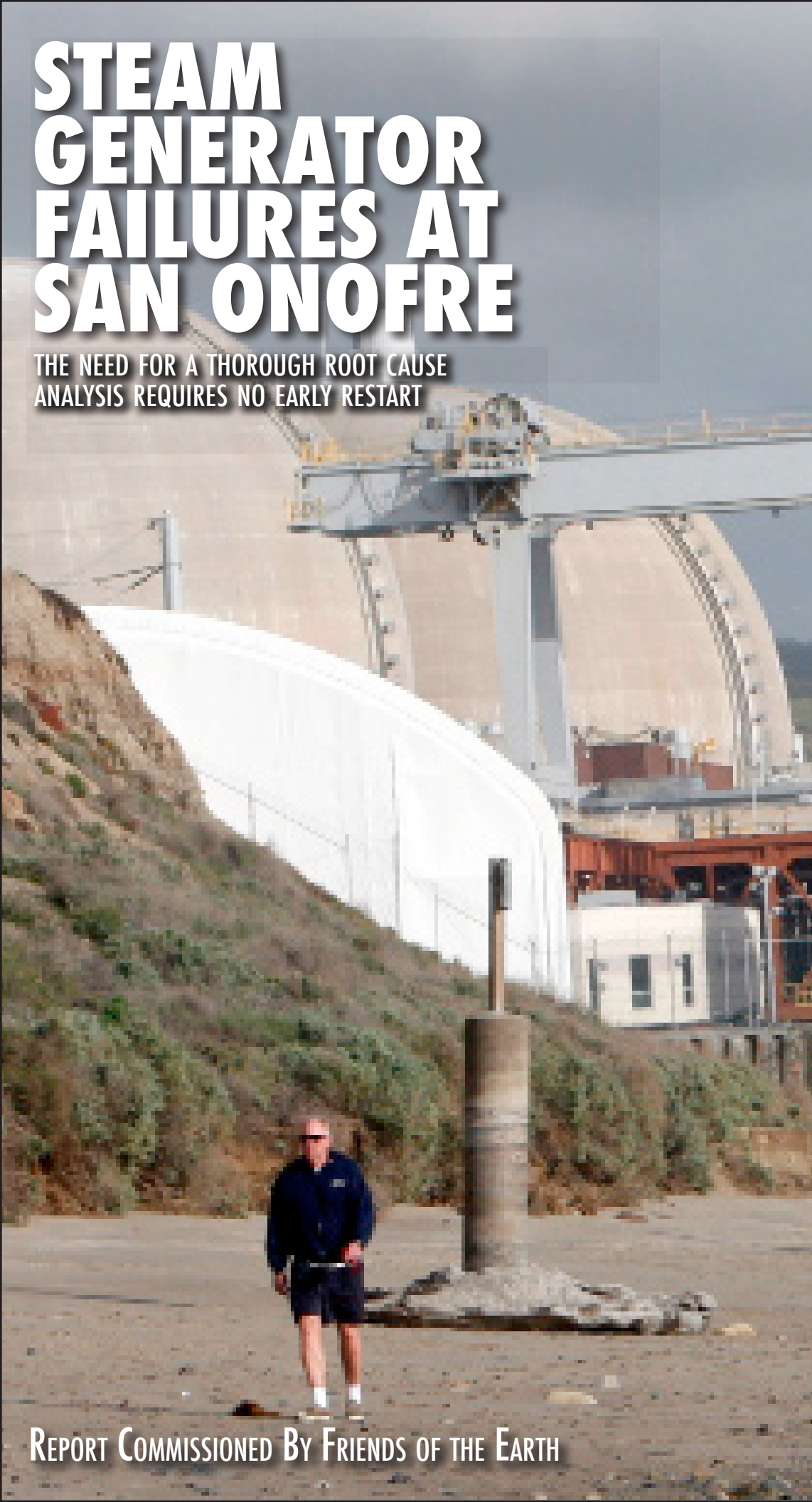


STEAM GENERATOR FAILURES AT SAN ONOFRE

THE NEED FOR A THOROUGH ROOT CAUSE
ANALYSIS REQUIRES NO EARLY RESTART



FAREWINDS ASSOCIATES

REPORT COMMISSIONED BY FRIENDS OF THE EARTH

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EXECUTIVE SUMMARY

Following 28 and 29 years of operation, the two San Onofre Nuclear Generating Station reactors owned by Southern California Edison (Edison) are unable to safely generate the necessary electricity for the people of California. An investigation conducted by Fairewinds Associates has identified that a series of major modifications to the internal design of replacement steam generators in both San Onofre Units 2 and 3 are likely the cause of excessive wear, leaks and pressure test failures in the steam generator tubes. Despite Edison's rush to make an early restart of at least Unit 2 if not Unit 3, and the apparent relaxed approach of the NRC as to their role in the timing of any start up by Edison, Fairewinds Associates recommends that both San Onofre Unit 2 and Unit 3 remain shut down until the "root causes" of the nuclear power plant's rapid tube failures are understood and repaired, reliability is assured, and radioactive releases are prevented.

BACKGROUND

There are 104 nuclear power plants generating electricity in the United States (US). Pressurized Water Reactors (PWR's), like San Onofre, account for almost 70% of all US reactors; the remaining 30% of nuclear power reactors are Boiling Water Reactors (BWR's). The San Onofre nuclear power reactor is a very unique design originally built by Combustion Engineering (CE) and is very different from the Westinghouse or Babcock & Wilcox nuclear power reactor designs. While most of the Westinghouse U-Tube PWR designs have three or four steam generators, all of the CE nuclear reactors use only two steam generators. Because there are only two steam generators in this Combustion Engineering design, each steam generator is 50% larger than those built by Westinghouse for a similar reactor power output. In fact, only the 14 CE PWR nuclear reactors, out of the 104 nuclear reactors in the US, have this very unique and extra large sized steam generator system. This means that the replacement steam generators at San Onofre are some of the largest steam generators that have ever been designed or manufactured.

Unlike a Boiling Water Reactor (BWR), the water that cools the nuclear core inside a PWR never boils. In order to prevent boiling the cooling water is pressurized to more than 2,000 pounds per square inch (psi). However, in order to make a turbine spin and generate electricity, the nuclear power plant must produce steam. In a PWR, a steam generator is used to transfer heat from the pressurized, radioactive water that cools the reactor to the steam that turns the turbine and is supposed to be non-radioactive. To accomplish this engineering feat, the hot pressurized reactor water is pushed through thousands of U-shaped tubes inside the steam generator in order to remove the heat and by that process create non-radioactive steam on the outside of those same tubes to spin the turbine and generate electricity.

STATUS

The San Onofre reactors have significant problems because their newly installed steam generators have extensive degradation and are unable to perform their design function of containing the radioactive water in the facility. Concerned about the safety of these plants, Senator Barbara Boxer (D-CA), Chair of the Environment and Public Works Committee, sent a letter February 8, 2012, to the Chairman of the Nuclear Regulatory Commission (NRC), Dr. Gregory Jaczko, requesting that the NRC review and report on the safety conditions at the San Onofre nuclear plant due to the recently discovered problems related to tubes that carry radioactive water at the facility. Senator Boxer asked the NRC to assess the conditions at the plant, which is located in San Clemente, California, to determine if further action is needed.

Only one month later on March 13, 2012, Chairman Jaczko responded, “The root cause of the tube leak has not yet been determined. ...NRC approval is not required for the licensee [Edison] to restart Units 2 and 3.”

Steam generator tube degradation, like that which San Onofre is experiencing, causes a significant nuclear safety risk by substantially increasing the likelihood of an accident that releases radioactivity into the environment. Unfortunately, a leak or disintegration of one or more tubes would cause the radioactive water to escape the containment. Because there is a 1,000-pound-per-square-inch (psi) pressure difference between the high-pressure radioactive side of the tubes and the lower pressure steam that then leaves the containment, a leak will inevitably release radioactivity into the environment. Gross failure of one or more of the steam generator tubes could create a nuclear design basis accident and cause the nuclear reactor core to lose a portion of its cooling water. However, the unique concern of degraded steam generator tubes is that uncontrolled radiation releases from a tube break do not remain inside the containment building and instead leak out of the facility and into public areas via atmospheric dump valves and steam generator blowdown.

DESIGN CHANGES CREATE SIGNIFICANT RISK OF FAILURE

The design engineers for the San Onofre reactors believed that steam generator tubes would last for the lifetime of the nuclear reactor without any appreciable leakage. Because steam generators that hold those tubes were considered permanent components and would never need replacement, the nuclear containment buildings were never provided with access doors large enough to allow for the removal of degraded steam generators. Even though tubes were expected to last for the entire lifetime of each PWR, this has not proven to be the case. For example, the first steam generators were replaced at the Surry 2 reactor in Virginia in 1979 after only seven years of operation. The vast majority of PWR steam generators have required replacement due to significant degradation.

As a result of tube deterioration and degradation uncovered several years ago, Southern California Edison (Edison) decided to replace each of the steam generators at both of the San Onofre reactors. A review of the published literature shows that the specifications of four steam generators are identical and they were purchased together under a single contract. Edison signed a contract for these steam generators with Mitsubishi Heavy Industries. This challenging construction project required that a hole be cut in the side of the nuclear containment to remove and replace the old steam generators. It was akin to cracking someone's chest and performing a heart transplant.

It now appears that after new steam generators were installed at San Onofre Unit 2 and Unit 3, the new tubes began to seriously degrade very quickly. Technicians first detected the unanticipated problems of significant wear in the tubes during the Unit 2 refuelling outage in January 2012. The wear-rate for these steam generator tubes is extraordinary because tube thickness has been reduced by as much as 30% in less than two years. With their typical lack of transparency, Southern California Edison, San Onofre, and the NRC were not forthcoming to the public on the extent of the significant degradation in Unit 2's steam generator tubes. While Unit 2 was shutdown for refuelling, San Onofre Unit 3 was operating at full power when it experienced a complete perforation of one steam generator tube that allowed highly radioactive water from inside the reactor to mix with the non-radioactive water that turns the turbine. As a consequence, an uncontrolled release of radiation into the environment ensued, and San Onofre Unit 3 was also forced to shutdown due to steam generator failure.

ROOT CAUSE

The tube failure and ensuing radiation release at San Onofre Unit 3 made the public keenly aware that both San Onofre Units 2 and 3 are experiencing significant degradation and malfunction of their new steam generators. The public, including Senator Barbara Boxer, has demanded to know the extent of safety ramifications for the San Onofre Unit 2 and 3 steam generators and their leaking tubes.

What has changed that caused the leak?

What can the standard engineering practice of root cause analysis determine as the cause of such severe short-term steam generator degradation?

The most obvious change is that the old steam generators, that operated for more than 25-years, were recently replaced with new ones built by Mitsubishi Heavy Industries.

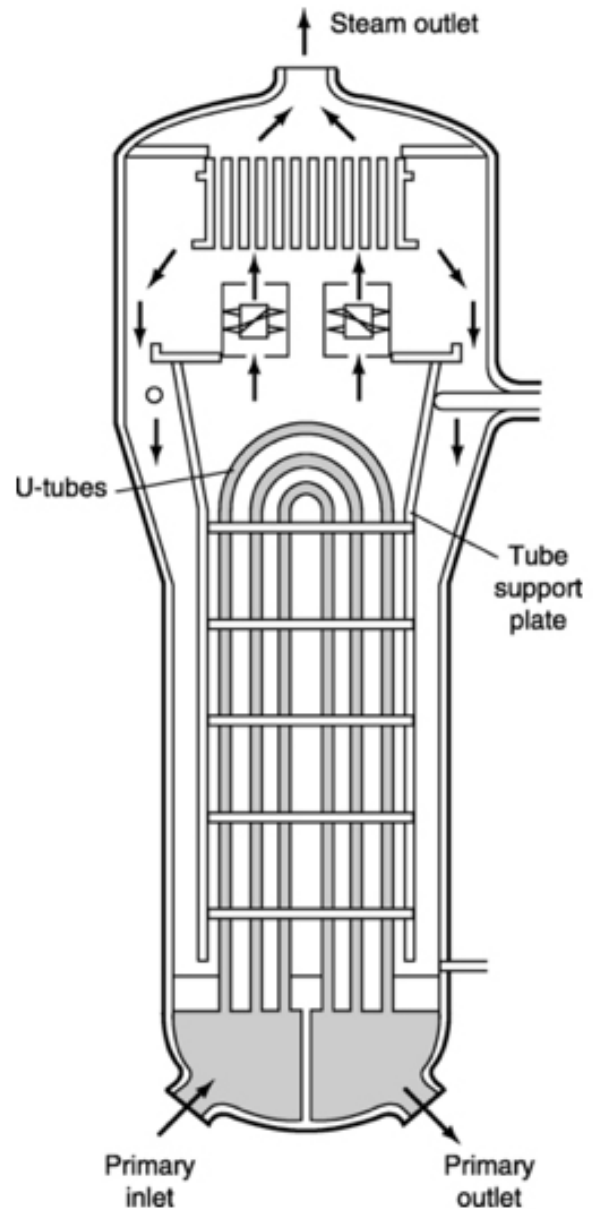
Why did the original design last for 25-years while the new design failed in only two years?

What did Edison and Mitsubishi modify in the new design that was different from the original design?

A report¹ by Southern California Edison and Mitsubishi published in January 2012 describes in great detail numerous changes to the original steam generator design.

Fairewinds review of the Edison/MHI report determined that the four most critical changes likely to be a cause of the current tube leaks at San Onofre 2 and 3 are:

1. The tube alloy was changed,
2. Reactor flow rate was changed,
3. More steam generator tubes were added, and
4. Modifications were made to the “egg crate” that holds the tubes separate in Unit 2 and Unit 3.



1. Improving Like-For-Like Replacement Steam Generators by Boguslaw Olech of Southern California Edison and Tomouki Inoue of Mitsubishi Heavy Industries, Nuclear Engineering International, January 2012, page 36-38. <http://edition.pagesuite-professional.co.uk/launch.aspx?referral=other&pnum=36&refresh=K0s3a21GRq61&EID=af75ecb1-5b23-49be-9dd6-d806f2e9b7b5&skip=&p=36>
 2. <http://products.asminternational.org/fach/data/fullDisplay.do?database=faco&record=843&trim=false>

While each of these changes is significant if reviewed individually, taken together they created a large risk of tube failure at the San Onofre reactors. The significant increase in the number of Mitsubishi steam generator tubes and the large flow rate of radioactive water through these tubes were impacted by this simultaneous change and combination of untested materials and techniques. Fairewinds believes that vibration within the tubes in both Unit 2 and Unit 3 were due to the simultaneous implementation of untested manufacturing and design changes made by the Edison/MHI to the replacement steam generators.

While Edison and San Onofre consider these steam generator replacements at San Onofre as a *like-for-like* replacement, such a distinction is actually part of a procedure that San Onofre developed in order to avoid the requisite NRC oversight of a steam generator replacement process. Several years prior to the design and installation of the new San Onofre steam generators, Edison/San Onofre completed the 10CFR50.59 review process of replacement steam generators. The Edison/San Onofre 10CFR50.59 review process of the replacement steam generators enabled Edison/San Onofre to have a so-called pre-review, so that the design and manufacture of the replacement steam generators at San Onofre did not receive any actual NRC oversight or technical review. The San Onofre application of the 10CFR50.59 review portrayed the steam generator replacement project as a *like-for-like* replacement¹ that therefore would not require a thorough NRC review and approval process.

As a result of the design and manufacturing changes implemented by Edison and Mitsubishi to the original San Onofre steam generator tubes and related components, both Units 2 and 3 have experienced extraordinarily rapid degradation of their steam generator tubes. Fairewinds believes that if the original steam generators had been replaced with duplicates (*like-for-like*) as regulators allow, the problems that San Onofre is currently experiencing would have been dramatically reduced or entirely eliminated. The extensive changes made by Edison/Mitsubishi to the new San Onofre steam generators are hardly a *like-for-like* change and are the likely cause of problems in both Unit 2 and Unit 3.

1. Improving Like-For-Like Replacement Steam Generators by Boguslaw Olech of Southern California Edison and Tomouki Inoue of Mitsubishi Heavy Industries, Nuclear Engineering International, January 2012, page 36-38. <http://edition.pagesuite-professional.co.uk/launch.aspx?referral=other&pnum=36&refresh=K0s3a21GRq61&EID=af75ecb1-5b23-49be-9dd6-d806f2e9b7b5&skip=&p=36>

URGENT EVALUATION REQUIRED

Unfortunately, progress on evaluating the extent of the problems at both San Onofre Units 2 and 3 has been slow, due in part to Edison's purchase of only one set of the steam generator nozzle dams required for tube inspections. Steam generator nozzle dams prevent reactor water from leaking into the bottom of the steam generators when inspections are taking place. Consequently, when only one set of dams is available, both units cannot be simultaneously inspected. The decision to procure only one set of nozzle dams indicates a penny wise and pound foolish procurement policy that has made it technically impossible for Edison to simultaneously conduct these critical steam generator examinations of both San Onofre Units 2 and 3 without draining both vessels below their nozzles and limiting the movement of nuclear fuel in each reactor.

Simple inspections, conducted by using Eddy Current tests, indicate that more than 300 tubes in both units show unacceptable wear rates that require further evaluation. (Eddy Current inspections are non-intrusive and send electrical signals through the pipe wall to get a rough approximation of wall wear and thickness.) Now these 300 damaged tubes must be removed from service by welding them closed (plugged) prior to resuming plant operation. Additionally, within this very small sample, Edison has pressure tested only a limited number of tubes in San Onofre 3 and apparently only tested a single tube in Unit 2. This is one tube out of more than 19,000. Moreover, at least eight tubes in San Onofre Unit 3 have completely failed the limited pressure tests performed by Edison, while many thousands remained untested. A pressure test is a destructive test designed to cause a degraded tube that is too weak to sustain necessary pressure to fail under the testing and repair scenario rather than during operation. Such testing weeds out defective tubes on the edge of failure.

Even though Unit 3 experienced a gross tube leak and Unit 2 did not, it is important to note that these inspections showed that more tubes in Unit 2 were degraded than in Unit 3. It is also important to note that both Unit 2 and Unit 3 were designed and manufactured to the same specifications. Since Unit 2 operated somewhat longer than Unit 3, it is not surprising that Unit 2 should exhibit more degradation than Unit 3 as well.

INADEQUATE INFORMATION AND TRANSPARENCY

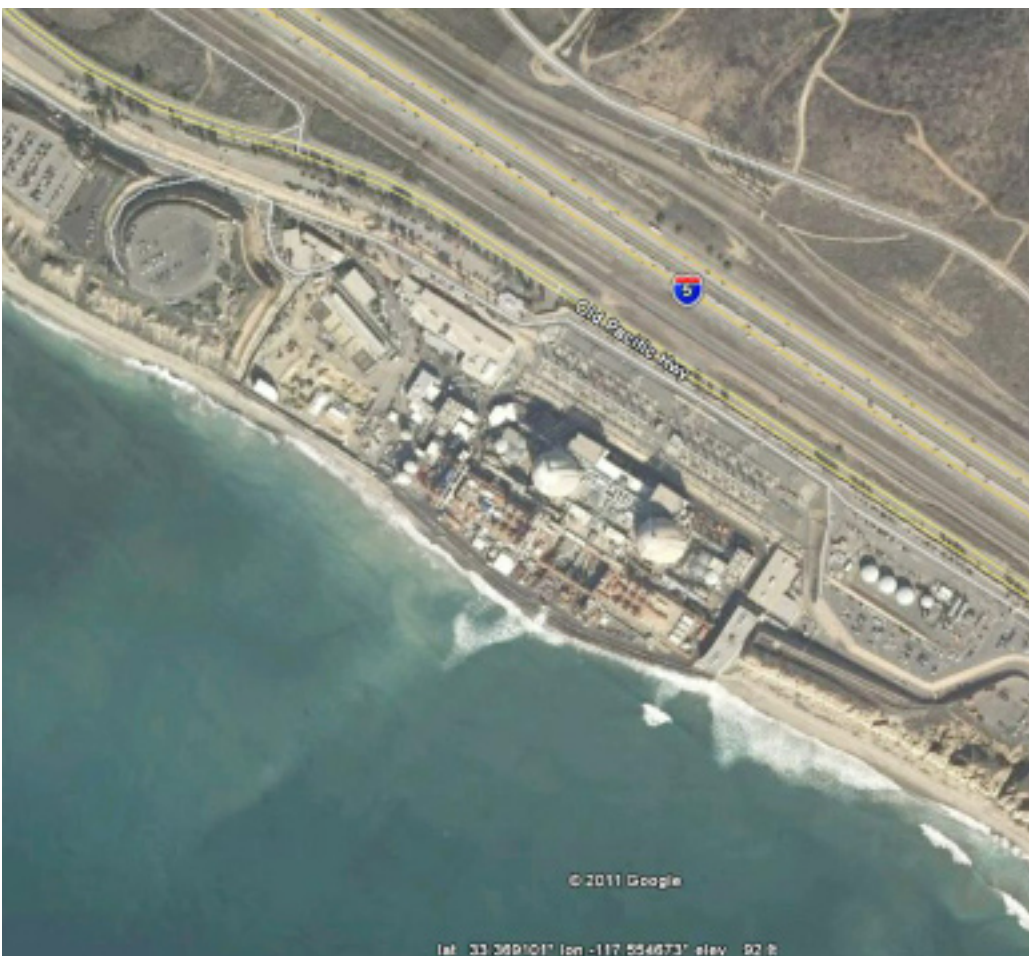
As is typical of the NRC and the nuclear industry, they have not been forthcoming to the public or its elected representatives with important details concerning where the leaking and degraded tubes at San Onofre have been detected. San Onofre engineers should have precise maps detailing the degraded and leaking tubes as well as the exact location of the leak(s) in each tube. Such data is just one piece of critical information required in conducting a thorough root cause analysis of the problem and determining an accurate solution.

By failing to pressure test a significant sample of tubes in San Onofre Unit 2, Edison will be unable to determine the full extent of this formidable safety issue. In response, Edison has attempted to focus political and media attention on Unit 3, while trying to obscure the reality, which is that Unit 2 has the same overarching problems as Unit 3. San Onofre Unit 2 has the same steam generators, the same significant wear in the tubes, and the same ongoing failed operational issues as reactor Unit 3. Therefore, Fairewinds believes that in order to prevent radiation releases and assure ongoing long-term reliability, Edison must keep San Onofre Unit 2 shutdown until thorough and systematic tube pressure tests and a root cause analysis have been completed.

Furthermore, a complete chemical analysis of a selection of individual tubes in each of the San Onofre reactors, conducted either by Southern California Edison or an independent outside team of consultants, is the only accurate engineering method available to ascertain if the tube failures are due to metallurgical problems or mechanical wear. If Edison is to accurately determine whether the problems at San Onofre are due to metallurgical insufficiencies or mechanical wear, orthodox engineering methodology requires that San Onofre technicians physically remove (pull) a selection of tubes and examine them. The U shape and long size of these tubes preclude replacement or repair, and therefore the hole from which they are removed must be plugged by welding the hole

shut. In order to answer long-term reliability and safety concerns, the metallurgy of the tubes must be compared to the old design and fabrication. Moreover, tubes from both San Onofre Unit 2 and 3 must be removed and thoroughly examined in order to compare any subtle differences in fabrication between the two units.

Unfortunately, it appears that the mobilization of an NRC Augmented Inspection Team to only Unit 3 is an effort by the NRC and Edison to obfuscate the issue at San Onofre and not conduct an orthodox, thorough, and requisite engineering root cause analysis. Without a thorough examination of the tubes in San Onofre Unit 2 the cause of the tube thinning will remain unresolved creating a significant safety issue. If the NRC allows either San Onofre reactor to restart without a thorough root cause analysis and another tube or tubes were to fail, radioactive releases might be significantly larger than those that occurred after the January 2012 tube leak. Such an accident would cause implementation of the California emergency evacuation plan and closing of the San Clemente beach and Interstate I-5, potentially for an extended period of time.



Aerial image of **San Onofre Nuclear Plant** proximity to US Interstate 5. Courtesy Google Images

http://dailygoogleearth.files.wordpress.com/2011/05/san_onofre_nuclear.jpg

According to the published literature, the replacement steam generators for Units 2 and 3 have identical specifications. Therefore, allowing San Onofre Unit 2 to restart on the mistaken belief that it is somehow different than Unit 3 before the root cause of the problem is definitively known defies logic. The NRC has failed to adequately protect public health and safety during a very similar incident involving serious cracking on a BWR. The Quad Cities reactor experienced severe vibration induced cracking of its steam dryer in 2002. In a BWR, the steam dryer is a major component in the reactor. In a PWR, such as at San Onofre, the steam dryer is an integral part of the steam generator. The owner of the plant and the reactor designer believed that they understood the problem and had made the appropriate repairs. They then started the reactor back up. One year later in 2003, the steam dryer had cracked yet again. In fact the second cracks were worse than the first.

If San Onofre Unit 2 is allowed to start up prior to a complete root cause analysis, steam induced dryer cracking like that at Quad Cities may occur in the steam generators at San Onofre. In 2002, Quad Cities told the NRC that the repairs would successfully solve the first failure. In the Preliminary Operating Experience Report OE16403, issued after the second steam dryer failure, the NRC said that:

- 1. After the first failure, “Several teams of Exelon Nuclear, General Electric and industry experts are assembled to ...determine the ...corrective actions.”**
- 2. Following the second steam generator failure, the NRC said that the second failure was caused when “GE Nuclear Energy and the licensee did not foresee this phenomenon.”**

What might San Onofre fail to foresee as the true problem in its rush to start Unit 2 back up?

Allowing either San Onofre Unit 2 or Unit 3 reactors to restart before the root cause of the problem is definitively known defies logic.

The Edison should not be rushing to restart these San Onofre reactors based upon a hunch or ‘preliminary conclusion’ that a safety problem may have been resolved and hoping that a root cause analysis, once finally attempted, may support an initial guess. If Edison restarts San Onofre Unit 2 or Unit 3, it will be impossible to conduct a thorough root cause analysis. The residents of southern California will be left wondering when the next break will occur and if that one break will cause a significant radiation release. Therefore, in conclusion and despite the Nuclear Regulatory Commission’s (NRC) refusal to exert its regulatory authority on when the plants are permitted to start up again, Fairewinds Associates recommends that both San Onofre Unit 2 and Unit 3 remain shut down until the root cause of each nuclear reactor rapid steam generator tube failures are understood and repaired, reliability is assured, and radioactive releases are prevented.

Friends of the Earth retained Fairewinds Associates (fairewinds.com) to conduct this review and issue this report. Arnie Gundersen, MSNE, and chief engineer for Fairewinds authored this report. Fairewinds Associates is a paralegal services and expert witness firm specializing in nuclear engineering and nuclear safety analysis in the US, Canada and overseas. Mr. Gundersen, who has 40-years of nuclear power engineering experience, is a former nuclear industry senior vice president who earned his Bachelor and Master Degrees in nuclear engineering from RPI, holds a nuclear safety patent, and was a licensed reactor operator. During his industry-centered career, Mr. Gundersen managed and coordinated projects at 70-nuclear power plants in the US. As part of the education mission of the 501(c) 3 non-profit organization Fairewinds Energy Education, Mr. Gundersen speaks to the public about the lack of adherence throughout the world to nuclear safety regulations.

