September 29, 2014

DECLARATION OF DR. ARJUN MAKHIJANI
IN SUPPORT OF MOTIONS TO REOPEN THE RECORD
OF NRC REACTOR LICENSING AND RE-LICENSING PROCEEDINGS

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

1.0 STATEMENT OF QUALIFICATIONS

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

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

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

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

1.5. I have served on a number of oversight and advisory committees and boards with respect to my areas of expertise. I have served as an expert consultant to numerous organizations regarding technical, economic, and public health issues related to radioactive waste management. And 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. In 2007, I was elected a Fellow of the American Physical Society (APS), an honor granted to at most one-half of one percent of APS members.

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

1.7. In 2009 and 2013, I prepared technical comments on NRC regulatory issuances related to storage and disposal of spent fuel. In 2009, I submitted comments on the NRC's proposed Waste Confidence Update and Temporary Storage Rule, 73 Fed. Reg. 59,551, 59,547 (Oct. 9, 2008).[1] In 2013, I submitted a declaration on the proposed rule regarding "na and the Draft Waste Confidence Generic Environmental Impact Statement (Sept. 2013).[2]

2.0 PURPOSE OF DECLARATION

2.1. The purpose of my declaration is to describe the process by which fuel is irradiated in a nuclear reactor creates a grave public health and environmental hazard that cannot be undone and that lasts for millennia. I will also discuss the reasons for my professional opinion that the only effective way to protect the public and the environment from the severe hazards of spent reactor fuel in the long-term would be to place it in a properly selected and engineered deep geologic repository. Finally, I will explain the reasons for my professional opinion that the NRC should not license reactors to generate this hazardous material unless and until it has made safety findings regarding the technical feasibility and sufficiency of capacity of repository disposal, and until it has supported those findings with an environmental analysis.

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[1] Comments of the Institute for Energy and Environmental Research on the Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update and Proposed Rule Regarding Environmental Impacts of Temporary Spent Fuel Storage (Feb. 6, 2009) (Makhijani 2009); Declaration by Dr. Arjun Makhijani in Support of Comments of the Institute for Energy and Environmental Research on the Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update (Feb. 6, 2009) (Makhijani Declaration 2009).

[2] Declaration of Dr. Arjun Makhijani Regarding the Waste Confidence Proposed Rule and Draft Generic Environmental Impact Statement (Dec. 20, 2013; corrected Jan. 7, 2014) (Makhijani Declaration 2013-12).

3.0 DOCUMENTS REVIEWED

3.1. In preparing this declaration, I reviewed the relevant portions of the Final Rule regarding Continued Spent Fuel Storage, 79 Fed. Reg. 56,238 (Sept. 19, 2014) ("Continued Storage Rule") and NUREG-2157, the Continued Spent Fuel Storage Generic Environmental Impact Statement (Sep. 2014) ("Continued Storage GEIS"). I also reviewed and commented on the proposed version of the Continued Storage Rule, 78 Fed. Reg. 56,777 (Sept. 13, 2013) and the Draft Waste Confidence Generic Environmental Impact Statement (Sept. 2013).[3]

3.2. In addition, I have reviewed a number of other relevant documents. These documents include the relevant reference documents cited in the Continued Storage GEIS. I have also reviewed spent fuel storage and disposal-related portions of the NRC's Final Rule regarding Revisions to Environmental Review for Renewal of Nuclear Power Plant Operating Licenses.[4] In addition, I have reviewed the relevant spent fuel storage and disposal-related portions of the License Renewal Generic Environmental Impact Statement.[5]

3.3. In addition, I am familiar with the proposed and final versions of the 2010 Temporary Storage Rule.[6]

3.4. Further, I am familiar with the NRC's uranium fuel cycle rule and relevant associated reference documents. And I am familiar with the NRC's now-suspended Long-Term Waste Confidence Project and related documents.[7]

3.5. Finally, I am familiar with relevant aspects of governing law and guidance, including the National Environmental Policy Act (NEPA) and relevant NRC implementing regulations.

4.0 PROCESS FOR GENERATION OF SPENT FUEL IN NUCLEAR REACTORS

4.1 The purpose of a nuclear power plant is to generate electricity through the process of nuclear fission, or the splitting apart of uranium-235 atoms. The uranium-235 atom is split by bombarding it with neutrons, which causes a chain reaction of splitting uranium atoms that generates energy in the form of heat. This process is also known as "irradiation" of the reactor fuel.

4.2. Reactor fuel is made starting with uranium oxide (U_3O_8) or "yellowcake" as the raw material. In the fuel fabrication process, uranium oxide is first converted to uranium hexafluoride, then "enriched" by increasing the concentration of the fissile isotope of uranium (uranium-235), relative to the non-fissile isotope of uranium (uranium-238), after which it is

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[3] *See* par. 1.7 above.

[4] 78 Fed. Reg. 37,282 (June 20, 2013) ("License Renewal Rule").

[5] NUREG-1437 (2013), Generic Environmental Impact Statement for License Renewal of Nuclear Plants ("License Renewal GEIS").

[6] NRC 2008b and NRC 2010b

[7] *See, e.g.*, NRC 2010a, p. 81040 and Borchardt 2012

converted into uranium dioxide and fabricated into pellets. (A fissile material can sustain a chain reaction with neutrons of very low, even zero energy.) These fuel pellets are put into long fuel rods. Bundles of fuel rods, called "assemblies," are loaded into the cores of nuclear reactors.

4.3. In reactors, uranium fuel typically is used over three refueling cycles. The length of the cycle depends on the enrichment of the fresh fuel; in the United States a typical refueling cycle would take place every 1 to 1.5 years.[8]. Once it is no longer efficient to use the fuel, it is called "spent fuel" and discharged from the reactor. A given batch of fuel assemblies is generally removed from the reactor core every third refueling cycle.

5.0 SPENT REACTOR FUEL POSES IMMEDIATE, LONG-LASTING AND IRREVERSIBLE RISKS TO PUBLIC HEALTH AND THE ENVIRONMENT.

5.1. Fresh uranium fuel is only slightly radioactive. The risk of uranium arises mainly if it is inhaled. Once the uranium dioxide is made into fuel pellets, which are ceramics, there is very low risk of inhalation; indeed, there is relatively little risk from handling it since the external radiation from unirradiated uranium is quite low. Figure 1 is a Department of Energy photograph showing fresh nuclear fuel pellets being handled by a worker wearing gloves. The photograph also shows a fuel rod.

Figure 1: Fresh nuclear fuel pellets and a cutaway view of a fuel rod
Source: DOE, at http://commons.wikimedia.org/wiki/File:Nuclear_fuel_pellets.jpeg

When it is initially placed in a reactor, a metric ton of 4.4 percent enriched fuel generates just 90 milliwatts (0.09 watts) of thermal power from the radioactive decay of the uranium in the fuel pellets. [9] An entire core of a nuclear power reactor would generate between a few watts and about 10 watts of thermal power, depending on the reactor. A person standing next to an unirradiated fuel equal to the amount in a reactor core would not feel such a small amount of

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[8] IPFM 2011, p. 122

[9] Calculated using a specific activity of 3 microcuries per gram of 4.4 percent enriched uranium from equation 3 in Rucker and Johnson 1997. Weight of fuel is in terms or uranium metal, unless otherwise mentioned.

heat; for comparison, a single adult emits (in the infrared spectrum) about 100 watts of thermal energy simply from the process of living (consuming the energy content of food). This is more than 1,000 times the thermal energy of a metric ton of fresh enriched fuel.

5.2. In order to generate electricity, it is necessary first to create a nuclear chain reaction in the reactor core. This chain reaction consists of a succession nuclear fission events, each of which splits a uranium-235 nucleus.[10] Each fission leads to one more fission. This sustained reaction results in heat, which is then used to make steam. The steam drives a turbine, which in turn drives an electricity generator.

5.3. By bombarding the reactor fuel's uranium-235 atoms with neutrons, the fission process drastically changes the characteristics of reactor fuel. The atomic fragments resulting from fission, known as fission products, are generally far more radioactive (in the sense of radioactivity per unit weight of material) than the uranium-235 itself. The longer the uranium-235 fission process goes on, the more new fission products are created. Many fission products are short-lived with half-lives of a few days, a few hours, or even much less. But these fission products also include long-lived radionuclides such as cesium-135, cesium-137, iodine-129, strontium-90, and technetium-99. As discussed below, plutonium-239 and other long-lived radionuclides are also created by nuclear reactions in the reactor.

5.4. The exact amount of fission products at the time the spent fuel is discharged depends on the initial enrichment of the fuel and the reactor type and the length of irradiation in the reactor. The weight of the fission products in spent fuel is typically 3.5 to 5 percent of the initial weight of the uranium loaded into the fuel rods. While the short lived radioactive materials decay away in days, weeks, or a few years, there is still a vast amount of radioactivity in the spent fuel even after 23 years of decay, the reference time used by the Department of Energy in calculating radionuclide inventories in spent fuel for the purpose of the Yucca Mountain EIS.[11]

5.5. The large amount of accumulated radioactivity in the spent fuel, mainly due to fission products, also makes spent fuel very hot thermally in comparison to the thermal power of unirradiated (fresh) fuel. In contrast to very low thermal energy emitted by a core of fresh fuel, the core of a reactor just after shutdown for refueling generates millions of times more heat than the uranium fuel. This can cause the entire contents of a huge reactor vessel to boil if the heat is not removed by cooling. Essentially all of that heat comes from the radioactive decay of the fission and other radionuclides created during reactor operation. A prolonged failure of cooling after the shutdown of the reactor leads to a meltdown of the fuel, as occurred at Three Mile Island and three reactors at Fukushima Daiichi. A person standing near (e.g., within a foot) of unshielded spent fuel at the time of shutdown would be dead in seconds from the intense radiation. While the rate of heat generated by spent fuel declines over time, spent fuel from a pressurized water reactor would still generate tens of thousands of times more heat than the corresponding fresh fuel even after ten years of storage.[12] Even after 100 years of storage, the

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[10] Initially only uranium-235 nuclei are fissioned. As explained below, plutonium-239 nuclei are also fissioned once it begins to build up in the reactor. Fresh uranium fuel made starting with natural uranium contains no plutonium.

[11] DOE 2002, v. II, Appendix A, Tables A-9, A-10, and A-11.

[12] Calculated from IPFM 2011, Figure 1.2, and Rucker and Johnson 1997.

radiation from spent fuel is enough to give a lethal dose[13] to someone standing about a yard away within a few hours.[14]

5.6. Many fission products have short half-lives. Iodine-135, for instance, has a half-life of 6.6 hours.[15] This means that it presents an intense danger if released to the environment, but only for a few days. In contrast, several important fission products have long half-lives. Strontiium-90, which is extremely radiotoxic and targets the bone marrow and bone surface, has a half-life of 28 years. Cesium-137, which mimics the potassium in our bodies, has a half-life of about 30 years. This means that they pose risks for hundreds of years. Contamination with cesium-137 is the central reason why the areas with heavy fallout from the Chernobyl and Fukushima accident cannot be safely reoccupied for hundreds of years.

5.7. Some fission products last for hundreds of thousands or even millions of years. Technetium-99 (half-life 213,000 years), cesium-135 (half-life 2.3 million years) and iodine-129 (half-life 15.7 million years) are important examples. Other important radionuclides that present risks over long periods are americium-241 (half-life 432 years) and neptunium-237 (half-life 2.14 million years. Both are bone seeking radionuclides.

5.8. Further, some of the uranium-238 in a reactor turns into plutonium-239 as a result of continued reactor operation. This is because some uranium-238 nuclei absorb some of the neutrons liberated by the fission of U-235. Radioactive decay processes then convert this heavier uranium isotope (uranium-239) into plutonium-239. While uranium-238 is not fissile, plutonium-239 is. Continued reactor operation results both in the fission of some of the plutonium that has been created and a buildup of a considerable amount of un-fissioned plutonium. Other plutonium isotopes are also created. Each 1,000 megawatt-electrical reactor creates enough plutonium each year to make roughly 30 Nagasaki-size bombs, if separated from the spent fuel. Plutonium-239 has a half-life of over 24,000 years; this means that spent fuel represents a proliferation threat for tens of thousands of years.

5.9. These characteristics mean that the serious public health and environmental risks posed by spent fuel will persist from hundreds of years to millions of years. For instance, the risk from strontium-90, with a half-life of 29 years, will last for hundreds of years. In its Yucca Mountain EIS, the Department of Energy projected the inventory of strontium-90 in U.S. spent fuel to be 5 billion curies.[16] If diluted uniformly, this inventory could contaminate the entire fresh water supply (groundwater and surface water) of the world[17] to about 60 times the U.S. drinking water

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[13] A "lethal dose" is generally defined as the dose that would result in the death of half the exposed people in 60 days if they were to receive no medical treatment. It is called the LD 50/60 dose.

[14] IPFM 2011, p. 7

[15] A half-life is the amount of time that half the nuclei of a radioactive material decay, thereby transmuting to another isotope or element. The amount of a radionuclide declines by a factor of about 1,000 in 10 half-lives.

[16] DOE 2002, v. II, Appendix A, Table A-11. All inventories in this paragraph are from this reference and are rounded for the purpose of these calculations. Drinking water limits are in EPA regulations at 40 CFR 141.66.

[17] USGS 2014. The water contamination calculations in this paragraph are order of magnitude estimates meant to illustrate the longevity of the threats from prolonged surface storage of spent fuel.

limit of 8 picocuries per liter. Even after 300 years, it would contaminate the world's fresh surface water supply to almost 50 times the drinking water limit.[18] The strontium-90 inventory of a single twin-reactor nuclear power plant on Lake Michigan, such as the Donald C. Cook plant, would contaminate all the water in Lake Michigan to more than the drinking water limit even after a time lapse of more than 300 years. Dispersal of strontium-90 and other radionuclides in the environment would cause devastating health and ecological impacts; it would make a wide area around the plant unlivable. There are other more long-lived radionuclides that would present severe risks of water contamination for thousands of years. The inventory of americium-241 (half-life 432 years) from that same twin-reactor plant would contaminate Lake Michigan water to more than the drinking water limit (in this case 15 picocuries per liter) for nearly 3,000 years.[19] Other more long-lived fission products like technetium-99, cesium-135, and iodine-129, while produced in considerably smaller quantities, would still pose significant health risks for unimaginably long periods. Consider plutonium-239. Its inventory at that same Lake Michigan plant would be sufficient to contaminate all its water to more than the drinking water limit for about 80,000 years. Moreover, since the contamination would not be uniformly dispersed, the water, lake sediments (where much of the plutonium would wind up), ecosystems, and economy around the plant where the contamination would be concentrated would likely be severely damaged essentially forever were a large fraction of the inventory at a single site dispersed into and near the water.

5.10. After spent fuel has been stored for several hundred years and its thermal and radioactivity levels have declined, risk of theft also poses a serious public security and safety concern. Theft of a single dry-storage cask containing ten metric tons of spent fuel would cause grave security risks since it would have enough plutonium, if separated, to make on the order of a dozen Nagasaki-size bombs. This risk *increases with time*, since the radiation barrier to theft decreases with time.[20]

5.11. The intense heat generation and radioactivity of spent fuel require it to be stored in pools of water for several years both for cooling and protection of personnel. After that it can be stored in dry casks, but these casks must be heavily shielded.

5.12. Storage in pools for prolonged periods of time increases the risk of radioactivity releases from loss of coolant accidents (triggered, for instance, by an earthquake) or from terrorist attacks. Cask storage of spent fuel also poses the risk that the casks and fuel rods will degrade over long periods of time. In such a case, the consequences of deterioration of the spent fuel and the casks would be disastrous, since radioactivity would be dispersed by the rain, wind, and snow over wide areas, severely harming the environment and creating large public health risks. Casks could also suffer degradation and accidents during inter-cask transfers, which will be necessary if the storage continues for hundreds or thousands of years. The degradation and accidents would

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[18] Fresh surface water is one percent of total freshwater. (USGS 2014)

[19] See List of lakes by volume, at http://en.wikipedia.org/wiki/List_of_lakes_by_volume (Wikipedia 2014)

[20] This dynamic of the risk of theft increasing with time was also noted by Chairman Macfarlane in the statement accompanying her vote on the Continued Storage rule: "As spent fuel ages, its radioactivity decreases, and hence it loses its self-protecting qualities that increase vulnerability to theft. As a result, security requirements for storage facilities will increase over time." (Macfarlane 2014, p. 5)

allow radioactive material to escape, causing environmental contamination. Further, as noted in paragraph 5.10 above, if spent fuel is stored on site for hundreds of years, it becomes more and more vulnerable to theft as its radioactivity declines and it becomes less dangerous to steal. If spent fuel were stolen, unauthorized parties could separate the plutonium in the spent fuel and use it to make nuclear bombs or dirty radiation bombs. The release of radioactivity from spent fuel through accidental environmental contamination or intentional theft could have catastrophic consequences for human and environmental health.

5.13. The severity and longevity of the risks are the central reasons that government authorities worldwide have concluded that long-term safety demands disposal of high-level waste and spent fuel in an appropriately sited and engineered repository. For instance, as stated by the Secretary of Energy's Blue Ribbon Commission on America's Nuclear Future:

> Deep geologic disposal capacity is an essential component of a comprehensive nuclear waste management system for the simple reason that very long-term isolation from the environment is the *only* responsible way to manage nuclear materials with a low probability of re-use, including defense and commercial reprocessing wastes and many forms of spent fuel currently in government hands. The conclusion that disposal is needed and that deep geologic disposal is the scientifically preferred approach has been reached by every expert panel that has looked at the issue and by every other country that is pursuing a nuclear waste management program.[21]

5.14. Consistent with this federal policy, the Chairman of the U.S. Nuclear Regulatory Commission recently asserted, in the statement accompanying her vote on the Continued Storage rule, "Deep geologic disposal is necessary."[22] Previously, she had explained her view as follows:

> [T]he best way to ensure long-term isolation of high-level waste from the environment is emplacement of that material in a deep geologic repository. A policy of indefinite storage relies upon active controls and maintenance that will be an increasingly costly burden to our society. The continual maintenance and physical protection of thousands of storage casks spread among the current 69 sites in the U.S. would be an economic, logistical, and security burden to future generations. As the Nuclear Energy Agency has noted, "an 'open' solution such as indefinite storage, is probably not sustainable, because it relies upon speculations concerning future scientific, societal, or technological developments, and implies use of resources which cannot be quantified." Worst yet, failure to safely manage spent fuel for unknown times could lead to unacceptable environmental or security consequences.[23]

5.15. I share this view. While a repository may have some leakage of radionuclides over long periods of time after closure (tens of thousands or hundreds of thousands of years), a properly selected and engineered repository is the only reasonable means of safeguarding the public from the kinds of catastrophic environmental and security harm described above that can occur from

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[21] BRC 2012, p. xi (emphasis in original).

[22] Macfarlane 2014, p. 1

[23] Macfarlane 2013, p. 8 (ML13217A261).

prolonged surface storage. For instance, repository disposal makes theft extremely difficult, and much more so than any surface measures could accomplish. This drastically reduces the security risks from spent fuel. As another example, repository disposal would also greatly diminish the risks from the most plentiful long-lived fission products in the spent fuel, strontium-90 and cesium-137.

Currently, however, no geologic repository for spent fuel exists in the United States.

6.0 NRC LACKS AN ADEQUATE BASIS FOR LICENSING NUCLEAR REACTORS BECAUSE IT HAS NOT MADE CURRENTLY VALID "WASTE CONFIDENCE" SAFETY FINDINGS REGARDING FUTURE DISPOSAL OF SPENT FUEL OR CONDUCTED AN ENVIRONMENTAL ANALYSIS TO SUPPORT THOSE FINDINGS.

6.1. In my professional opinion, the NRC lacks an adequate basis for licensing nuclear reactors because it has not made currently valid "waste confidence" safety findings regarding future disposal of spent fuel or conducted an environmental analysis to support those findings. A waste confidence finding with an adequate technical basis is needed for assurance that future generations are not being put at severe risk.

6.2. Until 2014, as part of its licensing and re-licensing decisions for nuclear reactors, the NRC made generic safety findings regarding the feasibility and capacity of repository disposal of spent fuel. Starting in 1977, the NRC stated that it "would not continue to license reactors if it did not have reasonable confidence that the wastes can and will in due course be disposed of safely."[24] And the NRC based all of its reactor licensing and re-licensing decisions in part on generic findings regarding the safety of waste disposal, including after the passage of the Nuclear Waste Policy Act in 1982, when spent fuel disposal in a geologic repository became the formal path for long-term disposition of spent fuel. These findings were published in the NRC's1984 Waste Confidence Decision ("WCD"), as updated in 1990 and 2010.[25]

6.3. NRC's Waste Confidence findings were supported by a technical approach to the feasibility and capacity of a repository, including geologic characteristics, waste packaging, and engineered safety barriers.[26] The NRC explained the role of this approach in the WCD as follows:

> The conclusion that safe radioactive waste disposal is technically feasible is based on consideration of the basic features of repository design and the problems to be solved in developing the final design. A mined geologic repository for disposal of high-level radioactive waste, as developed during the past three decades, will be based on

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[24] Denial of Petition for Rulemaking, 42 Fed. Reg. 34,391, 34,393 (July 5, 1977).

[25] Waste Confidence Decision, 49 Fed. Reg. 34,658 (Aug. 31, 1984) ("1984 WCD"); Waste Confidence Decision Review, 55 Fed. Reg. 38,474 (Sept. 18, 1990) ("1990 Revised WCD"); Waste Confidence Decision Update, 75 Fed. Reg. 81,037 (Dec. 23, 2010) ("2010 WCD Update") (NRC 2010a). The 2010 WCD Update was vacated by the U.S. Court of Appeals in *New York v. NRC*, 681 F.3d 471 (D.C. Cir. 2012).

[26] *See, e.g.*, 1984 WCD, 49 Fed. Reg. at 34,667-79; 1990 WCD Revision, 55 Fed. Reg. at 38,475-79; 2010 WCD Update, 75 Fed. Reg. at 81,059-67 (NRC 2010a).

> application of the multi-barrier approach for isolation of radionuclides. The high-level radioactive waste or spent fuel is to be contained in a sealed package and any leakage from the package is to be retarded from migrating to the biosphere by engineered barriers. These engineered barriers include backfilling and sealing of the drifts and shafts of the mined repository. We believe that the isolation capability and long-term stability of the geologic setting provide a final barrier to migration to the biosphere.[27]

6.4. With each revision to the WCD, the NRC updated the technical analysis and schedule underlying its findings. For instance, in 1990, the NRC revised the WCD to, among other things "reflect revised expectations for the date of availability of the first repository."[28]

6.5. As stated most recently in the 2010 WCD Update, the NRC's findings regarding the technical feasibility and capacity of safe repository disposal of spent fuel were as follows:

> Finding 1: The Commission finds reasonable assurance that safe disposal of high-level radioactive waste and spent fuel in a mined geologic repository is technically feasible. [29]
>
> Finding 2: The Commission finds reasonable assurance that sufficient mined geologic repository capacity will be available to dispose of the commercial high-level radioactive waste and spent fuel generated in any reactor when necessary.[30]

These updated findings are similar to the 1984 and 1990 findings regarding repository safety and capacity.

6.6. The NRC never prepared any Environmental Impact Statement ("EIS") or Environmental Assessment ("EA") in support of its Waste Confidence findings, however. As a result, the 2010 WCD Update was vacated by the U.S. Court of Appeals in *New York v. NRC*, 681 F.3d 471 (D.C. Cir. 2012) for failure to comply with the National Environmental Policy Act ("NEPA").[31]

6.7. In the Final Continued Storage Rule, recently issued by the NRC on remand from the Court's decision, the NRC chose not to replace the vacated Waste Confidence findings.[32] Instead, the NRC incorporated some of the language of Findings 1 and 2 into the Continued Storage GEIS as assumptions for that environmental analysis.[33]

6.8. In my professional opinion, the NRC should not license reactors to produce spent fuel unless it can affirmatively make predictive safety findings that it will be technically feasible to site repositories that are safe, in the sense of conforming to radiation protection norms similar to the ones that are in force for nuclear licensees at present, and have sufficient capacity to

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[27] 49 Fed. Reg. at 34,667.

[28] 73 Fed. Reg. at 59,552 (Oct. 9, 2008)

[29] 2010 WCD Update, 75 Fed. Reg. at 81,058 (NRC 2010a) (capitalization of some words omitted).

[30] 75 Fed. Reg. at 81,038 (NRC 2010a).

[31] 42 U.S.C. §§ 4321-4370h.

[32] Continued Storage Rule, 79 Fed. Reg. at 56,244; Continued Storage GEIS at B-30 (NUREG-2157 (2014))

[33] Continued Storage GEIS Section B.2.1 (NUREG-2157 (2014))

accommodate the spent fuel those reactors will generate, along with the spent fuel that already exists or will be generated under existing licenses. The findings should be supported by an up-to-date technical analysis of the factors that the NRC has previously analyzed in its Waste Confidence decision and updates: geologic characteristics, waste packaging, and engineered safety barriers. It is important to revise these technical findings and take public comment on a regular basis because the common technical understanding of repository feasibility may change over time. For instance, in 1979, the NRC believed that bedded salt would be suitable for spent fuel disposal. In the 2010 WCD, however, the NRC reversed that determination. *See* pars. 6.14 - 6.16 below.

6.9. Moreover, the NRC's technical safety findings regarding the feasibility and capacity of repository disposal must be accompanied by an environmental analysis. The NRC's feasibility determination, for example, should be supported by an environmental analysis of the probability that a repository will safely contain radioactivity for the hundreds of thousands of years required to a degree sufficient to keep radiation doses to future members of the public to levels similar to the ones society has deemed acceptable today. In order to evaluate that probability, it is necessary to evaluate the environmental impacts of disposing of spent fuel in a range of geologic media, with a range of engineered barriers and repository sealing systems.

6.10. Similarly, technical findings regarding the capacity of one or more repositories to accommodate all spent fuel to be generated would require both safety and environmental analyses of various factors. Every geologic location would have some limit to the amount of spent fuel it can hold due to considerations such as the characteristics of the host rock, seismic faults running through the site, groundwater characteristics, natural resources availability, and other factors. Yucca Mountain, for instance, had a legal limit of 70,000 metric tons (equivalent) of commercial and military waste. Proponents of disposal there argued that the technical limits could be raised to allow disposal of a much greater quantity of spent fuel. But no one, so far as I am aware, has asserted that there was no technical limit. Such a limit was considered, for instance, in a paper by Professor Per Peterson of the University of California at Berkeley in the context of a prospective increase in nuclear reactor orders in 2003. He argued that the technical capacity of Yucca Mountain could be increased, but it would still have a limit:

> This [analysis] suggests a minimum "technical" site capacity of approximately 75 x 2,000 = 150,000 MT of spent fuel, with a maximum site capacity greater by perhaps a factor of two or three. *Thus any substantial construction of new U.S. nuclear power infrastructure in the coming decades will almost certainly create a technical requirement (perhaps as soon as 2030 to 2050) either for additional repositories or for the construction of infrastructure for recycling spent fuel*.[34]

Thus, one of the most prominent authorities on nuclear power and nuclear waste in the United States[35] has opined that, in the absence of reprocessing, the capacity of Yucca Mountain may not be capable of expansion sufficient for a nuclear future, and therefore a second repository may be needed in the United States. Indeed, he stated that a new repository would "almost certainly" be

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[34] Peterson 2003, italics added

[35] Professor Peterson was a member of the Blue Ribbon Commission on America's Nuclear Future which delved into the problem of spent fuel at the behest of then-Energy Secretary Steven Chu.

needed in the event of a nuclear power resurgence. From a spent fuel disposal point of view, there is no practical difference between extending licenses of existing reactors to 60 and even 80 years (as is now being considered) and building new reactors licensed for 40 years as was the practice in the past. Accordingly, for every additional repository that is needed, questions must be addressed regarding the availability of additional geologic sites that have the characteristics required for safe disposal.

6.11. Further, the NRC has no valid environmental analysis on which it can rely for an evaluation of spent fuel disposal impacts. The NRC has never prepared an EA or EIS to support the WCD or any of its revisions. Neither of the two regulations on which NRC relies for a determination that spent fuel disposal impacts are insignificant -- Table B-1 of Appendix B to Subpart A to 10 C.F.R. Part 51 and Table S-3 of 10 C.F.R. § 51.51 – was issued in connection with waste confidence findings. In fact, the technical basis for both regulations is both illogical and fundamentally inconsistent with the NRC's most recent pronouncement on the technical infeasibility of spent fuel disposal in salt in the 2010 WCD Update.

6.12. Table B-1, for instance, concludes that the environmental impacts of spent fuel disposal are too small to influence license renewal decisions[36]:

> For the high-level waste and spent-fuel disposal component of the fuel cycle, the EPA established a dose limit of 0.15 mSv (15 millirem) per year for the first 10,000 years and 1.0 mSv (100 millirem) per year between 10,000 years and 1 million years for offsite releases of radionuclides at the proposed repository at Yucca Mountain, Nevada.
>
> The Commission concludes that the impacts would not be sufficiently large to require the NEPA conclusion, for any plant, that the option of extended operation under 10 CFR part 54 should be eliminated. Accordingly, while the Commission has not assigned a single level of significance for the impacts of spent fuel and high level waste disposal, this issue is considered Category 1.[37]

But the central assertion in Table B-1 is illogical. To say that environmental impacts will be small because higher impacts have been forbidden is like saying that the existence of a law against drunken driving allows society to conclude that the impacts of drunken driving would in fact not be large enough to worry about. One of the purposes of a NEPA analysis is to evaluate the likelihood that protective measures will fail and environmental harm will occur.

6.13. The NRC also asserts that the DOE's license application for Yucca Mountain supports a conclusion that spent fuel disposal is technically feasible. [38] But the NRC has never actually ruled on the impacts of Yucca Mountain and whether that site is licensable. Equally important, Yucca Mountain is only one possible site out of many. An EIS or EA to support reactor licensing should evaluate the range of geologic media that may be used, not just one. In any

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[36] Table B-1 is published in the Final Continued Storage Rule. 79 Fed. Reg. at 56,263

[37] 79 Fed. Reg. (Sept. 19, 2014) at 56,263

[38] 79 Fed. Reg. (Sept. 19, 2014) at 56,251

event, the licensing proceeding for Yucca Mountain was suspended for several years and has not been completed at this juncture, and thus no conclusions have been reached, upon which the NRC could rely, regarding the question of whether Yucca Mountain would meet the performance standards specified in 40 C.F.R. Part 197.

6.14. Table S-3 summarizes the NRC's conclusion that radioactive releases from a repository will be zero (and therefore the impacts of spent fuel disposal will be nil), based on the assumption that spent fuel will be disposed of in a bedded salt repository. But Table S-3 is not the product of an EA or an EIS. Instead it is the product of an Environmental "Survey" and a "Policies and Procedures" statement issues with 10 CFR Part 51 in 1979.[39] And the Environmental Survey, which was prepared in 1974-79, is decades out of date. It is not consistent with more current NRC determinations regarding repository risks. For instance, it is not consistent with Table B-1. Table B-1 appears to acknowledge that long-term doses could be as high as 100 millirem per year – a far cry from the zero dose assumed in Table S-3.

6.15 Table S-3 is also inconsistent with the NRC's most recent determination regarding the technical feasibility of spent fuel disposal as stated in the 2010 WCD Update. Table S-3 is based on the assumption that spent fuel will be disposed of in bedded salt and will have no radioactive releases of solid fission products.[40] But the 2010 WCD Update rejected bedded salt as infeasible for spent fuel disposal:

> 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.[41]

6.16. It is also clear from the Environmental Survey Supplement (NUREG-0116) that Table S-3's assumption of zero releases after repository closure from spent closure was **merely an untested assumption:** "With both uranium recycle and spent-fuel disposal, the salt is assumed to retain the solid radioactive fission products. *The validity of this assumption has not been tested for spent fuel.*"[42]

6.17. Thus, it would be at odds with the minimal standards of scientific soundness should the NRC rely on Table S-3 for support of any safety decision regarding the technical feasibility of safe spent fuel disposal in a repository. The safety and environmental impacts of any given geologic medium for spent fuel disposal must be the *subject* of analysis, not its foregone conclusion.

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[39] WASH-1248, Environmental Survey of the Uranium Fuel Cycle (1974) (WASH-1248 (1974)); WASH-1248 Supp. 1, also known as NUREG-0116 (1976), and the NRC statement of considerations, NRC 1979

[40] NUREG-0116 (1976), p. 4-114

[41] NRC 2010a, p. 81,059, emphasis added.

[42] NUREG-0116 (1976), p. 4-114, italics added.

7.0 CONSIDERATION OF WHETHER REPOSITORY DISPOSAL OF SPENT FUEL CAN BE DONE SAFELY AND WITH SUFFICIENT CAPACITY COULD LEAD TO A CONCLUSION THAT LICENSING OF REACTORS IS NOT JUSTIFIED UNDER THE ATOMIC ENERGY ACT OR COST-BENEFICIAL UNDER NEPA.

7.0. As discussed above, before licensing or re-licensing any reactors, the NRC should prepare waste confidence findings regarding the technical feasibility and capacity of repositories and whether they would conform to the kinds of safety and radiological norms prevalent today. As required by NEPA, the NRC's analysis should also include an evaluation of the costs of spent fuel storage and disposal.

7.1. It is essential for the NRC to examine a variety of sites, engineered barriers, and repository sealing systems. The suitability of any particular approach cannot be taken as a foregone conclusion. For instance, the NRC previously relied on the assumption that spent fuel could be safely disposed of in bedded salt repositories, only to conclude years later that salt is not a suitable medium for spent fuel disposal. So long as a repository is not actually licensed, it is important for the NRC to continually update and evaluate existing information regarding the safety of future spent fuel disposal. It is also critical to evaluate the cost consequences of enabling the creation of even more spent fuel when there is as yet no clear path to a suitable repository for the huge amounts of spent fuel that have already been created.

7.2. In this context, it is important to note that a reasonable evaluation of the feasibility and capacity of repository disposal would involve significant cost considerations. Long-term storage (or longer) followed by disposal in one repository could add up to between $214 billion and $351 billion, in 2012 dollars. A second repository could add $34 billion to $171 billion.[43] These are huge sums of money that the NRC should take into account when assessing the reasonableness of its assumptions regarding long-term storage followed by disposal – or indefinite storage, which would be even more expensive. If these costs were considered in the cost-benefit analysis for initial reactor licensing decisions under NEPA, they are high enough to affect the outcome of a comparison of the costs of nuclear power compared to the alternatives.[44] It could therefore materially affect the cost-benefit analysis and tip the balance against licensing or re-licensing of a nuclear reactor.

8.0 CONCLUSION

8.1. In sum, unirradiated reactor fuel presents few risks and those that it does are very small. It can be and is routinely handled in the process of fuel fabrication. The main reason is that uranium-238 and uranium-235, which constitute almost the entire mass of fresh fuel, are only slightly radioactive. This changes drastically once the fuel is used in a nuclear power reactor to sustain a chain reaction. The radioactivity in the fuel rods increases by millions of times in the course of reactor operation. Both heat and radiation rise to lethal levels. Further, plutonium-239 builds up during the course of reactor operation – roughly 30 Nagasaki bombs worth every year in every 1,000-megawatt reactor.

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[43] Cooper 2013, p. 25

[44] Cooper 2013, p. 7

8.2. The severe environmental, safety, and proliferation risks from spent fuel storage on the surface last for thousands of years and longer. The only way to materially decrease these long-term risks beyond a few decades of storage is to dispose of spent fuel in a properly selected, sized, and engineered deep geologic repository (or repositories).

8.3. The NRC has no currently valid safety findings regarding spent fuel disposal, nor has it done any environmental analysis on which it could rely for such findings. In my professional opinion, given the severe hazards posed by spent fuel to public health and the environment, the NRC should not license reactors until it has made the requisite safety findings regarding the disposal of spent fuel in a repository and supported them with an adequate environmental analysis.

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

Arjun Makhijani

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Dr. Arjun Makhijani

September 29, 2014

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