BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

Application of Pacific Gas and Electric Company for Approval of the Retirement of Diablo Canyon Power Plant, Implementation of the Joint Proposal, and Recovery of Associated Costs Through Proposed Ratemaking Mechanisms	Application 16-08-006 (Filed August 11, 2016*)*

PREPARED DIRECT TESTIMONY OF ARNOLD GUNDERSEN OF FAIREWINDS ASSOCIATES, INC., FOR SAN LUIS OBISPO MOTHERS FOR PEACE

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EXHIBIT SLOMFP_____

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Executive Summary

The closure of Diablo Canyon Nuclear Power Plant ("Diablo Canyon") has been inevitable for years. The degraded condition and economic infeasibility of the Diablo Canyon Units 1 and 2 make it imperative for economic, safety, and environmental reasons that the reactors join the long list of atomic power plants that will permanently close during the next several years. The proposed joint agreement which allows Diablo Canyon Unit 1 to continue to operate until 2024 and Diablo Canyon Unit 2 until 2025 is not substantiated by available engineering and/or economic data produced by Pacific Gas & Electric ("PG&E") or from published data regarding the operational longevity of any other nuclear power plant operated in the United States. The proposed shutting of the plant in 2024/2025 does not appear to be based on science and technical assessment of the condition of the plant and the best interests of ratepayers, but rather merely because 2024/2025 is the end of the operating license for the plant. The scientific and engineering evidence demonstrates that it is imperative that both PG&E atomic reactors are shut down in 2019.

Testimony of Arnold Gundersen of Fairewinds Associates, Inc., for San Luis Obispo Mothers for Peace

I. Retirement of the Diablo Canyon Nuclear Power Plant

A. A Brief History of Diablo Canyon Nuclear Power Plant

Diablo Canyon Unit 1 generated electricity for the first time in 1985, and Unit 2 began producing electricity one-year later, in 1986. The Nuclear Regulatory Commission ("NRC") hypothesizes that the operating life of a nuclear reactor is approximately 40-years from the time it receives its Operating License. Many atomic power reactors fail well before reaching this NRC regulatory limit. Furthermore, an atomic power operating license is normally issued very near the time when the power plant's electricity is first generated.

Though Diablo Canyon began generating electricity 32 years ago, the decision to purchase the two atomic reactors and construct them at Diablo Canyon was made by PG&E 20-years earlier – during the mid-1960s.

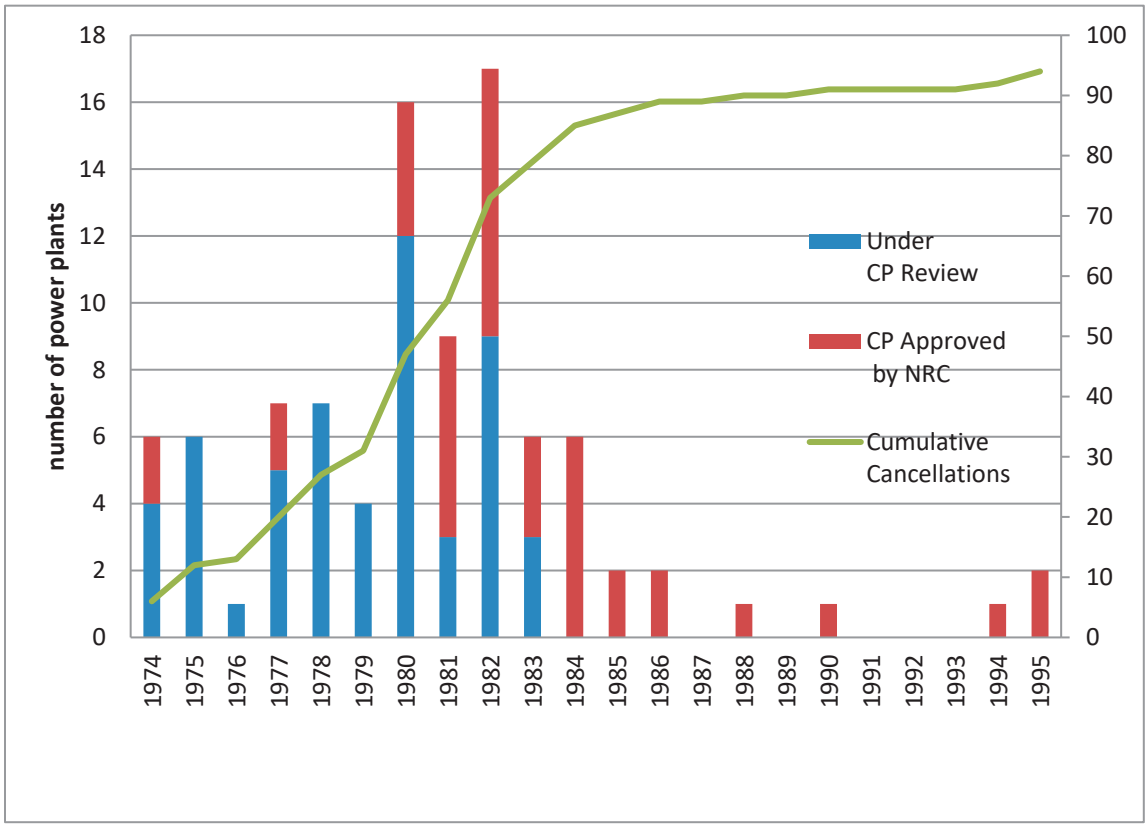
Following the 1950s institutionalization and governmental campaign promoting the *Atoms for Peace*[1] program, United States utilities contracted for more than 240 atomic power reactors during this halcyon period for nuclear power between 1960 and 1980. Prudently, more than half of the reactor contracts were cancelled before generating even one single kilowatt of electricity. Pacific Gas & Electric was one of the utilities that ignored the prudence of the majority when it chose Diablo Canyon as the site to construct two reactors. The nuclear industrial euphoria created by the rush to satisfy America's *Atoms for Peace* program lead to colossal engineering mistakes and cost overruns at Diablo Canyon, causing a major startup delay that lasted 15 years. The serious construction errors created by the atomic power industry rush to build nuclear power plants still haunt Diablo Canyon operations and reliability today, and Californians have been picking up the pieces from *Atoms for Peace* ever since.

While Diablo Canyon was in its 20-year construction period, the nuclear power industry bought and canceled more than 30 atomic power reactors before those companies ever applied to the NRC for Construction Permits, and another 90 atomic power reactors were canceled during either the design or construction phase after successfully completing construction permit applications with the NRC.

Figure 1 below is a graph of atomic power reactor cancellations for reactors that actually applied to the NRC for a Construction Permit ("CP").

[1] "…in a speech before the United Nations, he [Eisenhower] said, "I feel impelled to speak today in a language that in a sense is new—one which I, who have spent so much of my life in the military profession, would have preferred never to use. That new language is the language of atomic warfare." But in that same speech Eisenhower proposed another vision: the peaceful, controlled distribution of nuclear technology to all the countries of the world. In exchange for the potentially life-changing knowledge, countries would agree not to pursue atomic weapons. In outline it was a simple plan but a revolutionary one; it was, as Eisenhower put it, an attempt to ensure "this greatest of destructive forces can be developed into a great boon for the benefit of all mankind." " Jesse Hicks, *Atoms for Peace: The Mixed Legacy of Eisenhower's Nuclear Gambit* (Summer 2014) Chemical Foundation, <https://www.chemheritage.org/distillations/magazine/atoms-for-peace-the-mixed-legacy-of-eisenhower's-nuclear-gambit>.

Figure 1: NRC Construction Permits (CP) - Reactors Cancelled 1974-1995 [2]



B. The Diablo Canyon Predicament

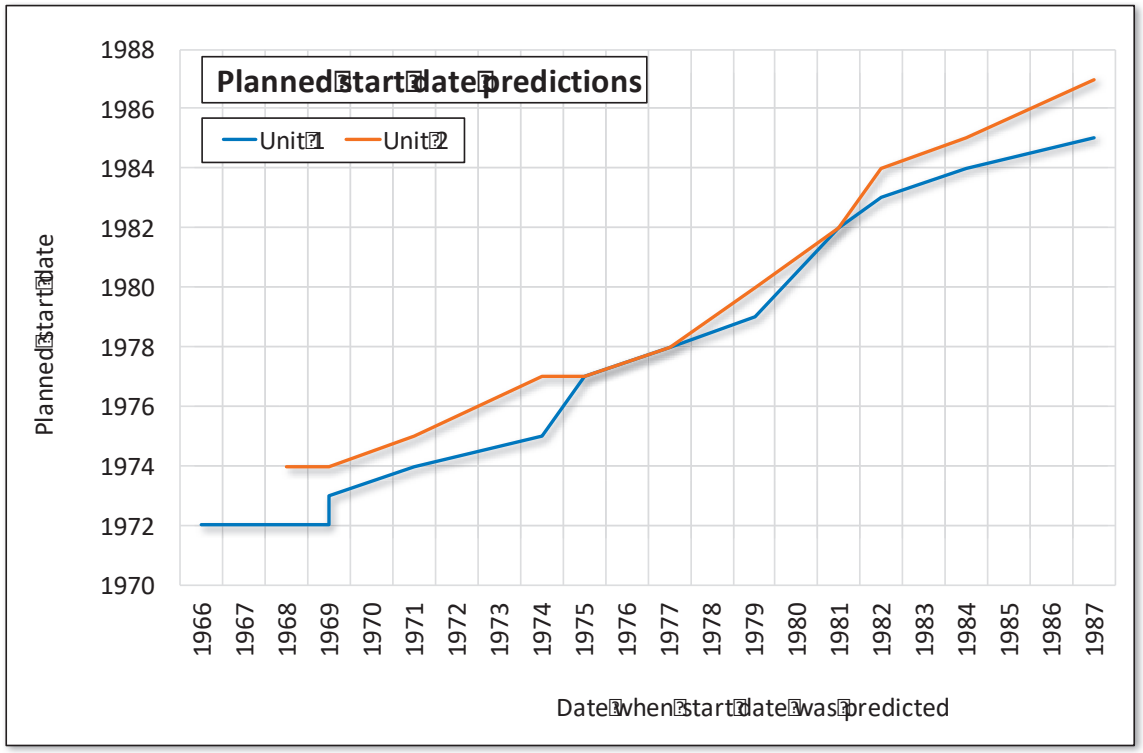
More than 100 atomic reactors were canceled after contracts were created, due to escalating construction costs and delayed and unmanageable construction schedules. While Diablo Canyon was not immune to either of those factors, its delays and cost overruns were so significant that PG&E became an example of what could go wrong during nuclear power plant design and construction.

- Figure 2 shows that PG&E so significantly underestimated the completion schedule for Diablo Canyon was repeatedly delayed for a total of 14 years, causing ratepayers to carry the overage charges.

[2] See United States Nuclear Regulatory Commission, *NRC Information Digest, 2016-2017*, Volume 28, Appendix D, p. 110 available at <https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/>.

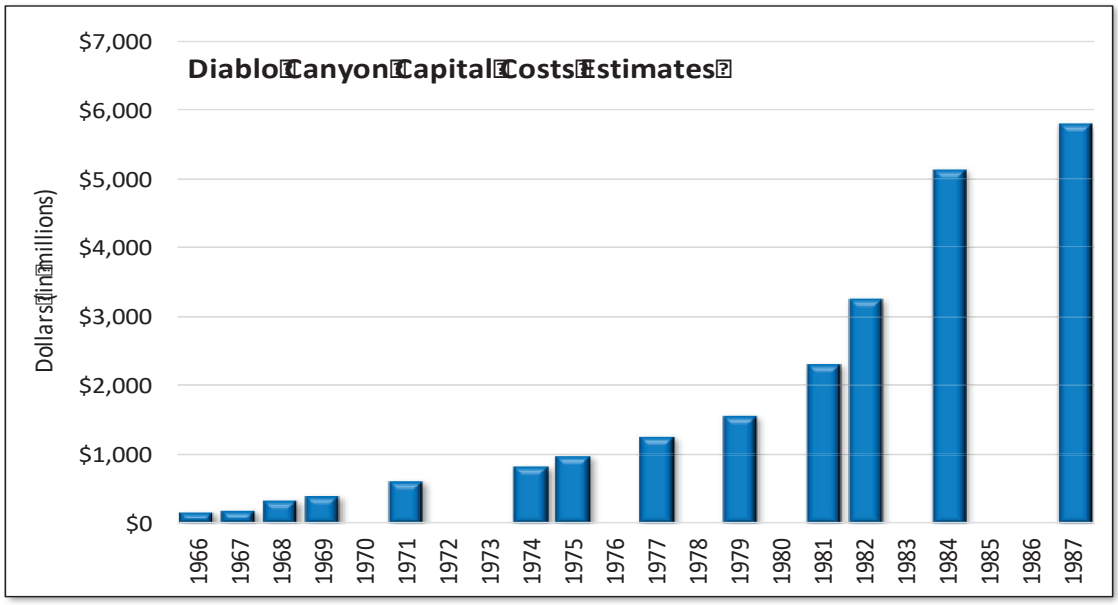
- Figure 3 shows more than a ten-fold increase in the projected construction cost of Diablo Canyon beginning from PG&E's 1966 announcement that it would open Diablo Canyon through completion of construction in 1985.[3]

Figure 2: Planned Start Date Predictions



[3] Supporting data and references are in Table 1 are included the end of this report.

Figure 3: Diablo Canyon Capital Cost Estimates by Year 1966 to 1987



While the majority of utility executives throughout the country began to recognize the enormous costs and risks of building new nuclear power plants, and therefore chose to terminate construction in order to minimize passing ever-increasing costs on to their ratepayers, PG&E forged ahead. Instead of terminating the construction of the two atomic reactors, PG&E passed the rapidly escalating Diablo Canyon cost overruns on to PG&E ratepayers.

Of the quagmire of issues associated with the 20-year construction period of the Diablo Canyon reactors, a number of truly significant PG&E errors still have a direct impact on the risks of continuing to operate the Diablo Canyon reactors. These previous PG&E errors create ongoing operational and regulatory risks examined in the following paragraphs.

The first serious mistake that PG&E made at the very onset of its design process during the mid-1960s was the decision to use its own staff to engineer the design and construction of the atomic power reactors at Diablo Canyon, rather than seek the skills of an engineering firm fully experienced in the nuanced and complex engineering necessary for atomic reactor construction projects. Ultimately, as construction was further delayed and costs escalated, PG&E transferred control of the two projects to an international architectural nuclear power engineering firm to complete the reactors. Unfortunately, by the time that firm was established as a replacement for PG&E, important engineering decisions had been made and major multi-million dollar physical

structures were already in place that continue to negatively impact the ongoing operation of Diablo Canyon. The inexperienced PG&E nuclear power design and construction engineering staff made errors at Diablo Canyon that created defects that impact its current operation. PG&E appears to recognize these defects as a factor in its decision to permanently shutter the Diablo Canyon reactors rather than attempt an NRC license extension application as the company had originally planned.

Briefly for introduction purposes, these flaws and defects include, but are not limited to, PG&E's:

1. Use of the wrong welding material for the nuclear reactor itself;
2. Determination to discharge billions of gallons of hot water directly into the Pacific Ocean every day, rather than installing cooling towers in order to mitigate the negative impact upon aquatic species;
3. Designation of specific criteria levels for evaluating the magnitude of earthquakes and/or the possible impact of nearby faults;
4. Judgment that the deterioration of major components [i.e. degraded mechanical equipment, rubber and concrete degradation, etc.] due to age of the reactors would likely increase the operational failure risk of the Diablo Canyon reactors at an accelerated rate.

Just as Diablo Canyon was finally ready to begin its operating life with its initial startup, the February 11, 1985 cover story in *Forbes Magazine* detailed the overall mismanagement of the United States nuclear power program:

> The failure of the U.S. nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale … only the blind, or the biased, can now think that the money has been well spent. It is a defeat for the U.S. consumer and for the competitiveness of U.S. industry, for the utilities that undertook the program and for the private enterprise system that made it possible.[4]

[4] See *Nuclear Follies*, Forbes Magazine (February 11, 1985) excerpts available at <http://cookslogblog.blogspot.com/2011/04/nuclear-follies.html>.

C. 2017 Nuclear Industry Overview

Power Engineering, a magazine catering to executives in the electric power industry, succinctly summed up the current status of the nuclear power industry:

> Regardless of one's views of the social values of nuclear power — compelling cases can be made all around — as a business proposition nuclear stinks. The business case for existing nukes in the U.S. is also ominous… This comes on top of multiple closings of U.S. nukes unable to compete in competitive markets in recent years, state subsidies in Illinois and New York to keep uneconomic plants open, and threats of even more shutdowns… If it weren't for actions by state governments in Illinois and New York, the picture would look worse.[5]

By considering the upcoming closure of the PG&E Diablo Canyon reactors as a natural progression and the predictable result of forces in energy economics, we have a clearer understanding of the economic demands and constraints confronting Pacific Gas & Electric. The four factors in energy economics that show no sign of abating, and were not anticipated by PG&E until relatively recently, are:

1. The significant impact of improved conservation and energy efficiency that has caused a reduction in electric demand throughout the United States and many other industrialized countries.
2. A dramatic reduction in the cost of renewable electric generation such as wind and solar that was not anticipated by the energy suppliers, utilities, and the energy marketplace.
3. The huge cost of maintaining atomic power reactors as their components wear out due to old age and material degradation as well as anticipated forced equipment upgrades to satisfy compliance with and implementation of post-Fukushima modifications.
4. The unanticipated downturn in corporate profits for the dated utility paradigm and the increased availability of natural gas at well-below forecasted market prices.

This trend in nuclear power plant closures was foreseen almost four years ago by Dr. Mark Cooper, Senior Research Fellow with the Institute for Energy and the Environment at the Vermont Law School**.** In his comprehensive 2013 report entitled *Renaissance in Reverse:*

[5] Kennedy Maize, *As a U.S. Business, Nuclear Power Stinks* (January 1, 2017) Power Engineering <http://www.powermag.com/blog/as-a-u-s-business-nuclear-power-stinks/>.

Competition Pushes Aging U.S. Nuclear Reactors to the Brink of Economic Abandonment,[6] Dr. Cooper expected that Diablo Canyon would be one of 38 United States nuclear reactors to close in the near future.

Like other aging atomic power reactors evaluated by Dr. Cooper, Diablo Canyon absorbs a disproportionate percentage of PG&E's financial corporate resources. Illustrative examples of the financial drain on PG&E resources and its ratepayers may be found in the 2017 General Rate Case[7] record. For example:

1. PG&E claims that capital expenses for Diablo Canyon total approximately 40% of its capital budget.[8]
2. More than half of the entire Operating and Maintenance expense budget for PG&E is appropriated for the ongoing operation of Diablo Canyon.[9]
3. While all these extensive costs are absorbed by PG&E ratepayers, the Diablo Canyon atomic power reactors provide only 22% of the power produced by PG&E[10].

The evidence submitted on this docket by Pacific Gas and Electric shows that the costs of operating Diablo Canyon are disproportionately high for the contribution it makes to PG&E's electrical generation capacity and, therefore, further investment in the continued operation of Diablo Canyon is not a prudent economical capital expense for the utility. Furthermore, continued operation of Diablo Canyon creates an ongoing unjustified burden on PG&E's ratepayers.

Age deterioration has a negative effect on the economic competitiveness of the PG&E Diablo Canyon reactors. Figure 4, below, provides a comparison combining both yearly actual and yearly forecast Diablo Canyon Operating and Maintenance costs for the years between 2011

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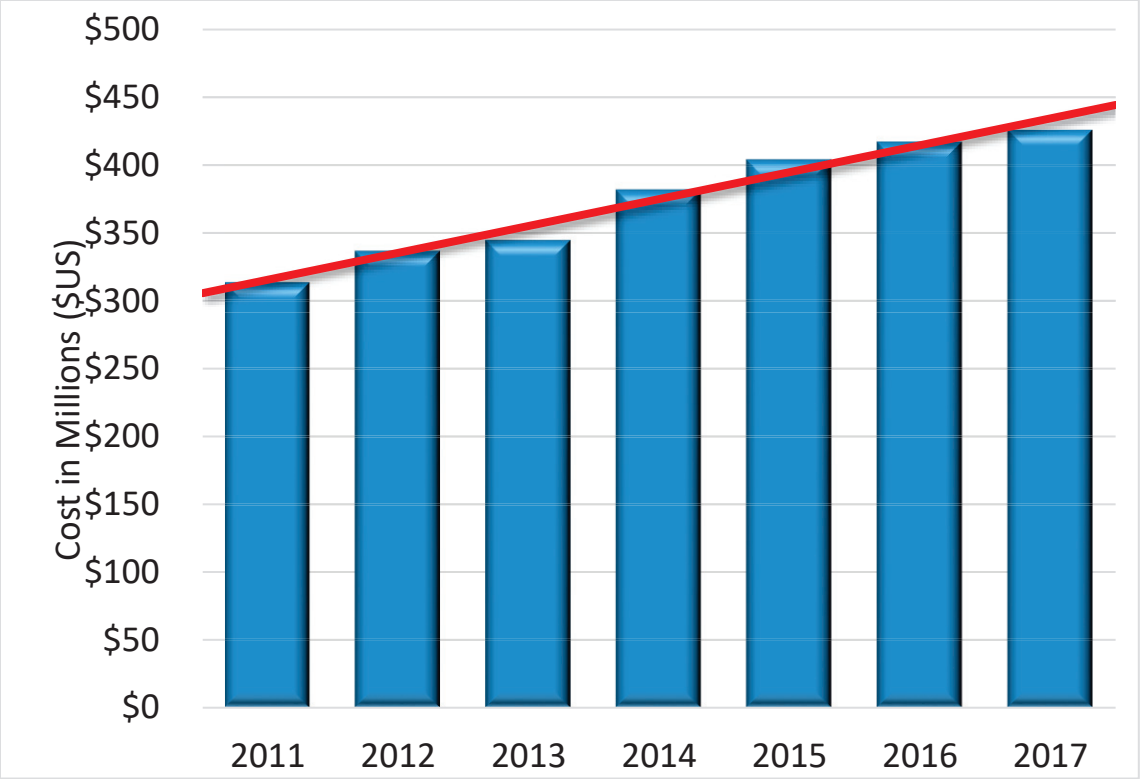
[6] Will Harwood, *Over Three Dozen U.S. Nuclear Reactors at Risk of Early Retirement, 12 Face Greatest Shutdown Pressure* (July 17, 2013) <http://216.30.191.148/atriskreactors.html>.
[7] See *PG&E Test Year 2017 General Rate Case,* Application 15-09-01, Exhibit PG&E-5.
[8] *Id*. at p. 1-10.
[9] *Id*. at p. 1-7.
[10] *Id.* at p. 1-1.

and 2017. Operating and Maintenance costs at Diablo Canyon have grown by $110 million during this 7-year period.[11]

Figure 4: Operating & Maintenance Costs for Diablo Canyon from 2011-2017



The evidence reviewed in this docket, coupled with economic evaluations of the nuclear industry as a whole by energy economists and energy financial analysts, shows that the closure of Diablo Canyon was inevitable and predictable well before the parties to the joint agreement even began negotiating.

The exhibits and data received in discovery show that Pacific Gas and Electric had reached the conclusion that the Diablo Canyon atomic reactors should be shut down rather than relicensed. As a nuclear engineer with more than 45 years of experience in nuclear operations and expert witness testimony, it is my opinion that this proposed joint agreement sets a disturbing precedent by allowing an aging and degraded reactor to continue operations until it is 60 years old (1965-2025). Furthermore, continued operation places the seismically sensitive

[11] *PG&E Test Year 2014 General Rate Case*, Application 12-11-009, Exhibit PG&E-6, p. 3-3, Table 3-1; *PG&E Test Year 2017 General Rate Case,* Application 15-09-001, Exhibit PG&E 5, p. 3-3.

region at greater risk of an atomic power disaster and significant release of radioactivity adjacent to highly populated and environmentally sensitive areas.

D. Implicit Assumptions in the Agreement

In my opinion there are numerous implicit assumptions in this negotiated agreement that require reexamination. There are two broad areas of implicit assumptions that appear to have been accepted without giving due consideration to the underlying issues. The first assumption concerns the remote possibility that Diablo Canyon might have been successful if it had applied for an operating license extension from the NRC to allow it to operate for an additional 20 years. The second assumption is based upon the belief that the Diablo Canyon atomic reactors are mechanically capable of operating reliably until 2025 with outmoded and degraded equipment.

When these basic assumptions are systematically and rigorously analyzed, the evidence submitted by PG&E shows there is almost no chance of Diablo Canyon obtaining a license extension allowing it to operate for 20 years more. Moreover, the likelihood that Diablo Canyon would remain operational through 2025 is extremely low.

i. Nuclear Reactor Embrittlement

Even though Diablo Canyon began operation in 1985, the atomic reactor for Unit 1 was purchased approximately 20 years earlier and delivered to the Diablo Canyon Site in 1973. The Diablo Canyon reactor vessel was one of the first ever manufactured for the nuclear power industry, by a company with no previous experience manufacturing a commercial reactor vessel.

As it turned out, PG&E used the wrong material to weld the Diablo Canyon Unit 1 nuclear reactor pressure vessel. Because the nuclear industry was in its infancy, it was not yet known that the material used to weld the Diablo Canyon Unit 1 reactor vessel is highly susceptible to radiation damage. Reactor vessels damaged by radiation become embrittled and are susceptible to cracking and vessel failure. This phenomenon is known as *embrittlement* and is the subject of a lengthy analysis by Fairewinds Associates, Inc., attached to this report as **Appendix A**. The NRC has labeled Diablo Canyon Unit 1 as one of the five most embrittled reactor vessels in the United States. Due to degradation and loss of integrity in this major component for the Unit 1

reactor, it is Fairewinds' belief that the approval by regulators for a 20-year license extension for Diablo Canyon Unit 1 would have been unlikely.

ii. The Need for Cooling Towers

Nuclear reactors are the least efficient means of electric production because they discharge more heat to the environment than any other method of electricity production. Atomic power plants are oftentimes defined by the iconic image of two large hyperbolic cooling towers. The reason cooling towers are associated with nuclear power is that NPPs have the lowest Carnot Cycle Efficiency[12] of any form of electric generation, meaning that atomic power reactors create a disproportionately large amount of waste heat for the electricity they produce compared to [13]coal, oil, and natural gas.

Cooling towers are used for two reasons: first, to prevent the entrainment of fish eggs and larva in the high temperatures that exist within the Diablo Canyon condenser and second, to ensure the tremendous amount of waste heat *is not* discharged directly into adjacent waterways, rivers, and oceans, where it can significantly damage aquatic species like spawning fish, oysters, crabs, and the plankton and other biota upon which all aquatic species are dependent for survival. The environmental damage caused by the waste heat from Diablo Canyon to the Pacific ecosystem is staggering according to the Natural Resources Defense Council:

> The plant's intake pipes draw in more than 2.5 billion gallons of water per day, or 2.8 million acre-feet annually. This large and continuous seawater withdrawal is estimated to kill roughly 1.5 billion fish in early life stages each year, as creatures are sucked into the cooling systems or become impinged against the screens on the open-water pipes.[14]

By contrast, when PG&E designed Diablo Canyon during the mid-1960s it allowed the waste heat from the nuclear reactors to be discharged directly into the Pacific Ocean, rather than

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[12] Carnot cycle is the most efficient thermal cycle possible, consisting of four reversible processes, two isothermal and two adiabatic. *Jones and Childers Glossary,* <http://www.mhhe.com/physsci/physical/jones/student/olc/student_glossary.mhtml> (last visited January 26, 2017.)

[13] The amount of cooling required by any steam-cycle power plant (of a given size) is determined by its thermal efficiency. It has essentially nothing to do with whether it is fueled by coal, gas or uranium. World Nuclear Association, *Cooling Power Plants* (November 2015) <http://www.world-nuclear.org/information-library/current-and-future-generation/cooling-power-plants.aspx>.

[14] Elizabeth Murdock, *Nuclear Plant Closure Will Benefit California Marine Species* (June 23, 2016*)* Natural Resources Defense Counsel < https://www.nrdc.org/experts/elizabeth-murdock/nuclear-plant-closure-will-benefit-california-marine-species>.

installing cooling towers. By approximately 1980, scientists had acknowledged that such a tremendous amount of heated plant discharge water would damage the Pacific ecosystem. While it would have been only slightly more expensive to factor cooling tower construction into the original Diablo Canyon initial design and construction plan, when PG&E engineers initially designed the Diablo Canyon site, retrofitting the Diablo Canyon plants for cooling towers during the early 1980s would prove to be an extremely expensive proposal and an additional cost that ratepayers would be expected to bear.

According to the April 15, 1982 edition of nuclear industry trade publication *Nucleonics Week: Global Market Reports - Platts*, the California Central Coast Region Water Quality Control Board began "battling" PG&E as early as 1981 over the need for cooling towers at its Diablo Canyon site. As a result, PG&E commissioned a study to investigate adding cooling towers to its Diablo Canyon reactors and commissioned Tera Corp.[15] to examine alternative cooling systems for Diablo Canyon.

In its article, *Nucleonics Week* stated that eight alternatives were available for retrofitting "technically feasible alternative cooling systems for Diablo Canyon" in the early 1980s. This was fully four years prior to the start-up of the Diablo Canyon Unit 1 atomic reactor and its legacy of dumping its waste heat into the Pacific Ocean with its marine aquatic biome. According to PG&E, the Tera Corp estimates for cooling towers to prevent damage to the Pacific Ocean would range "in cost from $1.6-billion to $5.3-billion,"

> "The plants cooling system as built – once-through saltwater shoreline intake variations – would raise the temperature of the Pacific Ocean in the vicinity to a maximum of 80 F. The regional board is seeking to prohibit heat discharges…"

[15] An engineering assessment prepared for PG&E in 1982 estimated an outage time of four months per unit at Diablo Canyon (Tera Corp 1982) while other estimates range as high as 12 months or more (BES 2003). This study estimated a construction-related shutdown of eight months for Diablo Canyon and six months for San Onofre, with the difference largely reflecting different facility configurations and the more compact nature of the Diablo Canyon facility. Tetra Tech Corporation, *Assessment of Alternatives to the Existing Cooling Water System (DCPP)*, *Prepared for Pacific Gas and Electric,* <http://www.opc.ca.gov/webmaster/ftp/project_pages/OTC/engineering%20study/Chapter_5_Engineering_and_Cost_Methodology.pdf>.

Despite public opposition, Diablo Canyon was allowed to operate without constructing the environmentally protective cooling towers. Significant public opposition would once again be expected at Diablo Canyon since its water discharge permit is currently due to expire in 2024. More stringent environmental laws are now in place than in 1980 concerning the discharge of waste heat, and those laws have been effectively used in opposition to license renewal at other NPPs.

Significant public and State opposition requiring the use of cooling towers as a condition for a 20-year operating extension has already occurred at three U.S. atomic power reactor sites. Rather than spend the money necessary to retrofit those plants and install cooling towers as demanded by appropriate state water control authorities, the reactor owners chose to close the reactors. Oyster Creek, located on Barnegat Bay in New Jersey and owned by Exelon Corporation, applied *unsuccessfully* for a 20-year license extension from the NRC in 2009 but was denied the ability to discharge its waste heat into the Bay at the State permit level. Environmental groups, the State of New Jersey, and Exelon negotiated an agreement that the plant would close by 2019 rather than operate till 2029 with a 20-year license extension, but no cooling towers would be installed. Exelon chose to give up the additional 10-years of operation of Oyster Creek and those profits rather than installing cooling towers. On January 9, 2017 Entergy Corp, the State of New York, and environmental groups agreed to close the Indian Point Units 2 and 3 nuclear reactors in 2020 and 2021 rather than install cooling towers for Entergy's proposed relicensure venture. The negotiated settlement determined that Entergy would not be required to build the cooling towers during the last three and four years of proposed operation prior to final shutdown.

In addition to these three reactors, two others in Connecticut will also be required to build cooling towers as a result of a legal decision in December 2016. According to a published decision:

> **CT Supreme court reverses lower court decision on Millstone**
> The Connecticut Supreme Court has reversed a lower court decision on the Millstone nuclear power station Clean Water Act permit, clearing the path for activists to nullify the permit on environmental grounds at an upcoming hearing. [16]

[16] *Burton v. Commissioner of Environmental Protection* (2009) 291 Conn. 789.

When 20-year license extensions without backfitting cooling towers have been opposed by environmental groups, state environmental boards, and state attorneys general, no nuclear power plant in the U.S. has successfully received its 20-year operating license extension. It is my professional opinion that Diablo Canyon would never have succeeded in obtaining its proposed 20-year license extension due to the environmental concerns and the legal jurisdiction of state environmental agencies for protection of water quality and aquatic species. PG&E has consistently fought back-fitting new cooling towers, even though that is the prudent environmental action to mitigate the ongoing damage of dumping more than two billion gallons of hot water directly into the Pacific Ocean daily. The situation at Diablo Canyon is strikingly similar to the failed attempts at Oyster Creek and Indian Point Units 2 & 3 to continue to operate without cooling towers in spite of significant environmental damage.

More importantly, the approval by the State of California to continue operating Diablo Canyon cooling towers expires in 2024. Based upon the experience at Oyster Creek, Indian Point Unit 2, Indian Point Unit 3, Millstone Unit 2 and Millstone Unit 3, it is highly unlikely that Diablo Canyon could continue to operate beyond 2024 without committing to installing cooling towers to mitigate damage to the Pacific ecosystem.

iii. The serious likelihood of Earthquake Damage

The disaster at Fukushima-Daiichi unequivocally determined that nuclear reactor design engineers have historically underestimated the intensity and the frequency of earthquakes. **Appendix B**, attached to this prepared testimony, is a detailed expert analysis prepared by Fairewinds Associates, Inc, entitled *Gundersen Affidavit Supporting Friends of the Earth's Petition to Intervene.* The purpose of my October 10, 2014 testimony was to examine the Central Coastal California Seismic Imaging Project to see if its assessment was congruent with previous statements made by PG&E regarding Diablo Canyon in its License Renewal Application.[17] My

[17] *Gundersen Affidavit Supporting Friends of the Earth's Petition to Intervene,* Before The United States Nuclear Regulatory Commission, Before The Atomic Safety and Licensing Board, In the matter of Pacific Gas & Electric Company Diablo Canyon Nuclear Power Plant, Units 2 and 3 License Renewal Application (October 10, 2014) available at <https://static1.squarespace.com/static/54aac5e4e4b0b6dc3e1f6866/t/5612cd1ce4b099e0ea16eda5/1444072732366/245766826-Attachment-2-Gundersen-Affidavit-CV.pdf>.

testimony shows that the increased earthquake risk to Diablo Canyon was not considered during its initial design engineering phase in the mid-1960s. Furthermore, my 2014 testimony shows that during the past 10 years, 12 nuclear power plants have experienced earthquakes that exceeded the seismic accelerations anticipated by design engineers and seismic geologists.

While a large ocean earthquake, such as the earthquake that caused the tsunami at TEPCO's Fukushima-Daiichi site, has not yet occurred near a U.S. nuclear power plant, Diablo Canyon's buildings, which were designed to withstand seismic activity, swayed significantly during earthquakes that were considerably less severe than either the engineers or reactor designers had anticipated. Swaying buildings put each atomic power reactor at substantial risk of pipe and/or electrical conduit damage that could impair the reactor cooling system and/or the equipment used to operate the reactors. Even if safety systems are not breached, repairs to vital operational systems may take as long as 10 years to complete.

While my affidavit in Appendix B was written in 2014, new information regarding the impacts of seismic activity on nuclear power reactors was released in Japan on January 17, 2017. The Tohoku Electric Power Company, owner of the Onagawa Diablo Canyon, informed Japan's Nuclear Regulatory Authority that it had discovered 1,130 cracks in the Onagawa reactor building that were caused by the Tohoku (Great East Japan) Earthquake of March 11, 2011 – the same earthquake that damaged part of one reactor at Fukushima-Daiichi prior to the tsunami landfall and damage to four of the six onsite reactors. The cracks at Onagawa have caused a 70% loss in the structural rigidity of the reactor building in a reactor specifically designed to withstand the impact of earthquakes.[18] Though the Onagawa reactor shut down safely, such massive, unanticipated repairs will add years of delays to the possible restart of a reactor closed since Fukushima Daiichi's triple meltdowns in March 2011. This is of particular concern, given the fact that such damage was not discovered for more than six years.

This raises similar concerns for Diablo Canyon should a major earthquake strike near Diablo Canyon. Dr. Michael Peck, NRC resident inspector for Diablo Canyon, has repeatedly

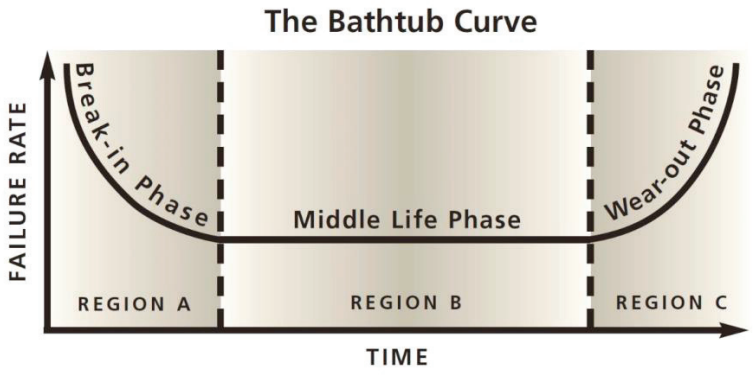
[18] *Japan Nuke Plant Onagawa Unstable-1,130 cracks, 70% rigidity lost at Onagawa reactor building* (January 18, 2017) THE ASAHI SHIMBUN <http://www.asahi.com/ajw/articles/AJ201701180054.html>.

expressed his deep reservations about the NRC's refusal to permit independent seismic and geologic experts to analyze the hypothesis and assumptions applied to PG&E's mathematical design calculations during the design, engineering, and construction phases for Diablo Canyon in the early 1970s. Again, it is of particular concern that PG&E had no experience with the sensitive nuances of atomic power reactor design when their in-house engineering staff designed the units.

It is my professional opinion that the seismic and geologic contentions associated with earthquakes and additional fault lines so near Diablo Canyon would adversely impact PG&E's ability to re-license the Diablo Canyon reactors for an additional 20 years. Of course, no one is able to forecast when and how extensive seismic earthquake amplitude may be. Consequently, Diablo Canyon should permanently close during 2019 because earthquakes pose both short-term and long-term operational risks and it is a clear hurdle to relicense Diablo Canyon as it was not adequately designed to withstand seismic risk.

iv. Likelihood of Mechanical Failures

As stated earlier, Diablo Canyon's procurement of mechanical components began more than 50 years ago. Engineers explain the aging phenomenon by using what is known as the "Bathtub Curve." [19]



The curve is a graph of failure rate according to age. The failure rate is relatively high in the beginning when "kinks" are being worked out; it flattens out during the middle life phase;

[19] Union of Concerned Scientists, *U.S. Nuclear Power Plants in the 21st Century: The Risk of a Lifetime* (March 2005) <http://www.ucsusa.org/nuclear-power/nuclear-power-accidents/us-nuclear-plants-in-the-21st-century-.WIkC9BjMyB4>.

and it rises again sharply in the end-of-life or at the "wear-out phase." On average, 20 years usually marks the beginning of the wear-out phase. Diablo Canyon is in the wear-out phase of the bathtub curve.

PG&E's Application ignores the reality of the Bathtub Curve and assumes that Diablo Canyon will operate without mishap or mechanical failure from now (2017) through 2025. Yet, an extended shutdown would force the immediate closure of Diablo Canyon well before the end of its current NRC license.

Based on nuclear industry data and the degraded condition of components within the plant, it is quite likely that an extended shutdown at Diablo Canyon will occur. The seminal work on long-duration NPP outages, entitled *Walking a Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages,* was published in September 2006 by The Union of Concerned Scientists (UCS).[20] In the report summary, UCS stated:

> The Nuclear Regulatory Commission (NRC) seems to be following the script of the movie *Groundhog Day*, reliving the same bad event again and again. This event—an outage at a nuclear power plant that lasts more than a year—has happened 51 times at 41 different reactors around the United States and shows no signs of stopping.

After this UCS report was released, even more nuclear power reactors have faced extended outages due to mechanical equipment failures. The primary reason for these extended outages is the age-induced degradation of components. A partial list is presented below of extended atomic power reactor outages that occurred after the release of the UCS technical analysis into this issue:

- **Arkansas 1 extended outage 2013 [Arkansas]**
  Dropped heavy load caused automatic shut down and killed one worker.
  http://allthingsnuclear.org/wp-content/uploads/2015/02/FS-181-PDF-File-with-links.pdf

- **Columbia Generating Station 2011 [Washington State]**
  Extended month outage in 2011 to rebuild and replace the failing brass condenser unit.
  http://www.psr.org/chapters/oregon/assets/pdfs/economic-analysis-of-the.pdf

[20] Union of Concerned Scientists, *Walking a Nuclear Tightrope: Unlearned Lessons of Year-plus Reactor Outages,* (September 2006) <http://www.ucsusa.org/nuclear-power/whos-responsible-nuclear-power-safety/walking-a-nuclear-tightrope - .WHqMPLHMzLE>.

- **Crystal River 2009-2011 [Florida] [when the decision was made to simply close plant.]**
  Repeated delamination of concrete containment resulted in closure of the plant in 2013.
  http://www.drmor.com/m1/CrystalRiver.html

- **DC Cook 2008 Turbine Failure [Michigan]**
  http://www.marketwatch.com/news/story/Return-Timeline-AEPs-Cook-Nuclear/story.aspx?guid=%7B525EBE26-2BEF-4AB2-8CF7-B6220A7A483A%7D

- **Duane Arnold 2012 [Iowa]**
  Repeated failure of protective coating on torus**.**
  http://allthingsnuclear.org/dlochbaum/duane-arnold-the-safety-upgrade-that-downgraded-safety

- **Fort Calhoun 2011-2013 [Nebraska]**
  Fire and Flood
  http://www.omaha.com/money/oppd-s-fort-calhoun-nuclear-plant-has-become-too-expensive/article_f8b86658-184e-11e6-b852-8f5144170b67.html

- **Indian Point [New York]**
  - **2000 -** Steam generator tube failure
    https://www.nrc.gov/docs/ML0037/ML003762242.pdf

  - **2016**- Extended outage due to degraded bolts.
    http://allthingsnuclear.org/dlochbaum/indian-points-baffling-bolts

- **James A. Fitzpatrick- 2014 [New York]**
  An extended outage to repair/replace leaky condenser tubes
  http://www.syracuse.com/news/index.ssf/2014/05/fitzpatrick_nuclear_plant_put_off_repairs_now_plagued_by_water_leaks.html

- **Quad Cities 2002 [Illinois]**
  Repeated steam line vibrations, hole discovered in steam dryer.
  http://www.ucsusa.org/nuclear-power/nuclear-power-technology/snap-crackle-pop#.WHmp_1eodSU

- **San Onofre 2012- 2013 [California] [when the decision was made to simply close plant.]**
  Degradation of steam generator tubes
  https://www.nrc.gov/docs/ML1501/ML15015A419.pdf

- **Vermont Yankee- 2007 [Vermont]**
  Cooling tower collapse.
  http://archive.boston.com/news/local/articles/2007/09/14/vt_yankee_reports_on_collapse_in_tower/?camp=pm

During the past five years, Californians became acutely aware that the two atomic power reactors at San Onofre were forced to close after developing steam generator leaks, well before reaching the end of their 40-year design life. Additionally, Floridians suddenly no longer had the service of Crystal River Unit 3 when its allegedly robust containment cracked and could not be repaired after repeated attempts, again, before the end of its 40-year design life.

The considerable available body of evidence indicates that many nuclear power reactors break and are permanently out of commission well before they reach the end of their 40-year anticipated operating life. Diablo Canyon is no exception to this evidentiary trend. The evidence I have reviewed shows that an extended outage due to equipment failure at Diablo Canyon is likely before 2024. If Diablo Canyon chooses to operate beyond its 2019 refueling outage, the financial risk of failure of any component and the ensuing repair outage costs and losses should be borne by PG&E's shareholders, and not charged to the PG&E ratepayers in California.

The risk matrix referenced in the PG&E 2017 General Rate Case prepared testimony[21] indicates that a significant number of the components at Diablo Canyon are tangibly degraded and in desperate need of replacement. Specifically, PG&E has labeled 320 components as degraded, but still functioning, while 3 components have downright failed.

It is important to recognize that repairing aging equipment also can be a cause for reactor failure. At San Onofre 2&3, Crystal River 3, and Arkansas Nuclear One, degraded components in the wear-out phase, as defined by the Bathtub Curve, were identified and replaced. The replacement of the old equipment caused the failure of each plant as a whole, not the original degraded components. In an attempt to improve reliability by making a replacement, the owner moved from the wear-out phase to the break-in phase, at which time each new component broke.

In its risk matrix[22] referenced in the PG&E 2017 General Rate Case prepared testimony, PG&E identified *major components* that are degraded, including and not limited to:

- Hydraulic shock absorbers ("snubbers") – which are required to mitigate an earthquake,

[21] See *PG&E Test Year 2017 General Rate Case,* Application 15-09-001, Exhibit PG&E-5, pp. 2-42.
[22] *Ibid.*

- Worn valves in the safety injection system that pumps water into the reactor at very high pressures,
- Worn expansion joints in the condenser – as the condenser heats and expands, it grows and shrinks and these expansion joints accommodate that movement,
- Degraded piping that has become too thin from flow-accelerated corrosion; this physical failure requiring replacement was identified by the Flow Accelerated Corrosion program. Pipes that have thinned from flow-accelerated corrosion have worn so thin that they unexpectedly exploded and killed nearby workers at Surry Nuclear Power Plant in Virginia and other plants in Japan, and
- An outdated 1980s era designed analog safety instrumentation needs to be entirely replaced because spare parts are no longer available. It is meant to turn critical valves and pumps and measuring equipment for the safety system on and off, but because it still works on analog circuitry it cannot be adequately computerized.

Additionally, PG&E rates its equipment and components with a *"safety risk score"* for each Diablo Canyon reactor, in order to determine which aging components must be replaced first. PG&E does not have the financial resources to replace them all at once. PG&E identifies categories for the failure of these components that include:

- "Aging/End of Life Risk" Bathtub Curve components (22 items in need of replacement).
- "Trip Risk" items that can cause the reactor to stop but still stay pressurized (12 items in need of replacement).
- "Shutdown Risk" after the reactor goes offline and power drops to zero, if these components do not work, the reactor pressure will drop to zero adding stress to the embrittled reactor (36 items in need of replacement).
- "Core frequency damage risk and Nuclear Risk" refers to risk that nuclear fuel could be damaged if these components and/or equipment breaks (6 items in need of replacement).
- "Greater than 2% Curtailment" the power level would be dropped by 2%, so the plant would have to run at reduced power (80 items in need of replacement).

Finally, below is a small sampling of the aging components that are significantly degraded at Diablo Canyon. Unfortunately, this list shows excessive deferred maintenance thereby indicating that imminent failure is not just a theoretical possibility, but rather a likely occurrence. A sampling of the PG&E list includes:

- A $35M project to "Replace Process Control Racks… The current instruments are extremely hard to troubleshoot and repair due to their 1960's architecture."[23]
- A $2.1M project to replace the doors into the control room because the hinges on the doors are excessively worn from years of use.[24]
- A $4.7M project to replace the ventilation fans in the Fuel Handling Building that have long been exposed to salt air and are in constant need of repair.[25]
- A $14.7M project to "Replace Incore Thermocouples…DCPP currently has 6 inoperable thermocouples and 4 unusable shortened ones in Unit 1, and as the plant continues to age, it is expected to have more failures due to age and moisture intrusion…"[26]
- A $14.0M project to Replace Main Generator Exciter Rotor …"The exciter rotor windings and insulation are subject to the same aging process as the main generator rotors and are vulnerable to failure. These rotors are designed with an internal ground detection system that has a 7-strand wire that currently has 6 broken wires."[27]
- A $5.0M project to "Replace 480 Volt Cubicle Buckets … DCPP has experienced multiple failures of the Cutler Hammer Citation system… Failure of the MCCB to open during over-current fault conditions can lead to extensive equipment damage and fires. All components of the 480V MCC buckets have exceeded their design life …"[28]
- A $4.3M project to "Replace 125VDC ITE Circuit Breakers … The ITE Gould HE2 breakers installed in the 125VDC distribution system are obsolete and unreliable and need to be replaced… There have been numerous problems with these breakers in the

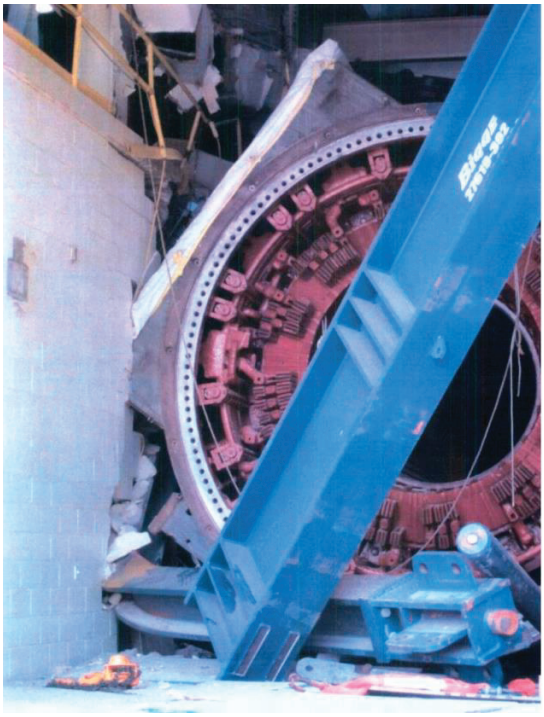
[23] *PG&E 2014 Test Year General Rate Case*, Application 12-11-009, Exhibit PG&E-6, p. WP3-100.
[24] *Id.* at p. WP3-108.
[25] *Id.* at p. WP3-111.
[26] *Id.* at p. WP3-118.
[27] *Id.* at p. WP3-120.
[28] *Id.* at p. WP3-121.

nuclear industry. Utilities are planning to replace them since there are no replacements that can be plugged directly into their old-style electrical service panel.[29]

- A $4.9M project to "Replace Lube Oil Demisters… The demisters… have degraded such that oil mist is entering various buildings and components via the HVAC system that causes continued oil fouling of adjacent equipment and occupied spaces. This also becomes a health hazard when the vapors are inhaled. These demisters are original equipment, beyond useful service life and must be replaced." [30]

This lengthy list provided by PG&E details the possibility of several major equipment failures, including the main generator stator, which is an extraordinarily large and expensive electrical generating component. The stator replacement featured in the photo below was the replacement part for Arkansas Nuclear One owned by Entergy Corp in Arkansas. The new replacement stator at Arkansas Nuclear One was dropped during installation.

Arkansas Nuclear One Stator



[29] *Id.* at p. WP3-122.
[30] *Id.* at p. WP3-128.

As atomic power reactors age around the globe, these types of component malfunctions and replacements have proven to be systemic and costly, further reducing the operational reliability of old plants like Diablo Canyon as the cost to ratepayers increases with the continuous maintenance required to operate such an antiquated behemoth. Even in the best case with no serious mechanical failures, aging will inevitably cause increased costs; this technology has repeatedly shown itself to be uneconomical. Mechanical failure is likely and there remains a finite possibility of a serious mechanical failure with a significant release of radiation from the Diablo Canyon atomic power reactors as they age further.

E. Conclusion:

1. It is more prudent that the California Public Utilities Commission permanently close Diablo Canyon as early as 2019 due to the magnified probability of equipment failures and the very real risk of earthquake damage.
2. An extended outage due to equipment failure at Diablo Canyon before 2024 is likely. If Diablo Canyon chooses to operate beyond its 2019 refueling outage, the financial risk for failure of any component and the ensuing repair outage costs and losses should be borne by PG&E's shareholders, and not charged to the PG&E ratepayers in California.

In my professional opinion, relicensure of Diablo Canyon was doomed to fail due to its overall equipment degradation, seismic, embrittlement, and aging management issues. It would not be a prudent management decision for PG&E to expend the huge legal, engineering, and capital costs required to attempt to extend licensure at Diablo Canyon. From an engineering management point of view and in consideration of the high costs of continued operation to its ratepayers, PG&E should shut down both Diablo Canyon Unit 1 and Unit 2 in 2019.

II. Proposed Replacement Procurement

No testimony at this time.

III. Proposed Employee Retention and Severance Program

No testimony at this time.

IV. Proposed Community Impacts Mitigation Program

No testimony at this time.

V. Recovery of License Renewal Costs

No testimony at this time.

VI. Proposed Ratemaking and Cost Allocation Issues

No testimony at this time.

VII. Land Use, Facilities and Decommissioning Issues

No testimony at this time.

VIII. Additional Issues Not Addressed Above

No testimony at this time.

Table 1
Construction Delays and Cost Overruns
Timeline for Diablo Canyon Units 1 and 2[31]

1966 – Cost estimate for Unit 1- $162,700,000 with a completion date of May 1972.

1967, Feb. 16 – Projected Cost (Unit 1 only) increased to $188,413,000. Estimated operating date remains 1972

1967, Feb. 16 – is also the first mention that there will be a Unit 2, and perhaps 4 additional reactors.
http://www.foe.org/projects/climate-and-energy/nuclear-reactors/diablo-timeline

1968, January 30 – Unit 2 estimated at $157,400,000.
Operational estimate: July 1974

1969, March 23 – estimate for Unit 2 is $183 million.
Est. Operating Date unchanged.

1969, May 6 – Estimate for Unit 1 increased to $212,300,000.
Est. Operating Date: February 1, 1973

1969, May 6 – Estimate for Unit 2 increased to $192-million
Est. Operating Date unchanged.

1971, July 20 – Estimate for Unit 1 increased to $330,000.000.
Est. Operating Date: spring 1974

1971, July 20 – Estimate for Unit 2 increased to $290,000,000.
Est. Operating Date: spring 1975.

1974, Dec. 20 – Estimate for Unit 1 increased to $395,000,000.
Est. Operating Date: Sept. 1975

1974, Dec. 20 – Estimate for Unit 2 increased to $435,000.000.
Est. Operating Date: March 1977

1975, June 24 – Estimate for Unit 1 increased to $550,000,000.
Est. Operating Date: March 1977. (Unit 2 cost unchanged)

1977, June 28 – Estimate for Unit 1 increased to $695,000,000.
Est. Operating Date: 10/15/78

[31] Neiburger, *From Groundbreaking to Start-Up*, San Luis Obispo Telegram-Tribune (Aug. 11, 1984) p. B-7, B-8; The Energy Net *Diablo Canyon Timeline* <http://www.energy-net.org/01NUKE/DIABLO1.HTM> (last visited Jan. 27, 2017).

1977, June 28 – Unit 2 increased to $560,000,000.
Est. Operating Date: 10/15/78

1979, Feb. 13 – Unit 1 increased to $870,000,000.
Est. Operating Date: 6/1/79

1979, Feb. 13 – Unit 2 increased to $700,000,000.
Est. Operating Date: 2/1/80

1981, Sept. 16 – Unit 1 increased to $1,270,000,000.
Est. Operating Date: 2/1/82

1981, Sept. 16 – Unit 2 increased to $1,040,000.000.
Est. Operating Date: 10/1/82

1982, Oct. 1 – Projected cost (Units 1 and 2 combined): $3,255,000,000.
Est. Operating Date for Unit 1 : 10/1/83
Est. Operating Date for Unit 2: 4/15/84

1984, June 29 – Projected Cost for both Units: $5,140,000,000.
Est. Operating Date Unit 1: Sept. 1984
Est. Operating Date Unit 2: May 1985

May 1985 – Unit 1 begins operation

March 1987 – Unit 2 begins operation

May 1987 – Final Two Unit Cost: $5,800,000,000[32]

~ End ~

[32] *PG&E Shouldn't Use Rates to Recover Most of Its Diablo Costs, Panel Urges,* Wall Street Journal, page 6, May 15, 1987

I declare that under penalty of perjury that the testimony submitted in this proceeding is true and correct to the best of my knowledge. The facts presented in this declaration are true and correct to the best of my knowledge, and the opinions expressed are based on my best professional judgment.

Executed in Burlington, Vermont this 27th day of January 2017.

(Electronically signed)

Arnold Gundersen, MSNE, RO
Fairewinds Associates, Inc
Burlington, Vermont 05401
Tel: (802) 865 9955
Email: fairewinds@mac.com
Date: January 27, 2017

Arnold Gundersen, Curriculum Vitae
Chief Engineer, Fairewinds Associates, Inc
January 2017

Education and Training

ME NE Master of Engineering Nuclear Engineering
Rensselaer Polytechnic Institute, 1972
U.S. Atomic Energy Commission Fellowship
Thesis: Cooling Tower Plume Rise

BS NE Bachelor of Science Nuclear Engineering
Rensselaer Polytechnic Institute, Cum Laude, 1971
James J. Kerrigan Scholar

RO Licensed Reactor Operator, U.S. Atomic Energy Commission,
License # OP-3014

Qualifications – including and not limited to:

- Chief Engineer, Fairewinds Associates, Inc
- Nuclear Engineering, Safety, and Reliability Expert
- Federal and Congressional hearing testimony and Expert Witness testimony
- Vermont Community Research Fellow, University of Vermont
- Former Senior Vice President Nuclear Licensee
- Former Licensed Reactor Operator
- Atomic Energy Commission Fellow
- 45-years of nuclear industry experience and oversight
    - Nuclear engineering management assessment, prudency assessment, contract administration, assessment and review
    - Nuclear power plant licensing and permitting – assessment and review
    - Decommissioning experience: including radioactive waste processes, storage issue assessment, and waste disposal
    - Nuclear safety and risk assessment, source term reconstruction, dose assessments, criticality analysis, and thermohydraulic assessment (i.e. power plant steam generation)
    - Systems engineering and structural engineering assessments
    - Cooling tower operation, cooling tower plumes, thermal discharge assessment, and consumptive water use
    - Technical patents, nuclear fuel rack design and manufacturing, and nuclear equipment design and manufacturing
    - Reliability engineering and aging plant management assessments, in-service inspection
    - Employee awareness programs, whistleblower protection, and public communications
    - Quality Assurance (QA) & records

Publications

Published Lecture — *The Lessons of the Fukushima Daiichi Nuclear Accident* published in the *International Symposium on the Truth of Fukushima Nuclear Accident and the Myth of Nuclear Safety,* August 30, 2012 University of Tokyo, Iwanami Shoten Publishers, Tokyo, Japan

Published Lecture -- *Crisis Without End: The Medical and Ecological Consequences of the Fukushima Nuclear Catastrophe, from the Symposium at the New York Academy of Medicine, The New Press, 2014, Chapter 12, What Did They Know and When*

Author — *The Echo Chamber: Regulatory Capture and the Fukushima Daiichi Disaster, Lessons from Fukushima,* February 27, 2012, Greenpeace International

Co-author — *Fukushima Daiichi: Truth and The Way Forward,* Shueisha Publishing, February 17, 2012, Tokyo, Japan.

Co-author — *Fairewinds Associates 2009-2010 Summary to JFC, July 26, 2010* State of Vermont, Joint Fiscal Office, (http://www.leg.state.vt.us/jfo/envy.aspx).

Co-author — *Supplemental Report of the Public Oversight Panel Regarding the Comprehensive Reliability Assessment of the Vermont Yankee Nuclear Power Plant July 20, 2010,* to the Vermont State Legislature by the Vermont Yankee Public Oversight Panel.

Co-author — The Second Quarterly Report by Fairewinds Associates, Inc to the Joint Legislative Committee regarding buried pipe and tank issues at Entergy Nuclear Vermont Yankee and Entergy proposed Enexus spinoff. See two reports: *Fairewinds Associates 2nd Quarterly Report to JFC* and *Enexus Review by Fairewinds Associates.*

Author — Fairewinds Associates, Inc *First Quarterly Report to the Joint Legislative Committee*, October 19, 2009.

Co-author — *Report of the Public Oversight Panel Regarding the Comprehensive Reliability Assessment of the Vermont Yankee Nuclear Power Plant*, March 17, 2009, to the Vermont State Legislature by the Vermont Yankee Public Oversight Panel.

Co-author — *Vermont Yankee Comprehensive Vertical Audit – VYCVA – Recommended Methodology to Thoroughly Assess Reliability and Safety Issues at Entergy Nuclear Vermont Yankee, January 30, 2008 Testimony to Finance Committee Vermont Senate.*

Co-author — *Decommissioning Vermont Yankee – Stage 2 Analysis of the Vermont Yankee Decommissioning Fund – The Decommissioning Fund Gap*, December 2007, Fairewinds Associates, Inc. Presented to Vermont State Senators and Legislators.

Co-author — *Decommissioning the Vermont Yankee Nuclear Power Plant: An Analysis of Vermont Yankee's Decommissioning Fund and Its Projected Decommissioning Costs*, November 2007, Fairewinds Associates, Inc.

Co-author — *DOE Decommissioning Handbook, First Edition*, 1981-1982, invited author.

Patents

Energy Absorbing Turbine Missile Shield – U.S. Patent # 4,397,608 – 8/9/1983

Honors

U.S. Atomic Energy Commission Fellowship, 1972

B.S. Degree, Cum Laude, RPI, 1971, 1st in nuclear engineering class

Tau Beta Pi (Engineering Honor Society), RPI, 1969 – 1 of 5 in sophomore class of 700

James J. Kerrigan Scholar 1967–1971

Publicly commended to U.S. Senate by NRC Chairman, Ivan Selin, in May 1993 – "It is true...everything Mr. Gundersen said was absolutely right; he performed quite a service."

Committee Memberships

Member Board of Directors of Fairewinds Energy Education Corp, 501(c)3
Vermont Yankee Public Oversight Panel, appointed 2008 by President Pro-Tem Vermont Senate
National Nuclear Safety Network – Founding Board Member
Three Rivers Community College – Nuclear Academic Advisory Board
Connecticut Low Level Radioactive Waste Advisory Committee – 10 years, founding member
Radiation Safety Committee, NRC Licensee – founding member
ANSI N-198, Solid Radioactive Waste Processing Systems

Expert Witness Testimony and Nuclear Engineering Analysis and Consulting

Nuclear Regulatory Commission Before the Secretary– May 2, 2016, – *Declaration Of Arnold Gundersen To Support The Petition For Leave To Intervene And Request For Hearing By The Blue Ridge Environmental Defense League Regarding Southern Nuclear Operating Company's Vogtle Electric Generating Plant Units 3 And 4 Request For License Amendment And Exemption: Containment Hydrogen Igniter Changes (LAR-15-003)*

Fairewinds Energy Education Report Submitted to NRC in Response to an Advance Notice of Proposed Rulemaking for Regulatory Improvements for Decommissioning Power Reactors: – March 17, 2016, *The Nationwide Failures of Decommissioning Regulation: Decommissioning Trust Funds or Slush Funds?*

Fairewinds Energy Education Report Submitted to NRC for Public Comment to Staff Regarding the Decommissioning of the Vermont Yankee Atomic Reactor – March 23, 2015, *Vermont Yankee's Decommissioning as an Example of Nationwide Failures of Decommissioning Regulation*

NRC Before the Atomic Safety and Licensing Board (ASLB) – December 1, 2014, *Gundersen Declaration Palisades Embrittlement,* Docket No. 50-255, Entergy, Palisades, *Petition to Intervene and for A Public Adjudication Hearing of Entergy License Amendment Request for Authorization to Implement 10 CFR §50.61a, Alternate Fracture Toughness Requirements For Protection Against Pressurized Thermal Shock Events*.

NRC Before the Commission – November 6, 2014, *Second Supplemental Declaration of Arnold Gundersen*, In the Matter of Florida Power & Light Co., Docket No. 50-389, St. Lucie Plant, Unit 2.

NRC Atomic Safety and Licensing Board (ASLB) – October 10, 2014 – *Diablo Canyon Nuclear Power Plant, Units 1 and 2 – Gundersen Affidavit Supporting Friends of the Earth's Petition to Intervene: In the matter of Pacific Gas & Electric Company Docket No. 50-275-LR & Docket No. 50-323-LR, License Renewal Application*.

NRC Hearing Request – March 10, 2014 – *Declaration of Arnold Gundersen Supporting Hearing Request* – retained by Southern Alliance for Clean Energy (SACE) in the matter of Florida Power & Light Co., Docket No. 50-389, St. Lucie Plant, Unit 2

NRC ASLB Proceeding Fermi Unit 3 52-033-COL – October 30, 2013 – Retained by Don't Waste Michigan, Beyond Nuclear et al, Oral Expert Witness Testimony regarding Contention 15: Quality Assurance.

State of Utah Seventh District Court of Emory County – September 25, 2013 – Retained by HEAL Utah et al as an expert witness testifying on cooling tower consumptive use of water for a proposed nuclear power plant owned by Blue Castle Holdings and located on the Green River. Defendants were Kane County Water Conservancy District.

Canadian Nuclear Safety Commission – May 29-30, 2013 – Retained by Durham Nuclear Awareness to present expert witness testimony in hearings regarding the proposed life extension for the Pickering Nuclear Station owned Ontario Power Generation.

Nuclear Regulatory Commission – May 30, 2013 – Expert witness report Before the Secretary NRC *in the Matter of Detroit Edison Nuclear Power Station: Rebuttal Testimony of Arnold Gundersen Supporting of Intervenors' Contention 15: DTE COLA Lacks Statutorily Required Cohesive QA Program.* Retained by Don't Waste Michigan, Beyond Nuclear et al.

Nuclear Regulatory Commission – May 20, 2013 – Expert witness report Before the Secretary NRC *in the Matter of Davis Besse Nuclear Power Station: Expert Witness Report of Arnold Gundersen to Support the Petition for Leave to Intervene and Request for Hearing by Beyond Nuclear, Citizens Environment Alliance Southwest Ontario Canada, Don't Waste Michigan, and The Sierra Club.* Retained by Beyond Nuclear, Citizens Environment Alliance Southwest Ontario Canada, Don't Waste Michigan, and The Sierra Club.

Nuclear Regulatory Commission – May 6, 2013 – Expert witness report Before the Secretary NRC: *Expert Witness Report of Arnold Gundersen to Support the Petition for Leave to Intervene and Request for Hearing by The Blue Ridge Environmental Defense League, Bellefonte Efficiency and Sustainability Team, And Mothers Against Tennessee River Radiation.* Retained by BREDL et al.

Nuclear Regulatory Commission – April 30, 2013 – Expert witness report to Atomic Safety and Licensing Board: *Testimony of Arnold Gundersen Supporting of Intervenors Contention 15: DTE Cola Lacks Statutorily Required Cohesive QA Program.* Retained by Don't Waste Michigan, Beyond Nuclear et al.

Canadian Nuclear Safety Commission (CNSC) – April 29, 2013 – Expert witness report to Canadian Nuclear Safety Commission (CNSC): *Analysis of The Relicensing Application for Pickering Nuclear Generating Station*. Retained by Durham Nuclear Awareness.

Nuclear Regulatory Commission – January 16, 2013 – Expert witness presentation to NRC Petition Review Board: *2.206 Presentation San Onofre Units 2 and 3 Replacement Steam Generators Meeting with Petitioner Friends of the Earth, Requesting Enforcement Action Against Southern California Edison Under 10 CFR 2.206*

Expert Witness Report for Friends Of The Earth – July 11, 2012 – *San Onofre's Steam Generators: Significantly Worse Than All Others Nationwide,* Fairewinds Associates, Inc

Expert Witness Report for Friends of the Earth – May 15, 2012 – *San Onofre Steam Generator Failures Could Have Been Prevented*, Fairewinds Associates, Inc

Expert Witness Report for Friends of the Earth – April 10, 2012 – *San Onofre Cascading Steam Generator Failures Created by Edison: Imprudent Design and Fabrication Decisions Caused Leaks,* Fairewinds Associates, Inc

Expert Witness Report for Friends of the Earth – March 27, 2012 – *Steam Generator Failures at San Onofre: The Need for A Thorough Root Cause Analysis Requires No Early Restart,* Fairewinds Associates, Inc

Expert Witness Report for Greenpeace – February 27, 2012 – *Lessons from Fukushima: The Echo Chamber Effect,* Fairewinds Associates, Inc

Nuclear Regulatory Commission – December 21, 2011 – Expert witness report to Atomic Safety and Licensing Board: *Prefiled Direct Testimony of Arnold Gundersen Regarding Consolidated Contention RK-EC-3/CW-EC-1 (Spent Fuel Pool Leaks)*

New York State Department of Environmental Conservation – November 15-16, 2011 – Expert witness report for Riverkeeper: hearing testimony regarding license extension application for Indian Point Units 2 and 3 – contention: tritium in the groundwater.

Nuclear Regulatory Commission – November 10, 2011 – Expert witness report entitled: *Fukushima and the Westinghouse-Toshiba AP1000, A Report for the AP1000 Oversight Group by Fairewinds Associates, Inc,* and Video. Submitted to NRC by the AP1000 Oversight Group.

Nuclear Regulatory Commission – October 7, 2011 – *Testimony to the NRC Petition Review Board Re: Mark 1 Boiling Water Reactors*, Petition for NRC to shut down all BWR Mark 1 nuclear power plants due to problems in containment integrity in the Mark 1 design.

New York State Department of Environmental Conservation – October 4, 2011 – *Prefiled Rebuttal Testimony of Arnold Gundersen On Behalf of Petitioners Riverkeeper, Inc., Scenic Hudson, Inc., And Natural Resources Defense Council, Inc. To The Direct Testimony of Matthew J. Barvenik (Senior Principal GZA Geoenvironmental, Inc.) Regarding Radiological Materials*

Southern Alliance for Clean Energy (SACE) submission to TVA Board of Directors – August 3, 2011– Expert witness report entitled: *The Risks of Reviving TVA's Bellefonte Project,* and Video prepared for the Southern Alliance for Clean Energy (SACE).

New York State Department of Environmental Conservation, July 22, 2011 – Prefiled Direct Testimony of Arnold Gundersen On Behalf of Petitioners Riverkeeper, Inc., Scenic Hudson, Inc., And Natural Resources Defense Council, Inc. Regarding Radiological Materials

Nuclear Regulatory Commission – May 10, 2011 – *Comment to the proposed rule on the AP1000 Design Certification Amendment Docket ID NRC-2010-0131 As noticed in the Federal Register on February 24, 2011* Retained by Friends of the Earth as Expert Witness.

Nuclear Regulatory Commission – May 10, 2011 – *Comment to the proposed rule on the AP1000 Design Certification Amendment Docket ID NRC-2010-0131 As noticed in the Federal Register on February 24, 2011* Retained by Friends of the Earth as Expert Witness.

NRC Advisory Committee on Reactor Safeguards (ACRS) – May 26, 2011 – Lessons learned from Fukushima and Containment Integrity on the AP1000.

Vermont Energy Cooperative (VEC) – April 26, 2011 – Presentation to the Vermont Energy Cooperative Board of Directors, *Vermont Yankee – Is It Reliable for 20 more years?*

Vermont State Nuclear Advisory Panel (VSNAP) – February 22, 2011 – Testimony and presentation entitled the *Vermont Yankee Public Oversight Panel Supplemental Report* regarding management issues at the Vermont Yankee Nuclear Power Plant to the reconvened Vermont State Nuclear Advisory Panel.

Vermont State Legislature Senate Committee On Natural Resources and Energy – February 8, 2011. Testimony: *Vermont Yankee Leaks and Implications*. (http://www.leg.state.vt.us/jfo/envy.aspx)

Vermont State Legislature – January 26, 2011 – House Committee On Natural Resources And Energy, and Senate Committee On Natural Resources And Energy – Testimony regarding Fairewinds Associates, Inc's report: *Decommissioning the Vermont Yankee Nuclear Power Plant and Storing Its Radioactive Waste* (http://www.leg.state.vt.us/jfo/envy.aspx). Additional testimony was also given regarding the newest radioactive isotopic leak at the Vermont Yankee nuclear power plant.

Vermont State Legislature Joint Fiscal Committee Legislative Consultant Regarding Entergy Nuclear Vermont Yankee – *Decommissioning the Vermont Yankee Nuclear Power Plant and Storing Its Radioactive Waste* January 2011. (http://www.leg.state.vt.us/jfo/envy.aspx).

U.S. Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards (NRC-ACRS) AP1000 Sub-Committee – *Nuclear Containment Failures: Ramifications for the AP1000 Containment Design,* Supplemental Report submitted December 21, 2010. (http://fairewinds.com/reports)

Vermont State Legislature Joint Fiscal Committee Legislative Consultant Regarding Entergy Nuclear Vermont Yankee – *Reliability Oversight Entergy Nuclear Vermont Yankee, December 6, 2010.* Discussion regarding the leaks at Vermont Yankee and the ongoing monitoring of those leaks and ENVY's progress addressing the 90-items identified in Act 189 that require remediation. (http://www.leg.state.vt.us/jfo/envy.aspx).

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – *Declaration of Arnold Gundersen Supporting Blue Ridge Environmental Defense League's Contention Regarding Consumptive Water Use at Dominion Power's Newly Proposed North Anna Unit 3 Pressurized Water Reactor* in the matter of Dominion Virginia Power North Anna Power Station Unit 3 Docket No. 52-017 Combined License Application ASLBP#08-863-01-COL, October 2, 2010.

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – *Declaration of Arnold Gundersen Supporting Blue Ridge Environmental Defense League's New Contention Regarding AP1000 Containment Integrity On the Vogtle Nuclear Power Plant Units 3 And 4* in the matter of the Southern Nuclear Operating Company Vogtle Electric Generating Plant, Units 3&4 Combined License Application, Docket Nos. 52-025-COL and 52-026-COL and ASLB No. 09-873-01-COL-BD01, August 13, 2010.

Vermont State Legislature Joint Fiscal Committee Legislative Consultant Regarding Entergy Nuclear Vermont Yankee – July 26, 2010 – Summation for 2009 to 2010 Legislative Year for the Joint Fiscal Committee Reliability Oversight Entergy Nuclear Vermont Yankee (ENVY) Fairewinds Associates 2009-2010. This summary includes an assessment of ENVY's progress (as of July 1, 2010) toward meeting the milestones outlined by the Act 189 Vermont Yankee Public Oversight Panel in its March 2009 report to the Legislature, the new milestones that have been added since the incident with the tritium leak and buried underground pipes, and the new reliability challenges facing ENVY, Entergy, and the State of Vermont. (http://www.leg.state.vt.us/jfo/envy.aspx)

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – *Declaration of Arnold Gundersen Supporting Blue Ridge Environmental Defense League's Contentions* in the matter of Dominion Virginia Power North Anna Station Unit 3 Combined License Application, Docket No. 52-017, ASLBP#08-863-01-COL, July 23, 2010.

Florida Public Service Commission (FPSC)
Licensing and construction delays due to problems with the newly designed Westinghouse AP1000 reactors in *Direct Testimony in Re: Nuclear Plant Cost Recovery Clause by The Southern Alliance for Clean Energy (SACE)*, FPSC Docket No. 100009-EI, July 8, 2010.

U.S. Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards (NRC-ACRS) AP1000 Sub-Committee – Presentation to ACRS regarding design flaw in AP1000 Containment – June 25, 2010 Power Point Presentation: http://fairewinds.com/content/ap1000-nuclear-design-flaw-addressed-to-nrc-acrs.

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – *Second Declaration of Arnold Gundersen Supporting Supplemental Petition of Intervenors Contention 15: DTE COLA Lacks Statutorily Required Cohesive QA Program* – June 8, 2010.

NRC Chairman Gregory Jaczko, ACRS, Secretary of Energy Chu, and the White House Office of Management and Budget – *AP1000 Containment Leakage Report Fairewinds Associates - Gundersen, Hausler, 4-21-2010.* This report, commissioned by the AP1000 Oversight Group, analyzes a potential flaw in the containment of the AP1000 reactor design.

Vermont State Legislature House Committee On Natural Resources and Energy – April 5, 2010 – Testified to the House Committee On Natural Resources and Energy – regarding discrepancies in Entergy's TLG Services decommissioning analysis. See *Fairewinds Cost Comparison TLG Decommissioning* (http://www.leg.state.vt.us/jfo/envy.aspx).

Vermont State Legislature Joint Fiscal Committee Legislative Consultant Regarding Entergy Nuclear Vermont Yankee – February 22, 2010 – The Second Quarterly Report by Fairewinds Associates, Inc to the Joint Legislative Committee regarding buried pipe and tank issues at Entergy Nuclear Vermont Yankee and Entergy proposed Enexus spinoff. See two reports: *Fairewinds Associates 2nd Quarterly Report to JFC* and *Enexus Review by Fairewinds Associates*. (http://www.leg.state.vt.us/jfo/envy.aspx).

Vermont State Legislature Senate Natural Resources – February 16, 2010 – Testified to Senate Natural Resources Committee regarding causes and severity of tritium leak in unreported buried underground pipes, status of Enexus spinoff proposal, and health effects of tritium.

Vermont State Legislature Senate Natural Resources – February 10, 2010 – Testified to Senate Natural Resources Committee regarding causes and severity of tritium leak in unreported buried underground pipes. http://www.youtube.com/watch?v=36HJiBrJSxE

Vermont State Legislature Senate Finance – February 10, 2010 – Testified to Senate Finance Committee regarding *A Chronicle of Issues Regarding Buried Tanks and Underground Piping at VT Yankee.* (http://www.leg.state.vt.us/jfo/envy.aspx).

Vermont State Legislature House Committee On Natural Resources and Energy – January 27, 2010 – *A Chronicle of Issues Regarding Buried Tanks and Underground Piping at VT Yankee*. (http://www.leg.state.vt.us/jfo/envy.aspx).

Submittal to Susquehanna River Basin Commission, by Eric Epstein – January 5, 2010 – *Expert Witness Report of Arnold Gundersen Regarding Consumptive Water Use of the Susquehanna River by The Proposed PPL Bell Bend Nuclear Power Plant* in the Matter of RE: Bell Bend Nuclear Power Plant Application for Groundwater Withdrawal Application for Consumptive Use BNP-2009-073.

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – *Declaration of Arnold Gundersen Supporting Supplemental Petition of Intervenors Contention 15: Detroit Edison COLA Lacks Statutorily Required Cohesive QA Program*, December 8, 2009.

U.S. NRC Region III Allegation Filed by Missouri Coalition for the Environment – Expert Witness Report entitled: *Comments on the Callaway Special Inspection by NRC Regarding the May 25, 2009 Failure of its Auxiliary Feedwater System,* November 9, 2009.

Vermont State Legislature Joint Fiscal Committee Legislative Consultant Regarding Entergy Nuclear Vermont Yankee – Oral testimony given to the Vermont State Legislature Joint Fiscal Committee October 28, 2009. See report: *Quarterly Status Report - ENVY Reliability Oversight for JFO* (http://www.leg.state.vt.us/jfo/envy.aspx).

Vermont State Legislature Joint Fiscal Committee Legislative Consultant Regarding Entergy Nuclear Vermont Yankee − The First Quarterly Report by Fairewinds Associates, Inc to the Joint Legislative Committee regarding reliability issues at Entergy Nuclear Vermont Yankee, issued October 19, 2009. See report: *Quarterly Status Report - ENVY Reliability Oversight for JFO* (http://www.leg.state.vt.us/jfo/envy.aspx).

Florida Public Service Commission (FPSC) − Gave direct oral testimony to the FPSC in hearings in Tallahassee, FL, September 8 and 10, 2009 in support of Southern Alliance for Clean Energy (SACE) contention of anticipated licensing and construction delays in newly designed Westinghouse AP 1000 reactors proposed by Progress Energy Florida and Florida Power and Light (FPL).

Florida Public Service Commission (FPSC) – NRC announced delays confirming my original testimony to FPSC detailed below. My supplemental testimony alerted FPSC to NRC confirmation of my original testimony regarding licensing and construction delays due to problems with the newly designed Westinghouse AP 1000 reactors in *Supplemental Testimony in Re: Nuclear Plant Cost Recovery Clause by The Southern Alliance for Clean Energy*, FPSC Docket No. 090009-EI, August 12, 2009.

Florida Public Service Commission (FPSC) − Licensing and construction delays due to problems with the newly designed Westinghouse AP 1000 reactors in *Direct Testimony in Re: Nuclear Plant Cost Recovery Clause by The Southern Alliance for Clean Energy (SACE)*, FPSC Docket No. 090009-EI, July 15, 2009.

Vermont State Legislature Joint Fiscal Committee Expert Witness Oversight Role for Entergy Nuclear Vermont Yankee (ENVY) – Appointment from July 2009 to May 2010. Contracted by the Joint Fiscal Committee of the Vermont State Legislature as an expert witness to oversee the compliance of ENVY to reliability issues uncovered during the 2009 legislative session by the Vermont Yankee Public Oversight Panel of which I was appointed a member along with former NRC Commissioner Peter Bradford for one year from July 2008 to 2009. At the time, Entergy Nuclear Vermont Yankee (ENVY) was under review by Vermont State Legislature to determine if it should receive a Certificate for Public Good (CPG) to extend its operational license for another 20-years. Vermont was the only state in the country that had legislatively created the CPG authorization for a nuclear power plant. Act 160 was passed to ascertain ENVY's ability to run reliably for an additional 20 years.

U.S. Nuclear Regulatory Commission – Expert Witness Declaration regarding Combined Operating License Application (COLA) at North Anna Unit 3 *Declaration of Arnold Gundersen Supporting Blue Ridge Environmental Defense League's Contentions* (June 26, 2009).

U.S. Nuclear Regulatory Commission – Expert Witness Declaration regarding Through-wall Penetration of Containment Liner and Inspection Techniques of the Containment Liner at Beaver Valley Unit 1 Nuclear Power Plant *Declaration of Arnold Gundersen Supporting Citizen Power's Petition* (May 25, 2009).

U.S. Nuclear Regulatory Commission – Expert Witness Declaration regarding Quality Assurance and Configuration Management at Bellefonte Nuclear Plant *Declaration of Arnold Gundersen Supporting Blue Ridge Environmental Defense League's Contentions in their Petition for Intervention and Request for Hearing*, May 6, 2009.

Pennsylvania Statehouse – Expert Witness Analysis presented in formal presentation at the Pennsylvania Statehouse, March 26, 2009 regarding actual releases from Three Mile Island Nuclear Accident. Presentation may be found at: http://www.tmia.com/march26
Vermont Legislative Testimony and Formal Report for 2009 Legislative Session – As a member of the Vermont Yankee Public Oversight Panel, I spent almost eight months examining the Vermont Yankee Nuclear Power Plant and the legislatively ordered Comprehensive Vertical Audit. Panel submitted Act 189 Public Oversight Panel Report March 17, 2009 and oral testimony to a joint hearing of the Senate Finance and House Committee On Natural Resources and Energy March 19, 2009. http://www.leg.state.vt.us/JFO/Vermont%20Yankee.htm

Finestone v Florida Power & Light Company (FPL) (11/2003 to 12/2008) Federal Court – Plaintiffs' Expert Witness in United States District Court for the Southern District of Florida. Retained by Plaintiffs' Attorney Nancy LaVista, from Lytal, Reiter, Fountain, Clark, Williams, West Palm Beach, FL. Case# 06-11132-E. This case involved two plaintiffs in cancer cluster of 42 families alleging that illegal radiation releases from nearby nuclear power plant caused children's cancers. Production request, discovery review, preparation of deposition questions and attendance at Defendant's experts for deposition, preparation of expert witness testimony, preparation for Daubert Hearings, ongoing technical oversight, source term reconstruction and appeal to Circuit Court.

U.S. Nuclear Regulatory Commission Advisory Committee Reactor Safeguards (NRC-ACRS) – Expert Witness providing oral testimony regarding Millstone Point Unit 3 (MP3) Containment issues in hearings regarding the Application to Uprate Power at MP3 by Dominion Nuclear, Washington, and DC. (July 8-9, 2008).

Appointed by President Pro-Tem of Vermont Senate Shumlin (now Vermont Governor Shumlin) to Legislatively Authorized Nuclear Reliability Public Oversight Panel – To oversee Comprehensive Vertical Audit of Entergy Nuclear Vermont Yankee (Act 189) and testify to State Legislature during 2009 session regarding operational reliability of ENVY in relation to its 20-year license extension application. (July 2, 2008 to present).

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – Expert Witness providing testimony regarding *Pilgrim Watch's Petition for Contention 1 Underground Pipes* (April 10, 2008).

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – Expert Witness supporting *Connecticut Coalition Against Millstone in Its Petition for Leave to Intervene, Request for Hearing, And Contentions Against Dominion Nuclear Connecticut Inc.'s Millstone Power Station Unit 3 License Amendment Request for Stretch Power Uprate* (March 15, 2008).

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – Expert Witness supporting *Pilgrim Watch's Petition for Contention 1*: *specific to issues regarding the integrity of Pilgrim Nuclear Power Station's underground pipes and the ability of Pilgrim's Aging Management Program to determine their integrity*. (January 26, 2008).

Vermont State House – 2008 Legislative Session –

- House Committee on Natural Resources and Energy – Comprehensive Vertical Audit: *Why NRC Recommends a Vertical Audit for Aging Plants Like Entergy Nuclear Vermont Yankee (ENVY)*
- House Committee on Commerce – Decommissioning Testimony

Vermont State Senate – 2008 Legislative Session –

- Senate Finance – testimony regarding Entergy Nuclear Vermont Yankee Decommissioning Fund
- Senate Finance – testimony on the necessity for a Comprehensive Vertical Audit (CVA) of Entergy Nuclear Vermont Yankee
- House Committee on Natural Resources and Energy – testimony regarding the placement of high-level nuclear fuel on the banks of the Connecticut River in Vernon, VT

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – MOX Limited Appearance Statement to Judges Michael C. Farrar (Chairman), Lawrence G. McDade, and Nicholas G. Trikouros for the "Petitioners": Nuclear Watch South, the Blue Ridge Environmental Defense League, and Nuclear Information & Resource Service in support of *Contention 2: Accidental Release of Radionuclides, requesting a hearing concerning faulty accident consequence assessments made for the MOX plutonium fuel factory proposed for the Savannah River Site*. (September 14, 2007).

Appeal to the Vermont Supreme Court (March 2006 to 2007) – Expert Witness Testimony in support of *New England Coalition's Appeal to the Vermont Supreme Court Concerning: Degraded Reliability at Entergy Nuclear Vermont Yankee as a Result of the Power Uprate*. New England Coalition represented by Attorney Ron Shems of Burlington, VT.

State of Vermont Environmental Court (Docket 89-4-06-vtec 2007) – Expert witness retained by New England Coalition to review Entergy and Vermont Yankee's analysis of alternative methods to reduce the heat discharged by Vermont Yankee into the Connecticut River. Provided Vermont's Environmental Court with analysis of alternative methods systematically applied throughout the nuclear industry to reduce the heat discharged by nuclear power plants into nearby bodies of water and avoid consumptive water use. This report included a review of the condenser and cooling tower modifications.

U.S. Senator Bernie Sanders and Congressman Peter Welch (2007) – Briefed Senator Sanders, Congressman Welch and their staff members regarding technical and engineering issues, reliability and aging management concerns, regulatory compliance, waste storage, and nuclear power reactor safety issues confronting the U.S. nuclear energy industry.

State of Vermont Legislative Testimony to Senate Finance Committee (2006) – Testimony to the Senate Finance Committee regarding Vermont Yankee decommissioning costs, reliability issues, design life of the plant, and emergency planning issues.

U.S. Nuclear Regulatory Commission Atomic Safety and Licensing Board (NRC-ASLB) – Expert witness retained by New England Coalition to provide Atomic Safety and Licensing Board with an independent analysis of the integrity of the Vermont Yankee Nuclear Power Plant condenser (2006).

U.S. Senators Jeffords and Leahy (2003 to 2005) – Provided the Senators and their staffs with periodic overview regarding technical, reliability, compliance, and safety issues at Entergy Nuclear Vermont Yankee (ENVY).

10CFR 2.206 filed with the Nuclear Regulatory Commission (July 2004) – Filed 10CFR 2.206 petition with NRC requesting confirmation of Vermont Yankee's compliance with General Design Criteria.

State of Vermont Public Service Board (April 2003 to May 2004) – Expert witness retained by New England Coalition to testify to the Public Service Board on the reliability, safety, technical, and financial ramifications of a proposed increase in power (called an uprate) to 120% at Entergy's 31-year-old Vermont Yankee Nuclear Power Plant.

International Nuclear Safety Testimony – Ten Days advising the President of the Czech Republic (Vaclav Havel) and the Czech Parliament on their energy policy for the 21st century.

Nuclear Regulatory Commission (NRC) Inspector General (IG) – Assisted the NRC Inspector General in investigating illegal gratuities paid to NRC Officials by Nuclear Energy Services (NES) Corporate Officers. In a second investigation, assisted the Inspector General in showing that material false statements (lies) by NES corporate president caused the NRC to overlook important violations by this licensee.

State of Connecticut Legislature – Assisted in the creation of State of Connecticut Whistleblower Protection legal statutes.

Federal Congressional Testimony –

- Publicly recognized by NRC Chairman, Ivan Selin, in May 1993 in his comments to U.S. Senate, "It is true...everything Mr. Gundersen said was absolutely right; he performed quite a service."
- Commended by U.S. Senator John Glenn, Chair NRC Oversight Committee for public – for testimony to NRC Oversight Committee

PennCentral Litigation – Evaluated NRC license violations and material false statements made by management of this nuclear engineering and materials licensee.

Three Mile Island Litigation – Evaluated unmonitored releases to the environment after accident, including containment breach, letdown system and blowout. Proved releases were 15 times higher than government estimate and subsequent government report.

Western Atlas Litigation – Evaluated neutron exposure to employees and license violations at this nuclear materials licensee.

Commonwealth Edison – In depth review and analysis for Commonwealth Edison to analyze the efficiency and effectiveness of all Commonwealth Edison engineering organizations, which support the operation of all of its nuclear power plants.

Peach Bottom Reactor Litigation – Evaluated extended 28-month outage caused by management breakdown and deteriorating condition of plant.

Presentations & Media

- *Arnie Gundersen Appears on Project Censored with Dan Simon, Ted Rall, and Maggie Gundersen,* November 27, 2016
- *Arnie Gundersen Appears on Solartopia's Green Power and Wellness Hour,* November 16, 2016
- *Nuclear Power Is Not "Green Energy": It Is a Fount of Atomic Waste,* Published in Truthout, November 14, 2016
- *Powerstruggle Sneak Preview Panel Discussion,* Northampton, MA (October 23, 2016) Brattleboro, VT (Nov 3, 2016), organized by Turning Tide Productions
- *Is Solar Power in Nuclear Disaster Exclusion Zones Advisable?,* Published in The Bulletin of the Atomic Scientists, September 15, 2016
- *CO2 Smokescreen Presentation,* Montreal, Canada, invited speaker at the World Social Forum at the University of Quebec at Montreal (August 8, 2016) & McGill University, (August 10, 2016)
- *American nuclear expert warns: "There is a possibility that now in Fukushima recontamination is occurring.",* June 14, 2016
- *Seacoast Anti-Pollution League Annual Meeting,* Seabrook, NH, organized by the Seacoast Anti-Pollution League, open to the public, May 16, 2016
- *Arnie Gundersen Appears on Project Censored with Medea Benjamin,* March 30, 2016
- *Pilgrim Coalition Decommissioning Forum*, Plymouth, MA, organized by the Pilgrim Coalition, March 23, 2016
- *Osaka Global Environment Forum 2016*, in Osaka City, Japan, organized by Choetsu Kiko Association of Osaka and Friends of the Earth, February 27, 2016
- *Peace Forum Presentation*, in Kobe City, Japan, organized by YMCA, UNICEF, and Kobe Cooperative, February 22, 2016
- *Nuclear and Human Beings after Fukushima Event*, in Hiroshima City, Japan organized by Hiroshima YMCA, and Hiroshima Cooperative HANWA (Hiroshima Alliance for Nuclear Weapons Abolition), February 20, 2016
- *Peace Event at Jimmy Carter Civic Center*, in Konu-town Miyoshi, Hiroshima, Japan organized by Peace Platform, February 17, 2016

- *Middlebury College Student Global Affairs Conference: Power and Protest*, Middlebury, VT at Middlebury College, invited speaker for a student organized event, January 22, 2016
- *Ready for the Big One? Diablo Canyon Earthquake Vulnerability*, San Luis Obispo, invited guest of the San Luis Obispo Mothers for Peace, December 2, 2015
- *Expect the Unexpected: Nuclear Power's Unlearned Lessons*, California Polytechnic Institute, December 1, 2015
- *World in Danger: From Fukushima to California*, University of California at Berkeley, in conversation with Joanna Macy, November 22, 2015
- *World in Danger: The Fukushima - California Connection*, Point Reyes Station, in conversation with Mary Beth Brangan, November 21, 2015
- *World in Danger: Fukushima,* Sonoma State University, in conversation with Majia Nadesan, November 18, 2015
- *Fukushima's Impact at Five Years,* World Uranium Symposium 2015: Fukushima Workshop, April 2015
- *Did Tesla Just Kill Nuclear Power?* May 1, 2015, Article written by journalist Jeff McMahon for Forbes Magazine that captures the excitement and buzz surrounding Tesla's big announcement and Arnie's auspicious speech
- *Building New Nukes Would Make Global Warming Worse* April 30, 2015, Speech presented at Northwestern University, Chicago, IL
- *Fairewinds' Report: Vermont Yankee's Decommissioning As An Example of Nationwide Failures of Decommissioning Regulation presented to the Senate Committee for Natural Resources and Energy* April 22, 2015, Presentation at the Vermont Statehouse, Montpelier, VT
- *An Economic Analysis of the Cost of Nuclear Power* April 14, 2015, Presentation at the World Uranium Symposium, Quebec City, Quebec, Canada, Keynote Speaker
- *Commemoration of Meltdown at Fukushima Daiichi: 4-Years Later* March 11, 2015, Presentation to the House of Commons in London, England
- *Should Nuclear Energy Be Expanded to Help Create a More Sustainable Future?* November 20, 2014, Invited guest speaker in Debate at Hofstra University
- *Radiation Knows No Borders* August 2, 2014, Invited speaker at The Wave Conference, Life Chiropractic West, San Francisco, CA
- *Thirty-five Years and Five Meltdowns Later: The Real Lessons of Three Mile Island* March 28, 2014, Three Mile Island at 35 (TMI@35) Symposium at Penn State, Harrisburg, PA, Keynote Speaker
- *The Nuclear Renaissance? Is It Too Big To Fail?* November 20, 2013, University North Carolina, Chapel Hill, NC.
- *Speaking Truth to Power* October 22, 2013 – Clarkson University, Potsdam, NY
- *The United States At A Crossroads: Two Futures* October 17 2013, Global Forum, Waitsfield, Vermont
- *A Road Less Taken*: *Energy Choices for the Future* – October 16, 2013, Johnson State College, Johnson, Vermont.
- *Fukushima: Ongoing Lessons for Boston* – October 9, 2013 – Boston, Massachusetts State House. Speakers were Arnie Gundersen, Former Japanese Prime Minister Naoto Kan, Former NRC Chair Gregory Jaczko, Former NRC Commissioner Peter Bradford, and Massachusetts State Senator Dan Wolf.

- *Fukushima: Ongoing Lessons for New York* – October 8, 2013 – New York City 82nd Street YMCA. Speakers were Arnie Gundersen, Riverkeeper President Paul Galley, Former Japanese Prime Minister Naoto Kan, Former NRC Chair Gregory Jaczko, Former NRC Commissioner Peter Bradford, and Ralph Nader.
- *Fukushima: Ongoing Lessons for California* – June 4, 2013 – New York City 82nd Street YMCA. Speakers were Arnie Gundersen, Riverkeeper President Paul Galley, Former Japanese Prime Minister Naoto Kan, Former NRC Chair Gregory Jaczko, Former NRC Commissioner Peter Bradford, and Friends of the Earth Nuclear Campaigner Kendra Ulrich.
- *What Did They Know And When? Fukushima Daiichi Before and After the Meltdowns,* Symposium: The Medical and Ecological Consequences of the Fukushima Nuclear Accident, The New York Academy of Medicine, New York City, NY, March 11, 2013
- *A Mountain of Waste 70 Years High,* Presentation: Old *and New Reactors*, University of Chicago, December 1, 2012
- Congressional Briefing September 20, 2012; invited by Representative Dennis Kucinich
- Presentations in Japan August/September 2012: Presentation at University of Tokyo (August 30, 2012), Presentation at Japanese Diet Building (members of the Japanese Legislature - August 31, 2012), Presentation to citizen groups in Niigata (September 1, 2012), Presentations to citizen groups in Kyoto (September 4, 2012), Presentation to Japanese Bar Association (September 2, 2012), and Presentation at the Tokyo Olympic Center (September 6, 2012)
- Multi-media Opera: *Curtain of Smoke,* by Filmmaker Karl Hoffman, Composer Andrea Molino, and Dramatist Guido Barbieri, Rome, Italy (2012-5-21,22)
- Curtain of Smoke Symposium (2012-5-21), with Dr. Sherri Ebadi 2004 Nobel Laureate
- The Italian National Press Club Rome (2012-5-21) with Dr. Sherri Ebadi 2004 Nobel Laureate: the relationship between nuclear power and nuclear weapons,
- Radio 3 Rome (2012-5-21) Discussion of Three Mile Island and the triple meltdown at Fukushima Daiichi (Japan),
- Sierra Club Panel Discussions (2012-5-5): Consequences of Fukushima Daiichi with Paul Gunter and Waste Disposal with Mary Olson,
- Physicians for Social Responsibility Seattle (2012-3-17),
- Fukushima Daiichi Forum with Chiho Kaneko, Brattleboro, VT (2012-3-11),
- Physicians for Global Responsibility Vancouver (2012-3-11) Skype Video Lecture,
- University of Vermont (2 – 2011),
- Boston Nuclear Forum, Boston Library (6/16/11),
- Duxbury Emergency Management (6/15/11),
- Vermont State Nuclear Advisory Panel (VSNAP),
- New Jersey Environmental Federation (5/14/11),
- Press Conference for Physicians for Social Responsibility (5/19/11),
- St. Johnsbury Academy – Nuclear Power 101.

Educational videos on nuclear safety, reliability and engineering particularly Fukushima issues. Videos may be viewed @ fairewinds.org (501c3 non-profit)

Expert commentary (many more unnamed): CNN (8), The John King Show (16), BBC, CBC, Russia Today, Democracy Now, Al Jazeera America, KPBS (Radio & TV) VPR, WPTZ, WCAX, WBAI, CCTV, NECN, Pacifica Radio, CBC (radio & TV) (4), Rachel Maddow Show, *Washington Post*, *New York Times*, *Tampa Bay Times, The Guardian*, *Bloomberg*

(print & TV), *Reuters*, *Associated Press*, *The Global Post*, *Miami Herald*, *Orange County Times, LA Times, Al Jazeera* (print)*, The Tennessean*, The Chris Martinson Show, *Mainichi News*, TBS Japan, *Gendai Magazine*, NHK television, *Scientific American*. *Huffington Post* (Paris) named Fairewinds.com the best go to site for information about the Fukushima Daiichi accident (5/9/11).

Special Remediation Expertise:

Director of Engineering, Vice President of Site Engineering, and the Senior Vice President of Engineering at Nuclear Energy Services (NES) Division of Penn Central Corporation (PCC)

- NES was a nuclear licensee that specialized in dismantlement and remediation of nuclear facilities and nuclear sites. Member of the radiation safety committee for this licensee.
- Department of Energy chose NES to write *DOE Decommissioning Handbook* because NES had a unique breadth and depth of nuclear engineers and nuclear physicists on staff.
- Personally wrote the "Small Bore Piping" chapter of the DOE's first edition Decommissioning Handbook, personnel on my staff authored other sections, and I reviewed the entire Decommissioning Handbook.
- Served on the Connecticut Low Level Radioactive Waste Advisory Committee for 10 years from its inception.
- Managed groups performing analyses on dozens of dismantlement sites to thoroughly remove radioactive material from nuclear plants and their surrounding environment.
- Managed groups assisting in decommissioning the Shippingport nuclear power reactor. Shippingport was the first large nuclear power plant ever decommissioned. The decommissioning of Shippingport included remediation of the site after decommissioning.
- Managed groups conducting site characterizations (preliminary radiation surveys prior to commencement of removal of radiation) at the radioactively contaminated West Valley site in upstate New York.
- Personnel reporting to me assessed dismantlement of the Princeton Avenue Plutonium Lab in New Brunswick, NJ. The lab's dismantlement assessment was stopped when we uncovered extremely toxic and carcinogenic underground radioactive contamination.
- Personnel reporting to me worked on decontaminating radioactive thorium at the Cleveland Avenue nuclear licensee in Ohio. The thorium had been used as an alloy in turbine blades. During that project, previously undetected extremely toxic and carcinogenic radioactive contamination was discovered below ground after an aboveground gamma survey had purported that no residual radiation remained on site.

Teaching and Academic Administration Experience

University of Vermont Community Research Fellow, appointed January 2016
Rensselaer Polytechnic Institute (RPI) – Advanced Nuclear Reactor Physics Lab
Community College of Vermont – Mathematics Professor – 2007 through Spring 2013

Nuclear Engineering 1970 to Present

Expert witness testimony in nuclear litigation and administrative hearings in federal, international, and state court and to Nuclear Regulatory Commission, including but not limited to: Three Mile Island, US Federal Court, US NRC, NRC ASLB, ACRS, and Petition Review Board, Canadian Nuclear Safety Commission, Diet (Parliament) Japan, Vermont State Legislature, Vermont State Public Service Board, Florida Public Service Board, Czech Senate, Connecticut State Legislature, Western Atlas Nuclear Litigation, U.S. Senate Nuclear

Safety Hearings, Peach Bottom Nuclear Power Plant Litigation, and Office of the Inspector General NRC, and numerous Congressional Briefings and Hearings.

Nuclear Engineering, Safety, and Reliability Expert Witness 1990 to Present

- Fairewinds Associates, Inc – Chief Engineer, 2005 to Present
- Arnold Gundersen, Nuclear Safety Consultant and Energy Advisor, 1995 to 2005
- GMA – 1990 to 1995, including expert witness testimony regarding the accident at Three Mile Island.

Nuclear Energy Services, Division of PCC (Fortune 500 company) 1979 to 1990

Corporate Officer and Senior Vice President - Technical Services – Responsible for overall performance of the company's Inservice Inspection (ASME XI), Quality Assurance (SNTC 1A), and Staff Augmentation Business Units – up to 300 employees at various nuclear sites.

Senior Vice President of Engineering – Responsible for the overall performance of the company's Site Engineering, Boston Design Engineering and Engineered Products Business Units. Integrated the Danbury based, Boston based and site engineering functions to provide products such as fuel racks, nozzle dams, and transfer mechanisms and services such as materials management and procedure development.

Vice President of Engineering Services – Responsible for the overall performance of the company's field engineering, operations engineering, and engineered products services. Integrated the Danbury-based and field-based engineering functions to provide numerous products and services required by nuclear utilities, including patents for engineered products.

General Manager of Field Engineering – Managed and directed NES' multi-disciplined field engineering staff on location at various nuclear plant sites. Site activities included structural analysis, procedure development, technical specifications and training. Have personally applied for and received one patent.

Director of General Engineering – Managed and directed the Danbury based engineering staff. Staff disciplines included structural, nuclear, mechanical and systems engineering. Responsible for assignment of personnel as well as scheduling, cost performance, and technical assessment by staff on assigned projects. This staff provided major engineering support to the company's nuclear waste management, spent fuel storage racks, and engineering consulting programs.

New York State Electric and Gas Corporation (NYSE&G) — 1976 to 1979

Reliability Engineering Supervisor – Organized and supervised reliability engineers to upgrade performance levels on seven operating coal units and one that was under construction. Applied analytical techniques and good engineering judgments to improve capacity factors by reducing mean time to repair and by increasing mean time between failures.

Lead Power Systems Engineer – Supervised the preparation of proposals, bid evaluation, negotiation and administration of contracts for two 1300 MW NSSS Units including nuclear fuel, and solid-state control rooms. Represented corporation at numerous public forums

including TV and radio on sensitive utility issues. Responsible for all nuclear and BOP portions of a PSAR, Environmental Report, and Early Site Review.

Northeast Utilities Service Corporation (NU) — 1972 to 1976

Engineer – Nuclear Engineer assigned to Millstone Unit 2 during start-up phase. Lead the high velocity flush and chemical cleaning of condensate and feedwater systems and obtained discharge permit for chemicals. Developed Quality Assurance Category 1 Material, Equipment and Parts List. Modified fuel pool cooling system at Connecticut Yankee, steam generator blowdown system and diesel generator lube oil system for Millstone. Evaluated Technical Specification Change Requests.

Associate Engineer – Nuclear Engineer assigned to Montague Units 1 & 2. Interface Engineer with NSSS vendor, performed containment leak rate analysis, assisted in preparation of PSAR and performed radiological health analysis of plant. Performed environmental radiation survey of Connecticut Yankee. Performed chloride intrusion transient analysis for Millstone Unit 1 feedwater system. Prepared Millstone Unit 1 off-gas modification licensing document and Environmental Report Amendments 1 & 2.

Rensselaer Polytechnic Institute (RPI) — 1971 to 1972

Critical Facility Reactor Operator, Instructor – Licensed AEC Reactor Operator instructing students and utility reactor operator trainees in start-up through full power operation of a reactor.

Public Service Electric and Gas (PSE&G) — 1970

Assistant Engineer – Performed shielding design of radwaste and auxiliary buildings for Newbold Island Units 1 & 2, including development of computer codes.

Media Organizations - including and not limited to:

Featured Nuclear Safety and Reliability Expert (1990 to present) for Television, Newspaper, Radio, & Internet – Including, and not limited to: CNN: JohnKingUSA, CNN News, Earth Matters; DemocracyNow, NECN, WPTZ VT, WTNH, VPTV, WCAX, RT, CTV (Canada), CCTV Burlington, VT, ABC, TBS/Japan, Bloomberg: EnergyNow, KPBS, Japan National Press Club (Tokyo), Italy National Press Club (Rome), The Crusaders, Front Page, Five O'Clock Shadow: Robert Knight, Mark Johnson Show, Steve West Show, Anthony Polina Show, WKVT, WDEV, WVPR, WZBG CT, Seven Days, AP News Service, Houston Chronicle, Christian Science Monitor, Reuters, The Global Post, International Herald, The Guardian, New York Times, Washington Post, LA Times, Miami Herald, St. Petersburg Times, Brattleboro Reformer, Rutland Herald, Times-Argus, Burlington Free Press, Litchfield County Times, The News Times, The New Milford Times, Hartford Current, New London Day, Vermont Daily Briefing, Green Mountain Daily, EcoReview, Huffington Post, DailyKos, Voice of Orange County, AlterNet, Common Dreams, Gendai Media, Truthout, Progressive Radio Network, Project Censored and numerous other national and international blogs

Public Service, Cultural, and Community Activities

2008 to Present –Fairewinds Energy Education Corp 501(C)3 non-profit board member

2005 to Present – Public presentations and panel discussions on nuclear safety and reliability at University of Vermont, Vermont Law School, Universities, Colleges, Nuclear Regulatory

Commission hearings, Federal Court, Town and City Select Boards, Legal Panels, Local Schools, and via National & International Media: Television, Radio, Print, & Internet.

2007-2008 – Energy Production – created concept of Solar Panels on Burlington High School; worked with Burlington Electric Department and Burlington Board of Education Technology Committee on Grant for installation of solar collectors for Burlington Electric peak summer use; Grant was developed with assistance from Senator Sanders.

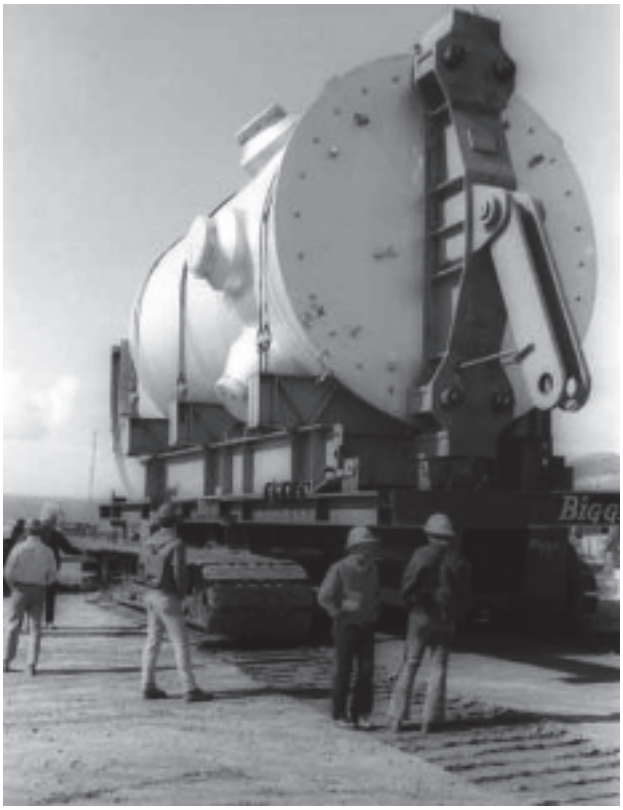
Vermont State Legislature – Public Testimony to Legislative Committees regarding nuclear power and energy issues

NNSN – National Nuclear Safety Network, Founding Advisory Board Member, meetings with and testimony to the Nuclear Regulatory Commission Inspector General (NRC IG)

Northeast Utilities Representative Conducting Public Lectures on Nuclear Safety Issues

End

Neutron Embrittlement at Diablo Canyon Unit 1 Nuclear Reactor



February 15, 1973
The Tribune News
"Workmen at Diablo Canyon hover around a 345-ton reactor vessel as it begins a cautious journey to its final resting place."[1]

Prepared by Fairewinds Associates, Inc

[1] http://sloblogs.thetribunenews.com/slovault/2010/03/diablo-canyon-reactor-vessel-installed/

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Executive Summary

1. When Pacific Gas and Electric (PG&E) designed and constructed the Diablo Canyon Atomic Power Plant 50-years ago, it did so without the assistance of a national Engineering and Construction (E&C) firm experienced in designing and constructing atomic power plants, and chose instead to use its own personnel. The first decision PG&E made at the onset was that Westinghouse Electric would supply the atomic reactor and its associated safety systems. When Diablo Canyon Unit 1 was designed 50-years ago, the nuclear corporations supplying these atomic reactors to the utilities knew very little about the reaction of welded steel when it is exposed to high levels of radiation.

2. Diablo Canyon Unit 1 was one of the first US atomic reactors ever designed and manufactured by the nuclear power industry, therefore unusual and consequential errors were made in design and engineering. The wrong material was used to weld the atomic reactor vessel introducing impurities in the weld material itself that have caused significant and accelerated radiation damage in the form of embrittlement to its Unit 1 reactor. Furthermore, the embrittlement caused by the poor weld material has made the atomic reactor vessel in Diablo Canyon Unit 1 among the most dangerously embrittled reactors in country. Diablo Canyon now ranks of one of the worst 5 reactors out of the 99 remaining operational reactors in the US.

3. Reactor embrittlement can cause an atomic reactor to shatter like glass creating what the Nuclear Regulatory Commission (NRC) calls a Class 9 Accident, which is the worst nuclear catastrophe presently acknowledged by the NRC. When the nuclear core leaves the atomic reactor and melts down into the containment, as it did at three of the atomic reactors at the Fukushima Daiichi site in Japan March 11, 2011, the NRC calls each one of these nuclear calamities a Class 9 Accident.

4. The defects in the Diablo Canyon Unit 1 will continue to threaten plant safety as the atomic reactor vessel continues to embrittle. Furthermore, even though it is currently planned that Diablo Canyon Unit 1 will shut down by in 2024,[2] Diablo Canyon Unit 1 will not operate safely due to its unsound condition, unless a special experimental and untried repair technique is conducted. The procedure is very expensive, and it is questionable whether it could even be successful on the fragile, embrittled and aged atomic reactor.

5. While the repair for such embrittled reactors, called dry recovery annealing, exists in theory, the operation would be very expensive, extremely risky and might prove entirely unworkable.

6. Rather than assuring intensive monitoring of the fragile embrittled reactor vessel, PG&E and the NRC are ignoring its severely degraded condition by allowing Diablo Canyon Unit 1 to continue to operate. PGE requested and in 2015 the NRC granted a waiver of inspection requirements for these critical reactor welds. The previous weld inspection was completed in 2005, but the next series of inspections have been delayed until 2025 as a result of the NRC waiver. This means that for the last 20-years of operation for Diablo Canyon Unit 1, there has not been and there will not be any inspection of these critical welds.

1. What Is Nuclear Reactor Embrittlement and How Does It Develop in An Atomic Reactor?

The earliest radiation studies show that any form of radiation can damage the material with which it comes in contact. This damage is caused when radioactive decay from inside an atomic nucleus emits one of several types of energetic particles that collide with surrounding material. Much like slow moving vehicles in a minor fender-bender, some particles move slowly, have little energy, and cause only a small amount of damage.

[2] Diablo Canyon Joint Proposal, 16-08-006

However, like an out of control NASCAR wreck, some particles move rapidly, and thus have more energy and therefore cause a great deal of damage.

For atomic power reactors made of steel, the most damaging type of radiation is high energy neutrons released when a Uranium atom fissions (splits).

> "Its like billiards," explains one expert. "Although metal atoms are much heavier than neutrons, when a high energy neutron collides with a metal atom, the neutron forces the atom from its lattice-the geometric array of atoms."[3]

The design life for each of the atomic reactors at Diablo Canyon is only 40-years and not the 60 or more years that PGE and the NRC have claimed in the past. Moreover, "irradiation embrittlement" is a "significant" issue for these reactors according to the Electric Power Research Institute (EPRI) documents reviewed by Fairewinds.[4]

Early nuclear reactors, like Diablo Canyon Unit 1, whose reactor was designed and purchased 50-years ago and finally installed in September 1973, contained chemical impurities in their weld material, such as copper, that significantly worsened the neutron damage to the welds. That the copper embedded in the welds of the Diablo Canyon Unit 1 reactor could amplify neutron damage was not understood by designers until after the atomic power reactor vessel had been manufactured and delivered to the site. These copper containing welds could not be removed from the reactor vessel without destroying the reactor itself, which had already been installed at Diablo Canyon Unit 1. Diablo Canyon Unit 2 was manufactured after the nuclear reactor industry identified problems with copper impurity in reactor vessel welds, and the weld materials were corrected by leaving out the copper. Therefore, Diablo Canyon Unit 2 has experienced less embrittlement than Unit 1, which appears due to the elimination of copper in its welds.

> Before the industry realized what was happening, which was about 1972, spools of copper coated wires were routinely used for these welds. The

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[3] *Thermal shock-new nuclear-reactor safety hazard*, Edward Edelson, *Popular Science* June 1983.
http://static1.1.sqspcdn.com/static/f/356082/25715973/1417195845950/June+1983+Popular+Science.pdf?token=a42WKwrX5fEjMEeVND6FGLOKmWc%3D

[4] *Welding and Fabrication Influence on Stress Corrosion Cracking (SCC), ATI-CSC-11, Lake Louise*, Alberta, Canada, Dana Couch, EPRI, September 29, 2011, slides 13, 14 and 21.

> copper was used to prevent rust…Reactor builders switched to nickel coated electrodes, but they couldn't replace the welds in the older reactors…It can take three weeks of repeated passes with electrodes to complete one of those welds. That type of weld, engineered to be a powerful bond between steel sections of reactor vessels, contained enough copper to become a potential hazard instead.[5]

The highest number of neutrons bombarding the nuclear reactor vessel occurs in the middle of the reactor vessel in what is called the vessel "beltline". The "beltline" region, is exactly where the major welds are located and is particularly vulnerable to embrittlement. According to the Nuclear Regulatory Commission,

> Reactor pressure vessels, which contain the nuclear fuel in nuclear power plants, are made of thick steel plates that are welded together. Neutrons from the fuel in the reactor irradiate the vessel as the reactor is operated. This can embrittle the steel, or make it less tough, and less capable of withstanding flaws which may be present. Embrittlement usually occurs at a vessel's "beltline," that section of the vessel wall closest to the reactor fuel. Pressurized water reactors (PWRs) are more susceptible to embrittlement than are boiling water reactors (BWRs). …Steels with a higher proportion of copper and nickel will tend to be more susceptible to embrittlement, than are steels with lower proportions of these two elements….[6]

2. How serious is the neutron embrittlement problem at Diablo Canyon?

Currently, there are 99 remaining operating nuclear reactors in the United States. Diablo Canyon Unit 1 is one of the five most embrittled reactors in the United States. Unit 1 is approaching its regulatory limit for embrittlement, and will exceed that limit on or about the time its original 40-year license expires. According to a Nuclear Regulatory Commission letter dated April 18, 2013[7] the NRC stated that:

> The NRC currently estimates that the following (five) plants will exceed the PTS[8] screening criteria of 10 CFR 50.61 during their 20-year period of operation beyond their original 40 year licenses ...Diablo Canyon Unit 1.

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[5] IBID
[6] *NRC Fact Sheet on Reactor Pressure Vessel Issues, Embrittlement*, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/prv.html
[7] *NRC letter to Entergy Nuclear Operations, Inc, April 18, 2013, Subject: Summary of the March 19, 2013, Public Meeting WEBINAR Regarding Palisades Nuclear Plant*
[8] PTS – Pressurized Thermal Shock

3. When did the State of California become aware of the seriousness of nuclear embrittlement of nuclear reactors?

Four years before Diablo Canyon 1 became operational, in 1981, personnel in the Office of the Governor of California were made aware that nuclear reactor embrittlement with its associated risk of a nuclear reactor failure and radiation leak was a serious problem. Peter H. Gleick, a specialist in the office of Gov. Edmund G. Brown's assistant for energy and environment wrote a Letter to the Editor of the *New York Times* dated in 1981. In that letter, Mr. Gleick said that nuclear reactor embrittlement "…may be the most serious known problem facing existing nuclear power plants… which could cause failure of the pressure vessel containing nuclear fuel." Mr. Gleick's full letter is pasted below.

If The Pressure Vessel Of A Reactor Cracks

To the Editor:
Your Oct. 24 editorial "Brittle Metal and Nuclear Safety" correctly calls attention to what may be the most serious known problem facing existing nuclear power plants - "pressurized thermal shock," which could cause the failure of the pressure vessel containing the nuclear fuel.

Although progressive embrittlement of the pressure vessel has always been anticipated, it now appears that many such vessels will become susceptible to cracking long before reaching their 30- to 40-year lifespan. This problem, however, is neither as avoidable nor as correctable as you suggest.

As you stated, both overcooling and high pressurization must exist before a vessel can crack. Yet there are situations where rapid cooling together with high pressurization is required in order to avoid a serious accident. The operator actions needed to avoid a serious reactor accident may be completely contradictory to those required to avoid cracking the pressure vessels.

For this reason, the Nuclear Regulatory Commission has taken the position that relying on operator action is not an acceptable solution to the risk of pressure vessel failure.
Similarly, the statement that correcting this problem involves catching the flaw early is accurate but misleading. Pressurized thermal shock is a problem that is most severe in the older generation of reactors - those built

before the mid-1970's (newer pressure vessels have better materials characteristics and are less susceptible to embrittlement).

As a consequence, catching the flaw early is not possible for most of these older reactors, which are already close to reaching unacceptable levels of embrittlement. Moreover, the "solution" described in the editorial, annealing of the vessel, requires emptying the entire core of nuclear fuel and heating the highly radioactive pressure vessel to several hundred degrees above its normal operating temperature for a very long period - perhaps up to several months.

Theoretically, the strength of the vessel is then recovered. In practice, however, no commercial nuclear reactor vessel has ever been annealed, and there are serious questions about the time required, the economic costs, the radiation exposure to workers and, in fact, whether or not this process will be successful.[9]

Mr. Gleick's 1981 letter to the New York Times was prescient. One reactor at Yankee Rowe was forced to shut down in 1992 due to embrittlement problems, while others, such as Palisades in Michigan and Diablo Canyon Unit 1, are continuing to experience serious embrittlement problems that increase risk and shorten each plant's operating life. Still, 36 years after the letter was written, no operating reactors in the US or Europe have ever been shut down and re-annealed due to the technical risks involved in that process.

4. What are the safety consequences of an embrittled nuclear reactor?

Each nuclear reactor vessel is designed to contain the radioactive nuclear fuel in its reactor core, so the reactor vessel must hold water in order to cool its radioactive fuel in the event of a nuclear calamity. First and foremost, the NRC makes the mathematical assumption that the atomic reactor vessel will maintain its strength during every accident or mishap scenario analyzed by Pacific Gas and Electric for the Diablo Canyon plants. If the reactor vessel were to crack open due to neutron embrittlement, all the nuclear power plant's critical safety systems will fail, leading to a catastrophic release of radiation.

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[9] *New York Times*, November 7, 1981 **http://www.nytimes.com/1981/11/07/opinion/l-if-the-pressure-vessel-of-a-reactor-cracks-084005.html**

The NRC and nuclear industry experts have long recognized the seriousness of reactor embrittlement and the radiation release consequences for the public should that failure occur. In 1982, Demetrios L. Basdckas, an NRC Reactor Safety Engineer, expressed his concerns and frustrations in his letter to the editor, also published in the New York Times:

> "There is a high, increasing likelihood that someday soon, during a seemingly minor malfunction at any of a dozen or more nuclear plants around the United States, the steel vessel that houses the radioactive core is going to crack like a piece of glass. The result will be a core meltdown, the most serious kind of accident, which will injure many people, and probably destroy the nuclear industry with it"[10]

5. How does nuclear reactor embrittlement lead to the failure of the reactor?

If the nuclear reactor were to suddenly shut down during one of dozens of atomic power mishaps that nuclear reactor design engineers and the NRC anticipate will happen, the safety system would immediately inject cool water into the reactor vessel in an attempt to cool the reactor core in hopes of preventing a meltdown. However, in a seriously embrittled reactor like Diablo Canyon 1, when that cool water is injected and comes in direct contact with the hot reactor vessel, it can cause what is called "Pressurized Thermal Shock" (PTS), and the 8-inch steel thick reactor vessel can crack causing it to break open and release massive amounts of radioactivity into the surrounding area and the environment. While no atomic reactor mishap, or accident as the industry names them, should be called "routine", this sequence of rapid cooling and sudden pressurization can cause what the NRC and nuclear industry term a "routine accident" to become a radioactive disaster.

> Another reason reactor vessel embrittlement is more of a concern for PWRs is because PWRs may experience pressurized thermal shock (PTS). PTS can occur under some accident scenarios that introduce cold water into the reactor vessel while the vessel is pressurized. Introduction of cold water in this manner can cause the vessel to cool rapidly, resulting in large thermal stresses in the steel. These thermal stresses, along with the high

[10] *New York Times*, March 29, 1982

> internal pressure and an embrittled vessel, could lead to cracking and even failure of the vessel.[11]

There have been several historical precursor sequences that prove that abrupt temperature and pressure changes can and do occur at operating nuclear power plants. The first such precursor event happened at California's Rancho Seco atomic power reactor on March 20, 1978. When a worker dropped a light bulb, it in turn caused a cascade of electrical faults. Instruments in the control room went haywire leaving the reactor operators with no accurate instrumentation to rely upon while attempting to control the reactor. The temperature inside the reactor dropped from 582 to 285 in one hour. The reactor pressure dropped from 2,200 psi to 1,600 psi. Then, when cold water was injected, the reactor pressure jumped back over 2,000 but at a low temperature.

The Rancho Seco "transient", as nuclear engineers call it, was a near miss that made it clear that pressurized water reactors are susceptible to abrupt changes in temperature and pressure. While the nuclear reactor welds were severely stressed by the pressure and temperature changes, the Pressurized Thermal Shock (PTS) and nuclear vessel failure was avoided at Rancho Seco, which was a new reactor, so its welds were not yet subject to embrittlement by long-term neutron bombardment, like Diablo Canyon or the Palisades reactor in Michigan.

Unfortunately, Diablo Canyon Unit 1 is particularly susceptible to a similar PTS (Pressurized Thermal Shock) near miss like the one that was previously experienced at Rancho Seco for two reasons. First, Diablo Canyon is one of the most embrittled reactors in the United States. Second, its location, in the most seismically active area of the United States, means that it is more likely to experience a very destabilizing seismic event which blinds the operators from the temperature of the reactor vessel in a similar manner to the conditions encountered at Rancho Seco.

This is not to say that an earthquake would necessarily crack the reactor. Rather, the earthquake would cause a sudden emergency shutdown that could defeat most safety

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[11] *NRC Fact Sheet on Reactor Pressure Vessel Issues, Embrittlement*, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/prv.html

systems, cause control room instruments to become unreliable because of "instrument chatter" (http://www.fairewinds.org/nuclear-energy-education/whose-fault?rq=chatter), and thus provide the control room operators with little or no accurate data about the temperature and pressure in the reactor. It is this lack of accurate operator data that is one of the hallmarks of both the Rancho Seco mishap and the triple meltdown disaster at Fukushima Daiichi.

In the hours immediately after a seismic emergency induced shutdown at Diablo Canyon Unit 1, atomic reactor operators, acting without accurate information, may mistakenly inject cold water at the wrong time, inducing PTS (Pressurized Thermal Shock) in the old embrittled Diablo Canyon reactor vessel. The net effect would be catastrophic cracking of the reactor vessel causing the release of its uncooled atomic fuel rods onto the floor of the containment building in a similar fashion to the disaster at the three Fukushima Daiichi reactors. All three Fukushima Daiichi atomic reactors cracked open and spilled their radioactive contents in meltdowns that are still ongoing.

More recent analyses now show that the atomic reactor vessel can crack even when it is not under pressure. Hence, the damage from what the industry has called "pressurized" thermal shock is now clearly understood as simply damage from thermal shock. According to the NRC's Advisory Committee on Reactor Safeguards as recently as 2014[12]:

> Mr. Kirk: well, they're - and that's one of the - in fact, that was very much a surprise because in the - in the early analysis - in the 1980s analysis the no-pressure events were a priori screened out.
> But what we found in running the calculation is you can run a crack pretty much all the way through the wall.
> Member Skillman: just with temperature.
> Mr. Kirk: just with temperature.
> Member Skillman: just with temperature.
> Mr. Kirk: yes.

[12] Advisory Committee on Reactor Safeguards, top of p.33, Oct. 16, 2014 transcript

6. What is Nil-Ductility Transition Temperature and why is it important?

In order to prevent catastrophic PTS induced reactor vessel failure in old reactors including Diablo Canyon Unit 1, administrative controls have been implemented to assure that control room operators are sure that the nuclear reactor is very hot before it is significantly pressurized. As the reactor ages and becomes more embrittled, the temperature must be increased higher and higher prior to increasing pressure in the vessel. The temperature that must be reached before pressure inside the vessel may be applied is called Nil-Ductility Transition Temperature. Above this Nil-Ductility Transition Temperature, the nuclear reactor is ductile (i.e. more flexible) and will not crack. Below this temperature, the vessel is not ductile and will crack if the pressure is increased. If pressure is increased at too low a temperature, the vessel can crack, hence the term "nil-ductility transition temperature." Each year as the nuclear reactor vessel ages, it becomes more embrittled causing the temperature necessary to assure Nil-ductility in the reactor vessel to increase.

It is disturbing to note that the *alleged "solution"* created by the NRC and Pacific Gas & Electric to protect Diablo Canyon Unit 1 against its increasing neutron embrittlement, is simply to create administrative controls that require Diablo Canyon atomic reactor operators to implement during a reactor emergency. These administrative controls require the reactor operators to raise the temperature of the reactor prior to increasing the pressure. This is analogous to being aware that the brakes on a tractor-trailer will fail at speeds above 50 miles per hour. Rather than fix the brakes, the administrative solution would be to insist that the truck driver never exceed 49 miles per hour. Just as reactor vessel embrittlement gets significantly worse over time, bad brakes on the truck would demand that the driver would reduce his speed further every year, rather than simply make the necessary mechanical repair to the brakes.

Rather than fix its aging embrittled atomic reactor vessel, PG&E's strategy for Diablo Canyon Unit 1 is to repeatedly modify its mathematical calculations so that operators use an ever higher nil-ductility transition temperature in PG&E's attempt to stretch the life of its embrittled reactor vessel until its projected shutdown in 2024. Since 2001, nuclear

industry experts such as Odette and Lucas continue to acknowledge that the service life of old atomic reactors is limited by embrittlement.

> Neutron irradiation embrittlement could limit the service life of some of the reactor-pressure vessels in existing commercial nuclear-power plants…. embrittlement remains a potential issue for some older vessels, and is an unknown for the extended life of others.[13]

7. How accurate is the science of predicting the extent of atomic reactor neutron embrittlement and is it really feasible to significantly extend the "useful life" of an atomic reactor based upon such modified calculations?

It is technologically impossible to measure the actual condition of the embrittled reactor vessel at Diablo Canyon without cutting into the vessel itself in search of metallurgical samples, and destroying the vessel by that process. So, instead of cutting into the vessel itself, engineers make estimates of the condition of the reactor vessel metal. These estimates of the "useful life" of an embrittled reactor have many mathematical uncertainties that engineers call "variables". The following excerpt from a 2001 paper on reactor vessel embrittlement is provided [with emphasis added] to give the reader a brief sampling of the complexity of the embrittlement calculation:

> Measurements of fracture toughness (e.g., K_{Ic}) require **special specimens and relatively sophisticated test procedures that were not available at the time surveillance programs were first implemented**… The T_{ndt} is the so-called **the nil-ductility transition temperature for the unirradiated steel, which is determined using a rather complex procedure**, generally based on either Charpy or drop weight tests. In irradiated steel, the K_{Ir} $(T - T_{ndt} - DT_t)$ curve is shifted up in temperature by the DT_t, which includes a margin term. While showing a great deal of early foresight, **this procedure is somewhat arcane and often lacks a rigorous physical justification… Plant-specific surveillance data are usually not sufficient to predict DT_t**. More commonly, the DT_t are evaluated using regulatory equations based on a large collection of surveillance data from many plants. …**Predictive models must also account for strong synergistic interactions between variables, such as**

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[13] *Embrittlement of Nuclear Reactor Pressure Vessels*, G.R. Odette and G.E. Lucas, 2001, *The Minerals, Metals & Materials Society,* http://www.tms.org/pubs/journals/jom/0107/odette-0107.html
* Note: G.R. Odette and G.E. Lucas are professors in the Department of Mechanical and Environmental Engineering at the University of California, Santa Barbara.

> **copper nickel… Because of the number of variables and variable combinations (e.g., Cu-Ni-Φ-Φt-T_i, T_a, t_a), coupled with various limitations in the surveillance and PIA databases, purely empirical DT_t predictions are unreliable particularly when extrapolated to conditions beyond the existing variable range (e.g., higher Φt)**… **Despite progress in predicting irradiation embrittlement and recovery, a number of issues are not fully resolved or quantified**… **Perhaps the most difficult issue is associated with material variability and the inherent uncertainties about the composition and properties of the steels in the RPV itself.** … (Embrittlement **assumptions) rests on a series of empirically based assumptions and faces a number of challenges related to its application to assessing the integrity of irradiated pressure vessels.** Issues regarding the key assumptions include the validity of a universal master-curve shape as well as both statistical and constraint- mediated size effects. Issues associated with the use of the master-curve method in integrity assessments include the applicability to dynamic and arrest toughness, effects of irradiation on the master-curve assumptions, ties to the Charpy-based surveillance database, effects of realistic surface/shallow flaw configurations, and the reliability of data from archival-surveillance materials to represent actual vessel steels.[14]

Clearly, the process of determining the Nil-ductility transition temperature is not an exact science. A paper written by Nikolaeva, Nikolaev, et al in 2000 supports Fairewinds' assessment of uncertainty and complexity in the development of the embrittlement calculations:

> The radiation embrittlement of reactor vessel materials is a **complex process**, which depends upon the conditions of a radiation in the microstructure and chemical composition of the steel. It is universally acknowledged that phosphorus, copper, nickel intensify the radiation embrittlement of vessel material the most…. **The presence of a synergistic interaction of elements in the irradiation process and the complex interaction of metallurgical factors and the radiation conditions make it difficult to determine the degree to which impurities and alloying elements influence radiation embrittlement**.[15]

The process of using engineering analysis to extend the "useful life" of embrittled nuclear reactors has the net effect of reducing the safety margin of those reactors. A paper

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[14] http://www.tms.org/pubs/journals/jom/0107/odette-0107.html
Embrittlement of Nuclear Reactor Pressure Vessels, G.R. Odette and G.E. Lucas, 2001, ***The Minerals, Metals & Materials Society***

[15] Embrittlement of Low-Alloy Structural Steel by Neutron Irradiation, Atomic Energy, Vol. 88, No.4, 2000: Nikolaeva, Nikolaev, Kevorkyan, Kryukov & Korolev, http://link.springer.com/article/10.1007%2FBF02673611#page-2

written in 2000 by the Nuclear Energy Agency Nuclear Science Committee states that safety margins will be reduced by extending the "useful life" of embrittled reactors [Emphasis added] [16]

> As many commercial light water reactors begin to approach the end of their licensed lifetime, nuclear utilities have started to investigate the possibility of extending the operating life of reactors beyond the originally licensed 30-40 years. **Longer reactor operating times mean higher neutron and gamma fluence levels and/or smaller safety margins …** High energy neutron bombardment degrades the structural integrity of RPVs.

In 1981, Robert Pollard, of the Union of Concerned Scientists, was one of the first scientists in the world to identify the danger and the degree of uncertainty in embrittlement calculations within the scientific community.[17]

> "If you really want a good fight, ask people about the reliability of those safety estimates. **The method the NRC and the industry uses is called probabilistic risk assessment. Its designed to get around a rather impressive lack of concrete evidence**… In a probabilistic risk assessment, you estimate the likelihood of an event that initiates a transient, then estimate the likelihood of the reaction to that event, the reaction to that reaction, and so on down the line. Westinghouse, for example, has a model that starts with 17 possible initiators and runs through event trees to more than 8,200 end points… But there are inevitable differences of opinion about the value of those calculations… Not everyone agrees with the calculations. **"The NRC may consult its Ouija board and come up with a number", says Robert Pollard of the Union of Concerned Scientists, "but the error bands are so large that it is essentially useless."** … "There's no dispute that current emergency systems would not be able to cope with the fracture of the reactor vessel… The defense in depth argument disappears when you talk about pressurized thermal shock." [**Emphasis Added**]

Dr. George Sih, Director of Fracture and Solid Mechanics at Lehigh University, echoed the Union of Concerned Scientists sentiments stating:[18]

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[16] PREDICTION OF NEUTRON EMBRITTLEMENT IN THE REACTOR PRESSURE VESSEL, Nuclear Energy Agency Nuclear Science Committee, 2000 https://www.oecd-nea.org/science/docs/2000/nsc-doc2000-5.pdf

[17] *Thermal shock-new nuclear-reactor safety hazard?* Edward Edelson, *Popular Science*, June 1983, http://static1.1.sqspcdn.com/static/f/356082/25715973/1417195845950/June+1983+Popular+Science.pdf?token=a42WKwrX5fEjMEeVND6FGLOKmWc%3D

[18] IBID

> …**the (NRC fracture) report is built on a foundation of sand**. "The samples are five inches long, and the vessel is 500 inches long," Sih said. "The sample is very thin, and the vessel is eight inches thick. We don't know how to transfer small-sample data to the design of large-scale structural components. [**Emphasis Added**]

8. Is it even feasible to repair an embrittled nuclear reactor?

When a nuclear reactor is first constructed in a dedicated manufacturing facility, many curved steel plates are welded together, almost like staggering bricks while laying a brick wall. Rather than placing cement between each brick, the curved plates are welded together.

The initial heat from welding these steel plates together causes stresses in the reactor vessel that must be eliminated prior to operating the atomic reactor. When the reactor is vessel is completely fabricated, it is heated in a process called "annealing", which occurs in the manufacturing facility in order to eliminate the original welding induced stresses.

In metallurgy, annealing is a heat treatment that alters the physical and chemical properties of the steel to increase its ductility, in order to improve the machinability of steel to make it more workable by softening the steel. Annealing also enhances the toughness of steel, improves its homogeneity, and refines the grain size of the steel. Annealing is a process by which steel is heated to a specific temperature and then allowed to cool very slowly. In reactors, this process usually takes about 168 hours, but that depends on where the reactor was made and what metal was mixed with the steel. After annealing, the reactor vessel is considered stress free and ready to be installed at the reactor site.

Once operational, the process of neutron embrittlement causes new stresses to build up as the reactor ages. Eventually, if no physical changes are made, the reactor will crack due to these stresses. In order to eliminate any of these new neutron embrittlement stresses created during reactor aging, the reactor must be re-annealed in place at the reactor site.

The initial annealing of the vessel at the manufacturing facility is a relatively straight forward process, however re-annealing a 40-year-old irradiated, embrittled reactor inside the nuclear containment building with additional pipes and wires attached is extraordinarily difficult.

Engineers were surprised when reactors began to become brittle and so fragile that they could shatter while under the duress of operating. According to Reijo Pelli and Kari Törrönen in *State-Of-The-Art Review On Thermal Annealing* [19]:

> "Radiation embrittlement in some pressurised water reactors has been so fast that, in spite of other applied mitigation methods, thermal annealing has been practically the only solution permitting further operation… In cases where the whole fuel core zone area of the reactor pressure vessel is to be annealed, **a fully successful annealing has yet to be convincingly proven. High thermal stresses may make the thermal treatment troublesome to carry out**. (**Emphasis Added**)

The process of repairing an embrittled nuclear reactor is called "recovery annealing" sometimes shortened to "re-annealing" and involves heating the nuclear reactor to a temperature much higher than that at which it normally operates in an attempt to allow the embrittlement stresses within the steal nuclear reactor to reduce as the steel softens. Recovery annealing can take two forms: wet and dry. In wet recovery annealing, the nuclear fuel is removed and the nuclear reactor is reheated with water inside to temperatures several hundred degrees higher than its normal operating range. There are approximately 450 reactors currently operating worldwide, and 13 Soviet reactors of the VVER 440 design have been wet annealed during the recovery annealing process. There is a significant difference between the Soviet and Western nuclear reactor designs as well as the character and quality of the steel because the Soviet steel contains more copper. Therefore, wet recovery annealing is not possible in the Western designed and fabricated Pressurized Water Reactors (PWRs).

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[19] European Network on Ageing Materials Evaluation and Studies, Espoo, March 1995, VTT Manufacturing Technology, P.O. Box 1704, FIN-02044 VTT, Finland.
http://capture.jrc.ec.europa.eu/sites/capture/files/files/documents/eur16278en.pdf

Dry recovery annealing is more complicated because it involves removing the nuclear fuel, all of the water, and all of the highly radioactive internal core structures from the reactor and then applying heat directly to the highly radioactive walls of the reactor. This technique has never been tried in an operating embrittled reactor. According to the International Atomic Energy Agency publication *Thermal Annealing of Reactor Pressure Vessels Is a Needed Mitigation Option*[20]:

- Dry anneals are performed at higher temperatures than wet anneals
  – Use air as the heating medium inside of radiant can
  – Electric-resistance heating source
- Dry annealing requires removal of core internal structures and primary water so that a radiant heating source can be inserted near the vessel wall to locally heat the embrittled beltline region

– Engineering difficulties of dry anneal process are quite complex and may need plant-specific evaluations to assure that other portions of the plant (eg., concrete) are not harmed by the high annealing temperatures. [**Emphasis Added**]

The Department of Energy has performed only one dry annealing simulation, [yes, a simulation, not an actual annealing or recovery annealing process], and that was back in 1996 on the Marble Hill reactor vessel in Indiana, a reactor that was abandoned before it ever began operating, thus it was not radioactive and the steel was not embrittled[21].

> In fact, an Annealing Demonstration Project (ADP) funded jointly by the U.S. Department of Energy and the nuclear industry was performed at the uncompleted Marble Hill nuclear plant in Indiana in 1996/1997 …. The Marble Hill RPV was a four-loop PWR with nozzle supports and designed by Westinghouse. The Marble Hill plant was a partially completed plant but the vessel was in place which allowed for a prototypic annealing demonstration to be executed….
> The method used was a dry annealing procedure with an indirect gas-fired method through a heat exchanger. The RPV was instrumented with strain gages and thermocouples to assess strain levels and temperatures over the entire RPV, including nozzles, during and after the annealing operation.

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[20] *Thermal Annealing of Reactor Pressure Vessels Is a Needed Mitigation Option, IAEA,* November 8, 2013 IAEA, Vienna, Austria, ,Slide 10 https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-11-05-11-08-TM-NPE/38.Server_USA.pdf

[21] Oak Ridge National Laboratory: Reactor Pressure Vessel Task of Light Water Reactor Sustainability Program: Initial Assessment of Thermal Annealing Needs and Challenges, Section 2.2, http://info.ornl.gov/sites/publications/Files/Pub32884.pdf

Currently there are 99 operating reactors in the U.S., while another 20 have been prematurely shutdown and more than 100 were cancelled while under construction. While Diablo Canon Unit 1 is fast approaching embrittlement limits, no attempts to repair embrittlement problems at any of the U.S. reactor fleet have even been attempted. One U.S. reactor was so seriously embrittled (Yankee Rowe) that its owner decided to permanently terminate its operating license and shut the reactor down rather than attempt a repair. According to the International Atomic Energy Agency (IAEA)[22], "**Thermal Annealing Generally is Considered a Last Resort Embrittlement Mitigation Method**". [**Emphasis Added**]

9. Is Pacific Gas and Electric frequently inspecting these embrittled welds in the Diablo Canyon Unit 1 reactor as a result of this increased neutron embrittlement?

No, PGE does not plan to inspect these embrittled welds with increased scrutiny. Normally, each weld of a nuclear reactor is inspected every 10 years. However, PGE requested and the NRC approved increasing this 10-year inspection interval to 20 years.

> By letter dated August 18, 2014, as supplemented by letter dated March 20, 2015, Pacific Gas and Electric Company (the licensee) proposed an alternative to the inservice inspection (ISi) interval requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section XI, Paragraph IWB-2412, "Inspection Program B," for Diablo Canyon Power Plant (DCPP), Unit 1. Inspection Program B requires volumetric examination of essentially 100 percent of reactor pressure-retaining welds identified in Table IWB-2500-1 once each 10-year interval. Pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), paragraph 50.55a(z) (50.55a(a)(3)(i) at the date of application), **the licensee requested to use a proposed alternative to extend the DCPP Unit 1 reactor pressure vessel (RPV) inspection interval from 10 to 20 years. …** The U.S. Nuclear Regulatory Commission (NRC) staff has completed its review of the licensee's submittal and, as set forth in the enclosed safety evaluation,

[22] *Thermal Annealing of Reactor Pressure Vessels Is a Needed Mitigation Option*, IAEA, November 8, 2013 IAEA, Vienna, Austria, Slide 2
https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-11-05-11-08-TM-NPE/38.Server_USA.pdf

> concludes that **extending the ISI interval from 10 to 20 years will provide an acceptable level of quality and safety**….[23] [**Emphasis Added**]

Previously, regulations required that all the welds in the Diablo Canyon reactor would be ultrasonically inspected at least every 10-years, with the latest ten-year inspection period to be completed by the end of 2015. PGE had previously committed to follow the requirements of the American Society of Mechanical Engineers for inspecting these welds to determine if any flaws were developing.

The ultrasonic technique for atomic power reactors is a process similar to that of an ultrasonic sonogram during pregnancy. Despite knowing that Diablo Canyon Unit 1's weld copper content is unacceptably high, and despite knowing that Diablo is one of the five most embrittled reactors in the United States, the NRC has allowed PGE to delay these critical weld inspections for 10 more years, until 2025. This prevents analysis by the public and by regulators of critical information determining that the reactor should be shut down sooner rather than the Diablo Canyon Retirement Joint Proposal date of 2024. It appears that the NRC is assisting PGE by withholding this critical weld embrittlement data until the aging Diablo Canyon reactor is no longer in operation.

10. If Diablo Canyon were to attempt a recovery annealing of its embrittled nuclear reactor, what would be the cost, risk and duration of the repair?

If Diablo Canyon continues to operate, the reactor will become so embrittled and damaged that embrittlement repair will necessitate using the yet untried dry recovery annealing technique. As a result, Pacific Gas and Electric (PG&E) will incur significant risks, large out of pocket expenses, and a long outage delay, *if the plant is ever able to actually restart*. The capitalized cost for the repair contractor's equipment and expertise alone will be at least $45,000,000 and may turn out to be as high as $100,000,000, according to a study conducted by Carnegie Mellon University. The data reviewed by

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[23] *Diablo Canyon Power Plant, Unit No. 1 - Request For Alternative RPV-U1-Extension To Allow Use of Alternate Reactor Inspection Interval Requirements*, NRC Approval Letter to PGE, June 19, 2015. http://pbadupws.nrc.gov/docs/ML1516/ML15168A024.pdf

Carnegie Mellon also shows that the duration of the repair outage would be approximately 11 months and might even last as long as two years.

> A process called annealing might resolve the RPV issue. With annealing, the entire RPV is raised to high temperatures for a duration of time to renew any weak or brittle welds. At the time, this process had never been performed in the United States. **The annealing process would require the facility to be off-line for no less than six months, and possibly much longer, resulting in lost generation sales. Moreover, without a proven annealing process prior to shutdown, the annealing process could be a failure**,
> leading to permanent shutdown and decommissioning. This issue represented the single largest liability to the continued operation of the nuclear power facility.
> Aside from the possibility of permanent shutdown, because the length of time that the plant would be offline is unknown**, the technical uncertainty creates an economic exposure in the project. The longer the plant is shut down, the greater the economic loss**. [**Emphasis Added**]
>
> The combinations of the above uncertainties and the timing at which they could occur require that a rational decision-making process be integrated into the model. Obviously, future decision would greatly influence the plant's cash flows. For example, if eight years into the future, the NRC requires that annealing be done or the plant shutdown permanently, then the plant owner must decide what to do. At the time of the decision, does annealing make economic sense? At that future decision point, the expected future earnings of the plant and the expected cost of annealing must be compared to the cost of retiring the plant.
>
> The expected value associated with plant shutdown (because of RPV embrittlement) is calculated by determining the shortfall in the decommissioning account for each year and then discounting this amount into the appropriate year's dollars... **The cost of repairs is assumed to average approximately $45 million … and an upper limit of $100 million …It is also assumed that the repairs will require the plant to be down for an average of 11 months. The shutdown time is modeled using a general probability distribution ranging form 6 months to two years** (see Figure 5). [**Emphasis Added**] [24]

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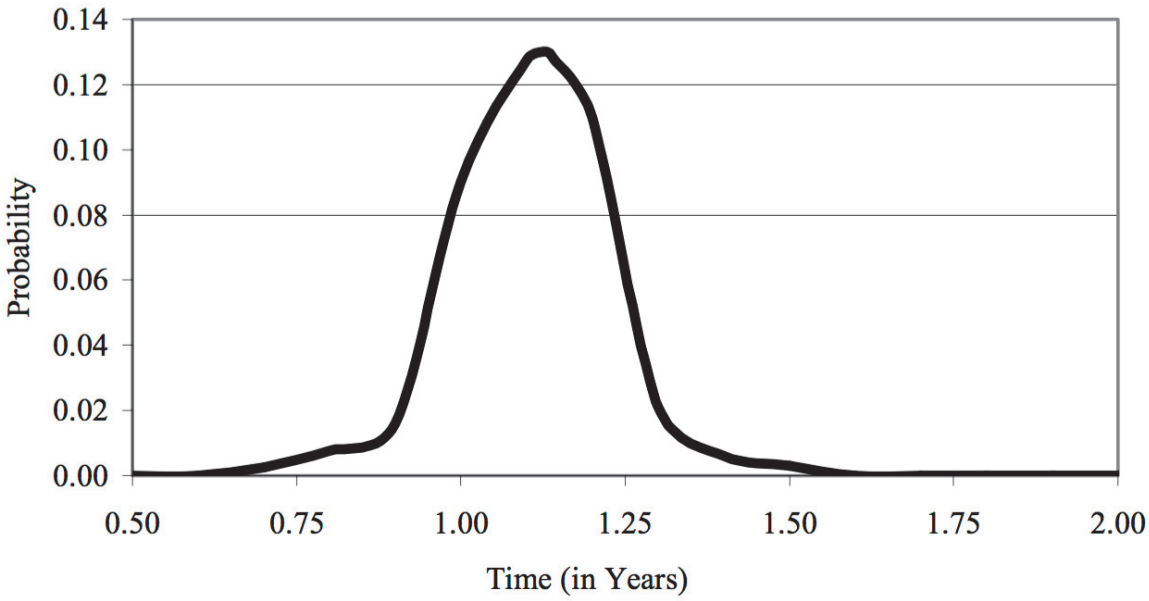
[24] *Monte Carlo Methods for Appraisal and Valuation: A Case Study of a Nuclear Power Plant, 2001,* Carnegie Mellon Electricity Industry Center CEIC Working Paper 02-01 (pages 16-19)
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.8.7026&rep=rep1&type=pdf

Figure 5: Probability Distribution of the Length of Time Needed to Anneal



Unfortunately, the Carnegie Mellon study did not analyze the additional financial impact of licensing schedule delays, which is a significant risk to a potential Diablo Canyon embrittlement repair project of recovery annealing and the extensive license application process determined by the NRC.

There are very strict protocols that both PG&E and Diablo Canyon have to follow along with the NRC to even consider the recovery annealing process, according to 10 CFR § 50.66:

> § 50.66 Requirements for thermal annealing of the reactor pressure vessel.
> (a) For those light water nuclear power reactors where neutron radiation has reduced the fracture toughness of the reactor vessel materials, a thermal annealing may be applied to the reactor vessel to recover the fracture toughness of the material. The use of a thermal annealing treatment is subject to the requirements in this section. **A report describing the licensee's plan for conducting the thermal annealing must be submitted in accordance with § 50.4 at least three years prior to the date at which the limiting fracture toughness criteria**

> **in § 50.61 or appendix G to part 50 would be exceeded.** Within three years of the submittal of the Thermal Annealing Report and at least thirty days prior to the start of the thermal annealing, the NRC will review the Thermal Annealing Report and make available the results of its evaluation at the NRC Web site, *http://www.nrc.gov.* [**Emphasis Added**][25]

Because recovery annealing is a significant change to a plant's operating license, federal statute requires that the Nuclear Regulatory Commission complete a 10 CFR §50.59 safety review that requires full public participation in the licensing process. Active public participation in such a license change would be highly likely in California, which could stop or delay the project for many years. According to the International Atomic Energy Commission, fear of public participation in an extended licensing process prevented the embrittled Palisades reactor from attempting the recovery annealing process:

> Why the Demonstration? – Palisades NPP
> - Palisades was limited to operate until 1999 based upon PTS concerns for the most-limiting weld metal heat (W5214 axial welds); other welds: 27204
> - Planned to anneal in 1998 to recover properties and continue operation to at least 2011 and hopefully beyond
> - **Annealing canceled due to revised fluence estimates; also concern about public hearings when authorized to anneal**[26] [**Emphasis Added**]

Conclusion

The neutron embrittlement problems at Diablo Canyon Unit 1 are some of the most serious in the United States. Unit 1 has been operating for more than three decades, and every year that passes increases the embrittlement risks. The continued operation of this

[25] 10 CFR § 50.66
[26] https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-11-05-11-08-TM-NPE/38.Server_USA.pdf

embrittled reactor in a location known for its seismicity presents safety risks unlike any other reactor in the United States.

While, it may be technically feasible to reduce the current embrittlement problems at Diablo Canyon by a recovery annealing of the reactor vessel using the "dry" annealing technique, there are two serious obstacles with this process. *First*, this is a process that has never been attempted on a U.S. reactor and may not be successful, and *second* there are serious risks and substantial costs that will be incurred with absolutely no guarantee that those costs will ever be recovered during the remaining *possible* operating life of these reactors.

Ultimately, the evidence reviewed that PG&E's continued operation of Diablo Canyon Unit 1 in such an embrittled and degraded condition is a real risk to public safety.

Docket No. 50-275-LR
Docket No. 50-323-LR

BEFORE THE UNITED STATES
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the matter of	)	
PACIFIC GAS & ELECTRIC COMPANY	)	Docket No. 50-275-LR
	)	Docket No. 50-323-LR
(Diablo Canyon Nuclear Power Plant, Units 2 and 3)	)	
		October 10, 2014

(License Renewal Application)

GUNDERSEN AFFIDAVIT
SUPPORTING FRIENDS OF THE EARTH'S PETITION TO INTERVENE

I, Arnold Gundersen, being duly sworn, state:

WITNESS BACKGROUND

Q1. Please state your name.

A. Arnold Gundersen

Q2. Please state your residential address.

A. Burlington, Vermont

Q3. What is the purpose of your testimony?

A. The purpose of my testimony is to examine the recently published *Central Coastal California Seismic Imaging Project* to see if its assessment is congruent with previous statements made by Pacific Gas and Electric (PG&E) regarding Diablo Canyon in its License Renewal Application.

Q4. Please summarize your educational and professional experience.

A. I earned my Bachelor Degree in Nuclear Engineering from Rensselaer Polytechnic Institute (RPI) cum laude. I earned my Master Degree in Nuclear Engineering from RPI via an Atomic Energy Commission Fellowship.

I began my career as a reactor operator and instructor in 1971 and progressed to the position of Senior Vice President for a nuclear licensee prior to becoming a nuclear engineering consultant and expert witness. An updated Curriculum Vitae is attached as Exhibit 1.

I have testified as a nuclear engineering expert witness before the Nuclear Regulatory Commission (NRC) Petition Review Board, Atomic Safety and Licensing Board (ASLB) and Advisory Committee on Reactor Safeguards (ACRS), in Federal Court, the State of Vermont Public Service Board, the State of Vermont Environmental Court, the Florida Public Service Commission, and the Canadian Nuclear Safety Commission (CNSC).

I am an author of the first edition of the Department of Energy (DOE) Decommissioning Handbook.

As an appointee of Vermont State Legislature for two years, I was charged with serving in an oversight role of the Entergy Nuclear Vermont Yankee power plant and an advisory role on nuclear reliability issues to the Vermont State Legislature.

My management experience as a nuclear industry vice president and senior vice president is pertinent to the seismic issues I am testifying about today. As a vice

president, I managed more than 70 engineers at Millstone Unit 3 who performed seismic calculations for power plant pipes and hangers. In addition, the division reporting to me was the responsible engineering firm preforming seismic calculations for the Lacrosse Boiling Water Reactor. Finally, this engineering division designed and fabricated seismically qualified nuclear fuel racks used at more than a dozen nuclear power plants throughout the United States.

I have more than 42-years of professional nuclear experience *including and not limited to*: Nuclear Power Operations, Nuclear Safety Assessments, Nuclear Power Management, Nuclear Quality Assurance, Archival Storage and Document Control, NRC Regulations and Enforcement, Licensing, Engineering Management, Contract Administration, Reliability Engineering, In-service Inspection, Thermohydraulics, Criticality Analysis, Radioactive Waste Processes, Decommissioning, Waste Disposal, Cooling Tower Operation, Cooling Tower Plumes, Consumptive Water Use, Source Term Reconstruction, Dose Assessment, Technical Patents, Structural Engineering Assessments, Nuclear Fuel Rack Design and Manufacturing, Nuclear Equipment Design and Manufacturing, Public Relations, Prudency Defense, Employee Awareness Programs, and Whistleblower Protection.

INTRODUCTION

Q5. Before we get into the specifics of your report, would you please explain recent changes relating to the seismic condition of the Diablo Canyon Nuclear Power Plant?

A. PG&E recently submitted a report entitled the *Central Coastal California Seismic Imaging Project* to the NRC. This new report continues to ignore current condition of the reactors and claims that the original design will still be adequate, despite seismic evidence to the contrary.

Q6. Before going into specifics, what is your broad conclusion?

A. My review of all the data shows that Diablo Canyon's License Renewal Application does not address the seismic protections PG&E claims it has reviewed in its newly released *Central Coastal California Seismic Imaging Project Report.* In my opinion, the new PG&E *Central Coastal California Seismic Imaging Project Report* raises serious concerns about the flaws in PG&E's license renewal application at Diablo Canyon. Rather than analyzing the effect of an earthquake on small and critical components, PG&E claims that its report and alleged analysis proves that the plant and its major components remain seismically qualified in the event of a rupture in the Hosgri fault. Small and critical operating components are not even addressed for seismic protections in the PG&E Diablo Canyon License Renewal Application. Moreover, according to the Seismic Imaging Project Executive summary:

> In all cases, the research confirmed previous analyses that **the plant and its major components** are designed to withstand—and perform their safety functions during and after—a major seismic event. …these study results will support a new NRC-mandated seismic hazard risk assessment for the DCPP …PG&E is using the review process required by the NRC, known as the Senior Seismic Hazard Analysis Committee (SSHAC) process, to incorporate and evaluate existing and new seismic information to update the seismic hazard analysis for DCPP. …PG&E is committed… to continually studying advances in seismic knowledge and assessing the implications on the seismic hazard analysis to ensure that the DCPP is designed to withstand the largest potential ground

motions produced by earthquakes from regional faults. That commitment extends beyond March of 2015 and will remain in effect throughout the operational life of the DCPP. (**Emphasis Added**)

HISTORICAL OVERVIEW OF DIABLO CANYON'S SEISMIC ISSUES

Q7. For the record, would you please delineate the protocol and basic timeline for the original licensure of Diablo Canyon?

A. Yes. Owned by Pacific Gas & Electric, the Diablo Canyon nuclear complex consists of two Westinghouse nuclear reactors, each with four steam generators in what is called a 'four loop design'. Each reactor produces slightly more than 1100 megawatts of electricity, and at the time these units were constructed, they were the largest designed in the world. In terms of its age and design features, Diablo Canyon is quite similar to the Zion nuclear complex in Illinois that was shut down 15 years ago and is currently being decommissioned and dismantled. When the Diablo Canyon nuclear plant design was developed during the mid-1960s, the ground acceleration of 0.40 g (40% the acceleration of gravity) was established as the worst seismic condition that any plant might be expected to experience. Although the construction was begun in 1968 with the reactors scheduled to begin operation in 1973, the operation of Unit 1 was delayed for 12 additional years until 1985 and Unit 2 began operation 1-year later due to numerous engineering and fabrication problems and newly discovered added earthquake hazards.

Q8. What seismic issues have impacted the Diablo Canyon site?

A. Four new earthquake faults were uncovered after Diablo Canyon's design was completed. The Hosgri Fault was the first, and seismological calculations show that it could produce ground accelerations almost twice as high as the Diablo Canyon plant is designed to withstand. Moreover, PG&E did not redesign all the plant features to accommodate the Hosgri fault data. Instead of strengthening the design to compensate for the fault data and applying for a license change, PG&E relaxed the safety assumptions it applied to the original design calculations. These manipulated calculations make the plant appear stronger than the original approved analysis can support.

Q9. In addition to the Hosgri Fault, what other faults were more recently discovered?

A. Unfortunately, the Hosgri Fault is not the only seismic danger facing PG&E's continued operation of the aging Diablo Canyon nuclear plant. In addition, three other significant geological faults were subsequently discovered in close proximity to the plant. The Shoreline Fault is one of the three additional faults found, and it is located only three football fields away from the safety related water intake structure for Diablo Canyon. Even though these three additional geological faults create significant seismological risk to the safe operation of Diablo Canyon, none of these faults has been analyzed and then filed in a public amendment to the Final Safety Analysis Report (FSAR) as required by federal statute 10CFR50.59.

Q10. Please compare the acceleration predicted in the original Diablo Canyon Design to accelerations caused by other faults after the original design was finalized.

Ground Acceleration Comparison with
Original Diablo Canyon Design Safe Shutdown Earthquake[1]

Local Earthquake Fault	Peak Ground Acceleration
Original Diablo Canyon Design SSE/DDE	**0.40 g**
Shoreline Fault	**0.62 g**
Los Osos Fault	**0.60 g**
San Luis Bay Fault	**0.70 g**
Hosgri Fault (Hosgri Exception)	**0.75 g**

Q11. What is the difference between the Richter Scale and Ground Acceleration?

A. While the Richter scale is a very useful public information tool when used to quickly convey the magnitude of total energy produced by a particular earthquake, it is not a scientific or engineering methodology sufficient to determine if structures and components have the physical integrity and ability to withstand the ground acceleration or g force[2] produced by seismic activity. Nuclear reactor seismic analysis must be completed using actual ground accelerations and not the total earthquake energy measured by the Richter scale. To design a nuclear plant, engineers use the postulated earthquake ground acceleration at the foundation of the structure as just one factor to begin to assess whether a nuclear plant can be built at a specific geological location. Above and

[1] Differing Professional Opinion – Diablo Canyon Seismic Issues (DPO), Michael Peck, Senior Reactor Instructor, Diablo Canyon, July 18, 2013, NRC Form 680

[2] A unit of inertial force on a body that is subjected to rapid acceleration or gravity, equal to 32 ft. per second per second at sea level or 970 meters per second; also written g-force http://dictionary.reference.com/browse/g+force?s=ts

beyond this single ground acceleration value, engineers must know the frequency at which the earth moves, the total distance the earth might move.

Q12. Can a single earthquake produce different ground accelerations?

A. The same earthquake will produce different ground accelerations depending upon the relative distance between the anticipated epicenter of the earthquake and the various locations within the nuclear plant. Of great concern is that different locations and buildings at a single nuclear power plant site may accelerate at different rates and vibrate at different frequencies during the same earthquake. The graph below shows that this change in acceleration from the same earthquake within a nuclear site was documented during the Kashiwazaki-Kariwa (K-K) earthquake in Japan, and it also shows that the K-K Design Basis assumed by the engineers was exceeded at almost every location. The values within the parenthesis are the design basis values. The value outside parenthesis is the actual acceleration.

SLIDE 19[3], Status of Kashiwazaki-Kariwa NPS

Observation Area	North-South Direction	East-West Direction	Vertical
Unit 1	311(274)	680(273)	408(235)
Unit 2	304(167)	606(167)	282(235)
Unit 3	308(192)	384(193)	311(235)
Unit 4	310(193)	492(194)	337(235)
Unit 5	277(249)	442(254)	205(235)
Unit 6	271(263)	322(263)	488(235)
Unit 7	267(263)	356(263)	355(235)

Despite the glaring differences evidenced at K-K in the seismic response of reactors on the same site, PG&E treats both Diablo Canyon reactors as if their response would be identical. (Acceleration values in the table are in Gall. Diablo's design basis ground acceleration of 0.4 g equates to 392 Gall.)

Q13. What factors other than ground acceleration must engineers consider in the seismic design of a nuclear power plant?

A. The seismic analysis does not stop with the displacement and movement of the foundation itself. Rather, as the forces move upward in the building, the building begins to sway through an ever-increasing arc as displacement increases, because the structure is not rigid. Called an "amplified response spectra" (ARS), the movement produced is similar to the movement that an upside down pendulum might experience.

[3] Source: Slide 19, *Status of Kashiwazaki-Kariwa NPS as of August 30, 2007*, ©2007 by The Tokyo Electric Power Company, Inc.

The acceleration and the building displacement become greater further above the building's foundation. Greater acceleration also creates greater force on safety-related systems that are at any level above the foundation level. Moreover, the movement at the top of the building may occur at an entirely different frequency than the movement applied to the foundation. For example, there will be less swaying in a building during an earthquake if the structure is a stiffer construction that has been specifically designed to withstand earthquake impact.

Q14. How is the stiffness of a structure described analytically?

A. For comparison, in describing a comfortable car with a soft ride, engineers would say that the car has a lower 'damping' than a low-slung sports car with a stiff ride. To compare stiff structures to ones that sway, engineers use a mathematical assumption for their calculations called a 'damping coefficient'. Larger damping coefficients imply that a building is stiff, smaller damping coefficients show that a building will sway more easily.

When Diablo Canyon was designed and built, the original design specified that it be built with small damping coefficients, meaning that the buildings where originally designed to sway more during a seismic event rather than less. However, when the Hosgri fault was discovered, those old calculations showed that an earthquake would most likely lead to reactor failure. By changing the damping coefficients without the requisite 10-CFR§50.59 license amendment, PG&E's calculations subsequently implied that the Diablo Canyon design could withstand the Hosgri earthquake.

Q15. Please compare the damping coefficients in the original FSAR with the changes made to accommodate the Hosgri Fault?

A. The following table compares the damping coefficients that the NRC accepted in the Diablo Canyon FSAR compared to the postulations actually applied by PG&E in its Diablo Canyon design for the premise entitled the Hosgri Exception.

Comparison of Critical Damping Values (% of critical damping)[4]

	Licensed by NRC in FSAR	Hosgri Exception
Containment/Concrete Structures	5.0	7.0
Welded Structural Steel	1.0	4.0
Bolted Steel	2.0	7.0
Vital Piping	0.5	3.0
Reactor Coolant Piping	1.0	4.0

Let me clarify these issues and facts: the physical structures at Diablo Canyon did not become stiffer and therefore more earthquake resistant, instead the mathematical assumptions and conditions that were applied to the calculations made the buildings only appear to be more earthquake resistant.

Q16. The *Central Coastal California Seismic Imaging Project* concluded that Diablo Canyon remains seismically safe. Does any evidence in the License Renewal Application support this statement?

A. The new PGE *Central Coastal California Seismic Imaging Project* report claims that the Diablo Canyon structures and "major components" are capable of withstanding a quake as large as Hosgri. This conclusion perpetuates these

[4] Differing Professional Opinion – Diablo Canyon Seismic Issues (DPO), Michael Peck, Senior Reactor Inspector, Diablo Canyon, July 18, 2013, NRC Form 680

unsupported damping assumptions for major structures, and yet completely ignores the impact the change in the dynamic response of the building will have on secondary equipment such as relay switches and pipe shock absorbers. These changes are simply not addressed in the License Renewal Application.

Q17. Can you say with any certainty that the acceleration from the Hosgri Fault will be the most severe acceleration that could be experienced at Diablo Canyon?

A. No. According to the historical earthquake data collected during the last 10 years at nuclear power plants throughout the world, the assumed design bases accelerations have been exceeded in every instance of a serious earthquake at a nuclear power plant site.

Q18. Would you please elaborate about the deviations about anticipated versus actual earthquake accelerations?

A. Yes. What follows below are nuclear industry wide historical examples of erroneous seismic assumptions.

The science of predicting the ground acceleration caused by earthquakes has a long history of underestimating both the magnitude and the probability of severe earthquakes. For example, the design criterion for an unanticipated severe earthquake and seismic event has already been exceeded at 12 nuclear power plants since 2007.

1. The first underestimated and unanticipated seismic activity occurred in 2007 at the Kashiwazaki-Kariwa (KK) reactor complex near Niigata in Japan. KK has seven nuclear reactors, and all seven reactors experienced ground acceleration higher than any of its designers had

anticipated. In the KK site comparison below, you will see that the anticipated ground accelerations exceeded the actual ground accelerations in every case. The design acceleration data in parenthesis proves that the owners and design engineers never anticipated the 2007 KK earthquake.

SLIDE 19[5], Status of Kashiwazaki-Kariwa NPS

Observation Area	North-South Direction	East-West Direction	Vertical
Unit 1	311(274)	680(273)	408(235)
Unit 2	304(167)	606(167)	282(235)
Unit 3	308(192)	384(193)	311(235)
Unit 4	310(193)	492(194)	337(235)
Unit 5	277(249)	442(254)	205(235)
Unit 6	271(263)	322(263)	488(235)
Unit 7	267(263)	356(263)	355(235)

The base of the turbine in Unit 3 at KK experienced the largest acceleration of 2058 Gal in the East-West direction (2.5 times the design-basis acceleration of 834 Gal). 'Gal' is a unit of seismic acceleration measurements similar to those given in terms of g. Simply put, 970 Gal is equal to 1 g of acceleration. *Visually, these are but a few examples of damage after the KK earthquake:*

[5] Source: Slide 19, *Status of Kashiwazaki-Kariwa NPS as of August 30, 2007*, ©2007 by The Tokyo Electric Power Company, Inc.

Earthquake Induced Fire at KK[6]

Buckled Concrete At The KK Reactor[7]

After the earthquake, it was clear that all seven reactors at the Kashiwazaki-Kariwa (KK) complex were significantly damaged. Safety system related fires, liquid and gaseous radioactivity releases from the

[6] Reuters Media http://s1.reutersmedia.net/resources/r/?m=02&d=20070716&t=2&i=1133170&w=580&fh=&fw=&ll=&pl=&r=1133170

[7] Reuters Media: http://s2.reutersmedia.net/resources/r/?m=02&d=20070721&t=2&i=1165383&w=580&fh=&fw=&ll=&pl=&r=1165383

spent fuel pools, and damage to the nuclear fuel racks had occurred at the KK site. Furthermore the post accident engineering and safety reviews identified more than 2,500 components that were significantly damaged by the earthquake, and at least two of the reactors at KK will never start up again.

Fairewinds believes that the earthquake that compromised the KK facilities has direct analogies to Diablo Canyon because such an accident was not anticipated to happen during the life of the reactors, its ground acceleration was higher than any original design engineering had anticipated, and the seismic activity damaged vital nuclear power plant safety-related equipment. This unanticipated earthquake shut down all seven nuclear reactors, some of which will never start up again, and it has resulted in a lengthy reanalysis of all the structures and systems on the entire site. The data also makes clear that acceleration varied widely from building to building on the same site, which is not included in the Diablo Canyon analysis.

2. The second underestimated and unanticipated seismic activity occurred in 2011 at the North Anna nuclear site located in Virginia. The ground acceleration that followed this earthquake was approximately 0.12 g, which was slightly larger than what the plant engineers had anticipated in the site's design bases as a once in a more than 1000-year probability earthquake. What makes the 2011

North Anna earthquake even more significant is that it was never anticipated to happen during the life of these nuclear reactors. When the North Anna site was designed during the 1960s and 1970s, a .12 g seismic event was the worst ever earthquake that was anticipated to occur at the North Anna site, yet it occurred only 30-years after the plants began operation. While the Nuclear Regulatory Commission has stated that the North Anna reactors safely survived this major seismic event, it is distressing that an earthquake anticipated only once in 1000 years actually occurred at this site during the first 30 years of nuclear power operation.

Contemporaneous accounts of the earthquake exceeding the design basis include the following:

> "Dominion has confirmed that the August 23, 2011 earthquake exceeded the spectral and peak ground accelerations for the Operating Basis and Design Basis Earthquakes ("OBE" and "DBE", respectively) for North Anna Power Station Units 1 and 2." [8]

> North Anna is designed to withstand 0.12G. Dominion told the Nuclear Regulatory Commission that ground acceleration at North Anna "may have exceeded plant standards," …"It seems there is some uncertainty about even understanding the relationship of [quake] magnitude and peak ground acceleration — even when the quake is nearby"[9]

[8] https://www.dom.com/about/stations/nuclear/north-anna/pdf/Earthquake_Summary_Report_and_Restart_Plan_091711.pdf
[9] http://articles.baltimoresun.com/2011-09-06/business/bs-bz-hancock-nuclear-earthquake-20110903_1_constellation-energy-nuclear-group-nuclear-plant-fukushima

> "A laboratory analysis of the plates indicated that the horizontal ground acceleration was greater than had been anticipated in the plant's design." [10]

These photos[11] of the spent fuel casks at the North Anna nuclear power plant in Virginia show that the ground moved four inches beneath the fuel casks during the recent earthquake.

North Anna Spent Fuel Casks

[10] http://www.nytimes.com/2011/09/08/science/earth/08nuclear.html?pagewanted=all
[11] http://www.nrc.gov/info-finder/reactor/na/dominion-slides-11-01-2011-meeting.pdf

Detailed View of Earthquake Movement Below North Anna Spent Fuel Cask

Of greater concern to this review of Diablo Canyon is the fact that the North Anna site is an East Coast site, so it has not been considered at as great a risk for geological activity as the Diablo Canyon site with its location on a major geological fault line. The North Anna site has two operating reactors built at approximately the same time as Diablo Canyon and its design basis earthquake is only 0.12 g. Now, since there are plans to build a third, new reactor at this same Virginia location, the newer more accurate estimated seismological ground acceleration figure of 0.53 g will be applied to all engineering design and fabrication calculations.

> "Experts hired by Dominion for the proposed North Anna project pegged the peak ground acceleration that should be factored into a new reactor's design at 0.535g—about half

> the force of gravity and likely to be produced only by a substantial earthquake." [12]

Surprisingly the calculations for this proposed Virginia nuclear power plant anticipate a design basis earthquake that is four times higher than the original design assumptions, and incredibly, is higher than the assumed worst case anticipated seismic activity ever calculated to occur at the Diablo Canyon site. The fact that a new East Coast reactor has higher seismic standards than the site of an old reactor in California speaks to better scientific understanding of earthquakes and ground acceleration since the design and construction of the Diablo Canyon plants. Such stringent new standards for the more modern reactors fly in the face of the NRC's desire to 'grandfather' existing fragile designs like that at Diablo Canyon in order to avoid more rigorous 21st century scientific scrutiny.

3. The third and final seismic activity that was underestimated and unanticipated by the nuclear industry struck the Fukushima Daiichi nuclear complex on March 11, 2011. While the earthquake in the ocean exceeded a 9.0 on the Richter scale, the ground movement on the site was less because it was separated by more than 100 miles from the epicenter of the earthquake. In the official 2011 analysis of the Fukushima Daiichi nuclear accident prepared by the Japanese government, officials said,

[12] http://online.wsj.com/news/articles/SB10001424053111904875404576528472240850378

> "…maximum acceleration of seismic ground motion observed in three components (east-west, north-south and vertical) at the base mat level of the reactor buildings. Maximum acceleration in horizontal direction was 550 Gal at Unit 2 (east-west) and that in vertical direction was 302 Gal at Unit 2."[13]

The unit of "Gal" is quite similar to the seismic acceleration measurements given in terms of g. Simply put, 970 Gal is equal to 1 g of acceleration. Converting 550 Gal to its equivalent g rating shows that the horizontal ground movement at Fukushima Daiichi was 0.56 g. The vertical acceleration then was 0.31 g.

The ground acceleration experienced at the Fukushima site was almost identical to that which was anticipated at Diablo Canyon in it's design phase in 1970 and is critically important to evaluate because both the magnitude of the quake and the frequency of its occurrence were underestimated.

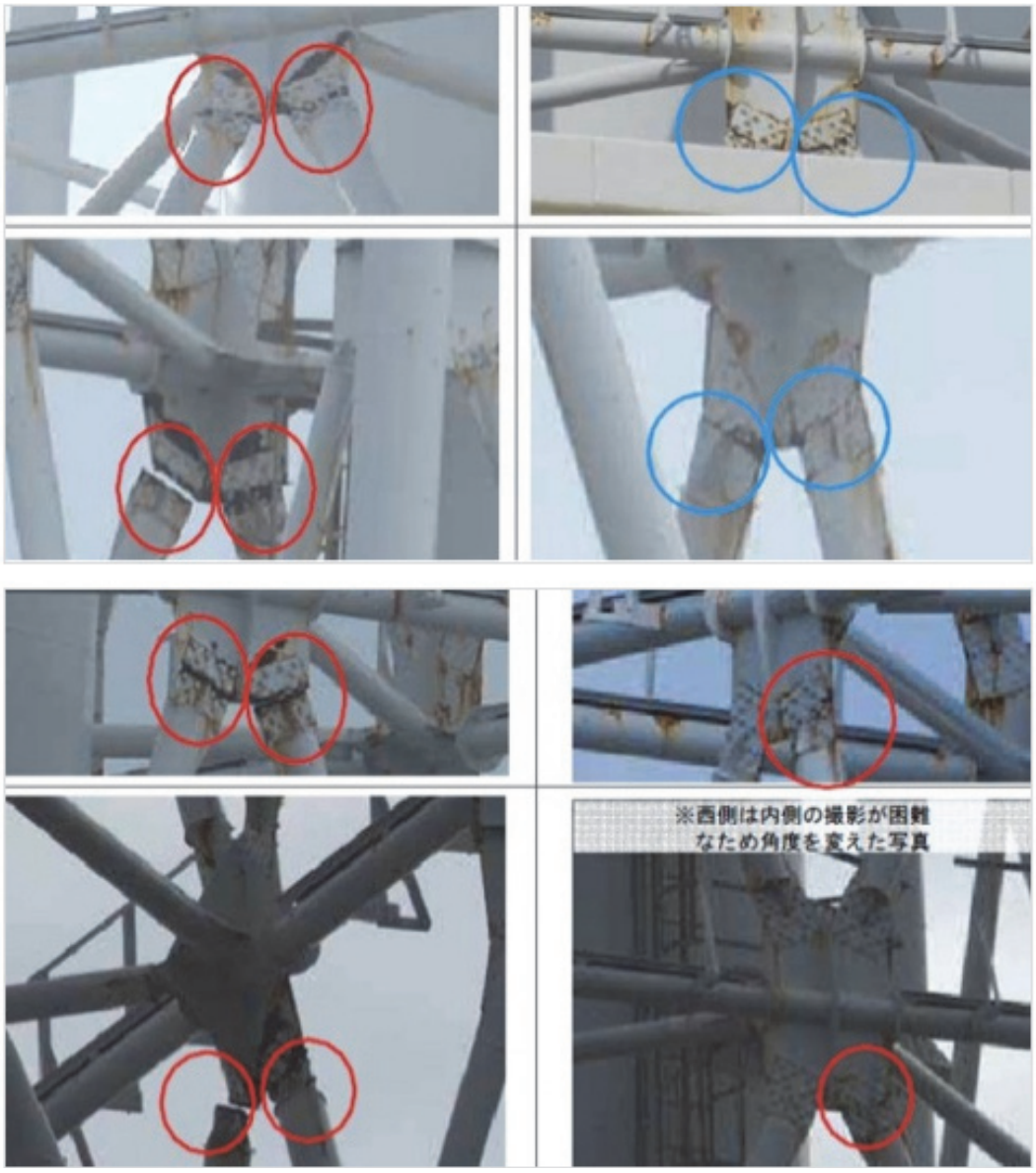
Ground Accelerations at Fukushima Daiichi Exceeded Design Basis

	Max. Actual Acceleration Gal- East to West Motion	New 2006 Design Basis Gal-East to West Motion	Original Design Gal
Unit 1	447	289	245
Unit 2	550	438	250
Unit 3	507	441	291
Unit 4	319	445	291
Unit 5	548	452	294
Unit 6	444	448	500

[13] Report by the Japanese government to the IAEA titled *Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety—The Accident at TEPCO's Fukushima Nuclear Power Stations*, *APPENDIX E, Comparison of the Earthquake and Tsunami to Design Basis in Japan*, Government of Japan (June 2011).

Many of the components, designed by the nuclear industry to withstand a force of the magnitude exhibited at Fukushima Daiichi, were severely damaged at the site by the earthquake's ground acceleration. Damage at the site includes severe cracking to the seismically qualified 100 meter tall ventilation stack, damage to the spent fuel pool floor, a first mode Euler strut buckle in the side of the reactor building as well as cracks in the reactor coolant piping. Additionally, the radiation levels at the Fukushima Daiichi site are so extraordinarily high, that a full assessment of the structural damage caused by this earthquake may never be possible.

1 **Earthquake Damage to the Fukushima Daiichi 100M Stack**[14]



2

[14] Title: (Systran Translation) Fukushima No. 1 nuclear power plant — Safety appraisal for the component damage of the machine chimney
Source: TEPCO
Date: Oct. 7, 2013

Q19. What is the implication of this historical overview on earthquake accelerations anticipated at Diablo Canyon?

A. The data shows that a more severe earthquake than those anticipated due to the Hosgri fault is likely to occur. The PG&E reanalysis to accommodate the accelerations anticipated by the Hosgri Fault has simply reduced design margins and has not improved earthquake resiliency at Diablo Canyon. The calculations that engineers applied to the seismic analysis at the Fukushima Daiichi site are identical to the calculations that engineers used at the Diablo Canyon site. The experience at Fukushima Daiichi shows that there is no certainty that the Diablo Canyon reactor will be able to withstand its current design bases accident of 0.4 g. Even with these new revelations from the tragic triple meltdowns at Fukushima Daiichi, both Pacific Gas & Electric and the NRC continue to ignore the Hosgri and Shoreline fault data that clearly indicates the ground acceleration will in fact be much, much worse.

The real lesson of the KK and North Anna earthquakes is that the science of predicting the frequency and intensity of large earthquakes is flawed. Moreover, it is evident by looking at the Fukushima Daiichi accident that existing seismic calculations used to protect safety systems failed. The evidence reviewed by Fairewinds shows that it is reasonable and prudent to understand that the continued operation at Diablo Canyon may be flawed because it is based upon inaccurate data that can no longer be substantiated.

DIABLO CANYON SEISMIC ASSESSMENT

Q20. What are the ramifications of seismic analytical changes on Diablo Canyon and its License Renewal Application?

A. The ramifications of seismic analytical changes are both electrical and mechanical.

Let's look first at the electrical ramifications: on the first page of its Central Coastal California Seismic Imaging Project Report executive summary, PG&E stated:

> *... the research confirmed previous analyses that the plant and its major components are designed to withstand—and perform their safety functions during and after—a major seismic event.*

Fairewinds disagreement with the PG&E *Central Coastal California Seismic Imaging Project Report* begins with this very first statement. The seismic issues at nuclear power plants are not only limited to buildings and "major components". During a seismic event, the dynamic response of the building causes many small but critical electrical components to be at greater risk for failure. I have seen no evidence that PG&E has analyzed these small and critical safety and operating components.

Q21. Exactly what critical electrical components were not adequately reviewed or addressed in the *Central Coastal California Seismic Imaging Project* or the PG&E License Renewal Application?

A. I believe that relay switches have not been adequately reviewed. Relays are mechanical switching devices that are used at Diablo Canyon to control the flow

of electricity to vital electrical motors and other components. Relay switches use a relatively low voltage control signal to switch high-voltage electrical compliments on and off. Normally the electrical contacts inside each relay switch is held closed because they are energized by an electromagnet. When the low voltage current used to control the electromagnet is stopped and the electromagnet is de-energized, the relays open using springs. This allows electricity to flow when energized and to stop when de-energized. When the electromagnet is not functioning properly, or when the relay switch is shaken during an earthquake, these relay switches open and close in an unpredictable manner that is called "relay chatter".

Relay switches also perform the critical function of turning on and off vital nuclear safety related electric pumps and motors that are used to cool the reactor in the event of an earthquake. Fairewinds searched the entire DCPP License Renewal Application for the keyword "relay" and found no references. Fairewinds also searched the Central Coastal California Seismic Imaging Project and found references to "large components" being seismically qualified but no discussion of smaller items such as relay switches. Fairewinds finds this lack of assessment of small critical electrical devices to be a glaring omission, especially considering the critical importance of relay switches to assure the safe shutdown of the Diablo Canyon reactors in an accident.

Q22. Why is Relay Chatter important to nuclear power plant safety?

A. *Relay Chatter* is one of the most critical and insidious problems that lies hidden within the detailed seismic engineering analyses that must be performed by Pacific Gas & Electric. An electric relay is similar to a large switch or a circuit breaker.

In the event that buildings at Diablo Canyon were to shake excessively, some of these electrical switches (relays) would bounce open and closed and would not remain in their correct open or closed position. Because the problem of relay chatter is so serious and so pervasive, it appears that the new Diablo Canyon Central Coastal California Seismic Imaging Project is completely ignoring this significant safety issue by claiming that its analysis applies only to *major components*.

Relay chatter is extremely dangerous because it can prevent electricity from reaching critical pumps that are needed to cool the nuclear reactor. After an earthquake, relay chatter will also prevent electrical signals that are necessary to monitor and safely operate the reactor from reaching the control room operators.

Q23. Is the NRC aware of these Relay Chatter safety issues?

A. This issue is so important that in 1987, the Nuclear Regulatory Commission issued a generic report notifying the nuclear industry that there was a 100% likelihood that safety related relays would not function properly in the event of an earthquake. Entitled *NUREG/CR-4910: Relay Chatter and Operator Response*

After a Large Earthquake, An Improved PRA Methodology With Case Studies was published in 1987 after Diablo Canyon had already received its operating license.

The critical *Relay* Chatter NRC safety report NUREG/CR-4910 is based upon a postulated small Midwest earthquake at a plant similar to Diablo Canyon. Although this earthquake postulated by the NRC was only a small one, the NRC still concluded that at least some instrument relay switches have a 100% probability that they will fail due to an earthquake. Because the report is written with engineering terminology, non-engineering readers often do not see the problem. For example this important *Relay Chatter NUREG/CR-4910* uses the engineering term "unity", which is defined a 100% probability of an event occurring. Relay failure of this magnitude will increase the frequency of reactor core damage so that necessary and critical nuclear power plant operator response is not assured. This is the pertinent excerpt from the report:

> For both Zion-I and LaSalle-2, assuming that loss of offsite power (LOSP) occurs after a large earthquake and that there are no operator recovery actions, the **analysis finds very many combinations** (Boolean minimal cut sets) **involving chatter of three or four relays and/or pressure switch contacts**. The analysis finds that the number of min-cut-set combinations is so large **that there is a very high likelihood (of the order of unity) that at least one combination will occur after earthquake-caused LOSP**. This conclusion depends in detail on the fragility curves and response assumptions used for chatter. Core-damage frequencies are calculated, but they are probably pessimistic because assuming zero credit for operator recovery is pessimistic. The project has also developed an improved PRA methodology for quantifying operator error under high-stress conditions such as after a large earthquake. Single-operator and multiple-operator error rates are developed, and a case study involving an 8-step procedure (establishing feed-and-bleed in a PWR after an earthquake-initiated accident) is used to demonstrate the methodology. **High-stress error rates are found to be significantly larger than those for no stress**, but smaller than

found using methodologies developed by earlier investigators.
(Emphasis Added)[15]

Q24. In the event of an earthquake, what action is required to assure that the relay switches are in the proper position?

A. Operators must move throughout the plant to reposition any failed relay switches.

Q25. Is it plausible that after a seismic event at Diablo Canyon operators will be able to freely move throughout the plant to correct relay switches?

A. No, it is not plausible. The NRC report is not realistic because it totally discounts the reality of the post earthquake and accident plant condition evidenced at Three Mile Island and Fukushima Daiichi. The report anticipates that following an earthquake, the operators would be able to repair individual relay switches that are not operating properly by easily walking around the plant and taking manual action to change the position of the relay.

However, history has clearly shown that in the event of a design basis earthquake the nuclear plant will be littered with rubble that would impede operator access to failed relays.

Not only are large structures and safety related components more likely to collapse and thereby limit operator access. There are also many smaller components that could also collapse during an earthquake, especially because these smaller components are usually designed to a much lower seismic standard

[15] *NUREG/CR-4910: Relay Chatter and Operator Response After a Large Earthquake, An Improved PRA Methodology With Case Studies Manuscript Completed: June 1987,* Page iii

than larger safety-related components. Smaller components are commonly called Seismic Class II compared to the Seismic Class I larger components.

Seismic Class II components have been known to collapse at nuclear power plants. For example, as recently as 2007, such an incident occurred at the Wisconsin Monticello nuclear power plant when, a non-safety related component weighing approximately 50,000 pounds fell directly onto safety-related equipment destroying itself and shutting down the nuclear reactor. While this component was seismically qualified, it did not fail in an earthquake, and rather simply fell during normal operation. A NRC review determined that this failure was due to structural problems with the initial design created 35 years earlier.[16] According to the NRC Licensing Event Report (LER):

> The root cause of this event was determined to be latent shortcomings in the design and construction of the turbine control valve enclosure support system during initial construction.

Monticello's failed equipment was also supposedly seismically designed, yet as an aging plant with a 35-year-old design, it was not even capable of the normal day-to-day operation in an area of the country where the seismic design burden is for the much less stringent, Midwestern earthquake standard. The message is simple: Operator access will be impeded to safety related relays in the event of an earthquake.

Of course, the aftermath of the accident at Fukushima Daiichi shows just how much earthquake-induced rubble can impede access to areas where important safety related relays are located. Numerous first hand accounts and photographs

[16] LER 2007-001: Reactor Scram due to Turbine Control Valve Housing Support Failure

taken by robots inside the Fukushima Daiichi plants that show the extent of rubble that fell from the ceiling during a real accident event and impeded access to critical parts of the plant as safety-related components were destroyed. In the photo below, look at the condition of the relay cabinets at Unit 4 of the Fukushima Daiichi Complex.

Accident Rubble and Relay Cabinets At Fukushima Daiichi[17]

Q26. How do the seismic accelerations in the Zion nuclear plant study compare to those at Diablo Canyon?

A. The relay chatter problems that were identified at the Zion nuclear plant located in Illinois are much LESS serious than those that have been identified at Diablo Canyon. Although the power plant designs are almost identical, the seismic accelerations would be much greater and more severe at Diablo Canyon. The

[17] http://www.powerandpolicy.com/wp-content/uploads/2011/09/fukushima-june-9.jpg

Zion nuclear plant is a Westinghouse PWR with four primary coolant loops, and has already been shutdown for more than 15 years. Like Diablo Canyon, Zion was also designed during the 1960s. It generated slightly more than 1,000 MWe and came online in 1973, when Diablo Canyon was also designed to start up. Diablo Canyon also is a Westinghouse four-loop design that generates 1,100 MWe, but it did not start up in 1973 as originally planned. Diablo Canyon did not start generating electricity until 1985 due to long delays in construction. More importantly, Diablo Canyon received its operating license prior to this NRC recognition and review of this critical *Relay Chatter* issue.

Q27. Has the issue of Relay Chatter ever been evaluated for Diablo Canyon?

A. No, the Relay Chatter problem was not analyzed as it pertains to the Diablo Canyon Operating License, which first became operational in 1985. According to the 1987 *Relay Chatter and Operator Response* Report introduced and discussed above,

> Other papers and research reports have identified various methodological weaknesses in seismic PRA methodology. An example is the review of seismic PRA accomplished as part of NRC's "seismic margins program" (Ref. Budnitz et al., 1986), which identified various inadequacies, and focused attention on relay chattering and circuit-breaker tripping. …**Relay chatter was not treated at all in the three important early utility sponsored full-scope seismic PRAs**.[18] **[Emphasis Added]**

Q28. Based upon your review of the *Central Coastal California Seismic Imaging Project Report* and the Diablo Canyon License Renewal Application, do you have any new technical concerns related to relay switches at Diablo Canyon?

[18] Page. 1-3 and 1-4

A. Yes, following my review of this new material, I have two new serious technical concerns related to relay switches.

Concern 1:

The relay switches that were designed and installed at Diablo Canyon were purchased, tested and installed during the 1970s well prior to the purported seismic reanalysis of Diablo Canyon due to the discovery of the Hosgri fault. I can find no record that these old relay switches were ever seismically qualified and reassessed using a deterministic methodology to meet new design bases standards due to the discovery of the Hosgri Fault. As I previously detailed, PGE changed the damping coefficients of the buildings that in turn would have changed the seismic response qualifications of each of the hundreds of relay switches that would be impacted by an earthquake.

Based on the newly released PG&E *Central Coastal California Seismic Imaging Project Report* stating that the seismic design focus was only on "major components", it appears that Diablo Canyon has never reanalyzed the relay chatter issue using a deterministic methodology. With the discovery of the Hosgri fault, the changes to Diablo Canyon's existing 1970s seismic design basis as they apply to electrical relay switches appear to ignore any damage that is likely to occur. Look again at the earthquake induced Fukushima Daiichi post-accident photo. Not only are the relay switches inaccessible due to all the debris, but also they are totally destroyed.

In my expert opinion, PG&E should have conducted a major reanalysis of all the seismic qualifications and reliability of all relay switches at Diablo Canyon for the increased seismic design basis identified in *the Central Coastal California Seismic Imaging Project*.

Concern 2:

While Fairewinds has found no evidence to support relay chatter reanalysis occurred at Diablo Canyon, we believe that even if the electrical relay switches at Diablo Canyon had been reanalyzed with new seismic assumptions, other aging management concerns related to relay chatter still remain.

As stated earlier in this report, relay switches are mechanical devices designed to allow and/or prevent the flow of electricity by using springs, electromagnets, and mechanical couplings (called armatures) designed to pivot. As these relays age, the mechanical components within them deteriorate. This mechanical deterioration within the relay switch itself will change the relay's response to a seismic event and will definitely increase the likelihood of relay chatter.

Neither the *Central Coastal California Seismic Imaging Project Report* nor the Diablo Canyon License Renewal Application address mechanical deterioration of the relay switches due a seismic event, yet the Imaging Project makes the claim that it proves that "major components" are seismically protected. Such an assertion implies that the existing License Renewal Application for Diablo Canyon is inadequate to address relay chatter in the event of the very earthquakes

possible along the Shoreline or Hosgri faults identified that were by the Central Coastal California Seismic Imaging Project.

Specific examples of the failure of the Diablo Canyon License Renewal Application to address the seismic effects on electrical relays include:

1. Industry experience indicates that the heat dissipated by energized relay switches has accelerated aging and hardened the lubrication applied to the armatures. Neither the License Renewal Application nor the latest *Central Coastal California Seismic Imaging Project Report* includes any affect on relay chatter due to hardening of the lubrication as the relays age. Therefore, the License Renewal Application cannot provide adequate assurance that the relays will function correctly in the event of an earthquake at Diablo Canyon as analyzed in the Seismic Imaging Project.

2. It is well known that as a function of age the spring constant of any spring changes over time, use cycles, and temperature. Yet, it appears that PG&E's sole focus on "major components" in the Central Coastal California Seismic Imaging Project assumes that the springs in Diablo Canyon's relays behave no differently now than they did when they were newly fabricated installed back in the 1970's.

3. The electric current traversing the relay switches has increased the temperature of the spring causing the "spring constant" to change with age. The spring constant is a mathematical value unique to each spring that characterizes the force the spring can exert. Furthermore, the relay

switches have been repeatedly cycled on and off. This repetitious movement also changes the spring constant. Neither the License Renewal Application nor the latest *Central Coastal California Seismic Imaging Project Report* include the study of any impact such wear and aging has had on relay chatter. These relay switches have experienced changes in the spring constant due to temperature fluctuations and the number of times each relay switch has been cycled on and off.

Therefore, it simply is not enough for PG&E to test the Diablo Canyon relay switches to see if they turn on and off properly. Testing the relay switches by simply turning them on and off will not determine the internal condition of the springs and other moving parts or how this aged pieces of equipment may behave when subjected to relay chatter from the newer Hosgri assumptions. The License Renewal Application fails to test every relay switch to determine its actual condition in 2014 and assess whether or not it should be replaced or if it is strong enough to withstand the relay chatter postulated in the original Diablo Canyon design as modified by the Hosgri Exception.

According to NUREG/CR-4910, in the event of an earthquake the relay switches will definitely chatter. However, due to aging, the mechanical characteristics of each relay switch have changed over time since these switches were fabricated and specified in the original pre-Hosgri design. These aging induced changes will definitely impact seismic response of each relay switch, and that response will not be the same as previously predicted by any seismic analysis performed PG&E. It is unclear whether the switches were analyzed and specifications changed to

accommodate the Hosgri exception. There is no assurance from either the License Renewal Application or the *Central Coastal California Seismic Imaging Project Report* that the relay switches will function properly in the event of an earthquake.

Q29. You have discussed electrical concerns, in your review of this new data. Did you uncover any mechanical concerns?

A. As I discussed earlier in my review of electrical relay concerns, PG&E stated in the first page of its executive summary of the *Central Coastal California Seismic Imaging Project Report* that:

> …the research confirmed previous analyses that the plant and its **major components** are designed to withstand—and perform their safety functions during and after—a major seismic event.

Concern 3:

Relay switches are not the only small component that deteriorates with age. Mechanical shock absorbers and snubbers will also show significant deterioration during their 40-year lifespans of fabrication and installation at Diablo Canyon. The designer adjusts the stiffness (damping coefficient) of these components. Therefore changing the assumptions for the dynamic response of the building as part of the Hosgri exception causes many small but critical mechanical components to be at greater risk for failure. By focusing only on the impact an earthquake may have on "*major components*", PG&E has failed to analyze any of these small but critical components including the snubbers and shock absorbers.

Major components, such as pipes, are prevented from excessive movement in an earthquake by small components like shock absorbers and snubbers. It is not clear from the License Renewal Application, or from the *Central Coastal California Seismic Imaging Project Report*, that mechanical shock absorbers and snubbers will act to limit seismic damage in the event of a Hosgri earthquake.

When contemplating seismic damage, most people think of damage to large pipes and the buildings' concrete as the most significant problems. Safety related pipes containing large amounts of radiation are certainly prone to failure in the event of an earthquake similar to those postulated at Diablo Canyon. These pipes are connected to the concrete structure by pipe hangers designed to handle the dead weight of the pipes, and snubbers. These specialized springs and devices are similar to the shock absorbers on cars, and have been constructed to allow the pipe to move slowly during an earthquake, yet not break. These snubbers are unique and are not a one size fits all fitting, but rather have specific damping characteristics that have been designed based upon specific mathematical calculations required for each unique application. Hundreds of engineering hours are required to analyze each hanger or snubber, and there are thousands of them that require reanalysis. The picture below is an example of how a nuclear pipe is restrained by snubbers in the event of a nuclear accident.

Snubbers Slow the Lateral Motion of Pipes During an Earthquake[19]

If the building accelerations have not been adequately calculated, a major redesign will be required to assure a component of this size and importance will not shatter during a major earthquake. Given the parameters under which it was designed, it is unlikely that critical safety equipment operating within the Diablo Canyon nuclear power plant could survive a major seismic event. For example, *the snubbers in the above photograph were installed in the KK reactors following the 2007 KK earthquake. In order to meet safety parameters and compensate for the increased seismic risk, the KK plants were shutdown for more than three years in order to facilitate seismic redesign calculations and the necessary modifications.*

PG&E changed the damping coefficient assumptions (identified earlier in this report) after the discovery of the Hosgri fault. These changes should

[19] http://www.jsm.or.jp/ejam/Vol.1.No.3/GA/7/article.html

have a direct impact on the License Renewal Application testing criteria of the shock absorbers and snubbers at Diablo Canyon. These analytical assumptions PG&E made in the late 1970's to stiffen the buildings and "major components" could only have been accomplished by changing the physical characteristics of the snubbers and shock absorbers that they had already installed at Diablo Canyon.

If indeed Diablo Canyon ever implemented the Hosgri Exception (HE) stiffness changes for its snubbers and shock absorbers, then the revised damping coefficients would have to be tested in the License Renewal Application. This implies that the technical speculations as implemented through the License Renewal Application would show stiffer (Hosgri) values, even though the plant design basis damping values identified in the licensing basis have not been changed.

The only way that PG&E can now claim in its Central Coastal California Seismic Imaging Project that "major components" are seismically protected is if the License Renewal Application using Hosgri Exception stiffness constraints. If so, then the Design Basis Damping Coefficients in the FSAR are being ignored.

This presents an obviously confusing dilemma. The Central Coastal California Seismic Imaging Project focuses on the effect of an earthquake on "major components." Snubbers and shock absorbers are attached to these major components to limit their motion. The Central Coastal

California Seismic Imaging Project implies that damping coefficients have been changed to add stiffness after the Hosgri fault was discovered, even though the licensing basis in the FSAR was never approved using these stiffer damping coefficients.

Based on the statements in the Central Coastal California Seismic Imaging Project stating that "major components" are protected in the event of an earthquake on the Hosgri fault, it appears that the Diablo Canyon snubbers and shock absorbers have always been tuned to the stiffness required by the Hosgri Exception.

Diablo Canyon's snubbers and shock absorbers appear to have been adjusted prior to 1985 to higher stiffness without a 10CFR50.59 license submittal and have never been in compliance with the original design basis of the plant. The Hosgri Exception damping values appear to be included in the License Renewal Application without an amended license. The License Renewal Application as proposed by PG&E contains information that is in contradiction with the original FSAR.

CONCLUSION

Q30. Has your review of the *Central Coastal California Seismic Imaging Project Report* created any new concerns about the Diablo Canyon License Renewal Application?

A. Yes, it has. The Diablo Canyon License Renewal Application is not consistent with the newly released *Central Coastal California Seismic Imaging Project*

Report for either electrical relays or shock absorbers and snubbers. The Diablo Canyon nuclear station is operating in direct contradiction to its license and the ability of the plant to withstand a Hosgri fault earthquake cannot be assured.

End

I declare that under penalty of perjury that the testimony submitted in this proceeding is true and correct to the best of my knowledge. The facts presented in this declaration are true and correct to the best of my knowledge, and the opinions expressed are based on my best professional judgment.

Executed in Accord with 10 CFR 2.304 (d),

(Electronically signed)

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