WRITTEN STATEMENT

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TO THE
SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

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Senator Boxer, Ranking Member Vitter, and Members of the Committee,

Thank you for the invitation to testify at today's hearing titled 'NRC's implementation of the Fukushima near-term task force recommendations and other actions to ensure and maintain nuclear safety.' The Fukushima meltdowns raised important concerns about nuclear reactors and one of those concerns relates to seismic safety. As a geophysicist and former California State Senator, I authored AB 1632, a bill that required PG&E to conduct seismic hazard research of the faults near the Diablo Canyon Nuclear Power Plant (Diablo) housed in the community that I reside in and represented for 8 years as a state legislator. Just two months ago, PG&E published the Coastal California Seismic Imaging Project (CCCSIP) Report and the results were astonishing. The Report documents the presence of a number of earthquake faults discovered after the design and construction of the plant that have been found to be larger and more dangerous than previously understood. In a post-Fukushima regulatory environment, it is important that policymakers and regulators understand the ramifications of these findings.

EXECUTIVE SUMMARY

PG&E has a long history of grappling with California's earthquake faults when trying to site its nuclear plants. It had previously proposed a nuclear power plant on the California coast at Bodega Bay but abandoned the plan when it was discovered that the site was to be built overtop the Shaft Fault and within 1000 feet of the San Andreas Fault. Later, PG&E built a small nuclear power plant on the California coast at Humboldt Bay, but the plant was shut down after the discovery of three faults within few thousand meters of the plant. PG&E selected the location for the Diablo plant, representing that the seismic activity in the area was minimal.

In the late 1970s, when Diablo was still under construction, data surfaced on the presence of a large active fault (named the Hosgri) located just three miles offshore from the plant. PG&E first denied its existence. When that assertion was disproved, it argued the fault was likely inactive. When PG&E had to concede it was active, it argued it was not capable of producing particularly large earthquakes. It turned out it that was capable of generating very large earthquakes.

In a recent replay of these events concerning a newly discovered fault system, the Shoreline fault was discovered in 2008 and analyzed with state-of-the-art methods and found to be capable of generating an M7.3 earthquake within a mere 600 meters of the plant.

There is no getting around the fact that PG&E has consistently downplayed seismic hazards on the coast near its nuclear plants. Especially disturbing is that during these past decades the NRC has repeatedly relaxed its seismic standards to accommodate the operation of Diablo Canyon.

Now that the data about the faults near Diablo is indisputable, PG&E has changed tactics and declared the plant safe on the basis of a new set of equations it has developed. PG&E has undertaken major revisions to the complex ground motion equations that have been used to estimate how much shaking can be produced by earthquakes. Unsurprisingly, PG&E's changes to its methodologies have dramatically reduced estimated shaking at the plant from all hypothetical earthquakes. So far, NRC has largely gone along with these changes.

With PG&E's history of playing down seismic concerns these recent developments are cause for deep concern. So is PG&E's documented history of co-opting the very regulatory bodies tasked with overseeing it. Just this year:

- PG&E was found to be inappropriately, and possibly illegally, lobbying California Public Utilities Commissioners and staff to successfully "judge shop" in a case before the CPUC. The revelation resulted in the firings of three senior PG&E executives, the reassignment of the CPUC's chief of staff, and the decision by the President of the CPUC to recuse himself from future PG&E decisions and to not seek re-appointment. The CPUC was just fined a $1.05 million for this back-channel lobbying.

- PG&E was indicted on 12 criminal charges related to safety violations in its gas distribution, including an accusation that PG&E officials obstructed a federal investigation and that the utility "knowingly relied on erroneous and incomplete information" to avoid inspections that would have exposed risks that ultimately killed 8 people in a 2010 gas pipeline explosion

- PG&E was discovered, through email disclosures, to be exploring how and when the Diablo Canyon Independent Peer Review Panel could be disbanded. This is the state-mandated panel tasked with providing third-party quality control of seismic risk analysis at Diablo that is quantified by the Report, which is my subject here.

In 2013, because of steam generator failures, San Onofre, California's only other nuclear power plant was permanently shut down at great cost to ratepayers, shareholders, and grid operations. Last month, the Office of the Inspector General at the NRC issued a report criticizing the NRC's failure to call for a license amendment process, which might have identified the shortcomings of the utility's technical analysis that ultimately led to those leaks. The safety ramifications of steam generator leaks at San Onofre, as serious as they were, are dwarfed by the risks to the public should PG&E's Diablo seismic analysis prove to be incomplete or inaccurate. You would think that after Fukushima the NRC would go beyond a "check the box" review process when confronted, as it is at Diablo, with the possibility of a 7.3 magnitude earthquake within a half-mile of the plant. So far we have been disappointed.

Remarkably, in all the years of its operation, the facility has never gone through a formal license amendment process to deal with even the Hosgri Fault discovered in the 1970s. Instead, its possible ramifications were more or less explained away in a separate document. More significant faults have been discovered since, which speaks poorly of PG&E's original examination of the area, and of the NRC's supervision of that process. One should not be discovering such faults after building a plant. The potential earthquakes affecting the plant have increased with each major study. But what's equally striking is that the shaking predicted by PG&E for these increasing threats has systematically decreased as PG&E adopted less and less conservative analytical methodologies, and they did so with NRC approval.

It is time to end this hodge-podge of licensing rationalizations. We know a great deal more about seismic issues than we did when Diablo Canyon was licensed. It's time for the NRC to reassess the seismic standards for the plant and submit them to a formal licensing amendment process. The thing that both PG&E and NRC fear most is a public hearing in which they would have to justify what they have done. It is also what we need most to assure seismic safety, and it is what the public deserves.

INTRODUCTION

In 2005, as the elected State Assemblyman representing the Central Coast and as a geophysicist, I became concerned that PG&E's prior seismic hazard analysis in the vicinity of the Diablo Canyon Nuclear Power Plant had failed to utilize modern state-of-the-art geophysical techniques that have proven highly effective at mapping seismic faults. In 2006, I authored, the state legislature passed, and Governor Schwarzenegger signed AB1632, which directed the California Energy Commission to assess existing scientific studies to determine the potential threat of earthquakes to the future reliable operation of Diablo. After extensive review the California Energy Commission concluded that significant seismic uncertainty existed and charged PG&E with the task of acquiring new state-of-the-art geophysical data to reassess the seismic threats to Diablo. In the furtherance of AB1632 the California Public Utilities Commission provided $64M of California ratepayer funds to compensate PG&E for the Coastal California Seismic Imaging Project that resulted in the Report.

At the time of the bill's passage few appreciated the potential threat that large earthquake faults posed to operating nuclear facilities. Since then the public's awareness of the importance of the issue has increased significantly:

- In 2007 the Kashiwazaki-Kariwa Nuclear Power Plant, the largest in the world, was severely damaged and shuttered due to an M6.6 earthquake 19 kilometers offshore from the facility.

- In 2008 the USGS discovered a previously unknown Shoreline Fault only 600 meters from the Diablo Nuclear Power Plant and only 300 meters from the intake.

- In 2011 the Fukushima Daiichi nuclear disaster resulted in the meltdown of three of the plant's six reactors, triggering an emergency review by the NRC of US nuclear reactors and their ability to withstand shaking from earthquakes. This tragedy was caused by an earthquake and Tsunami far larger than the utility believed possible, which produced greater shaking than the plant was designed to withstand.

Two months ago, eight years after the passage of AB1632, PG&E issued its Report, which will likely be relied upon by state and federal regulators in the course of their immediately upcoming deliberations regarding PG&E's request to extend the operating license of the Diablo through 2044-2045. My review of this Report addresses important historic, technical, and regulatory issues that are central to the final conclusion of the Report; specifically, that the facility has been shown to be safe from seismic threats.

PG&E's Report makes a number of key findings regarding earthquake threats. In virtually every instance, the faults surrounding Diablo are now understood to be larger and more connected than previously believed as recently as 2011. Of course the plant was initially licensed assuming these seismic threats were non-existent. Whereas the Hosgri Fault had previously been believed to be the most dangerous fault near Diablo, newly released research shows that the prior Hosgri maximum earthquake assumption is eclipsed by five other fault-rupture threats:

1. <u>SHORELINE FAULT</u>: The newly discovered Shoreline Fault located within 600 meters of the plant, is now twice as long as thought in 2011 and almost three times as long as the lower bound proposed in 2009. With a length now understood to be 45 km long it is capable of generating M6.7 strike-slip earthquake, which is larger than estimated in PG&E's previous 2009 and 2011 reports.

2. <u>SAN LUIS BAY FAULT</u>: The newly reinterpreted 16 km San Luis Bay Fault located within 1,900 meters of the plant, is capable of generating a M6.4 reverse earthquake, which is larger than previous estimated in PG&E's 2011 report.

3. <u>LOS OSOS FAULT</u>: The newly reinterpreted 36 km Los Osos Fault located within 8.1 km of the plant is capable of generating a M6.7 reverse earthquake which is smaller than the M6.8 estimate in PG&E's 2011 report, but still estimated to produce more ground motion than the Double Design Earthquake (DDE), also known as the Safe Shutdown Earthquake in the license.

4. <u>JOINT SHORELINE/HOSGRI FAULT SYSTEM:</u> The newly reinterpreted 145 km joint Shoreline/Hosgri Fault system now assumes that the Hosgri Fault and Shoreline Fault connect, whereas previously the two were considered to be wholly separate and incapable of failing in a larger single rupture. A joint Shoreline/Hosgri strike-slip rupture within 600 meters of the plant could theoretically generate approximately a M7.3 earthquake according to the Report.

5. <u>JOINT HOSGRI/SAN SIMEON FAULT</u>: The newly re-interpreted 171 km joint Hosgri/San Simeon Fault system now assumes that the Hosgri Fault and San Simeon Fault connect, whereas previously the two were considered to be wholly separate

and incapable of failing in a larger single rupture. A joint Hosgri/San Simeon rupture within 4.5 km of the plant is capable of generating a M7.3 strike-slip earthquake, which is larger than the previously estimated M7.1 utilized in numerous prior reports. The newly defined Hosgri Fault is considerably longer than previously presumed by PG&E and NRC.

The predicted ground motion generated by this list of earthquake scenarios are **all greater than the current ground motion estimates for a M7.3 Hosgri Fault earthquake located 4.7 kilometers from the facility**. This result is remarkable as the enormous Hosgri Fault, which can be seen easily on oil company seismic lines and passes the plant at a distance of only three miles, had been argued for many years to be the greatest threat to the facility. (Note: from a regulatory perspective the Hosgri Fault had previously been treated as the "controlling fault", which is to say the fault posing the greatest possible seismic threat to Diablo.)

However, in a seeming contradiction, rather than finding that larger or closer faults produce greater shaking and therefore a greater threat, PG&E argues in the Report that ground motion will be lower than the levels previously estimated. In other words, these newly discovered and re-interpreted faults are capable of producing shaking that exceeds the shaking from the Hosgri, yet that shaking threat would be much reduced from prior estimates.

Though discussed only in passing in the Report, the reason for this seeming contradiction is quite important when assessing whether or not the plant is safe or whether it is operating within its license conditions. The reason the earthquake threat purportedly went down when new faults were discovered is because the utility adopted significant changes to the methodology utilized for converting earthquakes (which occur at the fault) into ground motion (which occurs at the facility). This new methodology, which is less-conservative than the prior methodology, essentially "de-amplifies" the shaking estimated from any given earthquake relative to the prior methodology used during the licensing process.

DIABLO LICENSING BACKGROUND

The Diablo Canyon Nuclear Power Plant was licensed through a strictly adjudicated process that defined the Safe Shutdown Earthquake as the "maximum earthquake potential for which certain structures, systems, and components, important to safety, are designed to sustain and remain functional." In the unique parlance of the Diablo Canyon Nuclear Power Plant this Safe Shutdown Earthquake was defined as the "Double Design Earthquake." The NRC licensing process "ensures that the detailed operability requirements of the American Society of Mechanical Engineers' Boiler and Pressure Vessel Code are met at the higher ground motions."[i] The Design Earthquake (DE) for Diablo was defined during the construction permit process as the largest of four possible earthquake scenarios. The DE was assumed capable of generating a peak ground acceleration of 0.2 g. The Safe Shutdown Earthquake was then defined for Diablo as 0.4g, which is to say the plant must be able to shut down safely if a hypothetical earthquake generates double the 0.2g of shaking that was estimated to be possible from known surrounding threats. This hypothetical Safe Shutdown Earthquake is known as the Double Design Earthquake (DDE) and is a key element in establishing safety standards during the licensing process.

This formal NRC licensing process, which defined the DDE as the Safe Shutdown Earthquake for enforceable regulatory purposes, occurred prior to the discovery of the Hosgri Fault. Upon its discovery the USGS analyzed the Hosgri Fault and determined that it could generate a M7.5 earthquake at a distance of 4.5 km. The NRC negotiated with PG&E to create the 1977 Hosgri Evaluation (HE) exception under the theory that the plant could withstand shaking from this newly discovered fault under a narrow and specific set of assumptions. The HE used considerably less-conservative assumptions than those used for the DDE, which was applied to all other earthquake threats. The reduction of safety margins by the use of these special assumptions for the Hosgri Fault was quite controversial, and was strongly criticized by NRC Commissioners Gilinsky and Bradford in an opinion they issued on the Diablo seismic matters in 1981.[ii] The DDE is the Safe Shutdown Earthquake for Diablo and applies in the Current Licensing Basis to all faults that can affect Diablo, with the exception of the Hosgri Fault, to which the 1977 HE exception and its methodology and assumptions uniquely apply. Because of the differing assumptions the HE exception did not and was never intended at the time to eliminate or supersede the DDE standard.

To operate within its license the utility has been required to show that the plant will not be exposed to shaking beyond either the DDE basis or the less-conservative HE exception for a potential Hosgri earthquake. Later, the 1977 HE exception was modified to assume a slightly smaller M7.2 earthquake but with a slightly more dangerous reverse component of slip. The combination of the two changes produced a modified spectrum that changed only modestly with small enhancement at higher frequencies. That modification became known as the 1991 LTSP spectrum;[iii] however, it never became part of the Current Licensing Basis. (For the rest of this letter the Hosgri shaking estimates will be described as the HE/LTSP spectrum due to the fact that the HE and LTSP are used somewhat interchangeably and differ only slightly, even though the differences are important from a historic and regulatory perspective).

In 2008 history repeated itself and, as in the case of the Hosgri Fault, another offshore fault was discovered, but this time even closer to the plant. USGS found the Shoreline Fault within 600 meters of the reactors and within 300 meters of the intakes. When considering that the fault runs to a depth of 16 km, spatially the nuclear power plant lies virtually overtop the new fault. In the immediate aftermath of the discovery, PG&E's data demonstrates that the nearby faults could produce ground motions significantly higher than the 0.4g peak acceleration permissible under the DDE standard (see table below - note this analysis occurred prior to the seismic studies described in the Report which found that the faults were larger than assumed in table).

Table: Comparison of Reanalysis to Diablo Canyon SSE[iv]

Local Earthquake Fault	Peak Ground Acceleration
DDE	0.40g
Shoreline	0.62g
Los Osos	0.60g
San Luis Bay	0.70g
Hosgri	0.75g

In the face of this conflict with the license, PG&E began to compare the new seismic threats not to the DDE in the license, but rather to the HE/LTSP spectrum. If PG&E could ignore the DDE Safe Shutdown Earthquake standard in the license, PG&E could simply seek to prove that the newly discovered seismic threats were 'bounded' by the HE/LTSP spectrum, with their less conservative assumptions - ergo, notwithstanding the newly discovered and re-interpreted faults, the plant could be said to be operating consistent with its license.

Dr. Michael Peck, the Senior Resident NRC Inspector at the Diablo Canyon Nuclear Power Plant, was concerned that the newly discovered and re-interpreted faults (Los Osos, Shoreline, San Luis Bay) had been shown by PG&E to produce greater shaking than the .04g peak acceleration DDE design basis. He stated that the only approved exception to the DDE was the 1977 HE exception, which applied only to the Hosgri Fault, and that the exception was not transferrable to these other nearby faults - ergo a license amendment was required to correct the inconsistency between the existing license and the new seismic threats.

Buttressing Peck's argument that the less strict spectrum was not to supersede or replace the DDE, on October 12th, 2012 the NRC wrote to PG&E[v]: 'The DCPP Final Safety Analysis Report Update states in Section 2.5,

> "…the LTSP material does not alter the design bases for DCPP." In SSER 34 the NRC states, "The Staff notes that the seismic qualification basis for Diablo Canyon will continue to be the original design basis ***plus*** the Hosgri evaluation basis…" (emphasis added).

Faced with newly estimated ground motions in excess of the DDE Safe Shutdown Earthquake license requirement, PG&E proposed revising its license to eliminate the DDE requirement and have the HE/LTSP spectrum, with its considerably less protective methodological assumptions, apply not just to the Hosgri Fault as an exception to the DDE, but to all faults. The NRC declined to accept the request for review because it failed to meet certain required standards.

CRITICAL ISSUE EXPLORED

I do not seek to engage on Peck's important regulatory issue of whether the utility can now legally disregard the DDE standard and instead meet only the less-conservative HE exception. That is a matter for the NRC to determine based on its safety and regulatory standards and, hopefully, informed by the post-Fukushima understanding of the dangers of lax regulatory oversight. In the aftermath of this disagreement between the Senior Resident NRC Inspector at Diablo Canyon Nuclear Power Plant and NRC staff, deliberation on this regulatory issue is now the subject of a lawsuit filed before the US Court of Appeals for the District of Columbia.

Instead, this analysis seeks to explore a different issue; specifically, is PG&E correct when it asserts that the utility has shown that the new seismic threat is bounded by the 1977 HE exception? (By exploring only this second issue I do not mean to minimize the importance of the first issue, but this second issue is central to the critical conclusion of the Report). In other words, the question is whether or not the new seismic threats have in fact been shown to produce shaking that is smaller than the HE basis exception <u>when the same associated analytical methods used to create the HE basis exception are applied to the new seismic threats</u>.

Why is it important to add this caveat about the same "associated analytical methods?" Because the rest of the NRC statement cited above under SSER 34 goes on to say,

> "The Staff notes that the seismic qualification basis for Diablo continues to be the original design basis plus the Hosgri evaluation basis, ***along with associated analytical methods, initial conditions, etc***."(emphasis added).

If the utility seeks to argue that the 1977 HE exception can be used as an alternative standard to avoid the stricter DDE standard, which is controversial in itself, then the methods which were used to compute the HE exception become of paramount importance. This analysis seeks to document that the "associated analytical methods" used by the utility to analyze the new seismic threats in the Report are markedly less-conservative than those used for the 1977 HE exception.

Why is this change in methodology important, particularly when the methodology is less conservative? Under 10 CFR 50.59, a license amendment is required when the Final Safety Analysis Report (FSAR) is inadequate to describe the circumstances at the plant and there is a

> "departure from a method of evaluation described in the FSAR (as updated) used in establishing the design bases or in the safety analysis." NRC regulations define such a departure as: "(i) **Changing any of the elements of the method described in the FSAR (as updated) unless the results of the analysis are conservative or essentially the same**; or (ii) Changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application."

The NRC requires a license amendment when there is a <u>departure</u> from a method of evaluation that established the design basis unless that departure is essentially the same or more conservative. If the utility is allowed to employ less-conservative analytical methods to obtain more optimistic results then prior safety standards could be lowered without the full understanding or regulatory concurrence of the NRC.

It was this very problem that led to the shutdown of the San Onofre SONGS' plant. The failure of the NRC to recognize the need for a license amendment to replace San Onofre's steam generators was identified by the **Office of the Inspector General** at the Nuclear Regulatory Commission as a missed opportunity to identify weakness in Edison's technical analyses[vi]. There is a marked difference between NRC staff review of a utility's change in methodology versus the rigor and process associated with a license amendment.

This analysis contends that because a true apples-to-apples comparison was never made in the Report between the Hosgri and the new seismic threats using analytical methods that are **"conservative or essentially the same"** as those used for the Hosgri evaluation. Therefore, it is inaccurate to assert that the new seismic threats are shown to be "bounded by the Hosgri evaluation basis" – as that phrase has any bearing for regulatory purposes.

This contention is important because - If PG&E is allowed by the NRC to reject both the stricter standard of the DDE and the conservative analytical methods used when the 1977 HE exception was authorized, then the NRC's prior seismic safety licensing standards will have been, for all practical purposes, circumvented.

Making this particularly troubling is that this circumvention will have been achieved without a license amendment process, which would ensure a more robust process for including analysis of differing and minority findings and opinions – findings and opinions which have been proven over time to be right, more often than not.

GROUND MOTION PREDICTION RETROSPECTIVE

Methodologies employed to assess potential shaking at the nuclear power plant can be broken into three broad categories:

1) SOURCE: Estimated energy released by a specific earthquake on a given fault – based on equations that involve factors such fault mechanics, stress drop, radiation pattern, directivity, rupture history, rupture length and width, etc.

2) PROPAGATION: Estimated attenuation and amplification factors that convert the energy released during the fault rupture process to the actual observed free field ground motion at a particular site, based on:

   a. TRANSMISSION EFFECTS: Energy transmission involves absorption and scattering, otherwise known as attenuation, incurred along the propagation path from the earthquake to the vicinity of the particular site, and

   b. SITE EFFECTS: Site amplification and de-amplification effects due to the stiffness of the rocks and soils of the particular site and the impedance contrasts that give rise to a variety of scattering and reverberation effects.

3) TRANSFERENCE: Estimated shaking adjustments from reference free-field station to power-block, turbine-building foundation levels, and then to structures, systems, and components throughout the facility – based on certain projection, coherence, and damping factors.

This analysis seeks to examine #1 and #2a and #2b cited above.

A Ground Motion Prediction Equation (GMPE) is used to predict shaking at a particular distance from an earthquake based on a variety of parameters. A GMPE represents the statistical relationship that best fits the empirical distance-attenuation observations from some database of earthquake recordings. Some of the parameters used to make the estimate include: size of earthquake, fault mechanics, geometry of the fault to the recording station, and the velocity of the rocks immediately below the recording station. GMPEs incorporate a large range of phenomena and effects.

Since discovery of the Shoreline Fault PG&E has significantly changed the GMPE equations used to analyze potential shaking at Diablo. The following summarizes the changes and their net effect on seismic hazard estimates. To help track the evolution of GMPE's they are informally numbered in the following retrospective. (**GMPE-1,** nomenclature for the purposes of this letter would be the methodology used for the DDE and the HE exception from the construction permit).

In 1991, PG&E constructed the LTSP spectrum, which assumed a M7.2 earthquake at a distance of 4.5 km and used a GMPE **(GMPE-2)** derived from their own distance-attenuation relationship based on a database of strong-motion recordings of earthquakes at a range of distances along with regression analysis

In 2008 the Shoreline Fault was discovered which triggered a requirement that PG&E assess whether or not shaking caused by the newly discovered fault was 'bounded' by the DDE *and* the HE exception, as required by its current operating license. Rather than use the same GMPE to perform that analysis PG&E began introducing new methodologies making it difficult to perform historical comparisons with earlier standards approved through the NRC's regulatory process.

PG&E, in an initial sensitivity report[vii] to the NRC, assumed that the length of the Shoreline Fault was as much as 24 km long with a depth of 12 km and capable of generating a M6.5 earthquake. It then used an assortment of different recently developed GMPEs, known as the Next Generation Attenuation models, to create a new averaged GMPE **(GMPE-3)** to compute shaking estimates at the plant caused by a Shoreline earthquake. GMPE-3 resulted in a de-amplification effect of median estimated shaking, relative to the prior methodology, i.e. a decrease in shaking, relative to GMPE-1 or GMPE-2. This new GMPE was justified based on the use of the Pacific Earthquake Engineering Research Center (PEER) database of some 3,600 earthquake recordings. Using GMPE-3 PG&E reported that the shaking was substantially lower than, or bounded by, the LTSP/HE spectrum[1].

In 2009, NRC staff used PG&E's proposed **GMPE-3** equations but then analyzed the Shoreline Fault assuming it was 24 km long with a depth of 16 km, which was more conservative than PG&E's depth of 12 km. Using these parameters, and including a 1 standard deviation of magnitude estimate, the largest possible earthquake was computed to be M6.85 rather than M6.5. Assuming the somewhat larger earthquake their analysis found,

> "The motions are *very close to* the LTSP/HE in the high-frequency range but fall below the LTSP/HE in the long-period range". and "…seismic loading levels predicted for a maximum magnitude earthquake on the Shoreline Fault are *slightly below* those levels for which the plant was previously analyzed in the Diablo Canyon Long Term Seismic Program" (emphasis added).

Using GMPE-3 shaking from an assumed 24 km Shoreline Fault was found to be "*very close to*" and only "*slightly below*" the LTSP/HE spectrum when using the new GMPE-3 methodology (emphasis added).

The five NGA GMPEs which, when averaged, produce GMPE-3 are each shown in figure 10 from the NRC report. The NRC staff analysis also tested the significance of using the lower-bound estimate of rock velocity rather than the "best estimate" (lower velocity corresponds to higher shaking). Using a rock velocity of 800 m/s instead of 1,100 m/s resulted in a spectrum that, "exceeds the LTSP spectrum by a small amount over some frequencies." In summary, by using reasonable but somewhat more conservative approaches to the three available variables (the NGA model selection, earthquake magnitude estimate, or rock

[1] The LTSP and HE spectra are very similar and are used almost synonymously in some reports cited herein. To avoid confusion caused by switching back and forth, a single term LTSP/HE will be used in some instances even though they differ from a regulatory basis.

velocity) the spectrum was found to be "very close" or "exceeds…by a small amount." This result was quite significant because it showed that, even in the early days when the Shoreline Fault was still believed to be relatively small, shaking could exceed the LTSP Spectrum assuming certain models and certain rock parameters. The Chiou & Youngs (08) GMPE (dotted blue line) exceeds the LTSP Spectrum (solid black line) at about 7 Hz and above, the others are just a little below, hence the characterization that they are *"very close"* (emphasis added).

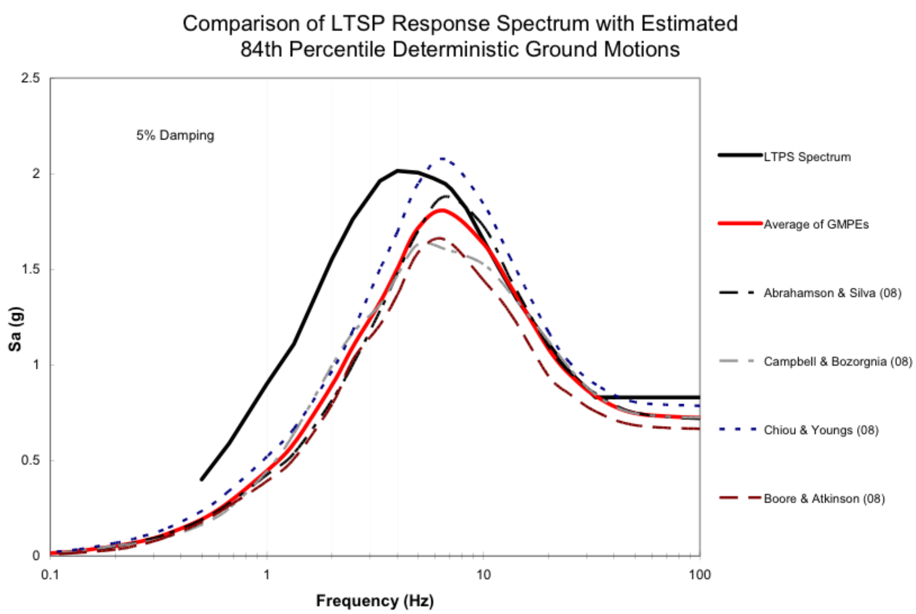

Figure 10. Comparison of Individual 84th Percentile Ground Motion Prediction Equations with Best Estimate Parameters and Diablo Canyon Review Spectrum

This result naturally raises important questions about the effect of the new GMPE applied to the Shoreline. For example: would estimation of shaking on a 24 km rupture of the Shoreline Fault have exceeded the LTSP if GMPE-1 was used rather than GMPE-3? Given what is shown in Figure 10 it appears that the answer would likely be "yes" if the difference between GMPE-3 vs GMPE-1 was anything other than de minimis, but that analysis was not performed in the 2009 Shoreline report.

The effect of which GMPE methodology is employed is highlighted in a NRC staff remark when it wrote, "…epistemic uncertainty in the GMPEs, which tends to be higher in the magnitude-distance ranges with sparse available seismological data (such as large magnitudes at short distances). Generally the GMPEs are the ***largest source of uncertainty*** in the ground motion values produced in seismic hazard analysis" (emphasis added). Here the NRC staff acknowledges that the new GMPEs are the source of the greatest uncertainty, and, that uncertainty is greatest for large earthquakes at short distances, which is exactly the situation for Diablo.

In 2011, PG&E issued its "Report on the Analysis of the Shoreline Fault Zone, Central Coastal California" assuming the same maximum M6.5 earthquake along a 23 km fault, but introducing a number of new factors creating yet another new GMPE, named here as

GMPE-4. The utility started with its 2009 GMPE-3 equation but then added a new hard-rock effect. The rationale for this equation was inferred from work by Silva (2008). The result adjusted estimated shaking downward still further from GMPE-3. Silva's work, which was specific to a particular range of rock hardness along with other factors, did not include the actual rocks at Diablo. Therefore PG&E extrapolated the findings of the published paper so they could be applied to Diablo where a faster rock velocity of 1,200 m/s was assumed (faster rocks equate to lower shaking).

Additionally, PG&E created new equations to reduce the standard deviation of the estimated shaking. Because 84th percentile shaking estimates are the sum of the median shaking plus one standard deviation the total spectrum can be lowered either by reducing the median, reducing the standard deviation, or lowering both.

With the issuance of the 2011 report PG&E reduced both the median and the standard deviation used in the analysis of the seismic threats – the first through yet another new GMPE with hard-rock de-amplification effects; and second, through a statistical approach described as "single-station sigma."

Using this new **GMPE-4** the resulting spectrum that was no longer "*slightly below*" and "*very close*" to the LTSP/HE spectrum, per the prior NRC's findings of 2009 (emphasis added). The new margin was significantly larger thereby allowing PG&E's to again assert that the LTSP/HE spectrum was not at risk of being exceeded by shaking on a M6.5 earthquake on the Shoreline Fault. Note how the PG&E's methodology to compute shaking changed not once but twice in the short period of time since the discovery of the Shoreline Fault in 2008. Both those changes produced reduced estimates of shaking from the newly-discovered Shoreline Fault.

<u>In 2012</u>, NRC staff issued its "Confirmatory Analysis of Seismic Hazard at the Diablo Canyon Power Plant from the Shoreline Fault Zone. The report details staff's review of PG&E's report. NRC staff decided to lower their maximum possible earthquake from M6.85 to M6.7, which was closer to PG&E's figure of M6.5 (smaller earthquakes correspond to lower shaking). Similarly staff decided to revise their estimate of rock velocity upward from 1,100 to 1,200 m/s which was the figure used by PG&E (faster velocities correspond to lower shaking).

They also reviewed PG&E's new hard-rock de-amplification adjustment and pointed out a number of problems with the approach including uncertainty in the estimate of Kappa, a factor that describes damping in basement rock. When NRC staff explored alternative methodologies they found, "the NRC results are conservative relative to the PG&E results at virtually all frequencies."[viii] Nonetheless, NRC staff incorporated a new hard rock effect and added that factor to GMPE-3. Staff elected not to use add "single-station sigma" effect to further lower the 84th percentile of shaking. They did however agree with PG&E's conceptual approach, albeit they noted statistical unreliability of its use at Diablo due to small amounts of available data.

To issue this report, NRC staff acquiesced to PG&E's use of the

1) Use of the new NGA GMPE's,
2) Averaging of NGA GMPE's to eliminate outliers,
3) Smaller earthquake magnitude estimate,

4) New hard-rock rock scaling factor,
5) Increased site rock velocities, and
6) New statistical single-station sigma.

The net effect of adding these factors allowed the NRC to issue a “confirmation” in 2012 of PG&E’s assertion that the Shoreline Fault would produce shaking below the LTSP/HE spectrum.

In 2014, after the offshore seismic studies were completed, PG&E issued its Coastal California Seismic Imaging Project (CCCSIP) Report. The Report concluded that the Shoreline Fault is 45 km long (a tripling of the utility’s 2009 lower-bound figure) and that a hypothetical joint Hosgri/Shoreline Fault rupture would be 145 km long generating a M7.3 earthquake within 0.6km of the plant (corresponding to a factor of 30 greater released energy relative to the earlier lower-bound estimate). The Report also details the size and location of the Los Osos and San Luis Bay Faults and the potential earthquakes they could generate. Again, all of these threats produce shaking that is greater than their new calculations of shaking from the Hosgri, which had previously been identified as the ‘controlling fault”

In Chapters 11 and 13 PG&E analyzes the new seismic threats, which are markedly larger than those analyzed in 2011 using their new GMPE-4 which was used successfully with the Shoreline Report to calculate lower levels of shaking than the earlier methodology. Analyzing the new threats using GMPE-4 the Report finds that even a massive M7.3 earthquake linking the Hosgri and Shoreline Faults, with rupture occurring within 600 meters of the reactors, could not exceed the LTSP/HE spectrum. Demonstrating just how effective these less-conservative methodologies are in lowering estimates of shaking, without a single retrofit, Diablo becomes virtually invulnerable to any imaginable earthquake regardless of size and proximity.

Evidence of the total cumulative effect of these new methodologies can be inferred by looking at the “before” and “after” calculations of shaking of a hypothetical Hosgri Fault earthquake. Such a comparison shows that the peak acceleration is reduced from 0.75g to 0.46g! The de-amplification effect is even larger than suggested by this 38% decrease in estimated shaking because the “before” Hosgri earthquake is smaller than the “after” Hosgri earthquake, which now assumes a joint rupture on the Hosgri/San Simeon Fault System. The importance of using a new methodology that reduces peak accelerations by at least 38% is never singled out for mention in the Report, nor is the prior less-conservative methodology applied to the new seismic threats.

IMPORTANCE OF NEW GMPEs

These changes to GMPEs, documented in the prior section, are crucial to the fate and future of Diablo and give rise to two important questions.

> First, from a technical perspective: Are these rapidly evolving GMPEs appropriate for application to Diablo given the statistics and science embedded in their assumptions?
>
> Second, from a regulatory perspective: Are these rapidly evolving GMPEs appropriate for application to Diablo when dealing with the safety margins and

adjudicated rules that define how nuclear power plant licenses are enforced or amended?

In this retrospective of evolving GMPEs I've made no arguments regarding the technical or scientific merit regarding the half-dozen changes to GMPEs that have occurred. This is a rapidly evolving field of research for which there is insufficient data to provide a simple "yes" or "no" answer. Instead it is more appropriate to identify concerns and to point out alternative interpretations to the existing data. Therefore, I address the first question in an attached appendix, which can be read separately from this letter.

However, as a former policymaker I do believe there is a clear-cut answer to the second question, which I will address here. Making this GMPE chronology troubling from a regulatory and safety perspective is that, as newly discovered or re-interpreted faults are progressively understood to be larger and more dangerous than previously believed the newly derived methodologies adjust shaking downward just sufficiently to accommodate the new threat. In fact, the safety of the facility no longer depends on whether or not dangerous faults actually surround the nuclear power plant and are capable of generating earthquakes that exceed the shaking predicted from the previously defined 'controlling fault.' That question has been answered unequivocally and the PG&E Report acknowledges the presence of such earthquake faults. Instead the safety of the facility depends upon the reliability of new less-conservative equations, which are going through major revisions literally with each newly issued report.[ix]

These facts raise significant regulatory issues that need to be addressed at the highest levels of the NRC. In this instance we see a nuclear power plant that is found to be exposed marked greater seismic threats than ever envisioned during the licensing process. This increase has happened not once, with the discovery of the Hosgri Fault, but twice. With this year's report an entire new class of earthquake threats have been identified that eclipse the prior Hosgri Fault threat. This fact alone should galvanize the NRC to act. But what makes the situation even more dire is that the methodologies used by the utility to analyze the new threats have changed as well. If the utility's associated analytical methods to compute ground motion were the same or more conservative the debate would be solely on the scientific questions surrounding the earthquake potential introduced by the new faults. However, in this case the associated analytical methods to compute ground motion beneath the plant are markedly less-conservative than those ever used before. These methods are less-conservative than when the plant was licensed and less conservative than even six years ago when the Shoreline Fault was first discovered. If the prior methodologies used during licensing were applied to these new faults it is possible, and perhaps likely, that shaking would exceed both the DDE and LTSP/HE spectrum. If true, this means that the plant is currently operating beyond the tolerances established under its license. That is why this is a critical regulatory issue. Threats are going up at the same time the utility's preferred method for analyzing all such threats has become markedly less conservative. From a regulatory perspective, it is this simultaneous convergence of higher threats and less-conservative methodologies that requires the NRC to act immediately.

CONCLUSION

In summary: The geophysical methodologies to locate faults and assess the size of potential earthquakes are well established and have been tested for innumerable instances over many decades. Similarly, the estimation of site effects when dealing with relatively simple geology is well understood. This history has allowed regulators to rely comfortably on the long record of published findings on these important elements of seismic hazards.

However, the geophysical methodologies for determining ground motion in the extreme near-field are in a rudimentary state of development. Similarly, the estimation of broadband site effects when dealing with highly complex and heterogeneous 3D geology is a difficult technical problem and an active area of research (see appendix).

PG&E has progressively used methodologies that produce less-conservative results to analyze the steadily increasing seismic threat. With each successive generation of new information about the threat prior methodologies are modified and more sanguine results are obtained.

Of course, from a research perspective, the fact that a whole series of new methodologies are being explored and new equations are being tested, albeit with limited data (see appendix), is a good thing. However, it is a quite perilous thing from a regulatory perspective, which requires high-levels of scientific and statistical certainty based on large datasets and well-vetted methodologies. The regulatory determination of safety should not hang tenuously upon the results of an ongoing science experiment. When faced with such a situation nuclear regulators must rely upon the existing, more conservative, and historically accepted methodologies to assess risk.

But beyond the imprudence of relying upon rapidly evolving methodologies to obtain lower risk estimates at a nuclear power plant, there is a regulatory reason why such an approach is not allowable. The NRC stated,[x] "The Staff notes that the seismic qualification basis for Diablo Canyon will continue to be the original design basis plus the Hosgri evaluation basis, ***along with associated analytical methods, initial conditions, etc."*** (emphasis added). Clearly the Hosgri evaluation basis, if it is to have any regulatory meaning, can only be applied to a new seismic threat if the same, or more conservative, analytical methods are employed to compare the two. This however is not how the utility is treating the Hosgri evaluation basis. Instead, the utility employs significantly less conservative analytical methods and then states that the lower shaking produced by new seismic threats is 'bounded' by the HE exception.

Finally, if altogether less-conservative methodologies are to be used to analyze altogether new and more dangerous faults it is important that such analysis be performed at arms length through a transparent, rigorous, and strict license amendment process so that the public can have confidence that safety is the foremost consideration of the NRC. This is why such analysis should be performed through the course of a license amendment process.

My overarching concerns with the Report include:

- Disregard of DDE basis: In a post-Fukushima setting the NRC must insist upon the high and robust seismic safety standards at the nation's only nuclear power plant that is ringed by numerous nearby faults capable of earthquakes, each larger than the earthquakes envisioned from previously assumed "controlling fault." However, to-date the NRC has ignored the cautions of experts and even its own resident inspector who has declared the plant is operating beyond its current operating license based on the DDE.

- Weakening of HE basis: The 1977 HE basis was allowed as an exception that applied only for an earthquake on the Hosgri Fault. However, while the utility is ignoring the DDE standard and is applying the HE exception to all faults, it is also simultaneously seeking to weaken the 1977 HE exception by creating new "associated analytical methods" that are markedly less conservative.

- Lack of Transparency: Notably, the Report never makes an apples-to-apples comparison wherein the same "associated analytical methods" are used to analyze new seismic threats and the HE exception. Nor are lower-velocity parameters input to the new analytical methods to assess their sensitivity to critical real world parameters and uncertainties at the site. The public is never given the opportunity to see the cumulative effect of each generation of new GMPEs or the range of effects due to rock velocity selection. This makes it impossible for PG&E to accurately assert in the Report that, from a regulatory perspective, the new seismic threats are shown to be 'bounded' by the HE basis. From what data are shown by the Independent Peer Review Panel such a transparent and apples-to-apples analysis would likely prove the opposite.

- Rapidly Evolving Analytical Methods: The utility is relying upon less-conservative methodologies that are evolving and changing rapidly, which reduces reliability and confidence from a regulatory perspective. The velocity parameters themselves, upon which some of these new methodologies depend, are in serious dispute. Furthermore, the methodology to compute extreme near-field ground motion in a setting ringed by large strike-slip and reverse faults is nowhere near developed enough to ascribe certainty to median or variance estimates of probable shaking.

- More Seismic Threats to Come?: Two future possible seismic threats remain unknown due to data limitations. It is not clear that the poorly imaged faults under the Irish Hills have been properly identified in the geologic cross-sections which could mean a whole new category of undiscovered threats may exist directly under the plant. The quality of the seismic data obtained onshore just under the Irish Hills is poor and due to the virtual absence of relevant geologic information from deep wells it is difficult to differentiate between active and dormant faults in the seismic data. Whether or not another class of active thrust faults exist under the plant remains an open question. The current data cannot be used to rule out such a possibility and the compressional nature of the topography argues that such faulting could be inferred. Additionally, the study area used by PG&E does not include the area that connects the more northerly San Simeon Fault with the San Gregorio Fault. The Report agrees that the Hosgri Fault is connected with the San Simeon Fault, which has caused the maximum possible earthquake to increase significantly. If the San Gregorio Fault to the north is similarly connected then the Report has underestimated the maximum earthquake that Diablo might need to survive.

- Troubling History: The utility has a long and remarkable history of producing sanguine technical reports that get the seismic hazard analysis at Diablo exactly wrong. Whenever new data has emerged identifying possible new seismic threats the utility has mobilized its internal and external experts to sequentially argue that nearby faults simply didn't exist, they did exist but were inactive, they were active but not large, and then that they were large but segmented and unconnected. Now that the evidence about the size and location of the faults is indisputable - the argument has suddenly changed again. Now the utility declares that although the faults are quite large, nearby, and interconnected the prior equations used during the licensing process to predict shaking should be abandoned and replaced with less-conservative methodologies which allows the utility to claim that the plant is safe……even from a M7.3 within 600 meters of the facility. One must ask, **"if the utility has been proven to be wrong so many times in the past on so many similar issues and given the high stakes of mishandling this critical issue, should the utility's new-found conclusions be relied upon without the direct regulatory oversight of the NRC's license amendment process?"** As a scientist and a policy maker I believe the responsible answer is "No."

In conclusion, if the NRC were to decide to rely upon the utility's assertion that the facility is operating in conformance with its license based on these new evolving less-conservative equations the NRC would be allowing the HE exception to be markedly weakened by the utility without the third party objectivity, regulatory safeguards, and technical rigor of the license amendment process. Such a decision in the aftermath of the difficult lessons of Fukushima could come back to haunt the NRC, the utility, and more importantly – the public.

APPENDIX

TECHNICAL CONCERNS

The following are some of the reasons I believe that these less-conservative equations and evolving GMPEs are still very much a work in progress, making it premature to apply the methodology to the Diablo Canyon Nuclear Power Plant. If the only possible way to prove that the plant is operating below the LTSP/HE basis is through the use of these new equations then a formal adjudicated license amendment process, especially if the LTSP/HE exception is to be relied upon in lieu of the DDE safety standard.

CONCERN #1 – Methodology limitations in applying PEER derived GMPE's distance-attenuation predications for extreme near-field applications: The Next Generation Attenuation models, which is the basis for GMPE-3 and many of the other subsequent GMPE's, is derived from the PEER database of some 3,600 recordings. The various peer-reviewed and published attenuation-distance equations are based on robust statistical best-fits to the very large PEER dataset. However, the proximity of the plant to the Shoreline and the San Luis Bay Faults are only 0.6 km and 1.9 km. Out of this entire PEER dataset only a couple dozen recordings exist within 2 km of the fault and of those only 8 recordings occur with 0.6 km. This number of recordings is insufficient to create a statistically significant estimate of ground motion in this **extreme near-field setting**. Any statistical estimate of an empirical distance-attenuation relationship in which *over 99% of the data* occur in a range outside of the distance where the relationship will be applied is unreliable for determining a mean or variance of shaking.

The uncertainty in the extreme near-field estimates of ground motion using NGA GMPE's is not reduced through an averaging approach. All of the GMPE's constructed from various subsets of the PEER dataset include the same systematic under sampling of extreme near-field recordings and over sampling of far-field earthquakes. Because this error is systematic rather than random the averaging process cannot be relied upon to improve confidence of extreme near-field shaking estimates.

The new Next Generation Attenuation models used for **GMPE-3** and the even-newer **GMPE-4** both suffer from data limitations that make them problematic for reliable application to Diablo. Simply adding geologic, site effect, and statistical correction factors to the underlying NGA equations does not overcome the statistical problem inherent in applying these equations in the extreme near-field.

CONCERN#2 – Methodology problems in PG&E's site-specific adjustments to shaking estimates at Diablo: As stated above, the Next Generation Attenuation models, which is the basis for GMPE-3 and GMPE-4 is derived from the PEER database of some 3,600 recordings. The vast majority of these recordings occurred in rock types that differed significantly from the rocks types under the Diablo Canyon Nuclear Power Plant.

The NRC pointed out in September 2012 that there are,

> "…only 51 recordings with sites defined with Vs30>=900 m/s. This is less than 1.4% of the database. There are only 15 recordings with Vs30>=1,200 m/s (less than one-half of one-percent)…….Hence, applying a Vs30 of 1,200 m/s directly in the

GMPEs increases uncertainty, as this value is beyond the range well constrained by the observational data.[xi]"

To deal with this deficiency NRC staff and PG&E began constructing a variety of rock type correction factors and single-site correction factors. These new adjustments were derived from the utility's own sparse database.

Such an effort could be justified if the proper dataset were available; however, the Diablo database is inadequate for this purpose. Over the past few years only a handful of strong-motion instruments at Diablo have recorded just two relevant-sized earthquakes (e.g., >=M6.0). These two earthquakes are the M6.0 Parkfield earthquake at a distance of 85 km and the M6.5 San Simeon earthquake at a distance of 35 km. It is simply not possible to perform rigorous statistical analysis on a sample size of two.

What makes the small size of this dataset even more troubling is that neither of these two reference earthquakes occurred to the west or south of the plant, which is where the Hosgri, Shoreline, and San Luis Bay Faults are located. Any site-specific Green's function[2] derived from the small amount of existing strong motion data would not include information about how the site responds to energy from a large earthquake arriving from the west or south.

Wellbore velocity profiles obtained at the site prove that the underlying soft and hard rock environment is neither homogeneous nor layer-cake 1-dimensional. Instead a high degree of 3D complexity with significant impedance heterogeneity is evident in the geology underlying the plant. Therefore a single azimuthally-independent site response will likely fail to incorporate the 3D heterogeneity at the site. Any empirically calculated Green's function based on limited-azimuth data from the north and east will be unreliable in predicting strong ground motion from the Hosgri, Shoreline, and San Luis Bay Faults.

Finally, neither of these two reference earthquakes occurred in the near field. A near-field earthquake cannot be treated as a virtual point source at a fixed azimuth. Instead a near-field earthquake must be treated as a distributed source whose azimuth varies as the rupture propagates up to, along side, and then past the nuclear power plant. This areal source propagates signal to the recording site from a range of azimuths and inclinations, potentially with different Green's functions. Two relatively distant point-source signals, Parkfield and San Simeon earthquakes, from the east and north cannot be used to infer the shaking from a rupture on the Hosgri or Shoreline Faults that actively propagates in the near-field past the plant, and/or stops directly adjacent to the plant to the west.

Given the significant number of large active faults that surround the plant, a dangerous neighborhood to be sure, it is imprudent to base the safety of the plant and the community solely upon reliance on site effects derived from this small dataset.

Future possible research designed to create a numerically simulated 3D site effect (which is reportedly underway and will become **GMPE-5)** to get around the deficiencies of both the

[2] Greens Function: A mathematical term of art defining a system response to an impulse signal which can be used to describe, through convolution and superposition, a system's response to a more complex signal

empirical data sets identified above, would face significant challenges. Accurate numerical elastic wave-equation simulation of a site-specific Green's function would require a 3-D velocity and impedance structure below and around the facility that extends to considerable depth, includes surficial topographic features, and accounts for accurate P-S and S-P and surface-wave conversions calculations, complex ray bending, critical refracting, scattering and focusing effects. To construct such a simulation would require higher-resolution and deeper data than is currently available from the wellbore or near-surface tomographic information.

If somehow such difficulties could be overcome, the numerically simulated site response would still need to be tested to determine how well it predicted the shaking generated by an actual earthquake >=M6.0 impinging on the site from the west and originating in the near-field. A prediction without a test to assess the accuracy of the prediction would be insufficient for regulatory purposes.

CONCERN #3 – Methodology problems in estimating shaking caused by an earthquake located in the extreme near field: This issue is different from the statistical issue regarding the paucity of data available in the near-field recordings or the lack of data for the rock-types in question - which were covered under concerns #1 and #2, respectively. At progressively greater distances from an earthquake the particulars of the dynamic rupture process becomes less important relative to the larger effects of total energy release and energy attenuation during transmission. However, in the extreme near field the location of a recording station relative to an earthquake's rupture history, asperity locations, heterogeneous stress drops, and starting and stopping phases, directivity, and a host of other effects become very important – in some cases the largest effect under consideration. Due to the location of the Shoreline, Los Osos, and San Luis Bay, and Hosgri Faults these effects would likely be significant. As more extreme near-field recordings have been obtained, although still relatively few in number, it has become clear that a simple estimation of an earthquake's magnitude and distance from a site may be insufficient to make precise estimates of shaking.

For example, in 2004, 48 strong-motion recordings within 10 km of the San Andreas Fault were made of the M6.0 Parkfield earthquake[xii]. This dataset was used to test three different attenuation-distance equations. These equations are shown to do a good job of making accurate predictions for distances beyond about 10 km, but the observed shaking becomes highly variable in close proximity to the fault. Rather than finding accurate predictions of mean shaking in the extreme near-field the paper notes,

> "Peak ground acceleration in the near-fault region ranges from 0.13 g at Fault Zone 4, to 1.31 g at Fault Zone 14, ten times larger, to over 2.5 g at Fault Zone 16 (where the motion exceeded the instrument capacity and the actual maximum value is still being estimated)."

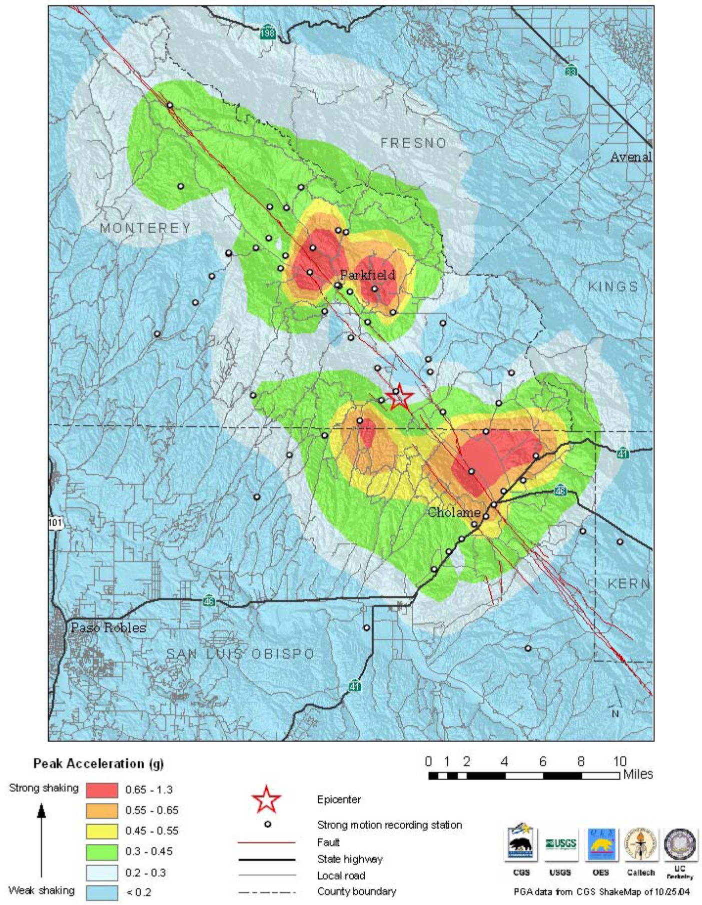

Figure 3: Shakal et. al., 2004 showing remarkably high and low accelerations in the extreme near-field (rupture started where the star is shown and then propagated to the north-east and south-west where they stopped)

The dense strong-motion Parkfield recordings are relevant to the conclusions of the Report for a number of reasons.

- First, these extreme near-field areas of high and low acceleration are not well predicted by a distant-dependent GMPE estimate of shaking. In this extreme near-field setting the particulars of how ruptures start and stop, the direction the rupture propagates, the potential focusing effect of the velocity structure of the fault zone, the locations of specific asperities become major factors that affect ground motion. These factors are not included in the current generation of GMPEs, which were never intended to describe these complex phenomena that are significant effects principally in the extreme near-field.

- Second, the Parkfield data shows that the high degree of variability in the extreme near-field is not a spatially random phenomenon. Instead the highest levels of acceleration are systematically found near the ends of the fault where stopping phases radiated energy during the rupture process of this specific earthquake. If the nuclear power plant happens to be located in a zone of focused seismic energy the 84th percentile estimate from the GMPE estimate will likely underestimate the observed shaking.

- Third, PG&E has argued in the Report that while an earthquake on 100 km of the Hosgri Fault could jump to the 43 km of the Shoreline Fault creating a 143 km rupture, the likelihood of such an event is purportedly low. They contend that a north-to-south Hosgri rupture that jumped to the Shoreline would terminate due to bending and segmentation before rupturing the full length of the Shoreline Fault. If PG&E is right in this assertion they would be correct to reduce the component of shaking that is derived from the size of the earthquake. But they would then need to account for the markedly higher accelerations produced by stopping phases that would radiate from the segments and asperities associated with terminating the rupture near the facility. Given the high accelerations observed in the Parkfield dataset, an earthquake that propagates the 100 km length of the Hosgri and only 20 km of the Shoreline but violently stops directly adjacent to the nuclear power plant could in fact be more dangerous than a scenario involving the full 145 km of propagation

There are a few ways to demonstrate the significant influence of these new equations. One obvious demonstration is to review the reduction in estimated shaking from an earthquake on the Hosgri Fault relative to PG&E's earlier estimates when creating the HE/LTSP spectrum.

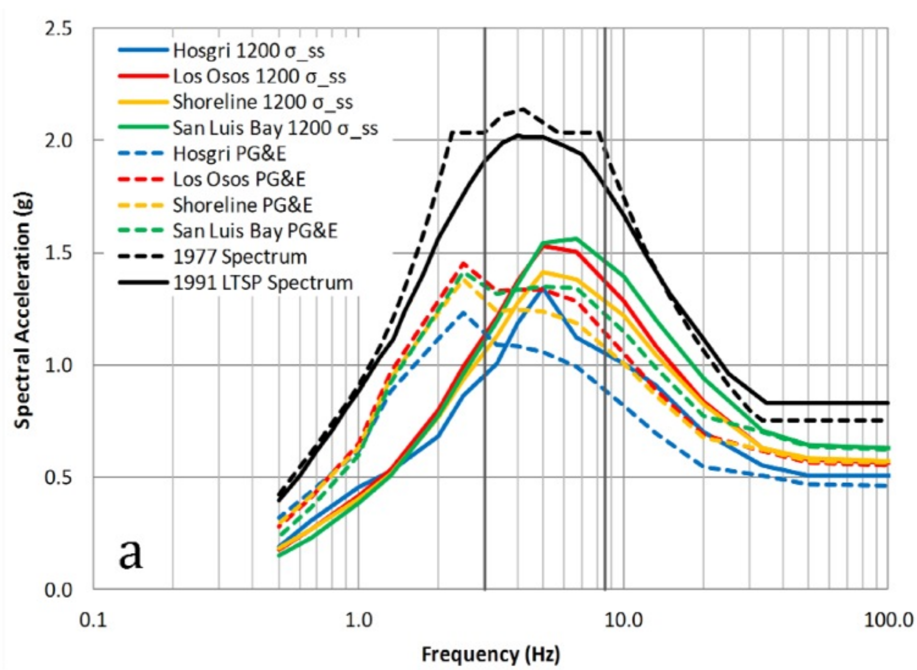

Figure 7. Comparison of deterministic ground motion spectra from PG&E for the DCPP site (dashed color curves; using site amplification term, its uncertainty, and single station sigma) with deterministic spectra of three sensitivity cases (solid curves): (i) a generic site with V_{S30} of 1,200 m/s and single station sigma (Figure 7a); (ii) a generic site with V_{S30} of 760 m/s and single station sigma (Figure 7b); and (iii) a generic site with V_{S30} of 760 m/s and sigma from GMPEs (ergotic sigma, Figure 7c). The PG&E 1991 LTSP/SSER 34, the 1977 HE (Hosgri Earthquake) design spectrum, and the frequency range important to DCPP (marked by vertical dark grey lines) are also plotted for reference.

(Figure 7a from IPRP Report)

As seen in Figure 7a from the Independent Peer Review Panel (IPRP) report and in a number of other related reports, the new less-conservative equations cause a major reduction in shaking across the entirety of the frequency spectrum from a hypothetical earthquake on the Hosgri fault (compare blue lines which use the newly devised methods with black lines which use the prior methods, in figure 7a above). In the frequency range from 2-10 Hz the less-conservative methodologies have cut the maximum estimated acceleration from 2 g down to about 1.3 g. At the peak-frequency range, from 30-100 hz, the maximum estimated acceleration as been reduced by a third from .75 g to under .50 g. In fact the de-amplification effect is even larger than this comparison suggests because the blue lines, which represent the shaking on the re-interpreted Hosgri, assume a larger rupture on the Hosgri Fault than the earthquake that was used to initially create the 1977 HE basis exception.

More importantly, as can be seen in Figure 7a the shaking from the Los Osos, Shoreline, San Luis Bay Faults all exceed the re-interpreted Hosgri (red, yellow, green lines are all above the blue line). **One can reasonably conclude that, if the original analytical methods had been used to estimate ground motion, the new seismic threats would exceed the original HE and LTSP spectra**.

This conclusion is supported by the sensitivity analysis shown in Figures 7b and 7c, which test the importance of various parameters to the new GMPE and site effects. The same IPRP report cited previously states,

> "These two figures also show that if DCPP site had a Vs30 value of 760 m/s rather than 1,200 m/s, and if the site behaves more like an average site in ground motion amplification, **some deterministic spectra would exceed the 1991 LTSP spectrum**[xiii]" (figure 7c below).

In fact, it is more than just "some." Under the scenario shown in Figure 7c the IPRP shows that the LTSP/HE spectrum is exceeded by **all** of the newly discovered and re-interpreted seismic threats, including earthquakes on the Shoreline Fault, the Los Osos Fault, and the San Luis Bay Fault (note that the red, yellow, and green lines are all above the solid black line). The fourth and largest hypothetical earthquake scenario, a M7.3 rupture on a joint Hosgri/Shoreline Fault, is not shown on this figure but could reasonably be assumed to exceed the LTSP/HE as well.

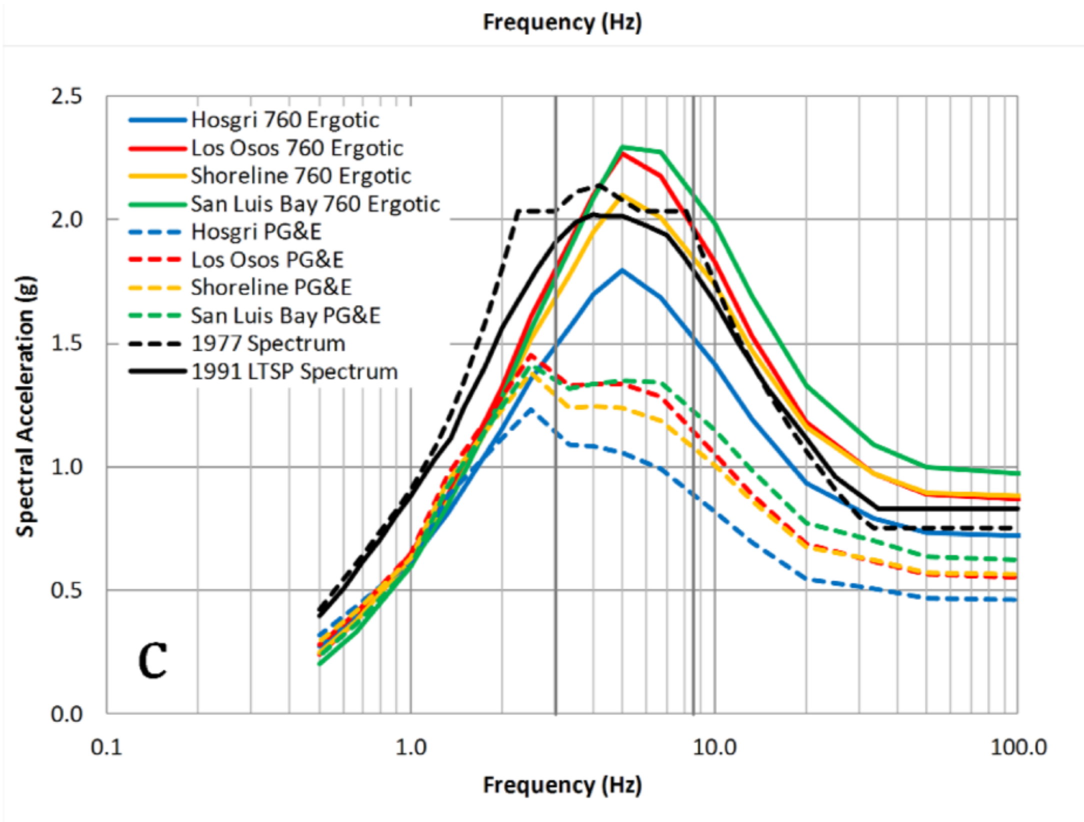

Figure 7. Continued.

(Figure 7c. from IPRP Report)

This sensitivity analysis shows that the cumulative effect of less-conservative fast rock velocities along with less-conservative GMPEs is clearly not a small issue, nor is it a only an academic issue. The IPRP reviewed the limited wellbore data (see IPRP Report 6 Figure 4) and concluded that the wellbore velocities appeared to be lower than those estimated by PG&E, which could result in the conclusion that PG&E has underestimated shaking from new seismic threats even if the new equations are allowed. The IPRP challenged PG&E's use of wellbore data at the ISFSI site to justify the higher 1,200 m/s velocity and instead focused on the velocities measured in the wellbore data closest to the facility.

Specifically, IPRP Report #6 says,

> "Consider the three usable measured profiles, A-2, C, and D, the mean value at 10 m is approximately 800m/s, considerably below PG&E's mean of 1200m/s." and "If A-2 had the same velocity as C at a depth of 5m, consistent with the relative weathering described in the borehole logs, the mean velocity at that depth would be about 650m/s, also below PG&E's mean value of 1000m/s."

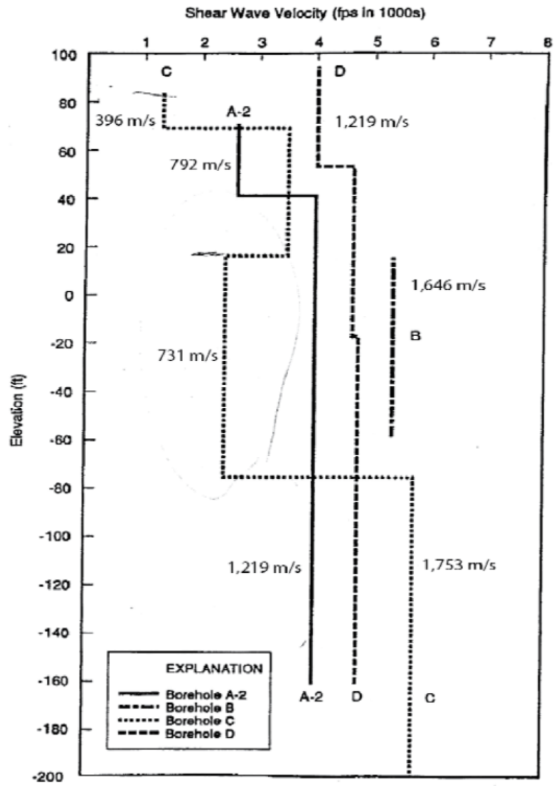

Figure 4. Shear wave velocity profiles from 1978 downhole velocity surveys (provided by PG&E).

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This appendix does not seek to weigh in on the question of which velocities are appropriate to use when computing site effects at Diablo. Instead, these stated concerns are intended to demonstrate that:

First, the de-amplification effects of moving from GMPE-1 to GMPE-4 are very large and likely determinative of whether or not the new seismic threats would produce shaking above the HE exception; and

Second, even if one were to accept the use of GMPE-4, which is problematic for the reasons previously stated, the critically important rock velocities upon which the de-amplification factors are based are complex, in dispute, and arguably lower than those used by PG&E, which would mean that shaking would be significantly larger than stated in the Report. Indeed, a conservative approach toward this technical question would have used of the lowest velocities found in the well data rather than the highest.

[i] Peck Differing Professional Opinion – Diablo Canyon Seismic Issues
[ii] Opinion of Commissioners Gilinsky and Bradford on Commission Review of ALAB-644 (Diablo Canyon Proceeding, Dockets 50-275 OL and 50-323 OL)
[iii] Safety Evaluation Report related to the operation of Diablo Canyon Nuclear Power Plant, Units 1 and 2. Docket Nos. 50-275 and 50-323; NUREG-0675, Supplement No. 34
[iv] PG&E submitted to the NRC "Report on the Analysis of the Shoreline Fault, Central Coast California, January, 7, 2011, ML 110140400
[v] Oct 12, 2012 NRC letter from Joseph M. Sebrosky, Senior Project Manager to Mr. Edward D. Halpin, Senior Vice President and Chief Nuclear Officer PG&E; Subject: Diablo Canyon Power Plant, Units Nos. 1 and 2 – NRC Review of Shoreline Fault
[vi] Office of the Inspector General US NRC: NRC Oversight of Licensee's Use of 10 CFR 50.59 Process to Replace SONGS' Steam Generators Case No. 13-006
[vii] Research Information Letter 09-001: Preliminary Deterministic Analysis of Seismic Hazard at Diablo Canyon Nuclear Power Plant from Newly Identified "Shoreline Fault." Pages 8-10.
[viii] U.S. Nuclear Regulatory Commission, 2012. Confirmatory Analysis of Seismic hazard at the Diablo Canyon Power Plant from the Shoreline Fault, Research Information Letter.
[x] Oct 12, 2012 NRC letter from Joseph M. Sebrosky, Senior Project Manager to Mr. Edward D. Halpin, Senior Vice President and Chief Nuclear Officer PG&E; Subject: Diablo Canyon Power Plant, Units Nos. 1 and 2 – NRC Review of Shoreline Fault
[xi] NRC Research Information Letter 12-01, page 56 (September 2012)
[xii] Shakal, A., Grazier, V., Huang, M., Borcherdt, R., Haddadi, H., Lin, K., Stephens, C., and Roffers, P.: Preliminary Analysis of Strong-Motion Recordings from 28 September 2004 Parkfield, California Earthquake. Submitted to SRL November 5, 2004
[xiii] IPRP Report No. 6, August 12, 2013