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C. Jordan Weaver
Natural Resources Defense Council (NRDC)

TO:

Borchardt, EDO

FOR SIGNATURE OF : ** GRN ** CRC NO:

Leeds, NRR

DESC:

2.206 - Passive Autocatalytic Recombiner System at Indian Point (EDATS: OEDO-2012-0208)

DATE: 04/17/12

ASSIGNED TO: CONTACT:

NRR Leeds

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NRDC
THE EARTH'S BEST DEFENSE

Via Electronic Mail

April 16, 2012

R. William Borchardt
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington D.C. 20555-0001

Subject: **NRDC's 10 C.F.R. § 2.206 Request Concerning PAR System at Indian Point Unit 2**

Dear Mr. Borchardt:

Pursuant to 10 C.F.R. § 2.206, the Natural Resources Defense Council, Inc. ("NRDC") hereby petitions the U.S. Nuclear Regulatory Commission ("NRC") to request the licensee of Indian Point Unit 2 ("IP-2") to remove the passive autocatalytic recombiner ("PAR") system from IP-2 because the PAR system could have unintended ignitions in the event of a severe accident possibly causing a detonation.

The rationale and the bases for this petition can be found in the enclosed materials, which cite numerous reports and studies that illustrate the risk involved with operating PAR units during a severe accident. The petition research and authoring was conducted by NRDC consultant Mark Leyse.

Please do not hesitate to contact us at (202) 289-6868 if you have any questions. NRDC appreciates your prompt consideration of this matter.

Sincerely,

C. Jordan Weaver, Ph.D.
Project Scientist

EDO --G20120253

April 16, 2012

R. William Borchardt
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington D.C. 20555-0001

10 C.F.R. § 2.206 REQUEST TO HAVE THE LICENSEE OF INDIAN POINT UNIT 2 ("IP-2") REMOVE THE PASSIVE AUTOCATALYTIC RECOMBINER ("PAR") SYSTEM FROM IP-2 BECAUSE THE PAR SYSTEM COULD HAVE UNINTENDED IGNITIONS IN THE EVENT OF A SEVERE ACCIDENT POSSIBLY CAUSING A DETONATION

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April 16, 2012

UNITED STATES OF AMERICA
U.S. NUCLEAR REGULATORY COMMISSION
BEFORE THE COMMISSION

In the Matter of: ENTERGY CORPORATION (Indian Point Nuclear Generating Station Unit No. 2; Docket No. 05000247)	TO:	R. WILLIAM BORCHARDT Executive Director for Operations U.S. Nuclear Regulatory Commission Washington D.C. 20555-0001 Docket No. ______
NATURAL RESOURCES DEFENSE COUNCIL, Petitioner		

10 C.F.R. § 2.206 REQUEST TO HAVE THE LICENSEE OF INDIAN POINT UNIT 2 ("IP-2") REMOVE THE PASSIVE AUTOCATALYTIC RECOMBINER ("PAR") SYSTEM FROM IP-2, BECAUSE THE PAR SYSTEM COULD HAVE UNINTENDED IGNITIONS IN THE EVENT OF A SEVERE ACCIDENT, WHICH, IN TURN, COULD CAUSE A HYDROGEN DETONATION

I. REQUEST FOR ACTION

This petition for an enforcement action is submitted pursuant to 10 C.F.R. § 2.206 by Natural Resources Defense Council ("NRDC").[1] 10 C.F.R. § 2.206(a) states that "[a]ny person may file a request to institute a proceeding pursuant to § 2.202 to modify, suspend, or revoke a license, or for any other action as may be proper."

NRDC (hereinafter "Petitioner") requests that United States Nuclear Regulatory Commission ("NRC") order the licensee of Indian Point Unit No. 2 ("IP-2") to remove the passive autocatalytic recombiner ("PAR") system (consisting of two PAR units[2]) from IP-2, because the PAR system could have unintended ignitions in the event of a

[1] Mark Leyse wrote this 10 C.F.R. § 2.206 petition for NRDC.
[2] Two NIS PARs designed by NIS Ingenieurgesellschaft mbH of Germany. See D. Shah, Consolidated Edison Company, "Use of Passive Autocatalytic Recombiners at Indian Point 2 Nuclear Power Plant," pp. 237, 239.

severe accident, which, in turn, could cause a hydrogen detonation.[3, 4] Experimental data demonstrate that IP-2's two PAR units could have at least one unintended ignition on their catalytic surfaces in the event of a severe accident.[5]

II. STATEMENT OF PETITIONER'S INTEREST

Petitioner is a national non-profit membership environmental organization with offices in New York City, Washington, D.C., San Francisco, Chicago, Los Angeles, and Beijing. Petitioner has a nationwide membership of over one million combined members and activists. Petitioner's activities include maintaining and enhancing environmental quality and monitoring federal agency actions to ensure that federal statutes enacted to protect human health and the environment are fully and properly implemented. Since its inception in 1970, Petitioner has sought to improve the environmental, health, and safety conditions at the nuclear facilities licensed by NRC and its predecessor agency.

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[3] A detonation is a combustion wave traveling at a supersonic speed, relative to the unburned gas. A supersonic speed is a speed that is greater than the speed of sound.

[4] "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)" states that "[i]n a situation when the hydrogen concentration rises, a delayed ignition [such as could be caused by a PAR system] enhances the risk because it may start a detonation." See K. Fischer, *et al.*, "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)," Nuclear Engineering and Design, 221, 2003, p. 146.

[5] "Studies on Innovative Hydrogen Recombiners as Safety Devices in the Containments of Light Water Reactors" states that "[d]uring experimental investigations at several institutions; *e.g.*, Battelle Model Containment, KALI facility, and SURTSEY facility, ignitions were observed." See Ernst-Arndt Reinecke, Inga Maren Tragsdorf, Kerstin Gierling, "Studies on Innovative Hydrogen Recombiners as Safety Devices in the Containments of Light Water Reactors," Nuclear Engineering and Design, 230, 2004, p. 49 (hereinafter "Studies on Innovative Hydrogen Recombiners as Safety Devices").

A. Plant Specific Characteristics, Regarding the Location of Indian Point

This 10 C.F.R. § 2.206 petition is plant specific, because New York City is located less than 25 miles south of IP-2 and more than 17 million people live within a 50-mile radius of IP-2.[6]

This 10 C.F.R. § 2.206 petition is also plant specific, because IP-2 was built within one or two miles of the Ramapo seismic zone: a "system [that] is not so much a single fracture as a braid of smaller ones, where quakes emanate from a set of still ill-defined faults."[7] Research suggests the area around Indian Point is susceptible to an earthquake of 7.0 in magnitude on the Richter scale.[8] The owner of Indian Point, Entergy Nuclear Operations, Inc. (hereinafter "Entergy"), indicates that Units 2 and 3 were built to withstand a 6.0 magnitude earthquake.[9] Even if this alleged, as yet unsubstantiated estimate were true, a 7.0 magnitude earthquake is approximately 30 times more powerful than a 6.0.[10] Thus, IP-2 is not capable of withstanding earthquakes that could reasonably occur in the area. An earthquake occurring in proximity of IP-2 could cause a severe accident. It would be reasonable to claim that the probability of having a severe accident at IP-2 is higher than it is for most other nuclear power plants licensed by NRC.

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[6] Edwin S. Lyman, Union of Concerned Scientists, "Chernobyl on the Hudson?: The Health and Economic Impacts of a Terrorist Attack at the Indian Point Nuclear Plant," September 2004, available at, http://www.riverkeeper.org/wp-content/uploads/2011/03/Chernobyl-on-the-Hudson_indianpointhealthstudy.pdf, p. 23.

[7] Lynn R. Sykes, John G. Armbruster, Won-Young Kim, & Leonardo Seeber, Observations and Tectonic Setting of Historic and Instrumentally Located Earthquakes in the Greater New York City–Philadelphia Area, Bulletin of the Seismological Society of America, Vol. 98, No. 4, pp. 1696–1719, August 2008 (hereinafter "Sykes, Earthquakes in New York"); The Earth Institute, Columbia University, "Earthquakes May Endanger New York More than Thought, Says Study: Indian Point Nuclear Power Plant Seen as Particular Risk," Press Release Posted on The Earth Institute website, August 21, 2008, available at,
http://www.earth.columbia.edu/articles/view/2235 (last visited March 24, 2011) (hereinafter "Columbia Earth Institute Earthquake Study Press Release").

[8] Sykes, Earthquakes in New York; Columbia Earth Institute Earthquake Study Press Release.

[9] See, e.g., CBS New York, Japan Crisis Raises Concerns About Indian Point Plant, March 15, 2011, available at, http://newyork.cbslocal.com/2011/03/15/japan-crisis-raises-concerns-about-indian-point-power-plant/ (last visited August 12, 2011) ("Indian Point spokesman Jerry Nappi said...the plant is built to withstand approximately a 6.0 magnitude earthquake.").

[10] FEMA, "Are You Ready?: Earthquakes," states that "[a] magnitude of 7.0 on the Richter Scale indicates an extremely strong earthquake. Each whole number on the scale represents an increase of about 30 times more energy released than the previous whole number represents. Therefore, an earthquake measuring 6.0 is about 30 times more powerful than one measuring 5.0." See FEMA, "Are You Ready?: Earthquakes," available at:
http://www.fema.gov/areyouready/earthquakes.shtm (last visited August 12, 2011).

Given IP-2 higher probability for severe accidents and the fact that New York City is located less than 25 miles south of IP-2 and more than 17 million people live within a 50-mile radius of IP-2, the safety issues raised in this 10 C.F.R. § 2.206 petition, need prompt resolution. Both of these concerns are discussed in a study conducted by Columbia University's Earth Institute, as documented in "Observations and Tectonic Setting of Historic and Instrumentally Located Earthquakes in the Greater New York City–Philadelphia Area." The study states: "Indian Point is situated at the intersection of the two most striking linear features marking the seismicity and also in the midst of a large population that is at risk in case of an accident... This is clearly one of the least favorable sites in our study area from an earthquake hazard and risk perspective."[11]

(Deborah Brancato of Riverkeeper helped write section II.A.)

III. FACTS CONSTITUTING THE BASIS FOR PETITIONER'S REQUEST

Describing PARs, an International Atomic Energy Agency ("IAEA") report, "Mitigation of Hydrogen Hazards in Severe Accidents in Nuclear Power Plants" states:

> [PARs] have been developed and have become commercially available in the last decades. PARs are simple devices, consisting of catalyst surfaces arranged in an open-ended enclosure. *In the presence of hydrogen (with available oxygen), a catalytic reaction occurs spontaneously at the catalyst surface* and the heat of reaction produces natural convection flow through the enclosure, exhausting the warm, humid hydrogen depleted air and drawing fresh gas from below. Thus, *PARs do not need external power or operator action*. Installation requires only to place PAR units at appropriate locations within the containment to obtain the desired coverage [emphasis added].[12]

"Mitigation of Hydrogen Hazards in SA" also states:

> [I]f PARs are present, only limited guidance may be needed, *as these devices work reliabl[y] and automatically* [emphasis added].[13]

Clearly, PARs would operate automatically in the event of a severe accident and would commence operation when enough hydrogen and oxygen were available to react

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[11] Sykes, Earthquakes in New York, supra Note 9, at 1717.

[12] IAEA, "Mitigation of Hydrogen Hazards in Severe Accidents in Nuclear Power Plants," IAEA-TECDOC-1661, July 2011, p. 77 (hereinafter "Mitigation of Hydrogen Hazards in SA").

[13] *Id.*, p. 79.

on the PARs' catalytic surfaces. As stated in "Mitigation of Hydrogen Hazards in SA," PARs commence operation without operator action. Furthermore, in the event of a severe accident, operators would not be able to turn off PARs or stop PARs from operating.

This 10 C.F.R. § 2.206 petition is specific to IP-2 because Indian Point Unit No. 3 ("IP-3") does not have a PAR system. IP-3 has two electrically powered thermal hydrogen recombiners, which do not have catalytic surfaces. In the event of a severe accident, operators would be able to control the operation of the two electrically powered thermal hydrogen recombiners in the IP-3 containment, if the thermal recombiners were functioning properly.

A. The Hydrogen Removal Capacity of Hydrogen Recombiners and Hydrogen Production Rates in Design Basis Accident Scenarios

Indian Point spokesman, James Steets, was quoted as saying that IP-2 and -3's containment buildings (pressurized water reactor ("PWR") large dry containments) each have two hydrogen recombiners and that one alone could eliminate all the hydrogen produced in a major accident. Steets is quoted in an article titled "U.S. Dropped Nuclear Rule Meant to Avert Hydrogen Explosions," by Matthew L. Wald, in the New York Times, "A Blog About Energy and the Environment," March 31, 2011.

Steets was quoted using the term "major accident," which could mean either a design basis accident or a severe accident. If Steets meant that one or two hydrogen recombiners could eliminate all the hydrogen produced in a design basis accident, it would be reasonable to claim that he is correct. In a design basis accident, it is assumed that "hydrogen generation is a slow process with a magnitude from 0.001 to 0.05 kg/sec. for typical [PWRs];"[14] and the hydrogen removal capacity per PAR unit is "several grams per second of H_2."[15]

However, investigations of PAR efficiency using GASFLOW, a 3D computational fluid dynamics ("CFD") code, to model PARs in a full-sized German PWR containment[16] indicate that "[t]he removal rate of a recombiner depends only on the *local* H_2 concentration at the [PAR] position, which, in turn, is largely determined by the global flow field in the containment. The natural draft of the [PAR] itself can be neglected in most cases because the [affected] space region is limited to a distance of a few meters. A good resolution of the local H_2 concentration is necessary for a realistic calculation of the individual [PAR] efficiency [emphasis not added]."[17] Furthermore,

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[14] E. Bachellerie, *et al.*, "Generic Approach for Designing and Implementing a Passive Autocatalytic Recombiner PAR-System in Nuclear Power Plant Containments," Nuclear Engineering and Design, 221, 2003, p. 158 (hereinafter "Designing and Implementing a PAR-System in NPP Containments").

[15] OECD Nuclear Energy Agency, "State-of-the-Art Report on Flame Acceleration and Deflagration-to-Detonation Transition in Nuclear Safety," NEA/CSNI/R(2000)7, August 2000, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML031340619, p. 1.6 (hereinafter "Report on FA and DDT").

[16] P. Royl, *et al.*, "GASFLOW Analysis Concerning the Efficiency of a Recombiner Concept in Case of a Postulated Surge-Line LOCA in the Power Plant Neckarwestheim-2," Report FZKA-6333, Forschungszentrum Karlsruhe, Germany, 1999.

[17] OECD Nuclear Energy Agency, "Report on FA and DDT," p. 1.8.

"[i]n the investigated small-break...and large-break loss-of-coolant accident...scenarios, the [PARs] did not provide a noticeable additional mixing effect because the small momentum of the [PAR] exhaust gases is dissipated in the near environment, and the succeeding exhaust gas motion is buoyancy dominated."[18]

The PAR system in IP-2's containment is intended to reduce the quantity of hydrogen that would be produced in a design basis accident. Entergy's technical information for IP-2's license renewal application states:

> The purpose of the hydrogen recombiners (HR system) is to reduce the hydrogen concentration in the containment volume *following a design basis accident*. The system includes two redundant passive autocatalytic recombiners that replaced earlier flame units [emphasis added].[19]

However, according to NRC, hydrogen recombiners are not needed to mitigate hydrogen in design basis accidents. In 2003, NRC eliminated the requirement for hydrogen recombiners. In 2003, NRC stated that "[t]he Commission has found that [a design-basis loss-of-coolant accident] hydrogen release is not risk-significant because the...hydrogen release does not contribute to the conditional probability of a large release up to approximately 24 hours after the onset of core damage."[20]

B. The Hydrogen Removal Capacity of Hydrogen Recombiners and Hydrogen Production Rates in Severe Accident Scenarios

In the New York Times blog article, "U.S. Dropped Nuclear Rule Meant to Avert Hydrogen Explosions," when Indian Point spokesman Steets used the term "a major accident," if he meant a severe accident, then he is grossly incorrect: one or two hydrogen recombiners could not eliminate all the hydrogen produced in a severe accident before a hydrogen deflagration[21] or detonation could occur.

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[18] *Id.*

[19] Indian Point Energy Center, License Renewal Application, Technical Information, 2.0, "Scoping and Screening Methodology for Identifying Structures and Components Subject to Aging Management Review and Implementation Results," p. 2.3-61.

[20] NRC, Federal Register Notice, Regarding Eliminating the Hydrogen Recombiner Requirement, Vol. 68, No. 186, September 25, 2003, p. 55419.

[21] A deflagration is a combustion wave traveling at a subsonic speed, relative to the unburned gas. A subsonic speed is a speed that is less than the speed of sound.

"Report on FA [Flame Acceleration] and DDT [Deflagration-to-Detonation Transition]" states that "[a] rapid initial H_2-source occurs *in practically all* severe accident scenarios because the large chemical heat release of the Zr-steam reaction causes a fast self-accelerating temperature excursion during which initially large surfaces and masses of reaction partners are available" [emphasis added].[22] In a severe accident, "hydrogen generation is a fast process due to the zirconium oxidation by steam, with a magnitude from 0.1 to 5.0 kg/sec. (degradation, reflood of the overheated core);"[23] and the hydrogen removal capacity per PAR unit is "several grams per second of H_2."[24]

Discussing investigations of PAR efficiency using GASFLOW, a 3D CFD code, to model PARs in full-sized German PWR containments, "Report on FA and DDT" states:

> [I]n one of the investigated cases with about 50 [hydrogen] recombiners and 530 kg H_2 total release, the integral H_2 removal rate was initially 180 kg/hr H_2 and then decreased proportionally to the residual H_2 or O_2 concentration in the containment.[25]

In a severe accident, during the reflooding of an overheated core up to 300 kilograms (kg) of hydrogen could be produced in one minute.[26] One report states that between 5 and 10 kg of hydrogen could be produced per second, during the reflooding of an overheated core;[27] this high rate of hydrogen production would not last long. It is important to remember that there is a finite amount of material in a reactor's core that can produce hydrogen. In the Three Mile Island accident, it is generally estimated that a total of 500 kg was produced.[28]

Therefore, the claim that one or two hydrogen recombiners could eliminate all the hydrogen produced in a severe accident is incorrect. To help mitigate hydrogen in a wide

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[22] OECD Nuclear Energy Agency, "Report on FA and DDT," p. 6.38.
[23] E. Bachellerie, *et al.*, "Designing and Implementing a PAR-System in NPP Containments," p. 158.
[24] OECD Nuclear Energy Agency, "Report on FA and DDT," p. 1.6.
[25] *Id.*, p. 1.8.
[26] E. Bachellerie, *et al.*, "Designing and Implementing a PAR-System in NPP Containments," p. 158.
[27] J. Starflinger, "Assessment of In-Vessel Hydrogen Sources," in "Projekt Nukleare Sicherheitsforschung: Jahresbericht 1999," Forschungszentrum Karlsruhe, FZKA-6480, 2000.
[28] Jae Sik Yoo, Kune Yull Suh, "Analysis of TMI-2 Benchmark Problem Using MAAP4.03 Code," Nuclear Engineering and Technology, Vol. 41, No. 7, September 2009, p. 949.

range of accident scenarios, it is recommended that PWRs have from 30 to 60 hydrogen recombiners distributed in their containment buildings.[29] Furthermore, there are reasons to believe that 60 hydrogen recombiners would not be capable of eliminating all of the hydrogen produced in some severe accident scenarios within a timeframe that would prevent a hydrogen explosion from occurring.

In 2003, NRC eliminated the requirement for hydrogen recombiners and stated that "[hydrogen recombiner] systems were ineffective at mitigating hydrogen releases from risk-significant beyond design-basis accidents."[30] Additionally, in "U.S. Dropped Nuclear Rule Meant to Avert Hydrogen Explosions," Eliot Brenner, an NRC spokesman, is quoted saying that "[hydrogen recombiners were not] needed for design basis accidents and they [did not] help with severe accidents."[31]

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[29] E. Bachellerie, *et al.*, "Designing and Implementing a PAR-System in NPP Containments," p. 159.

[30] NRC, Federal Register Notice, Regarding Eliminating the Hydrogen Recombiner Requirement, Vol. 68, No. 186, September 25, 2003, p. 55419.

[31] Matthew L. Wald, "U.S. Dropped Nuclear Rule Meant to Avert Hydrogen Explosions," New York Times, A blog About Energy and the Environment, March 31, 2011.

C. The Licensee of Indian Point Might Not have Sufficient Means to Effectively Mitigate the Hydrogen that Would Be Generated in the Event of a Severe Accident

Regarding the fact that PARs would be overwhelmed by the quantity of hydrogen produced in a severe accident, "Safety Implementation of Hydrogen Igniters and Recombiners for Nuclear Power Plant Severe Accident Management," published in 2006, states:

> Large quantities of hydrogen (release rate at 2 kg/sec.) will be released into the containment under severe accidents. In these cases, the hydrogen can not be removed by recombiners alone. Hydrogen will accumulate in the containment, and once the hydrogen concentration reaches the flammability limitation, deflagration and detonation may occur.[32]

It is not clear whether the licensee of IP-2 and -3 has sufficient means to effectively mitigate the hydrogen that would be generated in the event of a severe accident at either IP-2 or -3. If there were a severe accident at either IP-2 or -3, it is plausible that there would be hydrogen combustion in the form of a deflagration or a detonation.

In the Three Mile Island Unit 2 ("TMI-2")[33] accident, a rapid pressure increase of approximately 28 psi in the containment[34] was attributed to the combustion of hydrogen in the form of a deflagration that was most likely caused by an electric spark;[35] the deflagration may have even been initiated by a ringing telephone.[36] In the TMI-2 accident, "the hydrogen burn...resulted from a hydrogen concentration of 8.1 volume percent."[37]

At either IP-2 or -3, it is unlikely that a hydrogen deflagration in the containment that caused a rapid pressure increase of approximately 28 psi would cause a breach in the

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[32] Xiao Jianjun, Zhou Zhiwei, Jing Xingqing, "Safety Implementation of Hydrogen Igniters and Recombiners for Nuclear Power Plant Severe Accident Management," Tsinghua Science and Technology, Vol. 11, Number 5, October 2006, p. 556.

[33] TMI-2 was a PWR with a large dry containment.

[34] W. E. Lowry, *et al.*, Lawrence Livermore National Laboratory, "Final Results of the Hydrogen Igniter Experimental Program," NUREG/CR-2486, February 1982, p. 4.

[35] E. Studer, *et al.*, Kurchatov Institute, "Assessment of Hydrogen Risk in PWR," [undated], p. 1.

[36] OECD Nuclear Energy Agency, "Report on FA and DDT," p. 1.2.

[37] NRC, letter regarding Turkey Point Units 3 and 4, Exemption from Hydrogen Control Requirements, December 12, 2001, Attachment 2, "Safety Evaluation by the Office of Nuclear Reactor Regulation, Turkey Point Units 3 and 4," available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML013390647, p. 4.

containment. According to Entergy, the design pressures of IP-2 and -3's containments are both 47 psig;[38] and according to "Indian Point Probabilistic Safety Study," the failure pressures of IP-2 and -3's containments are both approximately 126 psig.[39]

For example, regarding the high-pressure loads that could result from hydrogen combustion, an NRC document discussing analyses for Three Mile Island Unit 1 ("TMI-1"), a PWR with a large dry containment, states:

> The NRC staff estimates the pressure for an adiabatic and complete hydrogen burn involving up to 75 percent core metal-water reaction to be 94 psig. ... For sequences involving up to 100 percent core metal-water reaction, the NRC staff estimated a pressure of 114 psig.[40]

Additionally, such NRC staff estimates for hydrogen combustion at Turkey Point Units 3 and 4, PWRs with large dry containments, found that "the pressure for an adiabatic and complete hydrogen burn involving up to [a] 75 percent core metal-water reaction [would] be 109 psig"[41] and estimated that there would be a pressure load of 135 psig for a scenario involving up to a 100 percent core metal-water reaction.[42]

These NRC staff estimates for TMI-1 and Turkey Point Units 3 and 4, most likely pertain to metal-water reactions of 75 percent and 100 percent of the fuel cladding *active* length—excluding the cladding surrounding the plenum volume. A document regarding the same issue for TMI-1, states that "NUREG/CR-5662 (1991) reports the computed

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[38] Entergy, "Technical Facts: Indian Point Unit 2, Plant Specific Information," available at: http://www.entergy-nuclear.com/content/resource_library/IPEC_EP/TechnicalFacts2.pdf (last visited August 14, 2011); and Entergy, "Technical Facts: Indian Point Unit 3, Plant Specific Information," available at: http://www.entergy-nuclear.com/content/resource_library/IPEC_EP/TechnicalFacts3.pdf (last visited August 14, 2011).
[39] Power Authority of the State of New York, Consolidated Edison Company of New York, "Indian Point Probabilistic Safety Study," Vol. 8, p. 4.2-1 and Appendix 4.4.1, p. 14.
[40] T. G. Colburn,. NRC, letter regarding Three Mile Island Unit 1, license amendment from hydrogen control requirements, February 8, 2002, Attachment 2, "Safety Evaluation by the Office of Nuclear Reactor Regulation, Related to Amendment No. 240 to Facility Operating License No. DPR-50, Three Mile Island Unit 1," available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML020100578, p. 5.
[41] Kahtan N. Jabbour, NRC, letter regarding Turkey Point Units 3 and 4, Exemption from Hydrogen Control Requirements, December 12, 2001, Attachment 2, "Safety Evaluation by the Office of Nuclear Reactor Regulation, Turkey Point Units 3 and 4," p. 3.
[42] *Id.*

containment peak pressure due to [a] global hydrogen burn based on *a 75% fuel cladding metal-water reaction*... [emphasis added]"[43]

Therefore, it is possible that in the event of a severe accident at either IP-2 or -3a hydrogen deflagration or detonation could cause a rapid pressure increase in the containment that would be not only greater than 28 psi but also approach the containment failure pressures for the India Point units.

D. The Unintended Ignitions of PARs that Occurred in Experiments

Discussing the unintended ignitions of PARs that occurred in three different experimental investigations, "Studies on Innovative Hydrogen Recombiners as Safety Devices" states:

> For mitigation of hydrogen released during a severe accident in light water reactors (LWR), containments are retrofitted with passive autocatalytic recombiners (PAR) in Germany as well as in numerous European countries. These devices recombine hydrogen with oxygen on catalytic active surfaces producing steam and heat. For present PAR systems the exothermal reaction may lead to an overheating of the catalyst elements and consequently cause an unintended ignition of the hydrogen/air-mixture. During experimental investigations at several institutions; *e.g.*, Battelle Model Containment,[44] KALI facility,[45] and SURTSEY facility,[46] ignitions were observed. Accordingly, the state-of-the-art report of the PARSOAR project,[47] within the scope of the 5th Euratom Framework Program, considers the hydrogen ignition risk as [the] most important open topic concerning PAR qualification.[48]

[43] Mark E. Warner, AmerGen Energy Company, letter regarding Three Mile Island Unit 1, Request for Exemption to 10 CFR 50.44, Etc., Attachment 1, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML003756521, p. 6.

[44] Kanzleiter, T., "Multiple Hydrogen-Recombiner Experiments Performed in the BMC," Battelle Ingenieurtechnik, Report BF-V68.405-02, European Commission, Draft Report CONT-VOASM(97)-D005, 1997.

[45] Braillard, O *et al.*, "Tests of Passive Catalytic Recombiners (PARs) for Combustible Gas Control in Nuclear Power Plants," Proceedings of the Second International Topical Meeting on Advanced Reactor Safety ARS, Vol. 97, 1997, pp. 541-548.

[46] Blanchat, T.K., Malliakos, A., "Performance Testing of Passive Autocatalytic Recombiners," Proceedings of the International Cooperative Exchange Meeting on Hydrogen in Reactor Safety, Paper 4.2.

[47] Bachellerie, E. *et al.*, "Designing and Implementing a PAR-System in NPP Containments," pp. 151-165.

[48] Ernst-Arndt Reinecke, *et al.*, "Studies on Innovative Hydrogen Recombiners as Safety Devices," p. 49.

According to the same paper, during the operation of PARs, "[a]t a hydrogen concentration of 4 vol.% maximum temperatures reach the ignition limit [which according to reports is] in the region of about 560°C [1040°F]. Any further increase in the inlet hydrogen concentration would lead to catalyst temperatures above the ignition limit and hence increase the risk of an unintended ignition."[49]

(It is noteworthy that another paper states that "[t]he catalytic oxidation of hydrogen in PARs results in temperature levels at the catalytic surfaces which can reach 900°C [1652°F] or more."[50])

Providing an overview of the results of experimental investigations (the same three mentioned in the quote above) in which PARs had unintended ignitions, "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)" states:

> Unintended ignition events were observed in several experiments with [PAR] boxes. In the Battelle Model Containment Multi-Reco test Zx03,[51] a Siemens type FR90-150 recombiner ignited the atmosphere of 79.4% air, 13% steam, and 7.6% hydrogen. In the KALI experiments performed by EPRI and EdF,[52] on a Siemens type recombiner, any hydrogen concentration of 7% and above led to an unintended ignition, such that it was not possible to determine recombination rates in this concentration regime. In the recombiner performance tests conducted at the Sandia SURTSEY facility,[53] unexpected ignitions from a NIS recombiner were observed in 3 out of 12 experiments.[54]

(It is noteworthy that the two PARs at IP-2 are NIS PARs, designed by NIS Ingenieurgesellschaft mbH of Germany.[55])

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[49] *Id.*, p. 52.
[50] Martin Sonnenkalb, Gerhard Poss, "The International Test Programme in the THAI Facility and Its Use for Code Validation," [undated: 2009 or later], p. 16.
[51] Kanzleiter, T., "Multiple Hydrogen-Recombiner Experiments Performed in the BMC."
[52] Braillard, O. *et al.*, "Tests of Passive Catalytic Recombiners (PARs) for Combustible Gas Control in Nuclear Power Plants," pp. 541-548.
[53] Blanchat, T.K., Malliakos, A., "Performance Testing of Passive Autocatalytic Recombiners," Proceedings of the International Cooperative Exchange Meeting on Hydrogen in Reactor Safety, Paper 4.2.
[54] K. Fischer, *et al.*, "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)," p. 146.
[55] D. Shah, "Use of Passive Autocatalytic Recombiners at Indian Point 2 Nuclear Power Plant," pp. 237, 239.

Therefore, experimental data from three different investigations demonstrates that the PARs in IP-2's containment could have unintended ignitions in the event of a severe accident. Furthermore, "the state-of-the-art report of the PARSOAR project, within the scope of the 5th Euratom Framework Program, considers the hydrogen ignition risk as [the] most important open topic concerning PAR qualification."[56]

1. Recent Reports State that PARs Behave like Igniters in Elevated Hydrogen Concentrations

Some recent reports have discussed the fact that PARs behave like igniters in elevated hydrogen concentrations.

Below are quotes from such reports:

1) A paper, "GASFLOW Analysis of Hydrogen Recombination in a Konvoi Type PWR Containment under Hypothetical Small Break and Large Break LOCA Conditions," published in 2000, states:

> In reality [PARs] in a combustible cloud with 8 to 10% hydrogen are likely to become igniters in a rather dry atmosphere with <40% steam.[57]

2) A paper, "The International Test Programme in the THAI Facility and Its Use for Code Validation," states:

> Ignition by a PAR has occurred in several experiments at higher hydrogen concentrations. Since PARs are used to recombine hydrogen without flame ignition, such events appear to be undesired. ... In the [THAI] experiments...the location of ignition is identified and the intensity of the PAR-induced deflagration is determined.[58]

3) An OECD Nuclear Energy Agency report, "Report on FA and DDT," published in 2000, states:

> [A] currently unresolved issue [regarding PARs] is ignition of the hydrogen-air-steam mixture under certain overload conditions, which depend on the recombiner design and steam concentration. It is

[56] Ernst-Arndt Reinecke, *et al.*, "Studies on Innovative Hydrogen Recombiners as Safety Devices," p. 49.
[57] P. Royl, J. R. Travis, W. Breitung, "GASFLOW Analysis of Hydrogen Recombination in a Konvoi Type PWR Containment under Hypothetical Small Break and Large Break LOCA Conditions," Jahrestagung Kerntechnik, Bonn, May 23-25, 2000, pp. 4-5.
[58] Martin Sonnenkalb, Gerhard Poss, "The International Test Programme in the THAI Facility and Its Use for Code Validation," p. 12.

> anticipated that new improved recombiner designs for H_2 concentrations above 10% will become available in the near future. Recombiner ignition should either be suppressed or become predictable, so that this effect could be taken into account in future containment analyses.[59]

4) An IAEA report, "Mitigation of Hydrogen Hazards in SA," published in July 2011, states:

> A number of plants have installed passive catalytic recombiners. Under elevated hydrogen concentrations (above about 10%), they may become igniters and initiate combustion, which may not have been foreseen by the designers. Their exhausts can be quite hot, as the recombination generates much heat, so that they can damage nearby equipment or even, if not properly located, the containment itself.[60]

5) The same IAEA report states:

> In a large dry PWR containment, about 40 recombiners are installed... It has to be stated that working in high concentrations (>8%) can initiate deflagration in the PARs due to the hot surfaces of the catalyst. Research is ongoing to create PARs with reduced probability of ignition. PARs are applied in many [nuclear power plants] in the world.[61]

Clearly, the problem of PARs incurring unexpected ignitions is still unresolved. The IAEA report, published in July 2011, states that "[u]nder elevated hydrogen concentrations (above about 10%), [PARs] may become igniters and initiate combustion."[62] Therefore, "new improved recombiner designs for H_2 concentrations above 10%" have not become available, as the OECD Nuclear Energy Agency report, published in 2000, predicted.[63]

(It is noteworthy that another problem with PARs is that Cesium Iodide ("CsI") particles transported through PARs could be converted into volatile iodine, in the event of a severe accident.

Regarding this problem, "The International Test Programme in the THAI Facility and Its Use for Code Validation" states:

[59] OECD Nuclear Energy Agency, "Report on FA and DDT," p. 1.6.
[60] IAEA, "Mitigation of Hydrogen Hazards in SA," p. 66.
[61] *Id.*, p. 77.
[62] *Id.*, p. 66.
[63] OECD Nuclear Energy Agency, "Report on FA and DDT," p. 1.6.

> The catalytic oxidation of hydrogen in PARs results in temperature levels at the catalytic surfaces which can reach 900°C [1652°F] or more and leads to elevated gas temperatures up to several hundred °C in the gas flow passing these surfaces. Suspended CsI particles transported with the convective gas flow through PARs under such conditions can be converted into volatile iodine creating an additional source term of volatile iodine. Considering even low conversion rates might lead to a significant influence on the concentration of gaseous iodine in the early phase of an accident when high CsI / I_2 ratios can be expected.[64]

It is evident that in addition to having unintended ignitions, there are other unresolved problems regarding how PAR systems would perform in the event of a severe accident.)

E. Unintended Ignitions of PARs Could Cause a Detonation in the Event of a Severe Accident

Discussing the risk of unintended ignitions of PARs, "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)" states:

> The unintended ignitions [of PARs] appear to be related to local hot spots generated on the recombiner box structures at higher hydrogen concentrations in the ambient atmosphere. In contrast to the catalytic recombination, ignition is not considered as a measure for improving the safety;[65] the recommendation[s] for installing recombiners are given with the aim to *avoid* ignitions. This means that the unresolved issue of unintended ignitions caused by box type recombiners is to be considered as a risk factor [emphasis not added].
>
> High local hydrogen concentration can occur near the primary system leak position or near the reactor cavity for limited time periods. While the melt in the cavity may act as a continuous ignition source that burns the hydrogen by a continuous diffusion flame, a recombiner box in the hydrogen plume from the leak probably acts as a delayed igniter because of its thermal inertia. *In a situation when the hydrogen concentration*

[64] Martin Sonnenkalb, Gerhard Poss, "The International Test Programme in the THAI Facility and Its Use for Code Validation," pp. 16-17.
[65] BMU, 1998. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Bekanntmachung von Empfehlungen der Reaktor-Sicherheitskommission und der Strahlenschutzkommission vom 13. Februar 1998. Bundesanzeiger Nr. 43, S. 2844 ff, 4. März 1998.

rises, a delayed ignition enhances the risk because it may start a detonation [emphasis added].[66]

Therefore, an unintended ignition of a PAR unit could cause a hydrogen detonation in the event of a severe accident.

1. Safety Issues Regarding Igniters Are Pertinent to PARs because PARs Can Behave like Igniters in Elevated Hydrogen Concentrations

Some recent reports have questioned the safety of using igniters to mitigate hydrogen at certain times in some severe accident scenarios and/or without having conducted thorough safety analyses with computer codes. Safety issues regarding igniters are pertinent to PARS, because PARs would be likely to have unintended ignitions and behave like igniters in the event of a severe accident.

Below are quotes from recent reports that: 1) question the safety of using igniters in a severe accident; 2) emphasize that igniters are effective at hydrogen mitigation but that igniters must be used at precisely the correct time in order for them to not cause detonations in a severe accident; and 3) emphasize that igniters are effective at hydrogen mitigation but that igniters must be only used in cases where the affects of their use is entirely predictable and that "[a] prediction must show, that the integrity of the containment will not be challenged by any turbulent deflagration caused by the...deliberate ignition of a mixture of hydrogen, air and steam."[67]

The quotes from such recent reports pertaining to the use of igniters in severe accidents are as follows:

1) An OECD Nuclear Energy Agency report, "Report on FA and DDT," published in August 2000, states:

> The main question in the application of the igniter concept is its safety orientation. The use of igniters should *reduce* the overall risk to the containment and should not create new additional hazards such as a local detonation [emphasis not added].[68]

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[66] K. Fischer, *et al.*, "Hydrogen Removal from LWR Containments by Catalytic-Coated Thermal Insulation Elements (THINCAT)," p. 146.
[67] Helmut Karwat, "Igniters to Mitigate the Risk of Hydrogen Explosions—A Critical Review," Nuclear Engineering and Design, 118, 1990, p. 268.
[68] OECD Nuclear Energy Agency, "Report on FA and DDT," p. 1.10.

2) A paper, "Studies on Innovative Hydrogen Recombiners as Safety Devices," published in 2004, states:

> The introduction of igniters as discussed in the past still seems to be very questionable as the prediction of hydrogen distribution and combustion in the containment is at present not reliable enough to ensure the safe application of this measure.[69]

3) A paper, "Current Knowledge on Core Degradation Phenomena, a Review," published in 1999, states:

> The concentration of hydrogen in the containment may be combustible for only a short time before detonation limits are reached. This limits the period during which igniters can be used.[70]

4) A paper, "Safety Implementation of Hydrogen Igniters and Recombiners for Nuclear Power Plant Severe Accident Management," published in 2006, states:

> For a postulated accident, hydrogen will accumulate in the upper region of the room because of buoyancy. Reasonable location of the igniter system and selection of the initial ignition time are critical to effective hydrogen removal and control of the hydrogen concentration and the high local thermal and pressure loads. Hydrogen can be removed by a slow diffusion flame, with flame acceleration and DDT excluded. With early ignition, the hydrogen will be eliminated by slow combustion without high thermal and temperature loads, but with late ignition, hydrogen detonation transition will quickly occur with high local thermal and pressure loads which will threaten the integrity of the containment.[71]

5) A SNL report, "Hydrogen-Steam Jet-Flame Facility and Experiments," states:

> [A] serious problem may be the formation of diffusion flames at the point-of-release of the hydrogen-steam mixture into the containment. The jet of steam and hydrogen will entrain and mix with the containment atmosphere, and possibly burn as a turbulent diffusion flame. The ignition source could be accidental (arcing switch contacts) or deliberate (glow plug[igniters]), and, if the jet mixture is hot enough, spontaneous ignition could occur (auto-ignition). The primary threat from diffusion flame

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[69] Ernst-Arndt Reinecke, *et al.*, "Studies on Innovative Hydrogen Recombiners as Safety Devices," p. 59.

[70] Peter Hofmann, "Current Knowledge on Core Degradation Phenomena, a Review," Journal of Nuclear Materials, Vol. 270, 1999, p. 208.

[71] Xiao Jianjun, Zhou Zhiwei, Jing Xingqing, "Safety Implementation of Hydrogen Igniters and Recombiners for Nuclear Power Plant Severe Accident Management," p. 557.

combustion will be the high thermal loads imposed by the flame on safety-related equipment.[72]

6) An NRC letter to licensees, "Completion of Containment Performance Improvement Program, Etc.," states:

> A potential vulnerability for Mark III [BWRs] involves station blackout, during which the hydrogen igniters would be inoperable. Under these conditions, a detonable mixture of hydrogen could develop which could be ignited upon restoration of power. ....
> The same situation could occur in [PWR] ice condenser containments as in Mark III containments relative to hydrogen detonations following restoration of power.[73]

7) On the importance of predicting the affects of the controlled ignition of hydrogen in a severe accident, "Igniters to Mitigate the Risk of Hydrogen Explosions—A Critical Review" states:

> The application of controlled ignition requires that the combustion process must be predictable for any case of its activation. A prediction must show, that the integrity of the containment will not be challenged by any turbulent deflagration caused by the incidental or deliberate ignition of a mixture of hydrogen, air and steam. Moreover, also highly energetic local deflagrations must not damage internal structures of steel containments leading to the formation of internal missiles.[74]

It is apparent from the quotes above that if PARs were to behave like igniters in elevated hydrogen concentrations at certain times in a severe accident, that the PARs' ignitions could cause a detonation. Furthermore, the ignition of PARs is not predictable: it would not be a controlled ignition, which "requires that the combustion process must be predictable for any case of its activation."[75]

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[72] Joseph E. Shepherd, "Hydrogen-Steam Jet-Flame Facility and Experiments," NUREG/CR-3638, October 1984, available at: www.nrc.gov, NRC Library, ADAMS Documents, Accession Number: ML071650392, p. 3.

[73] NRC, letter to all licensees holding operating licenses and construction permits for NPPs, except licensees of BWR Mark Is, "Completion of Containment Performance Improvement Program, Etc.," July 6, 1990, p. 1.

[74] Helmut Karwat, "Igniters to Mitigate the Risk of Hydrogen Explosions—A Critical Review," p. 268.

[75] *Id.*

IV. CONCLUSION

Petitioner requests that NRC order the licensee of IP-2 to remove the PAR system (consisting of two PAR units) from IP-2, because the PAR system could have unintended ignitions in the event of a severe accident, which, in turn, could cause a hydrogen detonation. Experimental data demonstrates that IP-2's two PAR units could have at least one unintended ignition on their catalytic surfaces in the event of a severe accident.

To uphold its congressional mandate to protect the lives, property, and environment of the people of New York, NRC needs to order the licensee of IP-2 to remove the PAR system from IP-2. If implemented, the enforcement action proposed in this petition would help improve public and plant worker safety.

To: R. William Borchardt
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Respectfully submitted,

/s/

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