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Mark Leyse's Response to the NRC Petition Review Board Assigned to Assess a 10 C.F.R. § 2.206 Petition Leyse Submitted on February 28, 2023

This is my (Mark Leyse's) response to the US Nuclear Regulatory Commission ("NRC") Petition Review Board ("PRB") that was assigned to assess a 10 C.F.R. § 2.206 petition I submitted on February 28, 2023.[1] The PRB performed an initial assessment of the petition that Perry Buckberg, the PRB manager, sent to me in an e-mail on July 21, 2023.

I. Did the Petition Review Board misunderstand what my petition requested?

The PRB's initial assessment states that the "[s]pecific concerns listed in [my] petition include":

1. An extreme solar storm might occur as frequently as once in 153 years to once in 500 years and initiate a widespread and long-term loss of the AC power grid and lead to widespread SFP coolant level challenges due to multiple loss-of-offsite power (LOOP) events.
2. An EMP with a magnitude that could cause widespread, long-term power outages and lead to widespread SFP coolant level challenges due to multiple LOOP events.
3. Diverse and Flexible Mitigation Capability (FLEX) equipment will work only 6 out of 10 times in arresting an accident involving an extended loss of AC power.
4. Without a timely restoration of AC power, a station blackout (SBO) will lead to a reactor core meltdown at each affected nuclear power plant unit, as occurred at Fukushima Daiichi.

[1] Mark Leyse, "10 C.F.R. § 2.206 request for the U.S. Nuclear Regulatory Commission to order licensees to promptly transfer all of the sufficiently-cooled spent fuel assemblies that are presently stored in each of the spent fuel pools at U.S. nuclear plants to dry cask storage; the density of fuel assemblies in pools must be reduced to the extent that any pool's remaining assemblies (provided they were properly configured) would not ignite—starting a "zirconium fire"—if it were to lose a significant portion or all of its coolant water," February 28, 2023, (ADAMS Accession No. ML23061A054).

5. The NRC's MELCOR Computer Code is incapable of simulating some spent fuel pool fire phenomena.
6. Power Grids are Vulnerable to Physical Attacks and Cyberattacks.
7. Many high-density SFP physical environment and chemical reaction scenarios, which were described in the petition, may result from a loss of SFP coolant and could lead to spent fuel zirconium fires, which may be severe.

Regarding some of the petition's "specific concerns," the PRB's initial assessment states: "The PRB's initial assessment is that the concerns represented in your petition which are within the NRC's regulatory authority (concerns 3, 4, 5 and 7) do not meet the DH 8.11 acceptance criteria in Section III.C.1(b)(ii)."

I want to clarify that I did NOT request that the NRC remedy any of the first six of the "specific concerns" that the PRB itemized. What I actually requested is clearly stated in the petition (on page 11). **Here is what I requested:** "Petitioner requests that the United States Nuclear Regulatory Commission ("NRC") order licensees to promptly transfer all of the sufficiently-cooled spent fuel assemblies that are presently stored in each of the spent fuel pools at U.S. nuclear plants to dry cask storage. Petitioner requests that the NRC order licensees to promptly reduce the density of spent fuel assemblies in spent fuel pools to the extent that any pool's remaining assemblies (provided they were properly configured) would not ignite—starting a "zirconium[2] fire"—if it were to lose a significant portion or all of its coolant water."

As stated in the petition (on page 26), in 2014, the NRC claimed that a severe earthquake (with a magnitude "expected to occur once in 60,000 years") is the prototypical initiating event that would lead to a spent fuel fire in a boiling water reactor's storage pool.[3] In my petition, I argued that a large earthquake is not the prototypical event that would lead to a spent fuel pool fire.

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[2] For consistency, Petition will use the term "zirconium" to refer to all the various types of zirconium alloys that comprise fuel cladding. Zircaloy, ZIRLO, and M5 are particular types of zirconium alloy fuel cladding. In a SFP accident, the oxidation behavior of the different fuel cladding materials, with various zirconium alloys, would be similar because of their shared zirconium content.

[3] Andrew Barto et al., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), pp. xxv, xxvii.

The specific concerns, the PRB listed as 1, 2, and 6, are discussed in my petition to show that a nationwide, long-term (a period of months to years) collapse of the U.S. power grid is estimated to have a relatively high frequency of occurrence. Some analysts estimate that a widespread, long-term collapse of the U.S. power grid may occur as frequently as once in 100 years.[4] In my petition, I argued that a widespread, long-term collapse of the U.S. power grid is the prototypical event that would lead to a spent fuel pool fire.

II. The Petition Review Board suggests it is inappropriate to discuss a number of different vulnerabilities of the U.S. power grid for the simple reason that the NRC does not regulate the U.S. power grid

I want to clarify that I did NOT request that the NRC remedy "specific concerns" numbers 1, 2, and 6.

In part of the PRB's response to "specific concern" **number 1**, the PRB states: "**Grid resilience (including under extreme solar storm conditions)** is outside the NRC's authority and is regulated by the Federal Energy Regulatory Commission (FERC) with participation from the North American Electric Reliability Corporation (NERC). **Therefore, in accordance with MD 8.11 Section II.A.2(d)(vi), this issue is not appropriate for a petition under 10 CFR 2.206**" [emphasis added].

In part of the PRB's response to "specific concern" **number 2**, the PRB states: "**As described above, grid resilience is outside NRC's regulatory authority**" [emphasis added].

In part of the PRB's response to "specific concern" **number 6**, the PRB states: "**Power grid security beyond NRC licensee-controlled areas is outside of the NRC's authority and is regulated by FERC. Therefore, in accordance with MD 8.11 Section II.A.2.(d)(vi), this issue is not appropriate for a petition under 10 CFR 2.206**" [emphasis added].

Is the PRB really criticizing me (a member of the public who took the time to write and submit a 2.206 petition) for discussing a number of different vulnerabilities of

[4] John Kappenman, "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," Metatech Report Meta-R–319, January 2010, pp. 3.14, 3.22, 3.26, 3.27; and Pete Riley, "On the Probability of Occurrence of Extreme Space Weather Events," Space Weather, Vol. 10, February 2012.

the U.S. power grid in my petition? Who the power grid's regulators are has nothing to do with one of the main points of my petition; that is, some analysts say the U.S. power grid has the potential to collapse as frequently as once every 100 years.

The PRB suggests that it is inappropriate to discuss a number of different vulnerabilities of the U.S. power grid for the simple reason that the NRC does not regulate the U.S. power grid. Does the PRB believe that it is inappropriate to discuss earthquakes in a 2.206 petition for the simple reason that the NRC does not regulate earthquakes?

III. David Lochbaum has commented on the Petition Review Board's response to "specific concern" number 3: "Diverse and Flexible Mitigation Capability (FLEX) equipment will work only 6 out of 10 times in arresting an accident involving an extended loss of AC power."

Please see David Lochbaum's comments, which are attached to this document in Attachment I.

IV. The Petition Review Board mischaracterized an EPRI report

In part of the PRB's response to "specific concern" **number 1**, the PRB states: "Further, the Electric Power Research Institute (EPRI) has documented research to better understand **the impacts of space weather on the current infrastructure. In a 2017 report on that research** (Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis. EPRI, Palo Alto, CA: 2017. 3002011969), **EPRI concluded, in part, that grid failures from extreme space weather** would likely result in transformer saturation that would cause overcurrent tripping before most transformers would be damaged. It also concluded that the largest shutdowns would be in the most densely populated areas in the northern latitudes. **The EPRI report evaluation did not show any scenarios where a national grid collapse would occur.** Based on this information and existing NRC requirements, staff asserts that recovery from this type of shutdown would happen within the timeframe encompassed by existing mitigating procedures" [emphasis added].

EPRI's 2017 report—with the title "Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis"—**is about the phenomenon of electromagnetic pulse, which is caused by the exo-atmospheric detonation of a nuclear weapon, NOT caused by a coronal mass ejection; that is, NOT caused by extreme space weather.**

The PRB **mischaracterized** EPRI's 2017 report.

The first two paragraphs of the abstract of EPRI's 2017 report state:

> The exo-atmospheric detonation of a nuclear weapon can generate a low-frequency electric field at the earth's surface. The resulting electric field, referred to as magnetohydrodynamic electromagnetic pulse (MHD-EMP) or E3, induces very low frequency currents in transmission lines and bulk power transformers. Similar to the effects from a severe geomagnetic disturbance (GMD), these geomagnetically induced currents (GICs) can cause part-cycle saturation of bulk power transformers, which can lead to adverse system impacts including voltage collapse and thermal damage in bulk power transformers.
>
> The assessment presented in this report, which evaluated the potential for E3 to cause instability or cascading of the bulk power system, is a continuation of a previous Electric Power Research Institute (EPRI) assessment that evaluated the potential for the GICs generated by E3 to cause thermal damage to bulk power transformers. As with the previous study, a single high-altitude burst over 11 different target locations within the continental United States (CONUS) was evaluated—that is, the assessment was comprised of 11 separate studies.

EPRI's 2017 report stated: "The GICs generated by the E3 environment that was simulated are large enough and of sufficient duration to cause part-cycle saturation of bulk power transformers over a large geographic region. For example, the geographic region associated with the E3 environment used in this study was on the order of **1,600 km x 1,600 km**"[5] [emphasis added].

EPRI's 2017 report also stated: "To minimize simulation time and potential numerical issues associated with performing a full dynamics analysis for the full 300+ second E3 waveform, **a simulation time of 112 seconds was chosen** to capture the peak

[5] EPRI, "Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis," 3002011969, 2017, p. 3.1.

of the E3A and E3B waveforms as well as approximately 1 minute after the E3B peak to account for later effects of load and generation loss"[6] [emphasis added].

A geographic region the size of 1,600 km x 1,600 km is small compared to the size of the geographic region that could be affected by a large coronal mass ejection. And a simulation time of a couple minutes is short compared to the length of time a large coronal mass ejection may affect vast regions of Earth. When an extreme solar storm's electrically-charged particles envelop the entire Earth they cause extreme geomagnetic storms affecting vast geographic areas for periods of hours if not days.

The Carrington event, an extreme solar storm that occurred in 1859, produced brilliant auroral displays—created by charged particles colliding with atoms and molecules in the atmosphere—over the course of eight days, terminating in early September 1859. In the Northern Hemisphere, auroras were reported as far south as the Caribbean and El Salvador, where "red light [in the sky] was so vivid that the roofs of the houses and the leaves of the trees appeared as if covered with blood." In the Southern Hemisphere, they were reported as far north as Santiago, Chile.[7]

The PRB should consider information that the NRC itself provided in a Federal Register notice regarding a rulemaking petition (PRM–50–96[8]).

My petition discusses this Federal Register notice, which was published on December 18, 2012. My petition (on pages 12-13) states: "In 2012, the NRC issued a Federal Register notice, regarding a rulemaking petition (PRM–50–96), submitted by Thomas Popik of the Foundation for Resilient Societies, in which the NRC posited that an extreme solar storm (geomagnetic disturbance) intense enough to cause hundreds of extra high voltage transformers[9] to fail[10] might occur as frequently as once in 153 years

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[6] EPRI, "Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis," 3002011969, 2017, p. 1.3.

[7] Committee on the Societal and Economic Impacts of Severe Space Weather Events, "Severe Space Weather Events: Understanding Societal and Economic Impacts: Workshop Report," National Academies Press, 2008, pp. 7, 8.

[8] Thomas Popik, PRM-50-96, March 14, 2011 (ADAMS Accession No. ML110750145).

[9] Extra high voltage transformers have a maximum voltage rating of 345 kilovolts (kV) or greater. See U.S. Department of Energy, "Large Power Transformers and the U.S. Electric Grid," April 2014, p. 4.

[10] Metatech, Executive summary of "Electromagnetic Pulse: Effects on the U.S. Power Grid," a collection of six technical reports written for ORNL by Metatech Corporation, January 2010, pp. i, ii. And NRC, "Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools:

to once in 500 years and initiate 'a series of events potentially leading to [reactor] core damage at multiple nuclear sites.'[11]

"According to some experts, the frequency of having a widespread, long-term blackout, caused by *extreme* space weather, might be as high as 10 percent per decade.[12] A report prepared for Oak Ridge National Laboratory explains that 'a once-in-100 year geomagnetic storm' could cause over 300 extra high voltage transformers to fail, 'leading to probable power system collapse[s] in the Northeast, Mid-Atlantic, and Pacific Northwest,' which could last months to longer than one year, 'affecting a population in excess of 130 million.' "[13]

It is noteworthy that EPRI's 2017 report, "Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis," states: "Part of the efforts to improve HEMP resiliency of a particular system may include recovery efforts in lieu of or in addition to installing devices to reduce or block the flow of GICs in bulk power transformers and thus minimize the impact of E3 on the system. **However, operational procedures designed to recover from voltage collapse resulting from E3 should consider the potential damaging effects of E1 and E2 on critical electronic systems such as communications systems, supervisory control and data acquisition (SCADA), and protection and control systems. Damage to these systems is the primary concern, since loss of these functions can potentially affect system recovery**"[14] [emphasis added].

Proposed Rules," Docket No. PRM–50–96, NRC–2011–0069, Federal Register, Vol. 77, No. 243, December 18, 2012, pp. 74793, 74794.

[11] NRC, "Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools: Proposed Rules," Docket No. PRM–50–96, NRC–2011–0069, Federal Register, Vol. 77, No. 243, December 18, 2012, p. 74790.

[12] John Kappenman, "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," Metatech Report Meta-R–319, January 2010, pp. 3-14, 3-22, 3-26, 3-27; and Pete Riley, "On the Probability of Occurrence of Extreme Space Weather Events," *Space Weather*, Vol. 10, Issue 2, February 2012.

[13] Metatech, Executive summary of "Electromagnetic Pulse: Effects on the U.S. Power Grid," a collection of six technical reports written for ORNL by Metatech Corporation, January 2010, pp. i, ii. And NRC, "Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools: Proposed Rules," Docket No. PRM–50–96, NRC–2011–0069, Federal Register, Vol. 77, No. 243, December 18, 2012, pp. 74793, 74794.

[14] EPRI, "Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis," 3002011969, 2017, p. 2.1.

Perhaps the PRB should read EPRI's 2017 report in order to glean information that is actually pertinent to my 2.206 petition's arguments about vulnerabilities of the U.S. power grid.

V. Solar storms have permanently damaged extra-high voltage transformers

As discussed above, **the PRB mischaracterized** a 2017 EPRI report, "Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis." The PRB mischaracterized the 2017 EPRI report in an apparent attempt to argue that solar storms do not have the potential to permanently damage extra-high voltage transformers. **The PRB mistakenly claimed** that the 2017 EPRI report discusses how extreme space weather (a coronal mass ejection) may affect the continental U.S. electric grid. In fact, the 2017 EPRI report is about the phenomenon of electromagnetic pulse, which is caused by the exo-atmospheric detonation of a nuclear weapon.

My petition (on pages 32-33) states: "…in late October 2003, relatively low intensity geomagnetic storms caused a blackout in southern Sweden and permanently damaged 15 large power transformers in South Africa by overheating them.[15] Solar storms have also caused fires. In April 1994, at Zion Nuclear plant[16]—located on Lake Michigan about 50 miles north of Chicago—a "moderate intensity" geomagnetic storm caused a transformer's cooling-oil tank to rupture and spill oil, which lead to a serious fire at the site."[17]

The late October 2003 geomagnetic storms (sometimes named the "2003 Halloween Solar Storms") are estimated to have had roughly one-tenth the magnitude of that of the 1859 Carrington event as well as a solar storm that occurred in 1921, which is sometimes named the "1921 New York Railroad Superstorm." The 1859 Carrington

[15] North American Electric Reliability Corporation, U.S. Department of Energy, "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," June 2010, p. 65; and John G. Kappenman, "An Overview of the Impulsive Geomagnetic Field Disturbances and Power Grid Impacts Associated with the Violent Sun-Earth Connection Events of 29-31 October 2003 and a Comparative Evaluation with Other Contemporary Storms," Space Weather, Volume 3, August 2005, p. 13.

[16] In January 1998, Zion's two nuclear reactors were permanently shut down.

[17] John Kappenman, "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," Metatech Report Meta-R–319, January 2010, p. 2-33.

event and the 1921 New York Railroad Superstorm are estimated to have each had magnitude of approximately 5,000 nanoteslas per minute (nT/min). The 2003 Halloween Solar Storms are estimated to have each had magnitude of approximately 480 nT/min.[18]

("Nanoteslas per minute" (nT/min) is the unit used for measurements of the local geomagnetic field's rate of change—or "the [local] rate of change in the magnetic field flux density over the Earth's surface."[19])

VI. Does the Petition Review Board's overoptimism undermine nuclear safety?

The PRB seems to believe the mere fact the NRC has issued regulations 10 C.F.R. § 50.155 (b)(1) and (c) is enough to ensure that all US nuclear power plants would successfully cope with loss-of-offsite power events if the US power grid were to collapse for a period of months to years.

In part of the PRB's response to "specific concern" **number 1**, the PRB states: "All U.S. NPPs are equipped to respond to an extended loss of AC power (ELAP), in accordance with 10 CFR 50.155 (b)(1) and (c). Further, it is the NRC's position that U.S. NPPs can safely shut down following an extreme solar storm event and maintain spent fuel pool cooling."

If widespread power outages were to last months to years, most if not all of the nuclear power plants in the U.S. would lose their supply of offsite alternating current (AC) electricity. In a loss-of-offsite power event, emergency diesel generators activate promptly to power cooling pumps as well as other safety equipment. Emergency diesel generators would likely fail to carry out the task of operating continuously for a period of months to years. **The longest loss-of-offsite power events in U.S. history have all lasted less than one week.**[20]

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[18] United States Government Accountability Office, "Critical Infrastructure Protection: Federal Agencies Have Taken Actions to Address Electromagnetic Risks, but Opportunities Exist to Further Assess Risks and Strengthen Collaboration," Report to Congressional Requesters, GAO-16-243, March 2016, pp. 40-41.

[19] John Kappenman, "Geomagnetic Storms and Their Impacts on the U.S. Power Grid," Metatech Report Meta-R–319, January 2010, pp. 1.1, 1.30, 4.1.

[20] Nancy Johnson and Zhegang Ma, "Analysis of Loss-of-Offsite-Power Events: 2021 Update," Idaho National Laboratory, INL/RPT-22-68809, August 2022, pp. 52-61.

Emergency diesel generators must be refueled once a week.[21] Most U.S. nuclear plants are required to have a seven-day supply of generator fuel onsite; many of them have additional fuel onsite and arrangements to receive prompt deliveries of fuel.[22] However, in the event of a nationwide blackout that lasted a period of months to years, it might be nearly impossible to maintain a steady fuel supply to every nuclear plant in the U.S. fleet.

Numerous of long-term loss-of-offsite power events would likely lead to many station blackouts ("SBO"), in which emergency diesel generators become inoperable. In a SBO, "reactor cooling is temporarily provided by systems that do not rely on AC power, such as turbine-driven pumps that are driven by steam from the reactor. Batteries also are used to provide direct current (DC) power to control the turbine-driven pumps and to power instrumentation."[23] Backup batteries would become depleted in four hours—for some reactors, depleted in eight hours.

Without a timely restoration of AC power, a SBO will lead to a reactor core meltdown at each affected nuclear power plant unit, as occurred at Fukushima Daiichi. And, if there were freshly discharged fuel assemblies in a spent fuel pool, its water could heat up and boil off in 49.3 hours or 125.0 hours (depending on whether there had been a 1/3 or full core discharge, five days prior).[24] Zirconium fires would likely occur at overpacked spent fuel pools.

VII. According to the OECD Nuclear Energy Agency, the NRC's spent fuel pool accident evaluation model of choice, MELCOR, is flawed

In part of the PRB's response to "specific concern" **number 5**, the PRB states: "The PRB is aligned with previous NRC responses regarding MELCOR which convey the

[21] NRC, "Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants," Regulatory Guide 1.9, Revision 4, March 2007, (ADAMS Accession No. ML070380553), p. 2.
[22] NRC, "Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools: Proposed Rules," Docket No. PRM–50–96, NRC–2011–0069, Federal Register, Vol. 77, No. 243, December 18, 2012, p. 74796.
[23] NRC, "Modeling Potential Reactor Accident Consequences," NUREG/BR-0359, January 2012, (ADAMS Accession No: ML12026A470), p. 11.
[24] NRC, "Regulatory Analysis for the Resolution of Generic Issue 82, 'Beyond Design Basis Accidents in Spent Fuel Pools'," NUREG-1353, April 1989, (ADAMS Accession No. ML082330232), p. 4-25.

following: The NRC disagrees with the petitioner's statements that MELCOR is flawed. MELCOR is the NRC's best estimate tool for severe accident analysis and has been validated against experimental data."

MELCOR is flawed, according to the OECD Nuclear Energy Agency.

My petition (on page 22) states: "[In 2015], the OECD Nuclear Energy Agency stated: 'The results of the simulation of the OECD/NEA Sandia Fuel Project show—in agreement with the experimental findings—that the phenomena under air atmospheres/air ingress are not fully understood and modeled. All codes considered air oxidation, but nitride formation was modeled only in one code explicitly [not MELCOR] and re-oxidation of ZrN was not modeled at all. All reactions in air atmosphere influence the temperature excursion, because they are exothermal… Additionally, ZrN forms a porous layer, leading to fast subsequent oxidation in oxygen or steam. For these phenomena, further model development is necessary on the basis of more separate effect and integral tests, although they are partially direct[ly] or indirect[ly] considered in current models.'[25]"

As the OECD Nuclear Energy Agency has stated, MELCOR is incapable of modeling reactions between zirconium and nitrogen.

My petition (on page 20) also states: "…an OECD Nuclear Energy Agency report from 2015 explains that 'fuel degradation in [spent fuel pool] accidents may occur in environments containing air, which accelerates zirconium alloy oxidation by nitriding and oxide layer breakup. Air also speeds up UO_2 fuel degradation and volatilization by oxidation, and may increase the release of *e.g*. ruthenium and otherwise less volatile fission products.'[26] Note also that a National Academy of Sciences report from 2016 lists some of MELCOR evaluation model's limitations, including the fact that MELCOR 'cannot model nitriding reactions with zirconium.'[27]"

[25] OECD Nuclear Energy Agency, "Status Report on Spent Fuel Pools under Loss-of-Cooling and Loss-of-Coolant Accident Conditions: Final Report," NEA/CSNI/R(2015)2, May 2015, p. 137.
[26] OECD Nuclear Energy Agency, "Status Report on Spent Fuel Pools under Loss-of-Cooling and Loss-of-Coolant Accident Conditions: Final Report," NEA/CSNI/R(2015)2, May 2015, p. 12.
[27] National Academy of Sciences, "Lessons Learned from the Fukushima Nuclear Accident for Improving Safety and Security of U.S. Nuclear Plants: Phase 2," May 2016, p. 140.

VII.A. By ignoring and censoring information on the deficiencies of its post-Fukushima MELCOR simulations, the NRC undermines its own philosophy of defense-in-depth, which requires the application of conservative models

As stated above, in part of the PRB's response to "specific concern" **number 5**, the PRB states: "The PRB is aligned with previous NRC responses regarding MELCOR which convey the following: The NRC disagrees with the petitioner's statements that MELCOR is flawed. MELCOR is the NRC's best estimate tool for severe accident analysis and has been validated against experimental data."

Previous NRC responses regarding MELCOR's flaws have been censored.

My petition (on pages 19-20) states: "In 2014, Leyse submitted a rulemaking petition to the NRC, requesting improvements to evaluations of spent fuel pool accidents.[28] The NRC docketed the petition as PRM-50-108. Among other things, PRM-50-108 requested that the NRC make a new regulation stipulating that the rates of energy release from the nitriding of the zirconium fuel-cladding, part of the zirconium-air reaction, be calculated by spent fuel pool accident evaluation models."

My petition (on pages 20-21) also states: "The NRC Staff advised the Commissioners to deny PRM-50-108 in November 2015.[29] In response, NRC Chairman Burns stated: 'I approve the staff's recommendation denying the petition for rulemaking and publishing the Federal Register notice and letter to the petitioner, subject to the attached edits.'[30] The "edits" were the censoring of a few pages on the science of spent fuel pool fires. The censored pages discussed the fact that the nitrogen content of air would intensify a spent fuel pool fire. (Of course, the term "spent fuel pool fire" is informal. In a fire, strictly speaking, there wouldn't be any nitriding, only oxidation.)"

[28] Mark Leyse, PRM-50-108, June 19, 2014, (ADAMS Accession No. ML14195A388).

[29] NRC, "Denial of Petition for Rulemaking Requesting Amendments Regarding Spent Fuel Pool Severe Accident Evaluations (PRM-50-108; NRC-2014-0171)," SECY-15-0146, November 19, 2015, (ADAMS Accession No. ML14307A134). NRC, "Fuel-Cladding Issues in Postulated Spent Fuel Pool Accidents," Docket No. PRM–50–108; NRC–2014– 0171, Federal Register, Vol. 81, No. 93, May 13, 2016, pp. 29761-29765.

[30] The censored Federal Register notice is in the April 4, 2016 Commission Voting Record, SECY-15-0146, Denial of Petition for Rulemaking Requesting Amendments Regarding Spent Fuel Pool Severe Accident Evaluations (PRM-50-108; NRC-2014-0171), (ADAMS Accession No. ML16103A375).

Among the sentences that Chairman Burns and the Commissioners redacted from the Staff's Federal Register notice draft was the simple statement: 'The NRC recognizes that the phenomena discussed in the petition are important to realistically evaluate the initiation and progression of SFP [spent fuel pool] fires in the unlikely event of a beyond design basis accident.'[31] The NRC recognized phenomena discussed in my petition are important to realistically evaluate spent fuel pool fires. Nonetheless, the NRC decided to deny the petition."

Chairman Burns and the Commissioners also redacted the following statement from the Staff's Federal Register notice draft: 'Nitriding is most relevant when nuclear fuel is undergoing a severe accident in an air environment and oxygen-starved conditions develop because of rapid consumption of oxygen from the air.'[32] That censored statement sums up one of the primary reasons why Leyse submitted PRM-50-108. Leyse cited reports asserting that the cladding of fuel assemblies degrades quickly when oxygen is not *locally* present and the effects of nitrogen prevail."

If the NRC really thinks the MELCOR computer code so great, why did it resort to censoring information from the Staff's Federal Register notice draft on phenomena of spent fuel pool fires and how MELCOR is incapable of simulating some of those phenomena?

VII.B. The NRC's Non-Conservative, Post-Fukushima MELCOR Simulations

A September 2014 NRC report, NUREG-2161, on how earthquakes could affect BWR Mark I spent fuel pools provides the results of a number of the NRC's MELCOR computer safety model simulations of loss-of-coolant accidents in spent fuel pools.[33] The MELCOR analyses of NUREG-2161 did not simulate the nitriding of the zirconium that

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[31] The censored Federal Register notice is in the April 4, 2016 Commission Voting Record, SECY-15-0146, Denial of Petition for Rulemaking Requesting Amendments Regarding Spent Fuel Pool Severe Accident Evaluations (PRM-50-108; NRC-2014-0171), (ADAMS Accession No. ML16103A375).

[32] The censored Federal Register notice is in the April 4, 2016 Commission Voting Record, SECY-15-0146, Denial of Petition for Rulemaking Requesting Amendments Regarding Spent Fuel Pool Severe Accident Evaluations (PRM-50-108; NRC-2014-0171), (ADAMS Accession No. ML16103A375).

[33] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365).

would occur in an accident.[34] As a consequence, the MELCOR analyses underestimated the severity of spent fuel fires and the amount of radioactive material a spent fuel fire could potentially release into the environment. The NRC used the non-conservative results of the NUREG-2161 MELCOR analyses to help justify its decision to not require the prompt thinning out of spent fuel assemblies from spent fuel pools.[35]

My petition (on pages 136-138) states: "An NRC Post-Fukushima MELCOR (version 1.8.6 of the code[36]) simulation of *a particular* BWR Mark I SFP fire scenario ("Unsuccessful Deployment of Mitigation for Moderate Leak (OCP3) Scenario"[37]) found that in the central area of the SFP, 'Radial Ring 1'—where the newly discharged, hottest, fuel assemblies were stored—the peak fuel-cladding temperature would reach approximately 1,800 K (1,527°C) (2,780°F) at "Axial Level 4."[38] However, the same simulation also found that '[a]fter the peak temperature [is reached] at [Axial] Level 4, the peak temperature in the zirconium fire front decreases with each successive [axial]

[34] J. Fleurot *et al*., "Synthesis of spent fuel pool accident assessments using severe accident codes," *Annals of Nuclear Energy*, 74, 2014, p. 70; J. Stuckert, M. Große, Z. Hózer, M. Steinbrück, Karlsruhe Institute of Technology, "Results of the QUENCH-16 Bundle Experiment on Air Ingress," KIT-SR 7634, May 2013, p. 1; O. Coindreau, C. Duriez, S. Ederli, "Air Oxidation of Zircaloy-4 in the 600-1000°C Temperature Range: Modeling for ASTEC Code Application," *Journal of Nuclear Materials*, 405, 2010, p. 208; and K. C. Wagner, R. O. Gauntt, Sandia National Laboratories, "Mitigation of Spent Fuel Pool Loss-of-Coolant Inventory Accidents and Extension of Reference Plant Analyses to Other Spent Fuel Pools," SAND1A Letter Report, Revision 2, November 2006, (ADAMS Accession No. ML120970086), p. 12.

[35] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. vi.

[36] The SFP models in MELCOR versions 1.8.6 and 2.1 are functionally the same. See Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), pp. 95-96.

[37] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 145.

[38] For MELCOR "[t]he core is nodalized into a number of axial levels and radial rings (each ring represents a collection of assemblies);" and "MELCOR core models were originally designed for the reactor core. Because of the code flexibility, the same modeling approach can be used for the spent fuel pool (with the addition of the rack as a separate component)." See Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 98 and p. 98, Note 12.

level. Radial heat transfer[39] from the fuel racks to the SFP wall…, *the buildup of the oxide layer on the fuel, and the depletion of the oxygen in the reactor building…cause the clad temperature to decrease*. After 24 hours, the fuel temperatures in [Radial] Ring 1 are relatively stable'[40] [emphasis added]. (In this scenario there is a depletion of the oxygen in the reactor building, because the reactor building was *not* breached by a hydrogen explosion. Note that a total of four reactor buildings were breached by hydrogen explosions in the Fukushima Daiichi accident.[41])

"This NRC MELCOR simulation—in which there is a depletion of the oxygen in the reactor building—would have had *different results* if it had modeled: 1) how nitriding would degrade the fuel-cladding's "protective" oxide layer and accelerate the zirconium oxidation, which would contribute additional heat; 2) the nitriding of zirconium under oxygen-starvation conditions; and 3) the significant additional heat that would be contributed from the exothermic nitrogen-zirconium reaction.

"In other NRC MELCOR simulations of BWR Mark I SFP accident/fire scenarios, the reactor buildings were breached by hydrogen explosions, so there was more available oxygen to facilitate zirconium oxidation. However, those simulations would have had *different results* if they had modeled: 1) how nitriding would degrade the fuel-cladding's "protective" oxide layer and accelerate the zirconium oxidation, which would contribute additional heat and 2) the significant additional heat that would be contributed from the exothermic nitrogen-zirconium reaction.[42]

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[39] "MELCOR attempts to model a multidimensional geometry with a simplified two-surface radiation model." See Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 113, Note 23.

[40] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), pp. 145-146.

[41] In the Fukushima Daiichi accident, hydrogen detonated in and essentially destroyed the secondary containments of Units 1, 3, and 4, causing large releases of radiation. And the secondary containment of Unit 2 was breached: a hydrogen explosion that occurred in the Unit 1 reactor building "caused a blowout panel in the Unit 2 reactor building to open, which resulted in a loss of secondary containment integrity." See INPO, "Special Report on the Nuclear Accident at the Fukushima Dai-ichi Nuclear Power Station," INPO 11-005, November 2011, p. 24.

[42] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365).

"In actual SFP fires, there would be quicker fuel-cladding temperature escalations, releasing more heat, and quicker axial and radial propagation of zirconium fires than MELCOR indicates."

VII.C. MELCOR is incapable of simulating criticality events

The MELCOR evaluation model is incapable of modeling criticality events.[43] To model the criticality events that may occur during SFP accidents, MELCOR can be used in conjunction with computer safety models (like the SERPENT code) that simulate criticality events.[44] **Why did the NRC choose not to simulate criticality events** in the very analyses it used to help justify its decision to not require the prompt thinning out of spent fuel assemblies from SFPs?[45]

My petition (on pages 77-79) states: "A major earthquake could cause a spent fuel pool to have a loss-of-coolant accident. The NRC report, NUREG-2161, warns that criticality events might occur if a drained SFP were reflooded with coolant water.[46] NUREG-2161 states that if a criticality event occurred at a point at which 'the fuel was only partially covered, the event could have an important impact on onsite dose rates.'[47] (As NUREG-2161 points out, increased onsite dose rates would impede efforts to

[43] OECD Nuclear Energy Agency, "Status Report on Spent Fuel Pools under Loss-of-Cooling and Loss-of-Coolant Accident Conditions: Final Report," NEA/CSNI/R(2015)2, May 2015, pp. 134-135.

[44] Piotr Darnowsk *et al*., "Investigation of the recriticality potential during reflooding phase of Fukushima Daiichi Unit-3 accident," Annals of Nuclear Energy, Volume 99, 2017, p. 495. And G. Caplin *et al*., "Why a Criticality Excursion Was Possible in the Fukushima Spent Fuel Pools," Proceedings of the International Conference on Physics of Reactors (PHYSOR) 2014, Kyoto, Japan, September 28-October 3, 2014.

[45] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. vi.

[46] NUREG-2161 points out that BWR SFPs do not use borated water, which is a neutron absorber that helps prevent criticality events, and that a drained BWR SFP would likely be reflooded with unborated water. See Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 30.

[47] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 29.

mitigate a SFP accident.[48]) NUREG-2161 also states that if criticality events 'were severe enough to produce significant heat, the fuel will be harder to cool.'[49]

"NUREG-2161 provides the results of a number of the NRC's MELCOR computer safety model simulations of loss-of-coolant accidents in SFPs in which there was a moderate leakage rate.[50] In the simulations, water drained from the pools to an extent that enabled spent fuel assemblies to become uncovered by coolant water, which, in some cases, increased the assemblies' cladding temperatures up to 3,140°F (1,727°C).[51] In some simulations, temperatures in the SFP reached the point at which neutron-absorber materials would become ineffective in preventing criticality events after either vitrifying or melting. In some simulations, spray cooling (200 gallons per minute) or water injection (500 gallons per minute of makeup water) was employed to cool the spent fuel assemblies and add water back into the pool after neutron-absorber materials would have become ineffective.[52] Nonetheless, the NRC MELCOR simulations of NUREG-2161 did not consider the possibility of criticality events occurring in the SFP as a consequence of the neutron-absorber materials having become ineffective.[53]

…

"The results of the MELCOR analyses of NUREG-2161 provided unrealistic results. For example, when water was reintroduced to the SFP in scenarios in which

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[48] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 87.

[49] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 29.

[50] A moderate leakage rate is "[a] state with leakage from the bottom of the SFP, corresponding to through-wall concrete cracking at the bottom of the walls and tearing of the liner that propagates to an extent such that water leakage is controlled by the size of the cracks in the concrete." See Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 61.

[51] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 217.

[52] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), pp. 216-218.

[53] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), p. 20.

neutron-absorber materials became ineffective, criticality events may have occurred. As the NRC itself pointed out, criticality events would increase onsite dose rates as well as increase fuel cladding temperatures. The MELCOR analyses of NUREG-2161 portray cladding temperatures rapidly decreasing in scenarios in which they might actually increase.[54]

Respectfully submitted,

_____/s/_____

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Dated: September 12, 2023

Attachment I David Lochbaum's response to the Petition Review Board's "specific concern" number 3: "Diverse and Flexible Mitigation Capability (FLEX) equipment will work only 6 out of 10 times in arresting an accident involving an extended loss of AC power."

[54] Andrew Barto *et al*., NRC, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, (ADAMS Accession No. ML14255A365), pp. 216-218.

Attachment I

David Lochbaum's response to the Petition Review Board's "specific concern" number 3: "Diverse and Flexible Mitigation Capability (FLEX) equipment will work only 6 out of 10 times in arresting an accident involving an extended loss of AC power."

In an email dated July 21, 2023, to Mark Leyse, NRC's Perry Buckberg provided the Petition Review Board's initial assessment of a 2.206 petition submitted February 23, 2023, by Mr. Leyse. The petition sought to accelerate the transfer of irradiated fuel assemblies from spent fuel pools into dry storage and provided numerous reasons for the requested actions. The PRB's initial assessment provided this response to one of those reasons:

3. Diverse and Flexible Mitigation Capability (FLEX) equipment will work only 6 out of 10 times in arresting an accident involving an extended loss of AC power.

PRB Response:
The petitioner's claim that FLEX will work 6 of 10 times is taken from the 2015 document, "Draft Regulatory Basis for Containment Protection and Release Reduction for Mark I and Mark II Boiling Water Reactors" (ML15022A214). **This was a conservative estimate developed before FLEX had been fully implemented at any plant and the estimate included seismic contributors to core damage frequency for an ELAP. In the context that the comment is being applied by the petitioner, one would have to assume an ELAP caused by space weather concurrent with a seismic event. The NRC does not assume concurrent beyond design basis events.** Further, FLEX response for SFP cooling typically only involves a single diesel pump with hand laid fire hose. This removes risk for other internal equipment and has much lower human factor contributors. [boldfacing added for emphasis]

This response is illogical by its contradictions. On one hand, it states that the NRC does not assume concurrent design basis events and suggests it is improper for the petitioner to "have to assume an ELAP caused by space weather concurrent with a seismic event." But the response's prior sentence refers to an analysis of a seismic event concurrent with an ELAP. As detailed below, the NRC staff and its Commission relief on this same 2015 document en route to rulemaking on post-Fukushima safety measures.

In SECY-16-0142, "Draft Final Rule – Mitigation of Beyond-Design-Basis Events (RIN 3150-AJ49)," dated December 15, 2016 (ML16291A186), the NRC staff sought the Commission's approval to publish a final rule on post-Fukushima safety upgrades.

Attachment 1 to SECY-16-0142 was the draft rule. Page 30 of the draft rule stated:

> The NRC concludes that the risk of offsite consequences from the beyond-design-basis events addressed by the rule is very small based upon a review of the recent work to understand plant risk. This conclusion is based on both the state-of-the-art reactor consequence analyses (see NUREG-1935, "State-of-the-Art Reactor Consequence Analyses (SOARCA) Report," November 2012), and the work performed for the containment protection and release reduction regulatory effort (see SECY-15-0085, "Evaluation of the Containment Protection & Release Reduction for Mark I and Mark II Boiling Water Reactors Rulemaking Activities (10 CFR Part 50) (RIN-3150-AJ26)," dated June 18, 2015, specifically the enclosure entitled, "Containment Protection and Release Reduction (CPRR) Rulemaking: Draft Regulatory Basis").

Attachment 1 to SECY-16-0142 was the draft rule. Section XIX on page 149 lists "Draft Regulatory Basis for Containment Protection and Release Reduction for Mark I and Mark II

> Boiling Water Reactors (10 CFR Part 50)," dated May 2015 (ML15022A214) under the Other References section.
>
> Attachment 1 to SECY-16-0142 was the draft rule. Section XIX on page 155 lists "SECY-15-0085, "Evaluation of the Containment Protection & Release Reduction for Mark I and Mark II Boiling Water Reactors Rulemaking Activities (10 CFR Part 50) (RIN-3150-AJ26)," enclosure entitled, "Containment Protection and Release Reduction (CPRR) Rulemaking: Draft Regulatory Basis," June 18, 2015 (ML15005A079) under the Other Documents section.
>
> Attachment 6 to SECY-16-0142 was the NRC staff's Regulatory Analysis of the draft rule. The Reference section of the Regulatory Analysis (pages 53-56) list 45 documents – none of which update, finalize, or supersede the Containment Protection and Release Reduction" draft Regulatory Analysis enclosed with SECY-15-0085.

The Staff Regulatory Memorandum dated January 24, 2019 (ML19024A073) for SECY-16-0142 informed the NRC staff of the Commission's approval of the Mitigation of Beyond-Design-Basis Events rule proposed by the SECY.

In October 2015, the NRC issued a document titled "Regulatory Analysis: Proposed Rulemaking to Address Mitigation of Beyond-Design-Basis Events" (ML15266A133). The last paragraph on page 61 of the Regulatory Analysis refers to the Containment Pressure and Release Reduction (CPRR) analysis enclosed with SECY-15-0085:

> The CPRR technical analysis includes a screening analysis for estimating a conservative high estimate of frequency-weighted ILCF risk. This screening analysis combined the highest ELAP frequency among all Mark I and II BWRs, **a success probability in the FLEX equipment of 0.6 per demand following core melt**, the highest conditional ILCF risk among all Mark I and II BWRs, and a worst case re-habitability assumption. [boldfacing added for emphasis]

Thus, the final rule proposed by the NRC staff and approved by the Commission explicitly relied on the draft evaluation of the Containment Pressure and Release Reduction analysis that was an enclosure to SECY-15-0085 without even implied dismissal or rejection of the 0.6 success probability for the FLEX equipment. If the NRC can rely on this draft analysis to make regulatory decisions about federal rules, the public can equally rely on the draft analysis. The NRC cannot employ a double standard by condoning its reliance and condemning the public's reliance on the draft analysis.