needed about the use of resources and defining the maximally exposed individual, normally taken to be a resident farmer family. The EIS must explore all reasonable combinations of geology, engineered barriers, sealing systems, and disposal casks to explore bounding dose.

7.8. Since the process for characterizing repository locations other than Yucca Mountain was abandoned early in the siting process (the Nuclear Waste Policy Act was passed on 1982 and the characterization was narrowed to Yucca Mountain in 1987) it will take a considerable amount of scientific effort and therefore time and resources to develop credible bounding doses so that a generic determination of upper limit impacts can be made for each scenario involving a deep disposal assumption.

8.0 The NRC currently lacks sufficient information to make a positive waste confidence finding or a finding of no significant impact from extended spent fuel storage or spent fuel disposal.

8.1. The NRC has indicated that it will use existing studies and analyses to prepare the Waste Confidence EIS,[49] including the Yucca Mountain EIS when "applicable and relevant."[50] For a number of reasons, the Yucca Mountain EIS is not adequate to support the Waste Confidence EIS. First, the scope of the Yucca Mountain EIS is, by its own terms, inadequate to cover the scope of inquiry necessary for the Waste Confidence EIS. Second, by the NRC's own admission, it has a great deal of additional research to do in order to understand the environmental risks posed by storage, handling and transportation of spent fuel over the long-term.

Inadequacy of Yucca Mountain EIS

8.2. In 2002, the Department of Energy issued a final Environmental Impact Statement for the then-proposed Yucca Mountain deep geologic repository for spent fuel and high level waste.

[49] Vietti-Cook 2012
[50] NRC 2012b. p. 24

The no-action alternative in the Yucca Mountain EIS was that the Yucca Mountain repository would not be licensed. As part of this alternative, the DOE considered onsite storage with institutional controls for 10,000 years ("Scenario 1"), during which "storage facilities would be completely replaced every 100 years" as well as onsite storage with institutional controls failing after 100 years ("Scenario 2"), allowing intruders, cask deterioration, etc. after that time.[51] DOE recognized that Scenario 1 would mean that sufficient political stability would exist for 10,000 years sufficient "to monitor and maintain the spent nuclear fuel and high-level radioactive waste to protect the public and the waste for 10,000 years."[52]

8.3. Scenario 2 of DOE's "no-action alternative" -- institutional controls lapse after 100 years – is reasonable. It has some basis in experience; it is also in conformity with existing NRC and EPA regulations, as discussed in Section 6 above. In the context of NRC licensing, it is plausible at least to consider controls up to at most the year 2250, as discussed in Section 6, though with the caveats discussed below in paragraphs 8.4 to 8.6.

8.4. Assuming institutional controls for 10,000 years – a period longer than recorded history and far longer than any human institution has existed – is without foundation in fact, experience, or common sense. It requires stability over a period 60 times longer than the period since March 1861 when the transfer of power to newly-elected President Lincoln brought secessionist sentiment in the South to a boil and triggered a Civil War a little more than a month later. It is also contrary to the NRC's own regulations for *low-level* waste disposal and the EPA's guidance in 40 CFR 191.

8.5. In addition, over the last 250 years, the United States has experienced the Revolutionary War, the War of 1812, innumerable violent conflicts with Native Americans, the U.S.-Mexican War, the 1941 Japanese attack on Pearl Harbor, and the 9/11/2001 terrorist attacks that destroyed the World Trade Center in New York and a significant portion of the Pentagon.

8.6. To its credit, 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. Throughout history, governments have ended abruptly, resulting in social instability, including some level of lawlessness and anarchy."[53] The DOE recognized that 10,000 years of institutional control is "unlikely"[54] but did not note that an assumption of 10,000 years of political stability has no foundation in fact, history, or experience. Indeed, there is no significant fact that would make such an assumption even remotely plausible.

8.7. The above considerations reinforce the facts and analysis in Section 6.0 that institutional controls should not go beyond about the year 2250 in the case of storage; intruder barriers cannot be assumed to last for more than 500 years. For storage times beyond 100 years, it would be important to include an analysis of social upheavals or malevolent acts in the analysis.[55]

[51] DOE 2002, Vol. I, pp. 2-70 to 2-71
[52] DOE 2002, Vol. II, Appendix K, p. K-35
[53] DOE 2002, Vol. II, Appendix K, p. K-35
[54] DOE 2002, Vol. I, pp. 2-64 to 2-65.
[55] See also Thompson 2013.

8.8. While it is of course useful to look at existing analyses, including the Yucca Mountain EIS, the NRC cannot use the specific environmental impact calculations in the no-action alternative scenarios of the Yucca Mountain EIS. Many of the assumptions in both Scenario 1 and Scenario 2 of the Yucca Mountain EIS No-Action Alternative are scientifically inappropriate for the Waste Confidence EIS.

8.9. A central reason that the Waste Confidence EIS cannot use the onsite storage impact calculations and conclusions in the Yucca Mountain EIS is that the DOE explicitly and deliberately underestimated the impacts of the no-action alternative scenarios in a number of ways. This is because the DOE 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. For instance, the DOE evaluated a scenario with 300 years of institutional control at the repository location but not in the no-action (onsite storage) alternative for this very reason:

> …DOE did not evaluate the 300-year institutional control case for the No-Action Alternative. **The primary reason** for not updating this part of the analysis [from the Draft EIS stage] was because if the institutional control period for the analysis of the No-Action Alternative were extended to 300 years, the short-term environmental impacts would have increased by as much as 3 times. **DOE did not want to overstate the environmental impacts of the No-Action Alternative.**[56]

8.10. Another example shows that DOE deliberately ignored some impacts in the No-Action Alternative:

> The Department 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 under Scenario 2. This decision is consistent with the Department's position **that care should be taken not to overestimate impacts from the No-Action Alternative.**[57]

8.11. The DOE took so much care not to overestimate impacts from the No-Action Alternative, that it ignored some of them altogether. For instance, in Scenario 1 of the No-Action Alternative (repackaging every 100 years for 10,000 years), the impacts of air pollution from casks transfer were assigned a zero value in cancer fatality calculations though they are not estimated because of the variability of canister degradation "from site to site" and the difficulty of dealing with the problem:

> Very small air quality impacts would be likely from repackaging materials removed from dry storage containers that could degrade to the point that they no longer met licensing requirements. However, overall impact estimates did not include these impacts because long-term dry **storage canister degradation would be highly variable and difficult to estimate from site to site and DOE**

[56] DOE 2002, Vol. I, pp. 7-9 and 7-10, emphasis added

[57] DOE 2002, Vol. I, p. 7-35, emphasis added

> **did not want to overestimate the accompanying air quality impacts from repackaging.**[58]

These are remarkable semantic acrobatics to avoid difficult problems in order to systematically underestimate impacts using the euphemism that "DOE did not want to overestimate" impacts. Whatever the rationale in the Yucca Mountain EIS for this systemic problem, it would be entirely inappropriate to adopt it or to use the estimates in the No-Action Alternative in DOE 2002 in the Waste Confidence EIS.

8.12. The Yucca Mountain No-Action Alternative estimated doses from drinking water in Scenario 2 of the No-Action Alternative, in which institutional control is lost after 100 years. The "latent cancer fatalities" were estimated at a total of 3,300 over almost 10,000 years, or just one in three years, compared to a total of 900 million from all other causes.[59]

8.13. The DOE calculated some cancer impacts, such as from contamination of surface water, but concluded that they would be small – less than 10 percent of the cancers it did calculate.[60]

8.14. 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.[61]

8.15. When food pathways other than drinking water are considered, the radiation doses and hence fatalities were estimated to triple. 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 is 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 a narrow view of latent cancer fatalities may indicate.

8.16. Even the estimates of latent cancer fatalities are presented in a very skewed way. Cladding degradation once the spent fuel is put into dry storage is assumed to begin after thousands of years and "less than 0.01 percent" of the cladding would fail in the first 10,000 years![62] Yet, the

---

[58] DOE 2002, Vol. I, p. 7-26, emphasis added
[59] DOE 2002, Vol. II, Appendix K, p. K-28
[60] DOE 2002, Vol. II, Appendix K, p. K-32
[61] DOE 2002, Vol. II, Appendix K, p. K-29
[62] DOE 2002, Vol. II, Appendix K, p. K-11

DOE acknowledges the centrality of this assumption by stating that different corrosion assumptions could reduce the dose estimates by a factor of 2 or increase them by thousands of times (or more):

> If the No-Action analysis had assumed larger or smaller deterioration rates [of zirconium alloy cladding], LCFs [latent cancer fatalities] could have **increased by several orders of magnitude** or decreased by less than a factor of 2.[63]

8.17. 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. Indeed, the practice of high burnup was only in its early stages in 2002 when the Yucca Mountain EIS was published. Given the evidence that oxidation, hydriding, and other degradation phenomena are far more severe with high burnup fuel, the No-Action Alternative analysis in the Yucca Mountain EIS must be regarded as fundamentally deficient and unusable even on those limited scientific grounds alone.

8.18. Critical uncertainties were not evaluated in the Yucca Mountain EIS. Perhaps the most important for the No-Action Alternative is the problem of climate change. It is reasonably clear that it is prudent and scientifically appropriate to assume more frequent and more severe storms, more frequent flooding or droughts, depending on the location of the nuclear power plant, and possibly more intense and frequent tornadoes.

8.19. Whatever uncertainties there may have been a decade ago about the severity of climate change, the picture is much clearer now and more data and analyses exist. The Waste Confidence EIS must consider and model climate factors in detail because they are likely to be among the most important factors in causing or aggravating damage from prolonged storage of spent fuel. The Yucca Mountain No-Action Alternative recognized that serious climate change impacts are highly likely over long periods of storage but failed to quantify the impacts." This is another reason that the NRC cannot rely upon the Yucca Mountain EIS's No-Action Alternative.

9.0 The EIS should acknowledge that certain impacts cannot be analyzed in a generic manner.

9.1. The scoping notice has ruled out "site specific issues or concerns" from the scope of the EIS and proposed to "bound the environmental analysis" based on "a set of general characteristics" alone.[64]

9.2. While some issues are generic and can, given adequate data, be bounded on that basis – as for instance, the impacts of transferring spent fuel from one cask to another – others 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.

[63] DOE 2002, Vol. II, Appendix K, p. K-38, emphasis added
[64] NRC 2012d, p. 65138

9.3. Consider health and property damage impacts. They will likely be bounded by high density population sites with high property value concentrations like Indian Point in the suburbs of New York City or Limerick, near Philadelphia, Pennsylvania.

9.4. 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 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.

9.5. It is impossible to bound 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 that the NRC consider the ecosystem impacts on a site specific basis unless it can classify sites based on types of ecosystems and address bounding impacts for similar sites. None of the sites mentioned in this paragraph could be put into a group with any other by that criterion.

9.6. From the above examples, it is clear that no scientifically valid examination of environmental impacts of prolonged storage can be done on a generic basis alone. While it is acceptable to bound each type of damage, separate estimates must be made for each type that is incommensurate with others. At a minimum, the EIS 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.

9.7. It is also essential for the scope of the EIS to include environmental justice impacts. Many of them are also site-specific. For instance, a spent fuel accident at the Columbia Generating Station in Washington State would seriously compromise the treaty rights, cultural values, and diets of the Yakama as well as other Indian tribes in the area. Such environmental justice impacts must be included in the scope of the EIS if it is to apply generally to future licensing actions.

10.0 The EIS should analyze, in depth, the alternative of not issuing a new Waste Confidence Decision and Rule.

10.1. As discussed above in Section 4, the NRC, by its own admission, has years of research to do in order to develop a sound database that is needed for a scientifically valid evaluation of the environmental impacts of prolonged storage of high burnup spent fuel. The NWTRB has also discussed the types of research and modeling that remain to be done as discussed in Sections 4 and 5 above. This agenda will likely take considerably longer. The data for MOX spent fuel and for Generation IV reactor types are far thinner for these designs than for light water reactor uranium spent fuel; as a result the task of estimating the impacts will likely be lengthier and more complex than for the current crop of commercial reactors.

10.2. The considerations, facts, and analysis in Sections 4.1 to 4.14 above, including the descriptions of data requirements and research by the NRC staff in NRC 2012a and by the NWTRB (2010), apply to essentially all operating commercial reactors in the United States and to new commercial light water reactors that the NRC may consider for licensing. Burnups have been increasing in the last decade. There are essentially no data available for high burnup spent fuel that has been stored in dry casks for extended periods of time. Reactor operators have been moving to higher burnup for over a decade; that trend is expected to continue at least for pressurized water reactors, as can be seen from the data and projections in Figure 3.

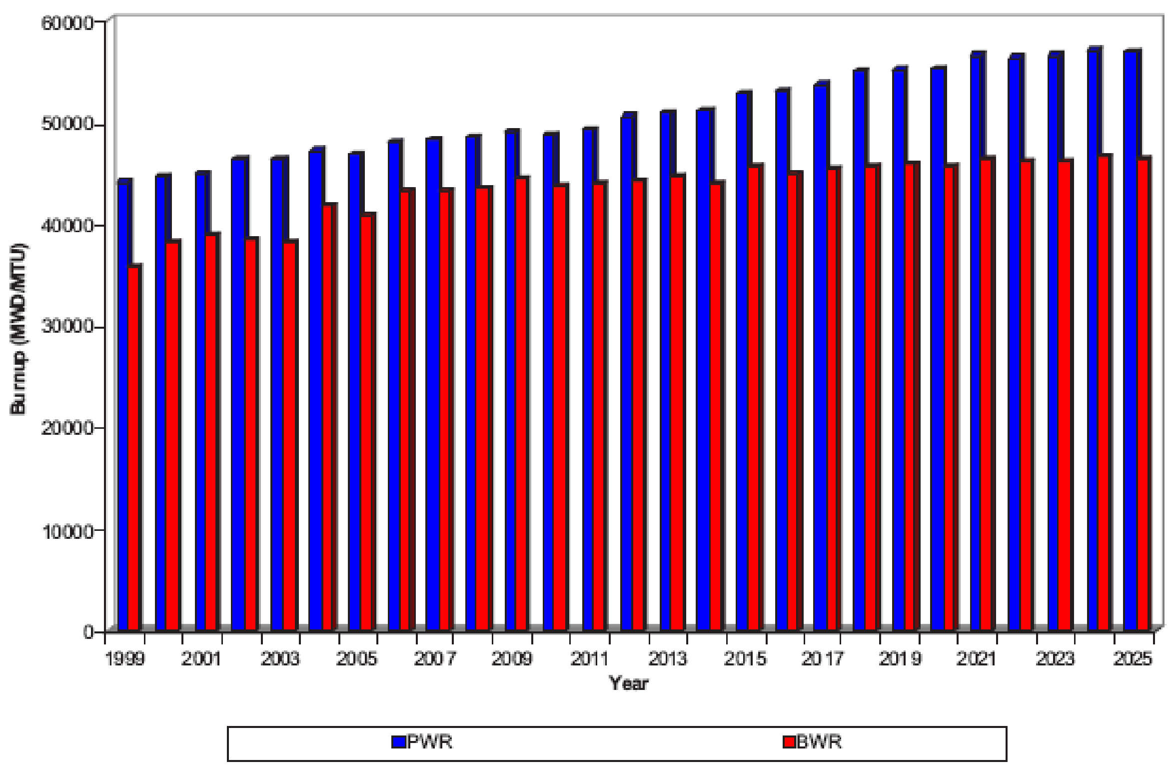

Figure 3. Burnup trends for PWR and BWR reactors in the United States (Reproduced from IAEA 2011, Fig. 6 (p. 9), with note: Courtesy of Energy Resources International)

10.3. In the absence of data on high burnup fuels stored for prolonged periods (discussed in Sections 4.1 to 4.14), it will be impossible to do a scientifically valid environmental impact evaluation whether it is generic for all commercial reactors or for one or more reactors particular to a single site.

10.4. In view of the above considerations, the no-action alternative that the EIS should clarify that a site-by-site analysis will also not be possible in the absence of data that is also needed for a generic waste confidence decision.

11.0 Summary and Scoping Recommendations

11.1. The data requirements for conducting a scientifically sound or even minimally valid waste Confidence EIS are varied and vast. It will take a long time, mostly likely well over a decade, to collect the data and do the needed modeling based on that data to make scientifically valid impact analyses for high burnup fuel stored for long periods. The NRC staff itself has laid out the data requirements and low knowledge base in many critical areas even for currently licensed reactors. The NWTRB has also discussed this issue, as noted in Sections 4 and 5 above. For new types of fuel and reactors, the needed research has not even been properly mapped out.

11.2. The NRC should add a scenario in which spent fuel is stored on site for 300 years from the first such storage (that is storage until about the year 2250) before being transported to a repository. Transportation accidents involving degraded spent fuel should be evaluated. The impacts on transfer of degraded high burnup spent fuel at the repository site should also be evaluated.

11.3. Some aspects of impacts can be evaluated on a generic basis but there are a variety of impacts that cannot be so evaluated. For instance, damage to riverine and/or estuarine ecosystems is qualitatively different than that arising from severe accidents or radioactivity dispersal in highly populated areas, such as the suburbs of New York City or Philadelphia. These must be evaluated on a site-specific basis or by a bounding approach to each type of damage, for instance: number of cancers, property damage, aquifers and irrigation systems damaged, drinking water affected, unique ecosystems affected, etc. No single nuclear power plant or group of plants will provide the bounding result for all these types of damage.

11.4. NRC waste regulations provide a good starting point for institutional control periods that are consistent with other regulations, analysis and guidance. For instance, assuming loss of significant institutional control 100 years after license expiry would be compatible with the NRC low level waste disposal rule (10 CFR 61) and EPA’s rule for deep geologic repositories (40 CFR 191). The problem is complicated by uncertainties about the future of nuclear energy, among other things. Whatever the uncertainties, it is unreasonable and technically unsupportable to assume institutional control for thousands of years as the DOE did in one of its Yucca Mountain EIS scenarios. For the purposes of the waste confidence EIS my recommendation is to assume storage up to about the year 2250 followed by the time needed for transportation of spent fuel to and its disposal in a geologic repository location as the longest period for the duration of institutional controls. This should also be the guide for the assumption about the lapse of institutional controls for the scenario in which a repository is never available.

History and science should provide a guide as to the severity of events to be considered over such a period of time. Resident farmer families should be used to estimate maximum individual doses after loss of institutional control. Environmental justice aspects needed to be considered; the resident farmer scenario will likely need to be modified in some of these cases.

11.5. For scenarios that include repository disposal, the scope of the EIS should also include the calculation of surface impacts at the site (including those from storage, unloading, repackaging, etc.) and post-closure repository impacts. In regard to post-closure repository impacts, the NRC cannot rely on the estimated zero radiation doses from salt disposal as specified in Table S-3 in 10 CFR 51.51(b) because (i) the NRC itself has admitted that salt disposal is inappropriate for spent fuel and (ii) all other media will have non-zero impact, and (iii) the impact is highly dependent on the combination of site characteristics, engineered barriers (including disposal casks), and sealing systems that are presumed to be used.

11.6. The EIS should have a no-action alternative that would be the non-issuance of a waste confidence decision and rule and a continued suspension of new reactor licensing and existing reactor license extension actions until data to make scientifically valid impact estimates of the consequences of long-term storage of high burnup spent fuel are collected and analyzed.

11.7. The No-Action Alternative should not rely on the No-Action Alternative of the Yucca Mountain EIS for its conclusions or analysis. Among other things, the environmental impacts in the Yucca Mountain EIS No-Action Alternative were deliberately underestimated by the DOE.

11.8. In case the NRC does not issue a generic Waste Confidence rule, the No-Action Alternative should not presume that sufficient information exists to resume site-by-site licensing decisions. It does not.

11.9. The No-Action Alternative as described in paragraph 11.6 above should be the preferred alternative.

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

Dr. Arjun Makhijani
1 January 2013

12.0 References

10 CFR 51, 2012	U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 – Energy. Part 51 – Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions.* 1-1-12 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2012. On the Web at http://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol2/pdf/CFR-2012-title10-vol2-part51.pdf.
10 CFR 61, 2012	U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 – Energy: Chapter I Nuclear Regulatory Commission; Part 61 – Licensing Requirements For Land Disposal Of Radioactive Waste*. 1-1-12 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2012. On the Web at http://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol2/pdf/CFR-2012-title10-vol2-part61.pdf.
40 CFR 191, 2011	U.S. Environmental Protection Agency. *Code of Federal Regulations. Title 40 – Protection of Environment. Chapter I – Environmental Protection Agency. Part 191 – Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*. 7-1-11 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; United States Government Printing Office, 2011. On the Web at http://www.gpo.gov/fdsys/pkg/CFR-2012-title40-vol26/pdf/CFR-2012-title40-vol26-part191.pdf. Accessed Dec. 10, 2012.
Borchardt 2012	R. W. Borchardt (Executive Director for Operations). Memorandum to: Chairman Macfarlane, Commissioner Svinicki, Commissioner Apostolakis, Commissioner Magwood, Commissioner Ostendorff. Subject: *Approach for Addressing Policy Issues Resulting from Court Decision to Vacate Waste Confidence Decision and Rule*. (COMSECY-12-0016) [Washington, DC: Nuclear Regulatory Commission], July 9, 2012. On the Web at http://pbadupws.nrc.gov/docs/ML1218/ML12180A424.pdf.
DOE 2002	U.S. Department of Energy. Office of Civilian Radioactive Waste Management. *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*. (DOE/EIS-0250) Washington, DC: DOE, OCRWM, February 2002. Links on the Web at http://energy.gov/nepa/downloads/eis-0250-final-environmental-impact-statement, including Vol. I, at http://energy.gov/sites/prod/files/EIS-0250-FEIS-01-2002_0.pdf. Vol. II, at http://energy.gov/sites/prod/files/EIS-0250-FEIS-02-2002.pdf.
DOE 2010	U.S. Department of Energy. Office of Nuclear Energy. *Next Generation Nuclear Plant: A Report to Congress*. [Washington, DC]: DOE, April 2010. On the Web at http://www.ne.doe.gov/pdfFiles/NGNP_ReporttoCongress_2010.pdf
DOE 1994	U.S. Department of Energy. *Spent Nuclear Fuel Discharges from U.S. Reactors 1992*. (SR/CNEAF/94-01) Washington, DC: DOE, Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, Survey Management Division, May 1994. On the Web at http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/25/070/25070038.pdf.

Einziger et al. 2003	Robert E. Einziger, Hanchung Tsai, Michael C. Billone, and Bruce A. Hilton. "Examination of Spent Pressurized Water Reactor Fuel Rods After 25 years in Dry Storage," *Nuclear Technology*, v.144 (November 2003): pp. 186-200. Links on the Web at http://www.new.ans.org/pubs/journals/nt/a_3439.
IAEA 2011	International Atomic Energy Agency. *Impact of high burnup uranium oxide and mixed uranium-plutonium oxide water reactor fuel on spent fuel management*. (IAEA Nuclear Energy Series No. NF-T-3.8) Vienna: IAEA, 2011. On the Web at http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1490_web.pdf.
Macfarlane 2012	Allison M. Macfarlane (Chairman, U.S. Nuclear Regulatory Commission). Letter to Diane Curran (Harmon, Curran, Spielberg & Eisenberg, L.L.P.), December 5, 2012. [Re: The scoping process for an environmental impact statement for the Waste Confidence Decision.]
Makhijani 2009	Arjun Makhijani. *Comments of the Institute for Energy and Environmental Research on the U.S. Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update and Proposed Rule Regarding Environmental Impacts of Temporary Spent Fuel Storage*. Takoma Park, MD: Institute for Energy and Environmental Research, 6 February 2009. On the Web at http://ieer.org/resource/testimony/comments-nrcs-proposed-waste-confidence/, to http://ieer.org/wp/wp-content/uploads/2012/06/WasteConfidenceComments2009.pdf. [NRC accession number: ML090680888.]
NAS-NRC 2000	National Research Council. Board on Radioactive Waste Management. Commission on Geosciences, Environment, and Resources. *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites.* Washington, DC: National Academy Press, 2000. On the Web at http://www.nap.edu/catalog.php?record_id=9949.
NRC 2001	U.S. Nuclear Regulatory Commission. "10 CFR Part 72: [Docket No. PRM-72-4]: Prairie Island Coalition; Denial of Petition for Rulemaking." *Federal Register*, v. 66, no. 25 (February 6, 2001): pp. 9055-9058. On the Web at http://www.gpo.gov/fdsys/pkg/FR-2001-02-06/pdf/01-3025.pdf. "FR Doc No: 01-3025"
NRC 2008	U.S. Nuclear Regulatory Commission. "10 CFR Part 51: [Docket ID–2008–0482]: Waste Confidence Decision Update." *Federal Register*, v. 73, no. 197 (October 9, 2008): pp. 59551-59570. On the Web at http://www.gpo.gov/fdsys/pkg/FR-2008-10-09/pdf/E8-23381.pdf. "FR DOC # E8-23381" "Proposed Rules"
NRC 2010a	U.S. Nuclear Regulatory Commission. "10 CFR Part 51: [NRC–2008–0482]: Waste Confidence Decision Update." *Federal Register*, v. 75, no. 246 (December 23, 2010): pp. 81037-81076. On the Web at http://www.gpo.gov/fdsys/pkg/FR-2010-12-23/pdf/2010-31637.pdf. "FR DOC # 2010-31637" "Update and final revision of Waste Confidence Decision."

NRC 2010b	U.S. Nuclear Regulatory Commission. "10 CFR Part 51: [NRC–2008-0404]: Consideration of Environmental Impacts of Temporary Storage of Spent Fuel After Cessation of Reactor Operation." *Federal Register*, v. 75, no. 246 (December 23, 2010): pp. 81032-81037. On the Web at http://www.gpo.gov/fdsys/pkg/FR-2010-12-23/html/2010-31624.htm. "RIN 3150–AI47" "Final Rule."
NRC 2011	U.S. Nuclear Regulatory Commission. *Draft Report for Comment: Background and Preliminary Assumptions for an Environmental Impact Statement – Long-Term Waste Confidence Update*. Washington, DC: NRC, December 2011. On the Web at http://pbadupws.nrc.gov/docs/ML1134/ML11340A141.pdf.
NRC 2012a	U.S. Nuclear Regulatory Commission. *Draft Report for Comment: Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fue*l. Washington, DC: NRC, May 2012. On the Web at http://pbadupws.nrc.gov/docs/ML1205/ML120580143.pdf.
NRC 2012b	U.S. Nuclear Regulatory Commission. *Public Scoping Meeting for the Environmental Impact Statement to Support an Updated Waste Confidence Decision and Rule: November 14, 2012. 1:00 P.M.. Transcript of Proceedings. Public Meeting*. Washington, DC: NRC, November 2012. On the Web at http://pbadupws.nrc.gov/docs/ML1233/ML12331A347.pdf.
NRC 2012c	U.S. Nuclear Regulatory Commission. Office of Nuclear Material Safety and Safeguards. Waste Confidence Directorate. *Scoping Process for the Waste Confidence Environmental Impact Statement*. Washington, DC: NRC, November 14, 2012. On the Web at http://pbadupws.nrc.gov/docs/ML1231/ML12314A352.pdf. [Slide presentation]
NRC 2012d	U.S. Nuclear Regulatory Commission. "10 CFR Part 51: [NRC–2012–0246]: Consideration of Environmental Impacts of Temporary Storage of Spent Fuel After Cessation of Reactor Operation." *Federal Register*, v. 77, no. 207 (October 25, 2012): pp. 65137-65139. On the Web at http://www.gpo.gov/fdsys/pkg/FR-2012-10-25/pdf/2012-26295.pdf. "RIN 3150–AJ20" "Request for comments on the notice of intent to prepare and environmental impact statement and notice of public meetings." Scoping notice.
NWTRB 2010	United States Nuclear Waste Technical Review Board. *Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel*. Arlington, VA: NWTRB, December 2010. On the Web at http://www.nwtrb.gov/reports/eds_rpt.pdf. "Prepared by Dr. Douglas B. Rigby, staff member, in support of the Board's analysis of issues associated with extended dry storage and transportation, an effort lead by Dr. Andrew C. Kadak, Board member."
Rivera et Meyer 1980	J. E. Rivera and J. E. Meyer. *Stainless Steel Clad for Light Water Reactor* Fuels. (Energy Laboratory Report No. MIT-EL 80-021) Cambridge: Massachusetts Institute of Technology, Energy Laboratory and Department of Nuclear Engineering, July 1980. On the Web at http://dspace.mit.edu/bitstream/handle/1721.1/60538/EL_TR_1980_021.pdf.

Thompson 2013	Gordon Thompson, *Declaration of Dr. Gordon Thompson Regarding the Scope of Proposed Waste Confidence Environmental Impact Statement*, Institute for Resource and Security Studies, Cambridge, Massachusetts, January 2, 2013.
U.S. Court of Appeals 2012	United States Court of Appeals. For The District Of Columbia Circuit. No. 11-1045. State of New York, et al., Petitioners v. Nuclear Regulatory Commission and United States of America, Respondents; State of New Jersey, et al., Intervenors. Consolidated with 11-1051, 11-1056, 11-1057. On Petitions for Review of Orders of the Nuclear Regulatory Commission Argued March 16, 2012 Decided June 8, 2012. On the Web at http://www.cadc.uscourts.gov/internet/opinions.nsf/57ACA94A8FFAD8AF85257A1700502AA4/$file/11-1045-1377720.pdf. Heading: "USCA Case #11-1045 Document #1377720 Filed: 06/08/2012"
Vietti-Cook 2012	Annette L. Vietti-Cook (Secretary). Memorandum to: R. W. Borchardt (Executive Director for Operations). Subject: *Staff Requirements – COMSECY-12-0016 – Approach For Addressing Policy Issues Resulting From Court Decision To Vacate Waste Confidence Decision And Rule*. [Washington, DC: Nuclear Regulatory Commission], September 6, 2012. On the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/comm-secy/2012/2012-0016comsrm.pdf.