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In the attached comments, dated February 11, 2016, Mark Leyse responds to the U.S. Nuclear Regulatory Commission's notice of solicitation of public comments on "10 CFR Parts 50 and 52: Mitigation of Beyond-Design-Basis Events;" Proposed Rules; NRC-2014-0240, published in the Federal Register on November 13, 2015.

February 11, 2016

Annette L. Vietti-Cook
Secretary
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Rulemakings and Adjudications Staff

Mark Leyse's Comments on the NRC's "10 CFR Parts 50 and 52: Mitigation of Beyond-Design-Basis Events;" Proposed Rules; NRC-2014-0240

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Attention: Rulemakings and Adjudications Staff

Subject: Response to the U.S. Nuclear Regulatory Commission's ("NRC") notice of solicitation of public comments on "10 CFR Parts 50 and 52: Mitigation of Beyond-Design-Basis Events" (hereinafter: "Mitigation of Beyond-Design-Basis Events"); Proposed Rules; NRC-2014-0240.

Mark Leyse's Comments on the NRC's "Mitigation of Beyond-Design-Basis Events;" Proposed Rules; NRC-2014-0240

I, Mark Leyse ("Commenter"), am responding to the Federal Register notice that the NRC published on November 13, 2015 soliciting public comments on its proposed rules on the mitigation of beyond-design-basis events.

I. Statement of Commenter's Interest

On March 15, 2007, Commenter submitted a 10 C.F.R. § 2.802 petition for rulemaking, PRM-50-84,[1] to the NRC. PRM-50-84 requested: 1) that the NRC make new regulations to help ensure licensees' compliance with 10 C.F.R. § 50.46(b) emergency core cooling systems ("ECCS") acceptance criteria and 2) to amend Appendix K to Part 50—ECCS Evaluation Models I(A)(1), "The Initial Stored Energy in the Fuel."

In 2008, the NRC decided to consider the safety issues raised in PRM-50-84 in its rulemaking process.[2] And in 2009, the NRC published "Performance-Based Emergency Core Cooling System Acceptance Criteria," which gave advanced notice of a proposed rulemaking, addressing four objectives: the fourth being the issues raised in PRM-50-84.[3] In 2012, the NRC Commissioners voted unanimously to approve a proposed

[1] Mark Edward Leyse, PRM-50-84, March 15, 2007 (ADAMS Accession No. ML070871368).
[2] NRC, "Mark Edward Leyse; Consideration of Petition in Rulemaking Process," Docket No. PRM–50–84; NRC–2007–0013, Federal Register, Vol. 73, No. 228, November 25, 2008, pp. 71564-71569.
[3] NRC, "Performance-Based Emergency Core Cooling System Acceptance Criteria," NRC–2008–0332, Federal Register, Vol. 74, No. 155, August 13, 2009, pp. 40765-40776.

rulemaking—revisions to Section 50.46(b), which will become Section 50.46(c)—that was partly based on the safety issues Commenter raised in PRM-50-84.[4]

Commenter also coauthored a paper, "Considering the Thermal Resistance of Crud in LOCA Analysis," which was presented at the American Nuclear Society's 2009 Winter Meeting.[5]

II. The Proposed Requirements of 10 C.F.R. § 50.155(b)(1)—in the Proposed Rules of "Mitigation of Beyond-Design-Basis Events"—Are Not Adequate (or Even Partial) Solutions to the Safety Issues Raised in PRM-50-96

PRM-50-96 addressed scenarios in which the North American power grids would experience long-term blackouts that would last months to years. PRM-50-96 cited and quoted reports stating that coronal mass ejections from the Sun could direct electrically-charged particles to Earth, causing "a 1-in-100-year geomagnetic storm." Such an event could, in turn, cause more than 300 extra high voltage transformers[6] to overheat and incur permanent damage, leading to large-scale, long-term blackouts.[7]

There are other events that could also lead to power blackouts that would last months to years, including cyberattacks. It is noteworthy that in 2015 Ted Koppel released a bestselling book, *Lights Out: A Cyberattack, A Nation Unprepared, Surviving the Aftermath*, addressing the threat of cyberattacks collapsing the U.S. power grid for a period of months. Koppel interviewed General Lloyd Austin III, Commander of U.S. Central Command for *Lights Out*. Koppel asked the General if he thinks that a

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[4] NRC, Commission Voting Record, Decision Item: SECY-12-0034, Proposed Rulemaking—10 CFR 50.46(c): Emergency Core Cooling System Performance During Loss-of-Coolant Accidents (RIN 3150-AH42), January 7, 2013, (ADAMS Accession No. ML13008A368).

[5] Rui Hu, Mujid S. Kazimi, Mark Leyse, "Considering the Thermal Resistance of Crud in LOCA Analysis," American Nuclear Society, 2009 Winter Meeting, Washington, D.C., November 15-19, 2009.

[6] The NRC has explained that "[l]arge transformers are very expensive to replace and few spares are available. Manufacturing lead times for new equipment range from 12 months to more than 2 years." See 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. 74794.

[7] Oak Ridge National Laboratory, 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.

cyberattack could disable a large portion of the U.S. power grid. "It's not a question of if," the General replied, "it's a question of when someone will try that."[8]

If large-scale power outages were to last months or longer, multiple nuclear power plants would lose their supply of offsite alternating current ("AC") power, which is necessary for daily operation and *preventing* severe accidents. Multiple loss-of-offsite power events—especially in the event of prolonged power grid failures—could lead to a number of station-blackouts; a station-blackout is a complete loss of both grid-supplied and backup onsite AC power. The Fukushima Dai-ichi accident was a station-blackout accident that led to three reactor core meltdowns.

PRM-50-96 recommends regulations for preventing spent fuel pool ("SFP") fires in the event of such long-term blackouts. PRM-50-96 states that in such an event: "the North American commercial grids…cannot be relied on to provide continual power for active cooling and/or water makeup of spent fuel pools. Moreover, existing means of onsite backup power are designed to operate for only a few days, while spent fuel requires active cooling for several years after removal from the reactor core."[9]

Commenter believes that PRM-50-96 is a very important petition; it has drawn attention to the vulnerabilities of SFPs in the event of blackouts that would last months to years. The NRC seems to agree. In December 2012, NRC staff members decided to consider safety issues raised in PRM-50-96 in its rulemaking process.[10]

In its Federal Register notice announcing that PRM-50-96 had been accepted, the NRC stated:

> The NRC's initial evaluation of available information indicates that the likelihood of an extreme solar storm (similar to the 1859 Carrington event[11]) is plausible with a frequency in the range of once in 153 to once in 500 years (2E–3 to 6.5E–3 per year). The probability of the petitioner's postulated catastrophic grid failure, given a Carrington-like event, is not known with certainty. However, based on the NRC's review of the existing data, the NRC believes that there is insufficient information for the NRC to conclude that the overall frequency of a series of events

[8] Ted Koppel, *Lights Out: A Cyberattack, A Nation Unprepared, Surviving the Aftermath*, (New York: Crown Publishers, 2015), p. 89.

[9] Thomas Popik, PRM-50-96, March 14, 2011, (ADAMS Accession No. ML110750145), p. 9.

[10] 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.

[11] The Carrington event occurred in 1859; it is the largest solar storm to hit Earth ever recorded.

> potentially leading to core damage at multiple nuclear sites is acceptably low such that no regulatory action is needed. Thus, the NRC concludes that the petitioner's scenario is sufficiently credible to require consideration of emergency planning and response capabilities under such circumstances. Accordingly, the NRC intends to further evaluate the petitioner's concerns in the NRC rulemaking process.[12]

The NRC's conclusion is that the frequency of a "catastrophic grid failure" from a Carrington-type event may be as high as once in 153 years. And the NRC also concludes that such a power failure, in turn, could initiate "a series of events potentially leading to core damage at multiple nuclear sites." But has the NRC ever conducted probabilistic risk assessments ("PRA") estimating the core damage frequency that could occur at "multiple nuclear sites" in the event of long-term catastrophic grid failures—blackouts that would last months to years? Or has the NRC conducted PRAs estimating the frequency of SFP fires that could occur at multiple nuclear sites in the event of long-term catastrophic grid failures?

An NRC Fact Sheet on PRAs explains: "One of the Nuclear Regulatory Commission's key responsibilities is to ensure the operation of nuclear power plants and other NRC-licensed facilities present no undue risk to public health and safety."[13] Given that the frequency of a catastrophic grid failure may be as high as once in 153 years, a PRA considering the frequency of core damage and SFP fires at multiple nuclear sites, in the event of a catastrophic grid failure, may find that the operation of nuclear power plants and their *over-packed* SFPs presents an "undue risk to public health and safety."

PRM-50-96 is invaluable: it identified one of the events—blackouts that would last months to years—that most threatens public health and safety. The NRC's Federal Register notice announcement on PRM-50-96's acceptance also warns about the threat of long-term-blackouts. However, the NRC has *failed* to properly address the fact that the safety of SFPs (as well as reactor cores) is threatened by long-term-blackouts.

The U.S. is particularly vulnerable to SFP fires, because its SFPs are *densely-packed* with spent fuel assemblies. For example, one SFP at a U.S. plant was originally

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[12] NRC, "Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools," Proposed Rules, Docket No. PRM–50–96, NRC–2011–0069, p. 74790.

[13] NRC, "Fact Sheet: Probabilistic Risk Assessment," October 2007, (ADAMS Accession No. ML032200337).

intended to store 600 fuel assemblies. Subsequently, the plant was permitted by the NRC to store up to 3300 assemblies in the same SFP.[14] Gordon R. Thompson, executive director of the Institute for Resource and Security Studies, Dave Lochbaum, director of the Union of Concerned Scientists' Nuclear Safety Project, and others, have argued for years that storing spent fuel less densely would help improve public safety.[15] However, the U.S. nuclear industry prefers high-density storage because it is cheaper. The NRC allows high-density storage to persist.

In the high-density storage racks of SFPs, the center-to-center distance between the spent fuel assemblies (the "pitch") is similar to the pitch of fuel assemblies in the reactor core. For example, some BWR reactor cores have a fuel assembly pitch of 6.0 inches[16] and some BWR SFPs have a spent fuel assembly pitch of 6.28 inches.[17] Additionally, some PWR reactor cores have a fuel assembly pitch of 8.587 inches[18] and some PWR SFPs have a spent fuel assembly pitch of 9.0 inches.[19]

The NRC once considered requiring licensees to expedite the transfer of spent fuel assemblies from SFPs to dry cask storage. That would have made SFPs far less vulnerable to SFP fires. However, in 2013, the NRC decided to not require licensees to expedite the transfer of spent fuel assemblies. As explained in COMSECY-13-0030, the

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[14] NRC, "On Site Spent Fuel Criticality Analyses NRR Action Plan," May 21, 2010, (ADAMS Accession No. ML101520463), pp. 1, 2.

[15] Here are examples of comments of Mr. Thompson and Mr. Lochbaum have made arguing that storing spent fuel less densely would help improve public safety. See Gordon R. Thompson, Institute for Resource and Security Studies, "Comments on the US Nuclear Regulatory Commission's Draft Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a US Mark I Boiling Water Reactor," August 1, 2013, (ADAMS Accession No. ML13225A397); see also Dave Lochbaum, Union of Concerned Scientists, "Comment On: NRC-2013-0136-0002 Draft Reports; Availability: Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," July 18, 2013, (ADAMS Accession No. ML13210A139).

[16] OECD Nuclear Energy Agency, "Boiling Water Reactor Turbine Trip (TT) Benchmark," Volume I, "Final Specifications," NEA/NSC/DOC(2001)1, February 2001, p. 9.

[17] 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," November 2006, (ADAMS Accession No. ML120970086), p. 57.

[18] NRC, "Pressurized Water Reactor, B&W Technology, Crosstraining Course Manual," Chapter 2.1, "Core and Vessel Construction," Rev 10/2007, (ADAMS Accession No. ML11221A103), p. 2.1-14.

[19] 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. 4-6.

NRC used the results of MELCOR computer simulations—comparing postulated SFP accidents for a reference plant's SFP with high-density storage to the same SFP with low-density storage[20]—to help justify its decision to not expedite the transfer of spent fuel assemblies. (MELCOR version 1.8.6—released to users in July 2005[21]—was used for the simulations.[22])

The NRC's MELCOR computer model analyses of SFP accidents and fires are described in the NRC's October 2013 document, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor" (hereinafter: "SFP Consequence Study").[23]

The "SFP Consequence Study" MELCOR analyses are seriously flawed because they under-predict the severity of SFP fires. For example, MELCOR *does not simulate* how nitrogen gas (in air) accelerates the oxidation (burning) and degradation of zirconium fuel cladding *in air*.[24] Nitrogen would accelerate the progression of and increase the severity of SFP accidents, including increasing their radiological releases. MELCOR also *does not simulate* the generation of heat from the chemical reaction of zirconium and nitrogen.[25] Neglecting to model a heat source that would also affect the progression and severity of SFP accidents is a second serious flaw.

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[20] NRC, COMSECY-13-0030, "Staff Evaluation and Recommendation for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel," November 12, 2013, (ADAMS Accession No. ML13273A601), p. 3.

[21] A Sandia National Laboratories website about MELCOR states that MELCOR version 1.8.6 was released to users in July 2005. See Sandia National Laboratories, "MELCOR: A computer code for analyzing severe accidents in nuclear plants and the design basis accidents for advanced power plant applications," available at https://melcor.sandia.gov/about.html (last visited February 10, 2016).

[22] 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," October 2013, (ADAMS Accession No. ML13256A342), pp. 92-93. It is noteworthy that the SFP models in MELCOR versions 1.8.6 and 2.1 are functionally the same.

[23] 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."

[24] 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; and 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.

[25] K. C. Wagner, R. O. Gauntt, "Mitigation of Spent Fuel Pool Loss-of-Coolant Inventory Accidents and Extension of Reference Plant Analyses to Other Spent Fuel Pools," p. 12.

(For a more in-depth criticism of the MELCOR analyses described in "SFP Consequence Study," see Mark Leyse, "PRM-50-108," June 19, 2014, (ADAMS Accession No. ML14195A388). Among other things, PRM-50-108 requests that the NRC enact new regulations requiring that computer simulations of postulated SFP accidents model how the affects of nitrogen would accelerate the progression of and increase the severity of SFP fires.)

The NRC's conclusions from its MELCOR analyses are non-conservative and *misleading*, because their conclusions *underestimate* the severity of SFP fires as well as the probabilities of large radiological releases from SFP fires. By overlooking the deficiencies of its MELCOR simulations, the NRC undermines its own philosophy of defense-in-depth, which requires the application of conservative models.[26]

On the basis of its non-conservative MELCOR analyses, the NRC decided to not require licensees to expedite the transfer of spent fuel assemblies from SFPs to dry cask storage. That was in 2013, the year after the NRC decided to consider PRM-50-96 in its rulemaking process and concluded that the frequency of the U.S. suffering a "catastrophic grid failure" may be as high as once in 153 years. The NRC is neglecting its duty to protect the public from potential SFP fires and their radiological releases.

PRM-50-96 did not ask the NRC to expedite the transfer of spent fuel assemblies from SFPs to dry cask storage; however, in Commenter's opinion, expediting the transfer of spent fuel assemblies would help remedy the serious safety issues that PRM-50-96 raised.

PRM-50-96—submitted on March 14, 2011, three days after a tsunami and earthquake struck Japan, leading to three meltdowns at the Fukushima Daiichi nuclear plant—requested that new regulations be enacted by January 1, 2013, addressing the vulnerability of SFPs in long-term power blackouts.

PRM-50-96 requested that the NRC require that:

> Licensees shall provide reliable emergency systems to provide long-term cooling and water makeup for spent fuel pools using only on-site power sources. These emergency systems shall be able to operate for a period of two years without human operator intervention and without off-site fuel

[26] Charles Miller *et al.*, NRC, "Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," SECY-11-0093, July 12, 2011, (ADAMS Accession No. ML111861807), p. 3.

> resupply. Backup power systems for spent fuel pools shall be electrically isolated from other plant electrical systems during normal and emergency operation. If weather-dependent power sources are to be used, sufficient water or power storage must be provided to maintain continual cooling during weather conditions which may temporarily constrict power generation.[27]

According to the NRC, the proposed requirements of 10 C.F.R. § 50.155(b)(1) and (c)—in "Mitigation of Beyond-Design-Basis Events"—largely solve the safety issues raised in PRM-50-96.[28] In Commenter's opinion, the proposed 10 C.F.R. § 50.155(b)(1) does not adequately (or even partly) solve the safety issues raised in PRM-50-96.

Regarding 10 C.F.R. § 50.155(b)(1), the proposed rules of "Mitigation of Beyond-Design-Basis Events" states:

> Proposed § 50.155(b)(1) would establish requirements for applicants and licensees to develop, implement and maintain strategies and guidelines to mitigate beyond-design-basis external events from natural phenomenon that result in an extended loss of ac power concurrent with…a loss of normal access to the ultimate heat sink… These provisions would require that the strategies and guidelines be capable of being implemented site-wide and include:
>
> i. *Maintaining or restoring* core cooling, containment, and *spent fuel pool cooling capabilities*;
>
> and ii. *Enabling the use and receipt of offsite assistance and resources to support the continued maintenance of the functional capabilities for* core cooling, containment, and *spent fuel pool cooling indefinitely*, or until sufficient site functional capabilities can be maintained without the need for the mitigation strategies[29] [emphasis added].

It is clear that 10 C.F.R. § 50.155(b)(1) does not solve the safety issues raised in PRM-50-96. The NRC cannot assure that the requirements of 10 C.F.R. § 50.155(b)(1) would be fulfilled in the event of a power blackout that would last for months to years. That is, the NRC cannot assure that there would be "offsite assistance and resources to

[27] Thomas Popik, PRM-50-96, March 14, 2011, (ADAMS Accession No. ML110750145), p. 9.
[28] NRC, "10 CFR Parts 50 and 52: Mitigation of Beyond-Design-Basis Events," Proposed Rules, Docket Nos. PRM–50–97 and PRM–50–98; NRC–2011–0189 and NRC–2014–0240, Federal Register, Vol. 80, No. 219, November 13, 2015, p. 70614.
[29] *Id.*, p. 70632.

support the continued maintenance of the functional capabilities for…spent fuel pool cooling indefinitely."

Discussing 10 C.F.R. § 50.155(b)(1), the NRC states that "licensees would need to plan for obtaining sufficient resources (*e.g.*, fuel for generators and pumps, cooling and makeup water) to continue removing decay heat from the irradiated fuel in the reactor vessel and spent fuel pool…until an alternate means of removing heat is established."[30] Licensees could devise a plan for obtaining sufficient resources in the event of a power blackout that would last for months to years; however, there is no way they could assure that sufficient resources would actually be obtained.

Commenter's claims are supported by statements the NRC published in its December 2012 Federal Register notice announcing that PRM-50-96 had been accepted.

In the NRC's Federal Register notice on PRM-50-96's acceptance, the NRC states:

> [T]he NRC believes that it is possible that a geomagnetic storm-induced outage could be long-lasting and *could last long enough that the onsite supply of fuel for the emergency generators would be exhausted*. It is also possible that a widespread, prolonged grid outage could cause some disruption to society and to the Nation's infrastructure such that *normal commercial deliveries of diesel fuel could be disrupted*. In such a situation, it would be prudent for licensees to have procedures in place to address long-term grid collapse scenarios[31] [emphasis added].

Furthermore, in the NRC's Federal Register notice on PRM-50-96's acceptance, the NRC also states:

> In extreme situations, it is *possible* that government assets could be called on to facilitate emergency deliveries of fuel to NPP sites before the fuel stored onsite is exhausted. *All these issues need further research, review, and analysis before formulating mitigating actions*. The NRC rulemaking process is an appropriate mechanism for consideration of the petitioner's issues[32] [emphasis added].

The proposed rules in "Mitigation of Beyond-Design-Basis Events" do not discuss any "further research, review, and analysis" that the NRC has done on how to

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[30] *Id*.
[31] NRC, "Long-Term Cooling and Unattended Water Makeup of Spent Fuel Pools," Proposed Rules, Docket No. PRM–50–96, NRC–2011–0069, p. 74791.
[32] *Id*.

deal with *extreme situations*. There is no mention of a plan for "government assets [to] be called on to facilitate emergency deliveries of fuel to NPP sites before the fuel stored onsite is exhausted."

The requirements of 10 C.F.R. § 50.155(b)(1) are based on the premise that offsite assistance and resources would be available whenever they were needed in the event of a power blackout that would last for months to years. This is a major flaw. The proposed rules in "Mitigation of Beyond-Design-Basis Events" need to be rewritten in accordance with what PRM-50-96 requests. The new rules need to stipulate a means to adequately protect SFPs in the event of a long-term blackout. (Adequately protecting rector cores at nuclear plants in such an event is also needed.)

The NRC should also make a regulation requiring licensees to expedite the transfer of spent fuel assemblies from SFPs to dry cask storage. Removing spent fuel assemblies from SFPs—making SFPs less densely packed—would be in accordance with the NRC's philosophy of defense-in-depth.

III. The Proposed Requirements of 10 C.F.R. § 50.155(b)(1)—in the Proposed Rules of "Mitigation of Beyond-Design-Basis Events"—Do Not Address a Means to Prevent Criticality Accidents in Certain SFP Accident Scenarios

According to the NRC, the proposed requirements of 10 C.F.R. § 50.155(b)(1) and (c)(4)—in "Mitigation of Beyond-Design-Basis Events"—largely solve the safety issues raised in PRM-50-100.[33] PRM-50-100 was submitted by Natural Resources Defense Council. PRM-50-100 is based on safety issues raised in "Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," SECY-11-0093.[34] Among other things, PRM-50-100 requests that nuclear plants "have an installed seismically qualified means to spray water into the spent fuel pools, including and easily accessible connection to

[33] NRC, "10 CFR Parts 50 and 52: Mitigation of Beyond-Design-Basis Events," Proposed Rules, Docket Nos. PRM–50–97 and PRM–50–98; NRC–2011–0189 and NRC–2014–0240, p. 70614.
[34] Charles Miller *et al.*, NRC, "Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," SECY-11-0093, pp. 43-46.

supply the water (*e.g.*, using a portable pump or pumper truck) at grade outside the building."[35]

10 C.F.R. § 50.155(b)(1) does not address a means to prevent criticality accidents in SFP accident scenarios in which the fuel assemblies would overheat after being exposed to air. Neutron-absorber materials could melt in such scenarios. If neutron-absorber materials melted, criticality accidents could occur if the SFP were partly or completely refilled with water.

Here is some background: neutron-absorber materials are needed in the SFP storage racks that have densely packed fuel assemblies—high-density storage racks. Neutron-absorber materials are needed *to help prevent criticality accidents*. In fact, "new rack designs rely heavily on permanently installed neutron absorbers to maintain criticality requirements."[36] (Discharged and fresh fuel assemblies are also placed into particular arrangements in high-density storage racks in order to help control reactivity in the SFP. In a SFP, fuel assemblies might be arranged within checkerboard configurations.)

In the event of a power outage that would last months to years, a nuclear power plant could have a station-blackout—a complete loss of AC power. In the event of a station-blackout, the SFP could boil off enough water to partly or completely expose the fuel assemblies to air. If fuel assemblies were uncovered, temperatures in the SFP could increase enough to cause neutron-absorber materials placed in high-density storage racks to melt. Boraflex and Boral are neutron-absorber materials. Boraflex vitrifies and melts at approximately 300°C (572°F) and 500°C (932°F), respectively; Boraflex would be ineffective once heated above approximately 300°C (572°F).[37] And Boral melts at approximately 657°C (1214°F).[38]

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[35] Natural Resources Defense Council, "PRM-50-100," (ADAMS Accession No. ML11216A240), July 26, 2011, p. 3.
[36] NRC, "On Site Spent Fuel Criticality Analyses NRR Action Plan," May 21, 2010, (ADAMS Accession No. ML101520463), p. 1.
[37] Electric Power Research Institute, "Severe Accident Management Guidance Technical Basis Report," Volume 2: "The Physics of Accident Progression," 1025295, October 2012, Appendix EE, p. EE-9.
[38] Zachary I. Franiewski *et al.*, "Spent Fuel Pool Analysis of a BWR-4 Fuel Bundle Under Loss of Coolant Conditions Using TRACE," Pennsylvania State University, NucE431W S2013, May 2013, p. 1.

As stated above in Section II, the "SFP Consequence Study" MELCOR analyses that the NRC conducted to help justify its decision to not expedite the transfer of spent fuel assemblies from SFPs to dry cask storage are seriously flawed. The NRC's MELCOR analyses are additionally flawed because they did not model criticality accidents.[39]

"SFP Consequence Study" provides the results of a number of MELCOR analyses of SFP loss-of-coolant accidents in which there was a *moderate leakage rate*.[40] In some of the NRC's simulations, SFP temperatures reached the point at which neutron-absorber materials would melt. Then spray cooling was simulated in the same MELCOR analyses. The SFP was, at least partly, refilled with water.[41] However, the MELCOR analyses did not even consider the possibility of criticality accidents.[42] In the real world, there could be criticality accidents in such SFP accident scenarios.

The MELCOR analyses of "SFP Consequence Study" did not model criticality accidents; however, the very same NRC report warns about criticality accidents.

Regarding criticality accidents, which "SFP Consequence Study" terms "inadvertent criticality events," the report states:

> Inadvertent criticality events (ICEs) may be possible for specific combinations of conditions (*e.g.*, *during reflood of a drained pool* for a region of the pool storing higher reactivity fuel assemblies where the boron poison in the rack panels has been significantly displaced as a result of the earthquake). If such an event affected a region of the pool (as opposed to only a portion of a particular assembly), and if it occurred at a point in the accident where the fuel was only partially covered, the event could have an important impact on onsite dose rates. Further, if an ICE were severe enough to produce significant heat, the fuel will be harder to cool and short-lived radionuclides will be produced[43] [emphasis added].

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[39] 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," p. 20.

[40] 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," p. 61.

[41] 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," pp. 211-213.

[42] *Id*., p. 20.

[43] *Id*., p. 29.

Hence, the NRC believes that criticality accidents, or inadvertent criticality events, could play a significant role in a SFP accident in cases in which neutron-absorber materials would become ineffective. If a critically accident were to occur, local fuel and fuel-cladding temperatures would rapidly increase. A critically accident would also "cause an increase in decay products, which [would] have a delayed effect on temperature increase[s]."[44] Increased onsite dose rates, caused by a criticality accident, would impede (or possibly prevent for significant time periods) efforts to mitigate a SFP accident.

"SFP Consequence Study" cautions that "[t]he possibility of a criticality event cannot be summarily dismissed."[45] Furthermore, the NRC has a regulation pertaining to preventing criticality accidents in the event that a SFP would be partly or completely refilled with either unborated or borated water—10 C.F.R. § 50.68 Criticality Accident Requirements. (Borated water would absorb neutrons and help prevent criticality accidents.)

Regarding refilling a SFP with unborated water, 10 C.F.R. § 50.68(b)(4) states:

> If no credit for soluble boron is taken, the k-effective [the estimated ratio of neutron production to neutron absorption and leakage] of the spent fuel storage racks loaded with fuel of the maximum fuel assembly *reactivity must not exceed 0.95* [below 1.0 is subcritical], at a 95 percent probability, 95 percent confidence level, if flooded with unborated water [emphasis added].

Nonetheless, the NRC has overlooked how SFP criticality "events" could make a SFP accident far worse: first) MELCOR analyses that the NRC conducted to help justify its decision to not expedite the transfer of spent fuel assemblies did not consider criticality accidents and second) 10 C.F.R. § 50.155(b)(1) does not have provisions for preventing criticality accidents in cases in which water would be sprayed into a SFP (the refilling of a drained SFP).

In the event of a SFP accident, in some scenarios, a SFP could be partly or completely refilled with unborated water. In the Fukushima Dai-ichi accident, SFPs were

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[44] Zachary I. Franiewski *et al*., "Spent Fuel Pool Analysis of a BWR-4 Fuel Bundle Under Loss of Coolant Conditions Using TRACE," pp. 1-2.

[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," p. 30.

refilled (at least to some degree) with seawater;[46] and reactors cores were injected with both unborated and borated seawater.[47]

The proposed rules in "Mitigation of Beyond-Design-Basis Events" need to be rewritten to stipulate a means that would adequately protect SFPs against criticality accidents in cases in which there would be the refilling of a drained SFP. Perhaps it should be stipulated and explicitly stated that drained SFPs—in cases in which neutron-absorber materials have possibly become ineffective—must be refilled with adequately-concentrated borated water.

Respectfully submitted,

/s/

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[46] Tokyo Electric Power Company March 25, 2011 Press Release, "Plant Status of Fukushima Daiichi Nuclear Power Station (as of 10:30 PM Mar 25th)," available at http://www.tepco.co.jp/en/press/corp-com/release/11032515-e.html (last visited February 11, 2016).

[47] Institute of Nuclear Power Operations, "Special Report on the Nuclear Accident at the Fukushima Dai-ichi Nuclear Power Station," INPO 11-005, November 2011, pp. 9-10, 21, 28, 79, 80.