A PRUDENT VIEW OF EARTHQUAKE RISKS, NUCLEAR PLANTS AND NUCLEAR WASTE ALONG THE CALIFORNIA COAST

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Introduction

The San Onofre Nuclear Generation Station (SONGS) has been shut down since Jan 31, 2012, but still has some 3.6 million pounds of high-level nuclear waste to deal with. At the February 16, 2017 San Onofre Community Engagement Panel (CEP) conducted by Southern California Edison (SCE), a presentation was given by Neal Driscoll of the Scripps Institution of Oceanography regarding a study of seismic risks at the San Onofre plant.[1] This study was originally prompted by AB 1632 in 2010. As a result, the California Energy Commission directed SCE to evaluate seismic risk at the then-operating SONGS. This paper provides an alternative view of this subject.

Seismic Risk

One of the most substantial risks regarding nuclear power plants and the storage of nuclear waste is earthquakes and their associated repercussions such as tsunamis. These are substantial but perhaps not even the most important at a nuclear plant in this location. Terrorist activity or military action, human error, and equipment failure, including corrosion, are on the list and may exceed the near-term risks due to earthquake threats. With all that said, this paper will focus on seismic risks since that was the topic of the recent CEP meeting.

Seismic science has made great strides, most particularly in the past 50 years or so since the theory of Plate Tectonics became the operating framework behind observations of current and future earthquakes.

We must also recognize the following:

1. Seismology is a very new science. Although it deals with time scales on the order of hundreds to millions of years, events may be only seconds or minutes in duration. Careful observations of

1 Presentation slides: https://www.songscommunity.com/docs/021617_CharacterizingtheSeismicSettingOffshoreSouthernCalifornia.pdf

the movement of the tectonic plates have only been within the last 50 to 100 years. The theory of Plate Tectonics really got its start after the 9.2 magnitude Alaska earthquake in 1964.[2]

2. Although a great deal can be discerned about the large-scale events in terms of the movement of the tectonic plates throughout the larger spans of time, it is much more difficult to know how disruptive a specific event might be, and it is very difficult to clearly test most theories as you have to successfully predict at least the magnitude of a future earthquake. Seismic scientists agree they cannot accurately predict earthquakes at this juncture although they can make approximate predictions.

3. What happened over thousands or millions of years is indeed interesting. But our concern is in the next 100 years or so, approximately one 40,000,000th of Earth history. No matter how good the science might be, accurately predicting anything in such a narrow window is next to impossible. Any predictions or risk calculations should make this clear. With this in mind, it is probably prudent not to make any predictions. Considering the time frame, it would be reckless indeed to make decisions based on seismic models or probability risk assessments.

4. Seismology is largely an observational science. It is not generally possible to conduct the gold-standard of scientific experimentation -- the double-blind study. Instead, we are left with peer-review, which can provide a false sense of security. Essentially, just because a bunch of people think something is written well, and all agree, does not mean it must therefore be true. The reality, unfortunately, is that the vast majority of peer-reviewed science, even in experimental fields, is false or unreliable.[3]

> "[A] research finding is less likely to be true when the studies conducted in a field are smaller; when effect sizes are smaller; when there is a greater number and lesser preselection of tested relationships; where there is greater flexibility in designs, definitions, outcomes, and analytical modes; when there is greater financial and other interest and prejudice; and when more teams are involved in a scientific field in chase of statistical significance."[4]

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2 http://www.aeic.alaska.edu/quakes/Alaska_1964_earthquake.html

3 Ioannidis JPA (2005) Why Most Published Research Findings Are False. PLoS Med 2(8): e124. doi:10.1371/journal.pmed.0020124 -- http://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.0020124

4 *ibid.* Underlining added.

We must note that in the field of seismology, testing is very limited, and in the case of evaluating the risks of nuclear plants, there is significant financial interest in the result. Thus these studies are subject to the risk that their results may be false or misleading.

5. Any estimate of earthquake risk in a specific area only provides the floor of the risk level, that earthquakes of a certain magnitude or greater can be expected at a specific location based on recent movements. There is no way to prove that a really big earthquake won't happen somewhere.

6. The implications of failure at a nuclear plant or nuclear waste storage site can be devastating, potentially resulting in uncontrolled and uncontained nuclear reactions, such as the triple melt-down in Fukushima which is still absolutely out of control and an on-going disaster.

   The consequences of a low probability event at a nuclear power plant can be widespread catastrophe, loss of life, and permanent contamination of large areas of land. There is very little relevant comparison with other areas of scientific prediction or risk assessment. It is therefore not prudent to judge any possibility as "unlikely" or "low risk," especially when there are so many unknowns and confounding factors. Traditional inferential statistics may be the norm for much of science, but they should not be applied in this situation. This is far different from estimating the outcome of a research experiment or even predicting an ordinary earthquake.

7. The standard system engineering risk assessment process is shown in Figure 1. It involves assessing the risk and the consequences of any failures. Storing nuclear waste at San Onofre includes very high risk, and remains dangerous for 2,500 centuries. The consequence of a failure and contamination of the surrounding area would cause serious damage and threaten the health of over 1 million people (approximately 8.4 million people live within the 50-mile zone.) Therefore any failure is unacceptable because the risk impact is too high.

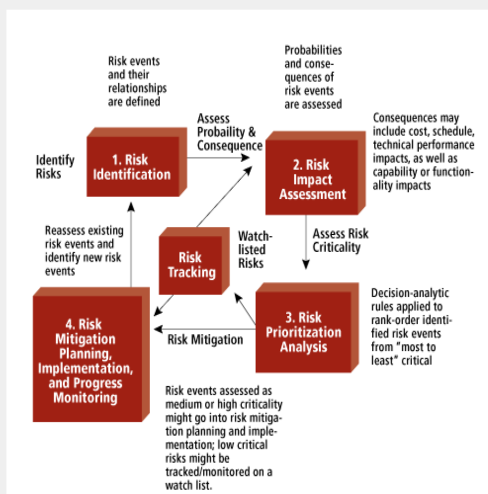


Figure 1. Risk Management: Fundamental Steps

8. On-site nuclear waste storage in an "ISFSI" (independent spent fuel storage installation) has been *generically* approved by the NRC using a "generic environmental impact statement" which allows these installations to remain for an indefinite period of time, certainly decades and perhaps centuries. This long time scale means we must also be concerned with relatively rare events. The Generic EIS should be challenged for applicability in this seismically active region, and indeed, no ISFSI's should probably be allowed as a result. The NRC has a problem in that they have already approved these based on immature seismology and any new analysis has a bias to support earlier positions rather than to undermine or reverse them, as they should.

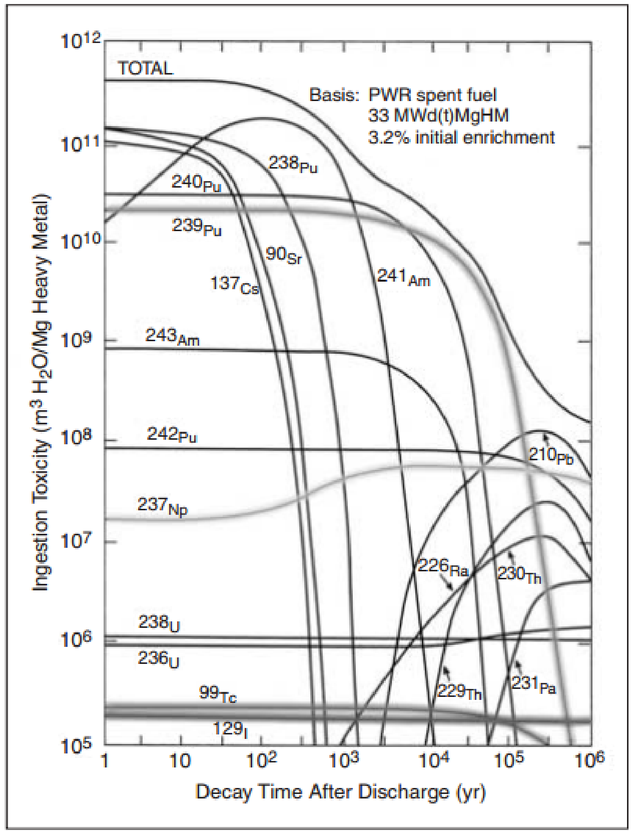


FIGURE 2 Toxicity from ingestion as a function of decay time for a number of nuclides in spent fuel from light-water reactors. Source: NRC, 1996.

9. Seismic risk assessment likes to use acceleration at the plant rather than the Richter scale. Peak Ground Acceleration (PGA) or Design Basis Earthquake Ground Motion (DBGM) is measured in Galileo units – Gal (cm/s^2) or **g** – the force (acceleration) of gravity, one **g** being 980 Gal. PGA has long been considered an unsatisfactory indicator of damage to structures, and some seismologists are proposing to replace it with Cumulative Average Velocity (CAV) as a more useful measure since it brings in displacement and duration.[5] On this basis alone, we should be very suspect of any claim that a system can withstand an earthquake of a given magnitude.

10. In addition, these simple numerical values do not include damage to structures and systems that can result from resonant magnification of ground movement vibrations.[6] Extensive damage can result if the system under consideration has components which have resonant frequencies which match spectrum components of the earthquake vibration. Thus, using peak acceleration in

5 http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/nuclear-power-plants-and-earthquakes.aspx
6 https://www.iris.edu/hq/inclass/animation/building_resonance_the_resonant_frequency_of_different_seismic_waves

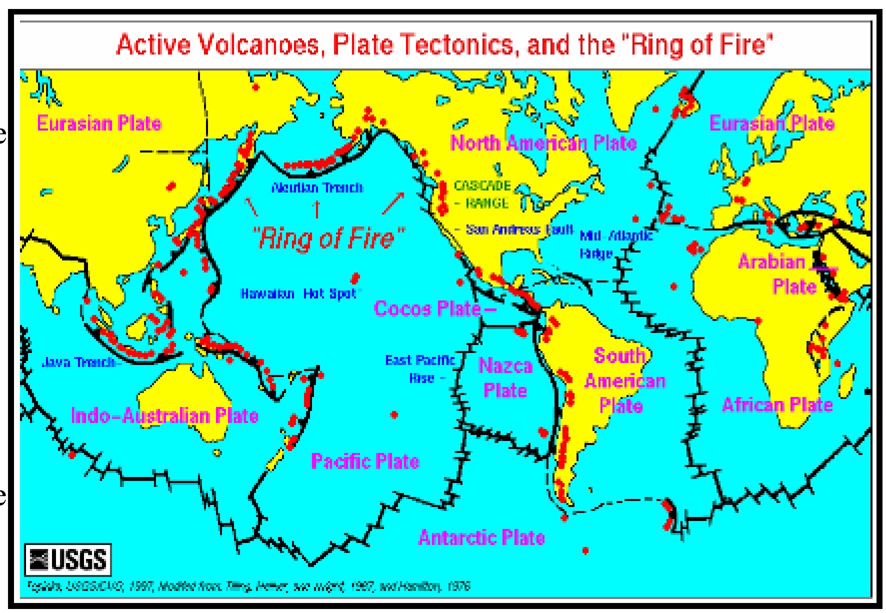
design basis analysis simply shows that system components can withstand that acceleration; it is hardly a robust analysis methodology which would also include resonant vibrations in the analysis.

Boundaries of the problem

Essentially when discussing earthquake risks, we are speaking about the vibrations imparted to a system of interest by an earthquake or the forces and effects of being flooded by a tsunami. Certainly, there is no absolute upper bound because a release of magma could occur at any spot on earth and destroy any material known to man. But putting that extreme case aside, there IS an upper limit of the amount of shaking the earth can impart if it does not result in a release of magma at the location of interest.

Largest Earthquakes

The world's largest earthquake with an instrumentally documented magnitude occurred on May 22, 1960 near Valdivia, in southern Chile. It was assigned a magnitude of 9.5 by the United States Geological Survey. The United States Geological Survey reports this event as the "largest earthquake of the 20th Century." Other earthquakes in recorded history may have been larger; however, this is the largest earthquake that has occurred since accurate estimates of magnitude became possible in the early 1900s.[7]



Of course, we haven't been measuring this for very long so we really don't know what the largest earthquake might be, and some areas are riskier than others.

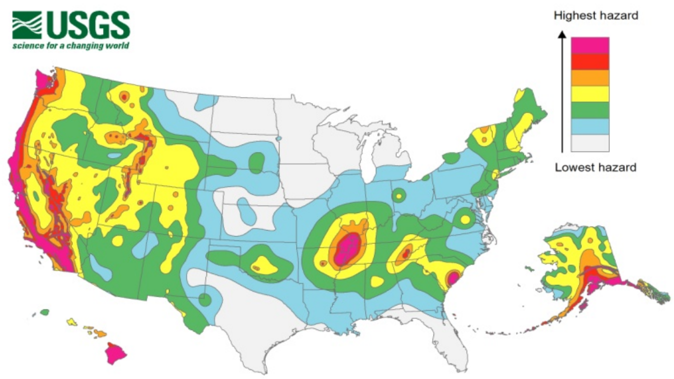
Where earthquakes occur

Earthquakes generally occur in the regions around tectonic plate boundaries, most specifically, in

7 http://geology.com/records/largest-earthquake/

the “ring of fire” around the Pacific Ocean, where about 90% of the world's earthquakes and 81% of the world's largest earthquakes occur.[8]

Anything built in the vicinity of tectonic plate boundaries may experience extremely large earthquakes.



More importantly, nuclear plants or nuclear waste along the California Coast is generally in a very vulnerable location.

The boundary between the Pacific Plate and North American Plate is along the San Andreas fault and nearby faults.

Geologic studies show that over the past 1,400 to 1,500 years large earthquakes have occurred at about 150-year intervals on the southern San Andreas fault. The last large earthquake on the southern San Andreas occurred in 1857.”[9] So we may expect movement here around 2007, meaning we are overdue for the “big one.” Since advanced scientific instruments were not in place in 1857 to measure the prior movement of the southern San Andreas, the magnitude of the upcoming earthquake is based only on informed guesses, and not hard data. In addition, we don't know how much nearby faults will also move in the “big one.”

Tsunami Risk

Tsunamis result from earthquakes or underwater rock slides. We have only limited information about the absolute maximum tsunamis. But it is actually easy to avoid tsunamis by avoiding coastal areas and building at higher elevations.

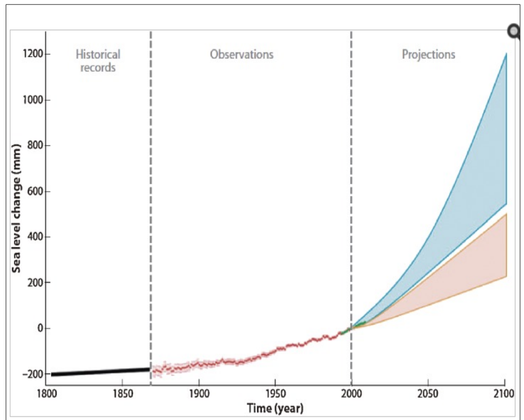
The largest tsunami ever: A tsunami with a record run-up height of 1720 feet occurred in Lituya Bay, Alaska. On the night of July 9, 1958, an earthquake along the Fairweather Fault in the Alaska Panhandle loosened about 40 million cubic yards (30.6 million cubic meters) of rock high above the northeastern shore of Lituya Bay.[10] But this is a very limited example that would not apply to the open ocean, and the actual height of the wave in this case was about 100 ft.

8 according to Wiki.
9 https://pubs.usgs.gov/gip/earthq3/when.html
10 http://geology.com/records/biggest-tsunami.shtml

The 50 foot Indian Ocean tsunami ten years ago traveled at speeds reaching 500 miles per hour and barged up to a mile inland. It killed some 200,000 people, making it the deadliest wave known.[11]

San Onofre is in a tsunami inundation area.

Again, it would not take much to avoid this risk, simply by building farther inland and above several hundred feet. Unfortunately, nuclear plants are typically built very close to mean sea level to make it easy to pump cold ocean water into the plant for cooling. Now, Southern California Edison has proposed building an Independent Spent Fuel Storage Installation (ISFSI) within 100 feet of the sea wall and only inches above the water table. There is no functional reason why the ISFSI needs to be close to the ocean. Building in this location subjects it to tsunami and corrosion risks.



Predicted Sea Level Rise

Furthermore, the tsunami wall is not maintained and is not included within the approval requirements for the ISFSI by the California Coastal Commission.[12]

Climate change scientists warn that Global Mean Sea Level (GMSL) will be rising in the future.[13] Estimates are 0.2 to 1.2 meters over the next 100 years.

NRC scientists disagree[14] about the safety of Diablo Canyon Nuclear Power Plant, which is located about 85 feet above MSL and theoretically safe from tsunami waves up to 32 feet in height. This is better than the situation at Fukushima which was doomed after the 20 foot wave in 2011.

Unfortunately, the planned location of the new ISFSI is only inches over the ground water level.

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11 http://www.smithsonianmag.com/science-nature/biggest-waves-recorded-history-180952432/

12 See page 7 of the California Coastal Commission permit: “No new shoreline protective device(s) shall ever be constructed to protect the development approved pursuant to Coastal Development Permit #9-15-0228, including the ISFSI facility, associated ancillary structures and any future improvements, in the event that the development is threatened with damage or destruction from erosion, landslides, waves, storm conditions, flooding, sea level rise or other natural coastal hazards in the future. By acceptance of this permit, the applicant hereby waives, on behalf of itself and all successors and assigns, any rights that may exist under Public Resources Code Section 30235 to augment, enlarge and/or replace any of the existing shoreline protective devices adjoining the NIA in order to protect the development approved by this coastal development permit. -- https://documents.coastal.ca.gov/reports/2015/10/Tu14a-10-2015.pdf

13 MIMURA N. Sea-level rise caused by climate change and its implications for society. HORIKAWA K, ed. Proceedings of the Japan Academy Series B, Physical and Biological Sciences. 2013;89(7):281-301. doi:10.2183/pjab.89.281. -- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3758961/

14 http://www.copswiki.org/Common/M1472 -- Diablo and the deep blue sea: A shelved NRC tsunami study is generating new interest 11 years later

Calls for Worst-case Design

Based on the fact that earthquakes have been observed up to 9.5 magnitude and that the California coast is on the ring of fire and is in a "highest hazard area," anything designed with a potential for devastating results should they experience damage (such as a nuclear plant or nuclear waste storage facility), SHOULD be designed to survive a worst-case quake. To be "conservative" we must give ourselves a margin of error. Thus, any such facility SHOULD be built to withstand quakes up and above the largest quakes observed so far, PLUS that margin for error. Therefore, we should probably assume an earthquake of magnitude 10.0, with the epicenter of the quake nearby and with rock with maximal transfer between, and with the design basis analysis using CAV rather than PGA and resonant vibration analysis. Obviously a prudent approach given the ultimate danger of a nuclear plant or nuclear waste storage facility is to simply avoid this location altogether.

It would likely be nearly impossible and very expensive to build any large rigid structure that would withstand such vibrations. Additionally, it is very difficult to actually design structures and systems that will endure any rare event because those systems are never adequately tested. Design methodology focuses on discrete components of the overall system which meet vibration ratings. It is very difficult to know how such vibrations will affect larger and interconnected systems.

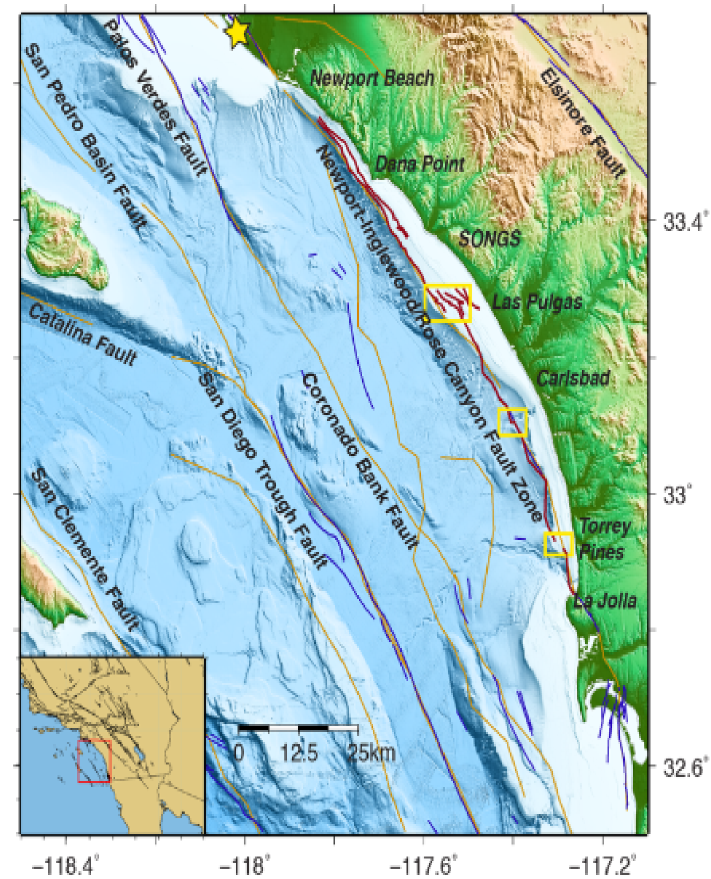
Proof to this point is clearly provided by the failure of the replacement steam generators at San Onofre which were carefully designed to withstand internal vibrations of their own during operation, but failed in record time, resulting in the demise of the San Onofre nuclear plant. Analysis of vibrations due to the expansion of boiling water into steam is VERY DIFFICULT and exceeds the computational capability of the best engineers and top super computers. Claims that a plant meet a specific "design basis" such as the Peak Ground Acceleration is convenient way to lie to ourselves, and convince us that a plant that was already built and operating can continue to do so safely. These analyses rarely challenge the design sufficiently and typically include limiting constraints, such as limiting the analysis to one failure at a time rather than multiple failures, because the problem then may grow almost without bound. They also typically assume other infrastructure (outside power, roads, access, water, etc.) is available when a huge and devastating earthquake would likely also impact if not eliminate those support systems.

Fukushima is a good example of how many issues combine to result in a catastrophe that is well beyond the capabilities of mortal man to contain.

Seismic Studies Give False Security

The nuclear plants built along the California coast, including San Onofre, Diablo Canyon, and Humbolt Bay, were designed and built just as we were starting to gain knowledge about earthquake risk. The small Humbolt Bay nuclear power plant was actively shut down in 1976 due the discovery of extreme seismic risks in that area and the resulting expense required to upgrade it.[15]

At the February 16, 2017 San Onofre Community Engagement Panel conducted by Southern California Edison, a presentation was given by Neal Driscoll of the Scripps Institution of Oceanography regarding such a study of the risks at the San Onofre plant.[16] The most significant result of the study was that the Newport-Inglewood/Rose Canyon (NI/RC) fault line immediately off the coast from San Onofre could result in a 7.4 magnitude quake. Due to the proximity to the plant, this would result in very high accelerations, dangerously close to the design limit of the plant, which is supposedly rated to magnitude 7.5.



Map of faults provided by Driscoll at the CEP meeting.

However, we also know that the plant was originally designed to withstand only a 6.0 quake, then upgraded to 7.0 and later to 7.5. The process of upgrading the ratings of the plant largely are performed by “sharpening the pencil” to provide reasons why such large quakes won't hurt anything rather than actually changing the design of the plant.

Had the plant been operating, the conclusion by Driscoll and his team should have been enough evidence that the plant should be shut down on this basis alone. Luckily, we don't have to fight that battle as the plant is no longer operating.

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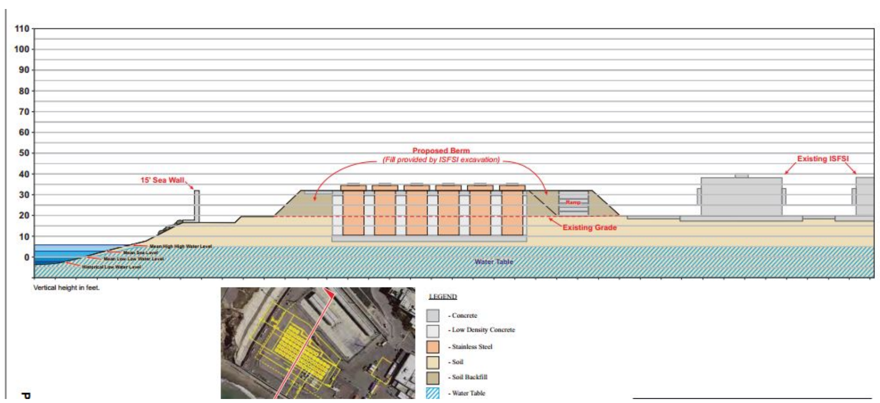
15 https://en.wikipedia.org/wiki/Humboldt_Bay_Nuclear_Power_Plant

16 Presentation slides: https://www.songscommunity.com/docs/021617_CharacterizingtheSeismicSettingOffshoreSouthernCalifornia.pdf

Interestingly, the study also considered an additional hidden fault line and then showed reasonable evidence that it most likely did not exist. News media covered this as “the danger is lower than we thought.” This is a very advanced form of sleight of hand to make a devastating result look better than it is. A fault which will likely result in a 7.4 magnitude quake only yards from the site should prevent the ISFSI from being built, that is if we could allow ourselves to think it through.

The result of this study was in harmony with the larger theory of plate tectonics in this area. This is a very dangerous location. But even though the study does support the notion that a 7.4 magnitude quake is certainly possible at the location, it is IMPROPER to then conclude that a 7.4 magnitude quake is the upper limit of what can occur. Actually, given the difficulty we have in studying the vast time scales of seismology of hundreds or thousands of years punctuated by rapid movements on the order of seconds or minutes, we have no idea how large the quakes at this location might be, except to say they are probably bounded at the top at perhaps magnitude 10.0 unless there was a release of magma at that exact location and the whole thing melted into a pool of lava.

Had we known more about seismology and assuming we would make rational decisions, no nuclear plants or nuclear waste storage facilities would be built along the ring of fire, such as in California. Indeed, knowing that the San Andreas fault is about to trip, the remaining operating plant, Diablo Canyon, should be shut down immediately and secured for the expected “big one” to occur at any time now.



Side cutaway view of the proposed Holtec ISFSI

Proposed ISFSI

Southern California Edison has proposed the installation of Holtec “UMAX” ISFSI on a pad near the existing reactors at San Onofre. They have gained approval of this plan by the California Coastal Commission.[17]

17 Citizens Oversight has filed a challenge to this approval in CA Superior Court. See http://www.copswiki.org/Common/NukeWasteLawsuit

The proposed system stores the canisters in a vertical orientation in an area only 100 feet from the seawall, only inches over the current mean sea level, in massive school-bus size but thin-walled, (5/8”) stainless steel canisters placed in cavities in a massive block of concrete.

Corroding Nuclear Waste Canisters

Storing nuclear waste this close to the ocean, just barely over Mean Sea Level, is difficult to square with the risk factors of this area. Proximity to salty ocean air means these canisters will start to corrode once canister surface temperature drops to below 85°C. Corrosion will encourage the development of cracks. These cracks may not extend through the thickness of the wall but will weaken the canisters and may result in complete failure, most particularly when extraction is attempted. However, over time, they may extend through the 5/8” thickness of these canisters, and begin to release radioactive particles.[18]

According to CFR Part 72.122[19]:

> (i) Structures, systems, and components important to safety must be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, lightning, hurricanes, floods, tsunami, and seiches, without impairing their capability to perform their intended design functions. The design bases for these structures, systems, and components must reflect:
>
> > (A) Appropriate consideration of the most severe of the natural phenomena reported for the site and surrounding area, with appropriate margins to take into account the limitations of the data and the period of time in which the data have accumulated, and
> >
> > (B) Appropriate combinations of the effects of normal and accident conditions and the effects of natural phenomena.

Clearly, when corrosion is combined with severe earthquakes for the area, existing designs are not sufficient to “withstand the effects natural phenomena.” We object to the notion that we should constrain our concerns only to such phenomena that have been “reported for the site” as we must also take a more prudent view of what may occur in the future, given the location on the ring of fire, the long period of time waste may be stored at the location according to the Generic Environmental Impact Statement for the ISFSI, and the relative immaturity of seismology.

18 D.G. Enos and C.R. Bryan Sandia National Laboratories, “Understanding the Risk of Chloride Induced Stress Corrosion Cracking” -- SAND2015-4671 PE http://www.nwtrb.gov/meetings/2015/june/enos.pdf

19 https://www.nrc.gov/reading-rm/doc-collections/cfr/part072/part072-0122.html

Given the history of delays in moving waste from nuclear power plants by the Department of Energy, it seems likely that if the proposed ISFSI is installed at this location and filled with waste, it will take longer than expected to move it to any other location. Assuming there may be complications with one or more canisters such that it becomes difficult or impossible to extract them from the ISFSI without risking inducing a critical nuclear reaction, it may then be necessary to seal over the ISFSI with concrete and ENTOMB it rather than move it. Proximity to the ocean risks that radioactivity will leak into the ocean, especially during storms, tsunamis or ocean rise due to climate change. This is absolutely possible and may result in an untenable situation that was never intended.

Some risks of degradation of these canisters may be reduced by adopting either thicker canisters or using a dual-layer approach, neither of which are being considered with any seriousness.

Canisters are too big to transport and store

There is a lack of integration between storage, transportation, and disposal in the nuclear waste management system. Utilities have moved to larger school-bus size canisters to optimize on their storage needs and reduce near-term costs. However, these large canisters may or may not be disposable into any future geologic repository. If large canisters are not directly disposable, the contents will need to be repackaged, with potential to increase costs, dose, and handling operations.[20] Consideration of a possible "Standardized Transportation, Aging, and Disposal (STAD) Canister Design" which would be compatible with a future geologic repository is complicated by the lack of a known geologic repository. We are continuing to use canisters that will likely be too big and too hot for a repository such as Yucca Mountain.

Conclusion

The presentation given at the recent CEP meeting on seismic concerns was covered in the media that the location is "safer than we thought." But in reality, it provided only more evidence that <u>this location is far too dangerous for nuclear plants or a nuclear storage facility</u>. Prudent design should required that it meets worst-case design criteria, to withstand a quake of up to magnitude 10.0 and tsunami of 100 ft, and not the hope and prayer of the sort of study provided by Driscoll. A better approach is to avoid the construction of an ISFSI in this area and store the high-level radioactive waste at a more suitable location, i.e. far from earthquake and tsunami risks.

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20 http://www.nwtrb.gov/meetings/2015/june/jarrell.pdf -- "Standardized Transportation, Aging, and Disposal (STAD) Canister Design" by Josh Jarrell, PhD.

A full review of the ISFSI at this location is obviously called for. It should include consideration of other locations far from seismic and ocean concerns, and review of the design of canisters to see if thicker or canisters with dual shells may be an effective way to reduce the risk so as to comply with worst-case design requirements.

To avoid most seismic risks, the spent fuel should be moved to a location far from the coast and preferably on the North American Plate, which is relatively stationary compared with the Pacific plate, and placed far from tsunami risks.

And this analysis does nothing to deal with perhaps the largest set of risks, that is of a terrorist attack of some sort at the site, given that it is easily accessible from the ocean and freeway.

Frankly, this is a really bad location for a nuclear plant or a nuclear waste site. We MUST reconsider our options and get serious about relocating it far from population concentrations, seismic areas, and waterways or oceans.