FAR OUTSIDE THE NORM: The San Onofre Nuclear Plant's Steam Generator Problems in the Context of the National Experience with Replacement Steam Generators

by
Daniel Hirsch
and
Dorah Shuey

with a Foreword
by
Dale Bridenbaugh

September 12, 2012

http://www.committeetobridgethegap.org

EXECUTIVE SUMMARY

Southern California Edison (SCE) and the Nuclear Regulatory Commission (NRC) have suggested that the problems experienced in the steam generators of the two San Onofre reactors are fundamentally different and that Unit 2's difficulties are merely "settling in" wear normal for new replacement steam generators. No data have been provided to date by SCE or NRC to support these claims, yet SCE has suggested that for these reasons it expects to request permission to restart Unit 2 and run it at somewhat reduced power, without repairing or replacing the damaged devices.

This report assembles national data from inspections of similar replacement steam generators after one cycle of operation. The conclusion is that both San Onofre Unit 2 and Unit 3 have experienced damage greatly in excess of the typical reactor:

- **The median number of steam generator tubes nationally showing wear after one cycle of operation is—FOUR. San Onofre Unit 2 had 1595 damaged tubes, approximately 400 times the median; San Onofre Unit 3 had 1806.**

- **The median number of indications of wear on steam generator tubes nationally after one cycle of operation is—FOUR. San Onofre Unit 2 had 4721, greater than a thousand times more. San Onofre Unit 3 had 10,284.**

- **The median number of steam generator tubes that were plugged after one cycle of operation is—ZERO. San Onofre Unit 2 had 510; Unit 3 had 807.**

Additionally, the replacement steam generators at San Onofre Unit 2 and 3 suffer from the same fundamental design errors. Indeed, the number of damaged tubes in each unit is approximately the same.

The conclusion is clear: San Onofre Unit 2 and Unit 3 are both very ill nuclear plants. Unit 3's fever is slightly higher, but both are in serious trouble. What they are experiencing is not just normal wear due to "settling in" purportedly experienced with similar replacement steam generators. They are far, far outside the norm of national experience. And Unit 2 cannot be said to be acceptable for restart, any more than Unit 3. Unit 2 has hundreds of times more bad tubes and a thousand times more indications of wear on those tubes than the typical reactor in the country with a new steam generator, and nearly five times as many plugged tubes as the rest of the replacement steam generators, over a comparable operating period, in the country combined. Restarting either San Onofre reactor with crippled steam generators that have not been repaired or replaced would be a questionable undertaking at best.

FOREWORD

SAN ONOFRE NUCLEAR GENERATING STATION REPLACEMENT STEAM GENERATOR PROBLEMS

by
DALE BRIDENBAUGH
NUCLEAR ENGINEER, RETIRED

As a retired professional nuclear engineer and long time citizen of California, I have followed the recent experience of the San Onofre Nuclear Generating Station with great interest. I am particularly troubled by the extent and causes of the early failures of tubes in the replacement steam generators at both of the San Onofre units (Units 2 and 3) that have not yet been thoroughly explained and reported. As this report makes clear, the conflicting failure data thus far made available by the San Onofre operating utility and the Nuclear Regulatory Commission, along with the lack of specificity detailing the mode(s) of failure, lend little credibility to Southern California Edison's claims that the large number of damaged steam generator tubes and indications of wear on the tubes are in fact completely understood. The data assembled in this report call into question assertions that the San Onofre damage is due primarily to normal "settling in" found commonly in other new replacement steam generators and that no immediate corrective action is needed before the restart of Unit 2.

As dramatically shown in Figures 3, 4, and 5 of this report, the San Onofre experience after only two or less years of operation with replacement steam generators lies far outside the bounds of normality when compared to the experience of other nuclear units with such replaced components. Steam generators, and more specifically the tube boundaries, play a critical role in assuring plant safety and the containment of possible radioactive releases. In spite of Edison's attempt to assert a different level of risk between Units 2 and 3, it seems clear that similar design and failure challenges are present in both units and that future operation of either unit has not been technically justified. It is my opinion that measures necessary for the future safe operation of either of these unit have not been adequately put forth at this time, and that operation with or without reduced power of Unit 2 should not be authorized.

TABLE OF CONTENTS

THE SAN ONOFRE NUCLEAR PLANT'S STEAM GENERATOR PROBLEMS IN THE CONTEXT OF THE NATIONAL EXPERIENCE WITH REPLACEMENT STEAM GENERATORS

Introduction

On January 31, 2012, a steam generator tube in Unit 3 of the San Onofre Nuclear Generating Station burst, leading to a shutdown of the reactor. Shortly thereafter, it was revealed that a previously scheduled inspection of Unit 2, which was down for refueling, had identified hundreds of damaged tubes in that reactor. Subsequent inspections of both units revealed approximately 3,400 tubes were showing indications of wear.

This was surprising because the steam generators in both units were virtually new. Unit 3's steam generators were about a year old, and Unit 2's were approximately two years old. Yet they were showing extensive wear.

Since then, further inspections have revealed serious problems with the steam generators in both units. 1317 tubes at San Onofre have been plugged to date, far more than have been plugged over a similar period of operation in all replacement steam generators in the country combined.

Southern California Edison, which operates San Onofre, has recently conceded that Unit 3 will not be operating anytime soon, if ever, and that the long-term viability of the plant as a whole is now in question.[1] However, the utility continues to suggest it may in the near future request approval from the Nuclear Regulatory Commission to restart Unit 2, even though its steam generators have been neither repaired nor replaced.

Underlying this anticipated action are two assertions: (1) that the problems in Unit 2 and Unit 3 are dramatically different, and (2) that the extent of the wear seen in Unit 2 is nothing out of the ordinary and commonly seen in similar new replacement steam generators, just a routine "settling in" phenomenon that stops soon after installation. The analysis that follows examines those two claims.

What Steam Generators Do and Why Their Proper Functioning is Important

Steam generators are critical components of Pressurized Water Reactors (PWRs) and their failure could lead to serious consequences. In a PWR, the primary coolant is kept under high enough pressure that it remains liquid at temperatures above the normal boiling point. That primary coolant, which picks up significant radioactivity from the nuclear fuel, must transfer its heat to a secondary coolant, which then becomes steam to turn turbines to generate electricity. The steam generators transfer heat from the primary to the secondary coolant and produce steam.

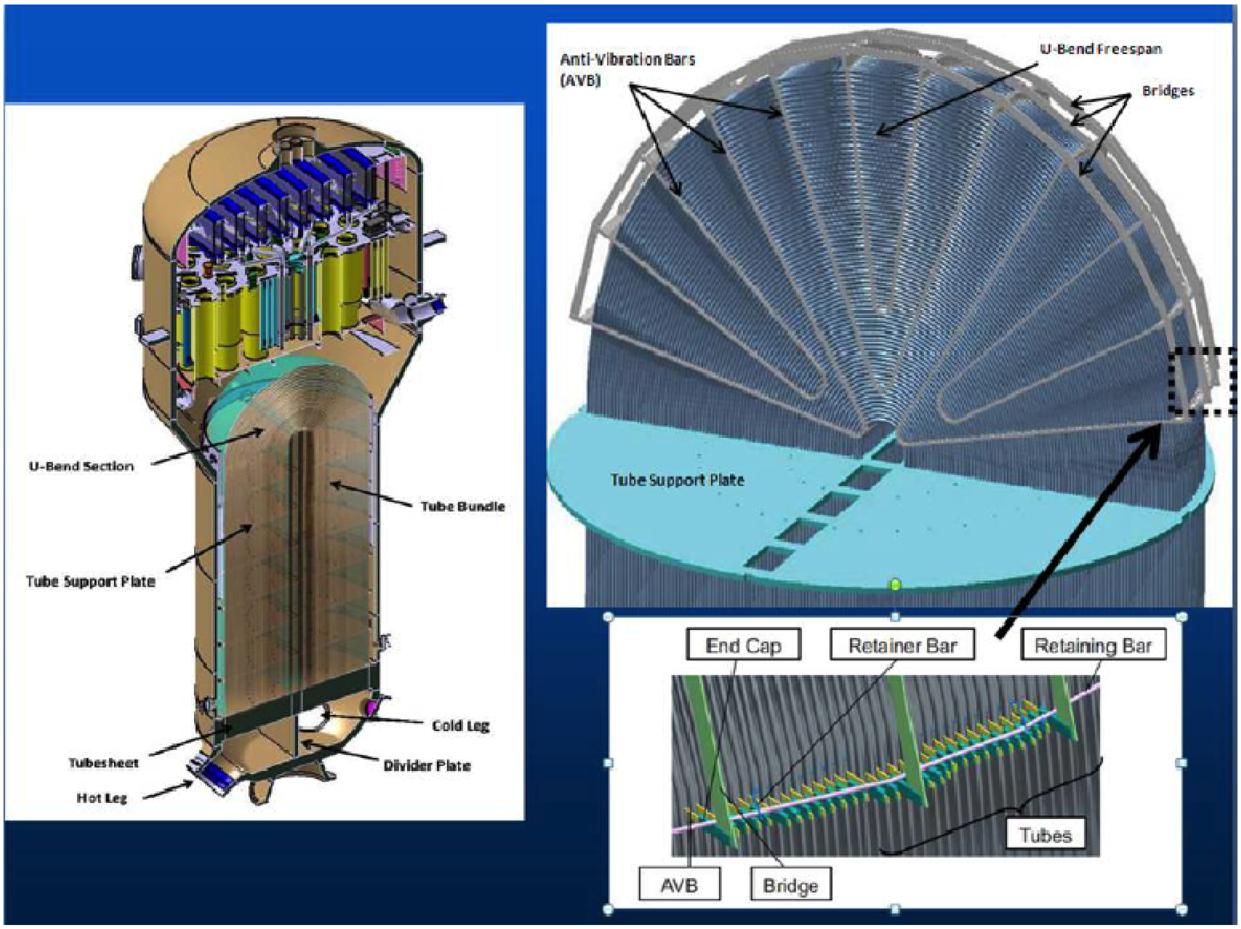
A steam generator is composed of a large number of very thin tubes through which the hot (both thermally and radioactively) primary coolant flows, transferring its heat to secondary coolant on the outside of the tubes. Significantly, while the steam generators are inside the containment structure, the large concrete dome designed to contain radioactivity in case of an accident, the secondary coolant loop/steam line travels outside the containment to run the turbines and generate power.

Therefore, the steam generators are critical because they are the primary coolant boundary that cannot be permitted to be breached significantly. Such a breach could both release radioactivity via a pathway to the outside environment and result in a loss of cooling to the reactor core, leading in some circumstances, if there are other failures, to a potential meltdown. The steam generator tubes must be very thin, in order to effectively transfer heat, and simultaneously very strong, so as to assure they do not burst and cause a loss of reactor cooling and release of radioactivity. Damage to the tubes can thus be problematic. The NRC has described their importance:[ii]

> The steam generator (SG) tubes in pressurized water reactors have a number of important safety functions. These tubes are an integral part of the reactor coolant pressure boundary (RCPB) and, as such, are relied upon to maintain the primary system's pressure and inventory. As part of the RCPB, the SG tubes are unique in that they are also relied upon as a heat transfer surface between the primary and secondary systems such that residual heat can be removed from the primary system; the SG tubes are also relied upon to isolate the radioactive fission products in the primary coolant from the secondary system. In addition, the SG tubes are relied upon to maintain their integrity, as necessary, to be consistent with the containment objectives of preventing uncontrolled fission product release under conditions resulting from core damage severe accidents.

Figure 1 below shows a schematic view of the San Onofre replacement steam generators.

Figure 1 San Onofre Replacement Steam Generator Schematic



Source: NRC[iii]

The tubes are in an inverted U shape: in the upper part of the steam generator, the tubes bend to return downward again. There are four key parts of the steam generators for the present discussion: the tube support plates, through which the tubes run; the anti-vibration bars (AVBs), designed to reduce vibration; the retainer bars, which help retain the AVBs; and the U-Bend Freespan, where the tubes bend near the top of the steam generator and have no immediate support.

There thus are at least four locations where steam generator tubes can get damaged: they can rub against the tube support plates, the AVBs, the retainer bars, or against each other in the U-Bend Freespan.[iv] Damage has occurred in the new steam generators at San Onofre at all four locations.

What Happened at San Onofre

The original steam generators for San Onofre Units 2 and 3 were supposed to last for forty years, the design life of the reactors. (Unit 1, a Westinghouse design system, was shut down long ago due in part to extensive steam generator tube degradation.[v]) Therefore, the containment structures were not built with a pre-engineered way to get the old steam generators out and the replacement ones in. The original steam generators, manufactured by Combustion Engineering, began failing earlier than anticipated, and within about twenty years of operation, SCE began planning to replace them.

Mitsubishi Heavy Industries was chosen to construct the new steam generators. It took nearly four years to fabricate the Unit 2 steam generators, and nearly six years for Unit 3's.[vi] They then had to be shipped from Japan and installed. This required cutting large openings into the containment structures, something generally to be avoided both from a cost standpoint and because of the importance of not risking reducing the integrity of the structures designed to prevent release of radioactivity into the environment in case of an accident.

At Edison's request, Mitsubishi made numerous changes to the design of the steam generators compared to those originally at San Onofre, such as using a different tube alloy, Inconel 690, and adding hundreds of more tubes. Yet, by asserting that it was making a "like for like" change, SCE bypassed the normal requirement to apply for a license amendment, which would have entailed a higher degree of scrutiny by the NRC and the opportunity for the public to request an evidentiary hearing. This turned out to be a fateful decision, because it appears possible that the greater degree of review that would have been required with a full license amendment application might have detected the problems that the design changes caused and that have since crippled San Onofre.

Regardless, the changes made from the original design resulted in the replacement steam generators failing within a year or two of installation. Subsequent reviews by NRC and SCE determined that computer modeling errors by Mitsubishi resulted in actual steam flows in parts of the steam generators being four times higher than originally estimated by Mitsubishi, leading to "fluid elastic instability," vibration, and damage to the tubes. *This fundamental problem exists for both Unit 2 and 3.*

Extensive Damage In Units 2 and 3

It has taken considerable effort to get SCE and NRC to disclose fully the number of damaged tubes and the magnitude of their wear. In early February, an NRC spokesman told the news media that 80% of the 9727 tubes in one of the two steam generators in Unit 2 had been inspected, with the following results: Two of the tubes showed more than 30% wall thinning, 69 had 20% thinning and more than 800 had 10% thinning.[vii] *Thus, as of early February, about 11% of the tubes inspected in Unit 2 had 10% or more through-wall wear, after just two years of operation.* This is significant because the full-power plugging limit is 8%, meaning that at the end of forty years of operation of steam generators, one isn't supposed to plug more than 8% of the tubes because of damage and still be able to run at full power. In just two years, therefore, San Onofre Unit 2 has suffered damage that normally takes decades.

Repeated requests for the complete data based on inspection of the remaining tubes in Units 2 and 3 were denied for several months. Then, after being pressed for updated figures by the author at a public meeting called by the NRC on June 18 to discuss its Augmented Inspection Team (AIT) review, a senior SCE executive stated:[viii]

> We will get you the specific numbers—I will share the percentages with you tonight… On Unit 3, 9% of the tubes in the Unit 3 steam generators -- so 19,454 tubes in the steam generators, 9% of them showed wear of greater than 10% through-wall indications, 9%. On Unit 2, 12% of the tubes showed wear greater than 10% through-wall indication.

Note that the percentage provided by the SCE official for Unit 2 matches fairly closely with the figures given by NRC in early February when 80% of the tubes in only one of the two steam generators in that Unit had been inspected. After giving the above percentages, the SCE spokesman stated, "Compared to other steam generators in the industry, those numbers by themselves are not alarming. What is alarming and the reason we are here tonight is the unexpected tube-to-tube wear." He went on to assert that problems are far worse in Unit 3 than Unit 2, because there are hundreds of tubes in Unit 3 showing tube-to-tube wear but only two in Unit 2.

Those statements, and others by SCE and NRC, assert that it is only the tube-to-tube wear that is of concern and that the amount of wear other than tube-to-tube wear is comparable to what is generally seen in other replacement steam generators in the industry. This report evaluates those assertions and assesses whether the severity of the problems with the San Onofre steam generators is in line with typical experience nationally.

Weeks passed without the actual tube wear numbers being provided for San Onofre. It took intervention by staff of the Senate Committee on Environment and Public Works before the data were finally posted on the NRC website. The data are critical and can be found below. Table 1 provides data for both steam generators in Unit 2 of the San Onofre Nuclear Generating Station (SONGS Unit 2). Table 2 provides the data for the two steam generators in Unit 3.

Table 1

SONGS Unit 2 Steam Generators
Wear Depths Summary

Steam Generator SG2E88 (Through-Wall Wear)	Anti-Vibration Bar	Tube Support Plate	Tube-to-Tube Wear	Retainer Bar	Foreign Object	Total Indications	Tubes with Indications (out of 9727 total per SG)
≥ 50%	0	0	0	1	0	1	1
35 - 49%	2	0	0	1	0	3	3
20 - 34%	86	0	0	0	2	86	74
10 - 19%	705	108	0	0	0	813	406
< 10%	964	117	0	0	0	1081	600
TOTAL	1757	225	0	2	2	1984	734*

Steam Generator SG2E89 (Through-Wall Wear)	Anti-Vibration Bar	Tube Support Plate	Tube-to-Tube Wear	Retainer Bar	Foreign Object	Total Indications	Tubes with Indications (out of 9727 total per SG)
≥ 50%	0	0	0	1	0	1	1
35 - 49%	0	0	0	1	0	1	1
20 - 34%	78	1	0	3	0	82	67
10 - 19%	1014	85	2	0	0	1101	496
< 10%	1499	53	0	0	0	1552	768
TOTAL	2591	139	2	5	0	2737	861*

* This value is the number of tubes with wear indications of any depth and at any location. Since many tubes have indications in more than one depth and location, the total number of tubes is less than the total number of indiations.

Source: NRC[ix]

Table 2

SONGS Unit 3 Steam Generators
Wear Depths Summary

Steam Generator SG3E88 (Through-Wall Wear)	Anti-Vibration Bar	Tube Support Plate	Tube-to-Tube Wear	Retainer Bar	Foreign Object	Total Indications	Tubes with Indications (out of 9727 total per SG)
≥ 50%	0	117	48	0	0	165	74
35 - 49%	3	217	116	2	0	338	119
20 - 34%	156	506	134	1	0	797	197
10 - 19%	1380	542	98	0	0	2020	554
< 10%	1818	55	11	0	0	1884	817
TOTAL	3357	1437	407	3	0	5204	919*

Steam Generator SG3E89 (Through-Wall Wear)	Anti-Vibration Bar	Tube Support Plate	Tube-to-Tube Wear	Retainer Bar	Foreign Object	Total Indications	Tubes with Indications (out of 9727 total per SG)
≥ 50%	0	91	26	0	0	117	60
35 - 49%	0	252	102	1	0	355	128
20 - 34%	45	487	215	0	0	747	175
10 - 19%	940	590	72	0	0	1602	450
< 10%	2164	94	1	0	0	2259	838
TOTAL	3149	1514	416	1	0	5080	887*

* This value is the number of tubes with wear indications at any depth and at any location. Since many tubes have indications in more than one depth and locations, the total number of tubes is less than the total number of indications.

Source: NRC[x]

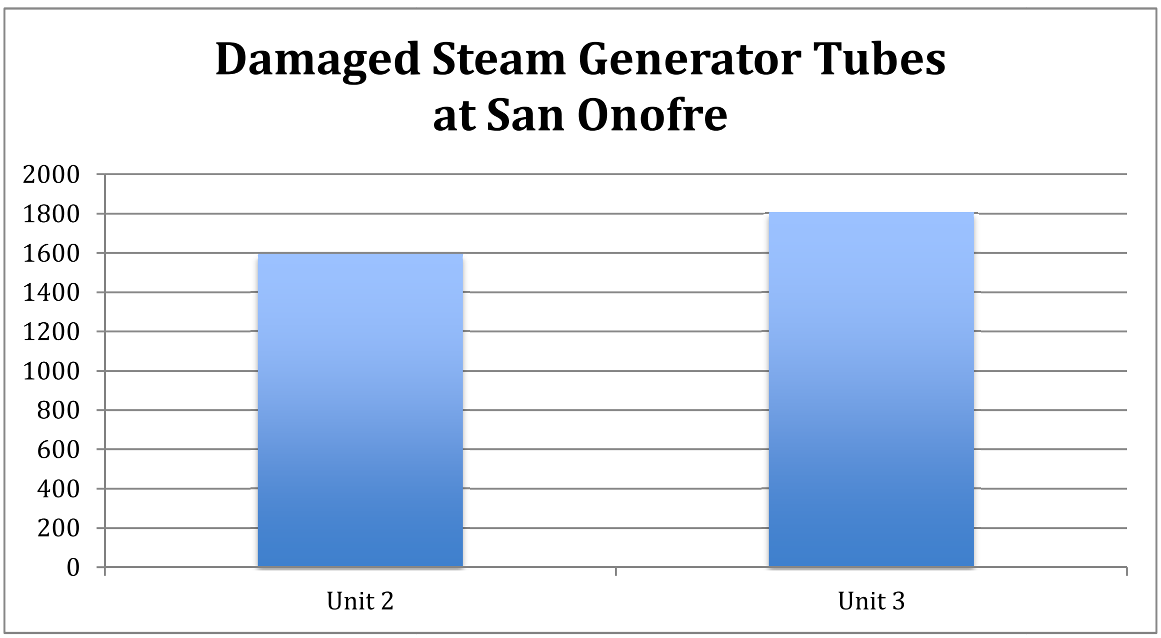
Note that the data tables do not comport with either the numbers given by the either the spokesman for NRC in early February or the spokesman for SCE in June. Whereas NRC indicated in February that, with only 80% of the tubes inspected in one of the 2 steam generators in Unit 2 as of that time, nearly 900 tubes with wear 10% or greater had been detected, the tables NRC posted months thereafter show neither steam generator in Unit 2, after inspection of 100% of the tubes, with more than 565 tubes with wear 10% or greater. And the NRC tables assert at most about 5% of the tubes in Unit 2 had wear of 10% or greater, whereas SCE had said the figure was 12%.

Efforts to have NRC clarify which of the three sets of data—NRC's summary from early February, SCE's from June, or the tables posted on NRC's website in July—is correct, and describe what is the cause of the discrepancies, have been unsuccessful to date. NRC personnel responsible for the San Onofre investigation indicated they do not know.[xi] For the purposes of this analysis, the NRC data tables above are employed, resulting in the use of the smallest estimate of damaged tubes. Should either the earlier NRC or SCE summaries be more accurate than the data tables used here, the disparity with the national experience with replacement steam generators would be even greater than shown in the discussion that follows.

Steam Generator Tube Damage is Not Dramatically Different Between San Onofre Units 2 and 3

The data tables posted by NRC show similar numbers of damaged tubes in the two units. Unit 2 has 1,595 tubes with wear, Unit 3 has1,806.

Figure 2



Additionally, as will be seen in Table 3 and Figure 5, the number of steam generator tubes that have had to be plugged in each reactor is in the same approximate range: 510 in Unit 2 and 807 in Unit 3. As this report shows, these numbers are dramatically higher than the national experience. Each San Onofre unit has had to plug many times more tubes than all reactors with new steam generators in the country, over a comparable operational period, combined.

Unit 3 has a somewhat greater number of wear indications than Unit 2 (i.e., tubes showing wear on more than one location per tube) and more tubes in the higher ranges of through-wall wear. And Unit 3 has hundreds of indications of through-wall wear due to tube-to-tube rubbing whereas Unit 2 has only two.

However, tube-to-tube wear represents less than 10% of the wear indications in Unit 3. The great majority of tubes that are in trouble in either unit are experiencing tube-to-AVB wear or tube-to-tube-support-plate wear. And both reactors are faced with thousands of such wear indications.

The focus by SCE and NRC on tube-to-tube wear and the effort to thus distinguish Unit 2 from Unit 3 is misplaced. By far, the majority of tubes showing wear are evidencing it from other kinds of wear and exist in large numbers in both units.

Furthermore, and most critically, both Unit 2 and 3 suffer from the same fundamental design defect. The computer model employed by Mitsubishi, coupled with the design changes inherent in the steam generators in both San Onofre reactors, resulted in considerably higher steam flows than predicted, causing vibrations resulting in rubbing and damage to the sensitive, very thin tubes.[xii] The same fundamental problem is crippling the steam generators in both reactors.

The Steam Generator Tube Wear at San Onofre Is Far Worse Than the National Experience

The NRC's AIT report dismissed all but the tube-to-tube wear (which is primarily in Unit 3) and four wear indications at retainer bars in Unit 2 as common in new steam generators. The report stated that, with those exceptions, "*the wear indications found are similar to those found at other replacement steam generators after one cycle of operation* ."[xiii] (emphasis added)

However, at other times NRC has stated the opposite. For example, the *Los Angeles Times* quoted an NRC spokesman on July 14: "Other large steam generators have exhibited wear after one cycle of operation which resulted in tube plugging...but not to the extent seen on San Onofre steam generators." Another NRC spokesperson was quoted as saying, "It is accurate to say San Onofre's demonstrated wear is unprecedented for the length of time the steam generators were used."[xiv]

Also, SCE has made assertions similar to the statement in the NRC AIT report. In a July press statement about the release of the tube wear tables, for example, SCE stated, "The majority of this wear is related to support structures. *The nature of the support structure wear is not unusual in new steam generators and is part of the equipment settling in*."[xv] (emphasis added)

So where does the truth lie? How does San Onofre compare to the national experience with new replacement steam generators?

Efforts to get NRC to provide data supporting the claim in its AIT report have not been successful. NRC staff in Region IV responsible for the San Onofre steam generator investigation stated that they believed the number of wear indications in Unit 2 was comparable to other similar steam generators. When asked for the basis for that belief, they said they had no data but had heard it anecdotally.[xvi] Obviously, a matter important for determining whether San Onofre Unit 2 should be permitted to restart should be based on more than an anecdote.

NRC regional staff indicated they would attempt to get supporting data on the national experience from NRC headquarters. NRC headquarters staff reported NRC had not compiled any such data.[xvii] This report, in the following sections, assembles and evaluates available data on replacement steam generator tube wear and describes where San Onofre falls within that national experience.

The Only Similar Replacement Steam Generators—at Fort Calhoun—Had NO Damaged Tubes

The claim has been made that San Onofre experience is comparable to that of reactors with similar replacement steam generators. However, the only similar steam generator in the country is found at the Fort Calhoun reactor; it has the only Mitsubishi steam generators in the U.S. outside of San Onofre. The number of steam generator tubes showing any wear at Fort Calhoun after one cycle of operation: zero. The number of wear indications: zero. The number of tubes that had to be plugged due to operation: zero.

San Onofre Unit 2, by contrast, has 1,595 damaged tubes, with 4,721 wear indications, and 510 tubes plugged. That is obviously not anywhere in the range of what the only similar steam generators in the country experienced. Furthermore, an assessment of the experience of replacement steam generators of other designs yields a similar disparity, as shown below.

As of 2002, the Majority of Replacement Steam Generators Had NO Damaged Tubes

How does San Onofre compare with the experience with replacement steam generators (RSGs) more generally? A January 2002 article in *Nuclear Engineering International*, entitled "Replacement Steam Generators," answers that question:

> Of the 30 RSGs now in operation, 26 have received 100% eddy current inspection during in service inspection. Of these, 12 have experienced limited fretting wear. The other 14 RSGs have no evidence of any wear. ECT [Eddy Current Testing] indications have resulted in 23 plugged tubes out of a total population of 176,282 in the 26 inspected SGs.

Thus, when the article was written, the majority of replacement steam generators showed "no evidence of any wear." The remaining minority showed limited wear—so limited, that a total of only 23 tubes had to be plugged out of 176,282 tubes in the 26 inspected steam generators. Unit 2 of San Onofre, the reactor asserted to be far healthier than Unit 3, had plugged more than twenty times as many tubes as the 26 replacement steam generators considered in that 2002 review, combined.

Analysis of Most Current National Replacement Recirculating Steam Generator Tube Wear Data Shows San Onofre Is Far Outside the Norm

Perhaps it could be argued that the data from the 2002 article are old and more recent replacement steam generators are having more trouble than was identified a decade ago. NRC staff, in stating that the agency has no compiled data on national experience with replacement steam generators, indicated that data for each individual plant should be found in each plant's first In-Service Inspection (ISI) report submitted to the NRC after installation of the replacement steam generators. The analysis that follows is based on reviewing the data from those ISI reports and numerous related documents for replacement recirculating steam generators that are available to the public through NRC's Agencywide Documents Access and Management System (ADAMS).

NRC staff provided a list of all replacement steam generators in the country and identified which, like San Onofre, are of the recirculating type and use Inconel 690 alloy tubes, and which few (a small minority) are once-through designs or use Inconel 600.[xviii] This analysis compiles the data for all recirculating replacement steam generators using Inconel 690 in the U.S., going back to ones installed around 1998 (data for earlier years are not available in the NRC's ADAMS database.) The results are striking, and are summarized in Table 3 and Figures 3 through 5 below. In short, the damage experienced by the replacement steam generators in both San Onofre reactors is far out of the norm of other comparable nuclear plants, even when taking into account the minor variation in the number of steam generator tubes at each plant.*

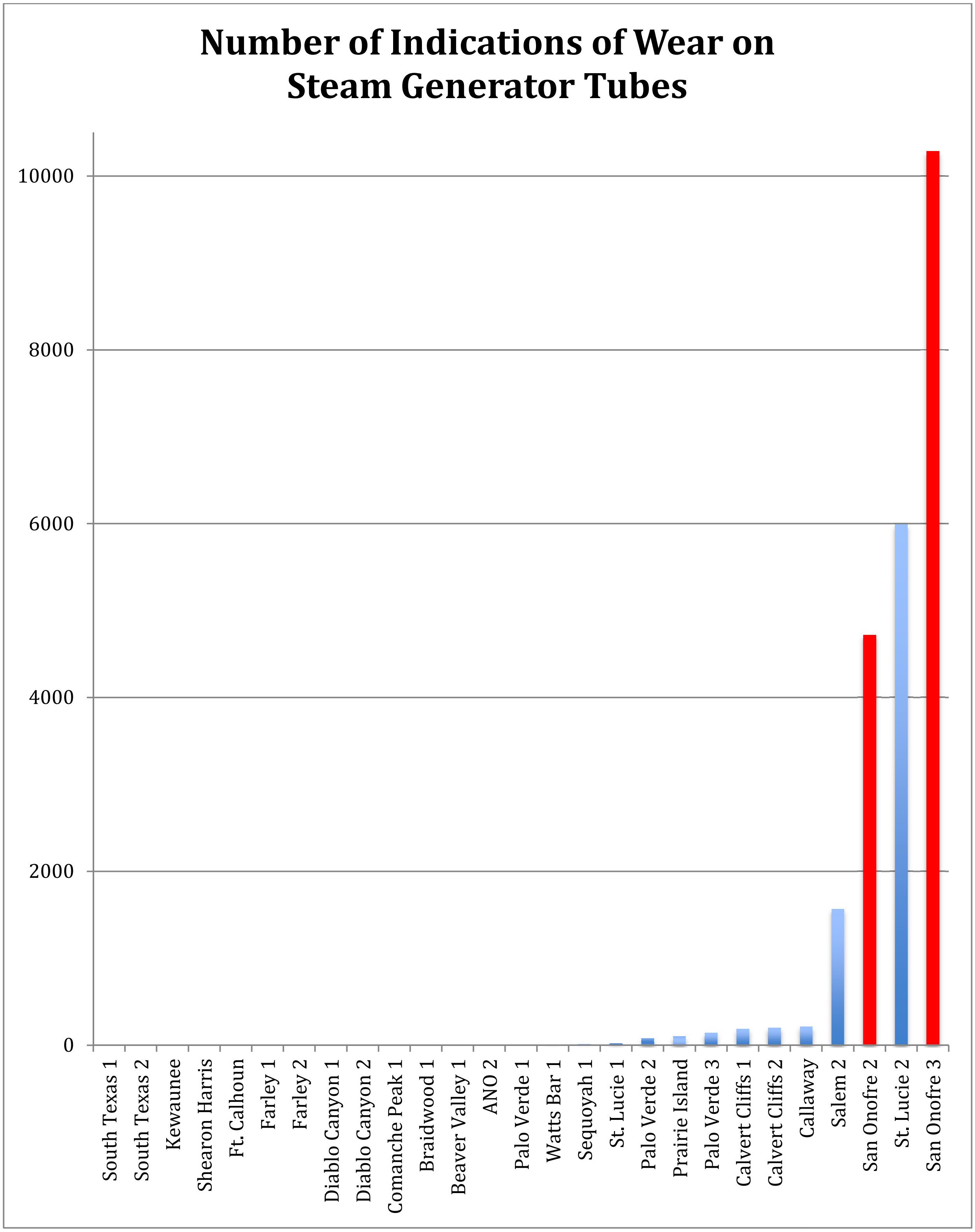
---

* SCE has attempted to compare its steam generator experience to St. Lucie 2, in order to assert that what is happening at San Onofre is typical for new replacement steam generators and is simply a "settling in" process common to them. These assertions are clearly misplaced. St. Lucie 2's steam generators are having great trouble, and as the data show, not in any fashion the norm. Indeed, St. Lucie 1 had only 17 damaged tubes at its first ISI. The serious problems at St. Lucie 2 have resulted in its operators having to conduct a root cause analysis which concluded that "the root cause was that the U-tubes were not effectively supported during SG [steam generator] manufacture, which caused the tubes to sag into the AVBs and led to slight AVB deformation that closed the tube-to-AVB gap at specific locations. This exacerbated tube wear in those locations."[xix] NRC's Advisory Committee on Reactor Safety concluded that the St. Lucie 2 tube wear is "different than the form of degradation reported to have occurred at San Onofre. There are a number of design differences between the SGs installed at San Onofre and those at St Lucie 2."[xx] Thus the problems at St. Lucie 2 are not standard "settling in" but due to a serious manufacturing error and unrelated to San Onofre's problems. Even with all the troubles St. Lucie 2 has, it had to plug only 14 tubes, compared to the hundreds plugged at San Onofre.

Table 3

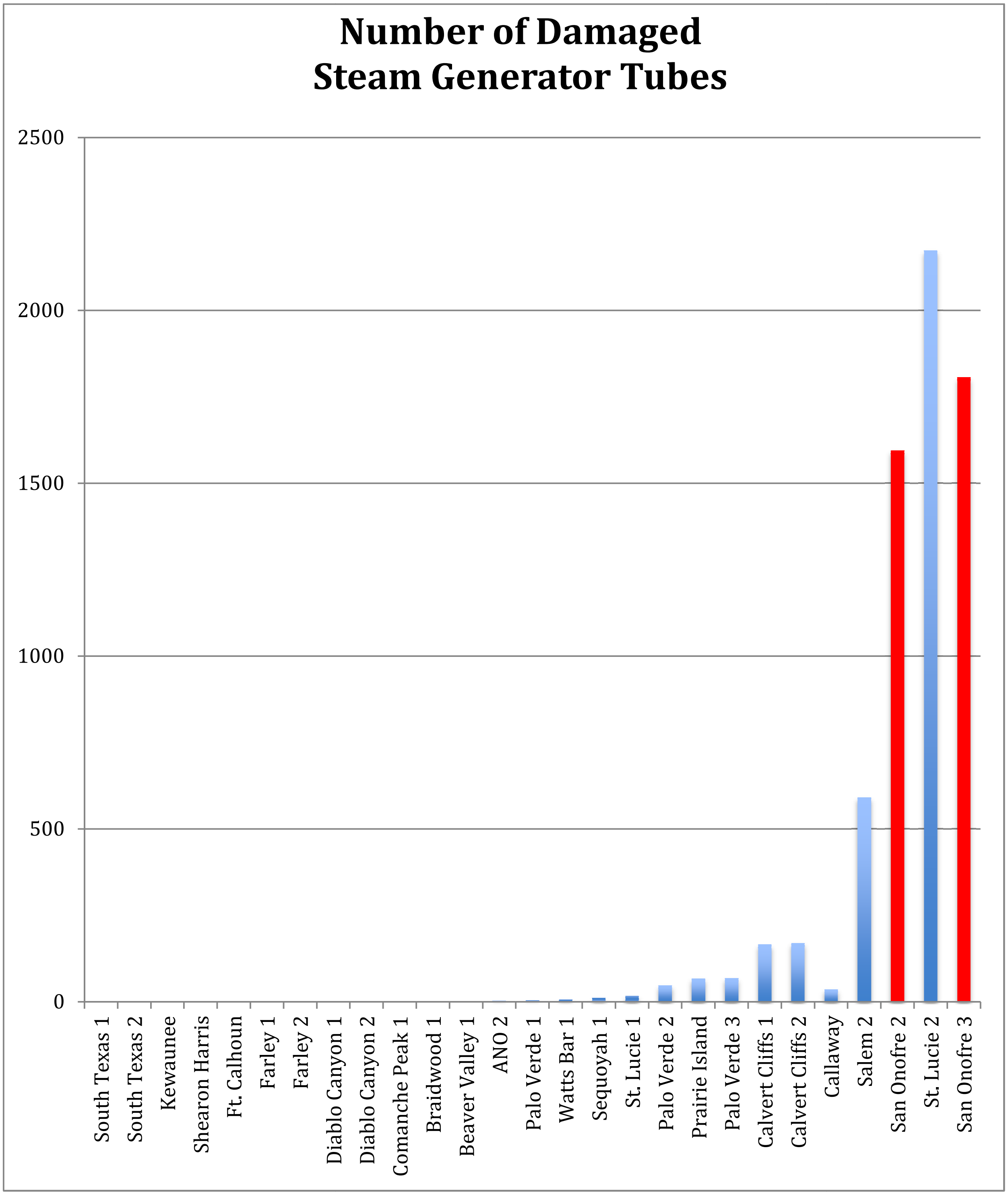
Nuclear Plant	**# of Wear Indications**	**# of Damaged Tubes**	**# of Tubes Plugged**	**Total Tubes**
South Texas 1	0	0	0	31,540
South Texas 2	0	0	0	30,340
Kewaunee	0	0	0	7,184
Shearon Harris	0	0	0	18,921
Ft. Calhoun	0	0	0	10,400
Farley 1	0	0	0	10,776
Farley 2	0	0	0	10,776
Diablo Canyon 1	1	1	0	17,776
Diablo Canyon 2	1	1	0	17,776
Comanche Peak 1	1	1	0	22,128
Braidwood 1	1	1	1	26,532
Beaver Valley 1	2	1	1	10,776
ANO 2	3	3	0	21,274
Palo Verde 1	4	4	0	25,160
Watts Bar 1	9	6	7	20,512
Sequoyah 1	11	11	11	19,932
St. Lucie 1	19	17	11	17,046
Palo Verde 2	81	48	15	25,160
Prairie Island	104	67	6	9,736
Palo Verde 3	140	68	4	25,160
Calvert Cliffs 1	189	166	0	16,942
Calvert Cliffs 2	200	170	29	16,942
Callaway	214	36	0	22,144
Salem 2	1,567	591	10	20,192
San Onofre 2	**4,721**	**1,595**	**510**	19,454
St. Lucie 2	5,994	2,174	14	17,998
San Onofre 3	**10,284**	**1806**	**807**	19,454

Figure 3



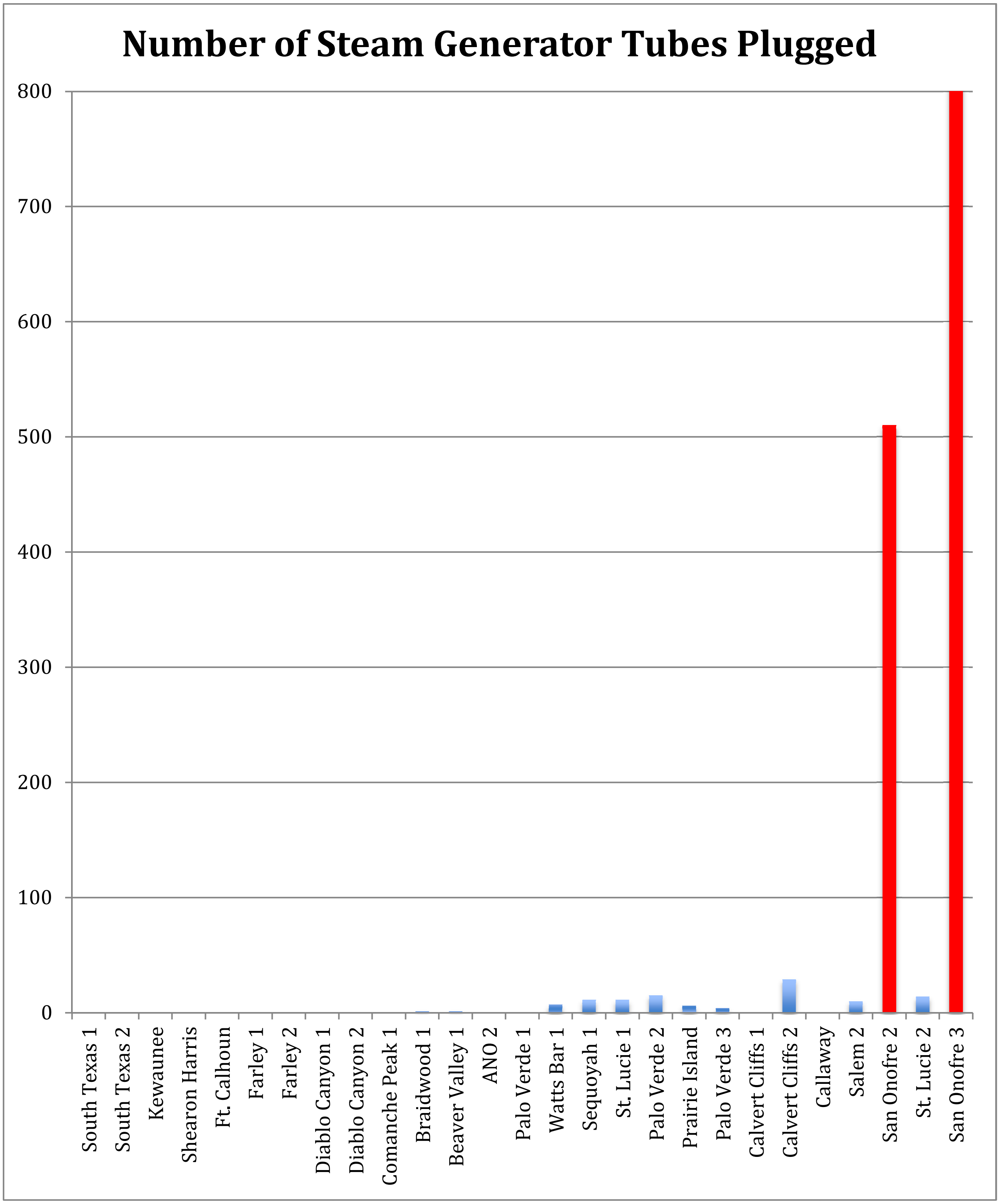
Number of Indications of Wear on Steam Generator Tubes
10000
8000
6000
4000
2000
0
South Texas 1
South Texas 2
Kewaunee
Shearon Harris
Ft. Calhoun
Farley 1
Farley 2
Diablo Canyon 1
Diablo Canyon 2
Comanche Peak 1
Braidwood 1
Beaver Valley 1
ANO 2
Palo Verde 1
Watts Bar 1
Sequoyah 1
St. Lucie 1
Palo Verde 2
Prairie Island
Palo Verde 3
Calvert Cliffs 1
Calvert Cliffs 2
Callaway
Salem 2
San Onofre 2
St. Lucie 2
San Onofre 3

Figure 4



Number of Damaged
Steam Generator Tubes
2500
2000
1500
1000
500
0
South Texas 1
South Texas 2
Kewaunee
Shearon Harris
Ft. Calhoun
Farley 1
Farley 2
Diablo Canyon 1
Diablo Canyon 2
Comanche Peak 1
Braidwood 1
Beaver Valley 1
ANO 2
Palo Verde 1
Watts Bar 1
Sequoyah 1
St. Lucie 1
Palo Verde 2
Prairie Island
Palo Verde 3
Calvert Cliffs 1
Calvert Cliffs 2
Callaway
Salem 2
San Onofre 2
St. Lucie 2
San Onofre 3

Figure 5


Number of Steam Generator Tubes Plugged
800
700
600
500
400
300
200
100
0
South Texas 1
South Texas 2
Kewaunee
Shearon Harris
Ft. Calhoun
Farley 1
Farley 2
Diablo Canyon 1
Diablo Canyon 2
Comanche Peak 1
Braidwood 1
Beaver Valley 1
ANO 2
Palo Verde 1
Watts Bar 1
Sequoyah 1
St. Lucie 1
Palo Verde 2
Prairie Island
Palo Verde 3
Calvert Cliffs 1
Calvert Cliffs 2
Callaway
Salem 2
San Onofre 2
St. Lucie 2
San Onofre 3

The Damage at Both San Onofre Units Greatly Exceeds That at Typical Reactors

The data for replacement recirculating steam generators nationally indicate:

- **The median number of steam generator tubes showing wear after one cycle of operation nationally is—FOUR. San Onofre Unit 2 had 1595 damaged tubes, approximately 400 times the median; San Onofre Unit 3 had 1806.**

- **The median number of wear indications on steam generator tubes after one cycle of operation is—FOUR. San Onofre Unit 2 had 4721, greater than a thousand times more. San Onofre Unit 3 had 10,284.**

- **The median number of steam generator tubes that were plugged after one cycle of operation is—ZERO. San Onofre Unit 2 had 510; Unit 3 had 807.[xxi]**

CONCLUSION

The conclusion is clear: San Onofre Unit 2 and Unit 3 are both very ill nuclear plants. Unit 3's fever is slightly higher, but both are in serious trouble. What they are experiencing is not just normal wear due to "settling in" purportedly experienced with similar replacement steam generators. They are far, far outside the norm of national experience. And Unit 2 cannot be said to be acceptable for restart, any more than Unit 3. Unit 2 has hundreds of times more bad tubes and a thousand times more indications of wear on those tubes than the typical reactor in the country with a new steam generator, and nearly five times as many plugged tubes as the rest of the replacement steam generators, over a comparable operating period, in the country combined. Restarting either San Onofre reactor with crippled steam generators that have not been repaired or replaced would be a questionable undertaking at best.

ENDNOTES

[i] Edison International, "Southern California Edison Announces Intent to Downsize Staffing at San Onofre Nuclear Generating Station," August 20, 2012, http://www.edison.com/pressroom/pr.asp?id=7986, last accessed September 9, 2012.

[ii] NRC Draft Regulatory Guide DG-1074**,** *Steam Generator Tube Integrity,* Dec 1998, ML003739223.

[iii] http://www.nrc.gov/info-finder/reactor/San Onofre/San Onofre-steam-generator-internal-diagram.pdf last accessed September 9, 2012.

[iv] There is a fifth potential damage mechanism, damage by foreign object (i.e., loose parts). Only two tubes at SAN ONOFRE showed this type of damage.

[v] Kenneth Karwoski, Leslie Miller, and Nadiyah Morgan, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, "Regulatory Perspective on Steam Generator Tube Operating Experience," in *Ageing Issues in Nuclear Power Plants* (undated).

[vi] NRC AIT report, p. 3-4.

[vii] Esmeralda Bermudez, "San Onofre nuclear power plant incidents draw attention: A radiation leak, the discovery of tube damage and a worker falling into a reactor pool all happened within days of one another*," Los Angeles Times,* February 5, 2012. See also the *Wall Street Journal*,. Rebecca Smith, "Worn Pipes Shut California Reactors," February 4, 2012.

[viii] The NRC meeting was videotaped and the answers by the senior SCE executive to questions about the tube data can be viewed at http://www.youtube.com/watch?v=VPxDYWa0b8o and http://www.youtube.com/watch?v=8tCQWeEauHo. last accessed 9/6/12.
The question asked was for the number of tubes in each SAN ONOFRE Unit that had greater than 10% through-wall wear, and also the total number of tubes showing any indication of wear. SCE provided data about the former.

[ix] http://www.nrc.gov/info-finder/reactor/songs/songs-unit-2-steam-generator-tube-wear-data.pdf last accessed September 9, 2012

[x] http://www.nrc.gov/info-finder/reactor/songs/songs-unit-3-steam-generator-tube-wear-data.pdf last accessed September 9, 2012.

[xi] email, Hirsch to Elmo Collins, July 13, 2012; response July 17; telcon with Tom Blount, Ryan Lantz, Michael Bloodgood, July 18.

[xii] NRC AIT report, pp. i, 46-56

[xiii] NRC AIT report, p. 10

[xiv] *North County Times*, "SAN ONOFRE: Rate of tube wear at nuke plant 'unprecedented,' NRC says," April 4, 2012

[xv] SCE press release, "Southern California Edison Releases Steam Generator Tube Wear Data," July 13, 2012
.
[xvi] Conference call July 18, *supra.*

[xvii] emails from Tom Blount, June 17, 2012; from Ryan Lantz, July 31; from Kenneth Karwoski, August 7.

[xviii] August 7 and 9, 2012, emails from Ryan Lantz, Chief, Reactor Projects Branch D, NRC Region IV.

[xix] Advisory Committee for Reactor Safeguards, NRC, July 23, 2012, letter to R.W. Borchardt, Executive Director for Operations, NRC, "SUBJECT: Final Safety Evaluation Report Associated with the Florida Power and Light St. Lucie, Unit 2, License Amendment Request for an Extended Power Uprate," p. 3

[xx] *ibid.,* p. 4

[xxi] Arnie Gundersen, in a July 2012 report, "San Onofre's Steam Generators: Significantly Worse Than All Others Nationwide," previously pointed out the high number of plugged tubes at San Onofre compared to plugging rates nationally, based on data in a 2006 NRC report. SCE tried to dismiss the significance of those findings by saying the data were old and that many tubes plugged at San Onofre were plugged preventively. The present study examines more current data, finding the same trend for plugged tubes, but also determines that this is not due to preventive plugging, since the number of damaged tubes and wear indications on tubes at San Onofre far exceeds the national median.

APPENDIX A

PLANT-BY-PLANT DESCRIPTIONS OF REPLACEMENT RECIRCULATING STEAM GENERATOR TUBE WEAR EXPERIENCE

A) PLANT-BY-PLANT DESCRIPTIONS OF REPLACEMENT RECIRCULATING STEAM GENERATOR TUBE WEAR EXPERIENCE

Arkansas Nuclear One, Unit 2: 2 replacement steam generators installed in 2000.
0 tubes plugged during first InService Inspection (ISI) of the steam generator tubes after installation, 1 tube plugged prior to service.

3 wear indications in 3 tubes identified during 1st ISI. Source: April 2002 ISI report, NRC Agencywide Documents Access and Management System (ADAMS) Accession Number ML031080421, pg 4 of PDF/pg 2 of attachment & pg 6 of PDF/pg 4 of attachment. (Note, hereafter NRC ADAMS Accession numbers will be given just by their ML #. Also note that the PDF page number is often different from the document's page number due to how pages are numbered in the cited documents). See also ML031820241, the 2003 NRC review of the licensee's ISI report.

The 2 replacement steam generators are Westinghouse model Delta 109,
pg 3 of PDF/pg 1 of attachment of April 2002 tube inspection ML031080421.

The total number of tubes is not explicitly stated in those reports but it is stated that 100% of unplugged tubes were tested with the bobbin coil according to the 2003 NRC review ML031820241, pg 3 of PDF/unnumbered in report. Pg 4 of PDF/pg 2 of the April 2002 tube inspection ML031080421 states that 10,637 tubes were inspected for SG A and 10,636 were tubes were tested in SG B, which had one tube plugged by the manufacturer prior to installation, for a total of 21, 273 inspected, and 21,274 total when the pre-installation plugged tube is included.

Beaver Valley, Unit 1 in Pennsylvania: 3 replacement steam generators 2006.
1 tube plugged during first ISI after installation.

1 tube with 1 wear indication of 29%, believed to have been caused by a burr left from the manufacturing process. Source: 2007 ISI report ML080800448, see the table in pgs 4-6 of PDF, pgs 3-5 of the report, source for explanation is on pg 7 of PDF/pg 6 of attachment 1

The 3 replacement SGs are Westinghouse Model 54s, manufactured by ENSA in Spain, and containing 3,592 tubes each according to the preservice inspection report ML061990398, pg 21 of the PDF/pg 1 of Appendix 2.

Braidwood, Unit 1: 4 replacement steam generators 1998.
1 tube plugged during first ISI, 3 tubes plugged prior to service.

One tube with one wear indication as stated in the 2000 tube inspection report ML010930262, pgs 8-10 of PDF/pg 7-9 of report. The single tube with one wear indication, that was subsequently plugged, had less than 10% through wall (TW) wear according to the 2000 steam generator inspection report ML010930262, pg 10 of PDF/pg 9 of report, this tube was preventively plugged (pgs 4-5 of PDF/pgs 3-4 of report).

The 4 replacement steam generators are Babcock and Wilcox models with 6,633 tubes per generator, see pg 4 of PDF/pg 3 of report

Callaway, Unit 1 in Missouri: 4 replacement steam generators 2005
0 tubes plugged during first ISI, 1 tube plugged prior to service.

214 wear indications on 36 tubes. The greatest through wall wear was 1 indication of 13%, the least was 1%. See Table 2, Summary of Wear Indications, pg 5-11 of PDF/pg 2-8 of attachment 1of the 2007 ISI, ML 073050323.

The steam generators have 5536 tubes each, SG A had one tube plugged prior to service for a total of 5,535 inspected and operational tubes. (pg 5 of PDF/pg 2 of report).

Calvert Cliffs, Unit 1 in Maryland: 2 replacement steam generators in 2002.
0 tubes plugged.

189 wear indications on 166 tubes. The great majority had wear under 10% and only two had wear equal or greater than 20%, at 20% and 22%, according to the 2004 tube inspection report ML050610714, attachment 1, pgs 4-8 of PDF/pgs 1-5 of attachment.

Both Babcock & Wicox replacement steam generators have 8,471 tubes each. See 2005 NRC review ML051440076, pg 3 of PDF/unnumbered in document.

Calvert Cliffs, Unit 2 in Maryland: 2 replacement steam generators in 2003.
29 tubes plugged in first ISI, 3 tubes plugged prior to service.

Of the 29 tubes plugged due to the 2005 inspection, 5 had wear indications and the other 24 were plugged as a precautionary measure due to a possible loose part in an area which cannot be visually inspected. See 2005 memo of NRC-licensee conference call, ML052410150, pgs 1-2 of PDF & memo.

All told, there were 200 wear indications on 170 tubes, with the majority having wear under 10%. 8 tubes had wear 20% or greater, with the highest indication being one tube with 25% wear. See 2005 tube inspection report ML060610081, pg 4-9 of PDF/1-6 of attachment.

The replacement steam generators have 8471 tubes each, with 3 plugged prior to service, according to the cover letter to the tube inspection report ML060610081, pg 1 of PDF/pg 1of letter, and are described as Babcock & Wilcox design and manufacture in 2005 memo ML052410150, pg 1 of PDF & memo.

Comanche Peak, Unit 1 in Texas: 4 replacement steam generators in 2007.
0 tubes plugged during first ISI, 1 tube plugged during manufacture.

1 wear indication on 1 tube, depth ,10% TW. See ISI report 2008 pg 7 of PDF/pg 5 of ISI report ML090300118, pg 9 of PDF/pg 7 of report.

The steam generators are Westinghouse Model Delta 76s with 5,532 tubes per steam generator, reference steam generator tube inspection 2008 ML090300118, pg 3 of PDF/pg 1 of report.

Diablo Canyon, Unit 1 in California: 4 replacement steam generators in 2009
0 tubes plugged.

1 wear indication on 1 tube, at 5% TW. See 2010 steam generator inspection report ML111160101, pg 3,4, and 11 of PDF/pg 2,3, and 10 of enclosure. This one wear indication was the first report of AVB wear in Westinghouse model 54s, leading PG&E to inform the NRC on Oct 15,2010 (pg 4 of PDF/pg 3 of enclosure for ML111160101).

The replacement steam generators are Westinghouse Model Delta 54s and each one contains 4,444 tubes, according to the 2012 Nuclear Regulatory Commission review ML120740373, pg 2 of PDF & review and the 2010 steam generator inspection report ML111160101, pg 2 of PDF/pg 1 of report.

Diablo Canyon, Unit 2 in California: 4 replacement steam generators in 2008
0 tubes plugged during first ISI, 3 tubes plugged prior to service.

1 wear indication on 1 tube, see 2009 steam generator inspection ML101330269, pg 3 of PDF/pg 2 of enclosure.

The replacement steam generators are Westinghouse Model Delta 54s with 4,444 tubes each, according to pg 2 of PDF/pg 1 of enclosure above.

Farley, Unit 1 in Alabama: 3 replacement steam generators in 2000.
0 tubes plugged.

NO wear indications, see Fall 2001 ISI report ML020300072, pg 12 of PDF/unnumbered in report and 2002 supplemental information ML021960109, pg 4 of PDF/pg 2 of letter.

Westinghouse model 54F steam generators, 2001 inservice inspection ML020300072, pg 12 of PDF/unnumbered in report.

3,592 tubes in each of the 3 replacement steam generators, as stated in 2003 NRC review ML031110259.

Farley, Unit 2 in Alabama: 3 replacement steam generators in 2001.
0 tubes plugged.

NO wear indications. See Fall 2002 ISI report ML030300235 pg 12 of PDF/unnumbered in report, Sept/Oct 2002 inspection.

Westinghouse model 54F steam generators with 3,592 tubes per steam generator; see 2008 NRC Review ML083100232, pg 3 of PDF/unnumbered in enclosure.

Fort Calhoun in Nebraska: 2 replacement steam generators in 2006.
0 tubes plugged in first ISI, 1 tube plugged prior to service.

NO wear indications. See 2008 eddy current test ML083440629, pg 3 of PDF/pg 2 of attachment, pgs 9-11 of PDF/pgs 8-10.

Both Mitsubishi MHI-49TT-1 steam generators have 5,200 tubes each. See steam generator tube inspection review ML093000157, pg 2 of PDF/unnumbered in report.

Kewaunee in Wisconsin: 2 replacement steam generators in 2001.
0 tubes plugged.

NO wear indications. See 2003 annual report ML0460650370, pg 6 of PDF/pg 2 of report, and 2003 ISI ML032250165 pgs 156 &157 of PDF.

Westinghouse model 54Fs with 3,592 tubes in each steam generator, from April 2003 steam generator inspection ML032250165, pg 155 of PDF/pg 1 of attachment 8.

Palo Verde, Unit 1 in Arizona: 2 replacement steam generators 2005.
0 tubes plugged during first ISI, 116 tubes plugged prior to service.

4 wear indications on 4 tubes, <20% TW. See 2007 ISI report ML080090193, pg 9 of PDF/unnumbered in report, pgs 14-17 of PDF/unnumbered in report, Appendices B & C.

Palo Verde Units 1, 2, and 3 have essentially the same design for their replacement steam generators. They were all "designed by Asea Brown Boveri/Combustion Engineering (ABB/CE) (now Westinghouse) and manufactured by Ansaldo, and are considered a modified System 80 design (no specific model number)." There are 12,580 tubes for each steam generator; see ML082890538, pg 3 of PDF, pg 1 of enclosure.

Palo Verde, Unit 2 in Arizona: 2 replacement steam generators in 2003.
15 plugged during first ISI, 24 plugged prior to service.

81 wear indications on 48 tubes. See the data tables in 2005 tube ISI report ML053130156, pg 11 of PDF/unnumbered in report, Table 2 Indication Summary, pgs. 29-38 of PDF, Appendices C & D of report.

[Dents found were pre-existing before operation and not due to operational wear. According to the supplement to the steam generator report ML 060890657, pg 10 of PDF/pg 8 of enclosure, the dents were present in the preservice inspection, 100% of the dents > or equal to 0.5 volts were inspected in 2005 and none exhibited any change between the preservice inspection and the 2005 inspection. Regarding the dents that were plugged, these were plugged preventively though they hadn't changed any either, reference pg 3 of PDF/pg 1 of enclosure.]

There are 12,580 tubes per steam generator.

Palo Verde, Unit 3 in Arizona: 2 replacement steam generators in 2007.
4 tubes plugged during first ISI, 118 plugged prior to service.

140 wear indications on 68 tubes, according to Palo Verde 3 ISI report ML093310442, pg 10 of PDF/ pg 8 of report, Appendices B & C, pgs 15-22 of PDF/pgs 13-20.

Steam generators have 12,580 tubes in each. NRC review ML112060490, pg 2 of PDF/unnumbered in review.

Prairie Island, Unit 1 in Minnesota: 2 replacement steam generators in 2004.
6 tubes plugged during first ISI.

104 wear indications in 67 tubes, 2006 teleconference re: tube inspection ML061680005, pg 4 of PDF/pg 2 of report.

Framatome Model 56/19s with 4,868 tubes each, according to revision to the ISI ML101530111, pg 9 of PDF/pg 1 of enclosure 2.

Saint Lucie, Unit 1 in Florida: 2 replacement steam generators in 1997.
11 tubes plugged preventively during first ISI.

19 wear indications on 17 tubes, 1999 ISI, ML 003684169, pgs 4-6 of PDF/unnumbered in report.

Each Babcock and Wilcox advanced series pressurized water reactor steam generator has 8,523 tubes, according to 2008 NRC review ML100960626, p. 2 of PDF/unnumbered in review.

Saint Lucie, Unit 2 in Florida: 2 replacement steam generators in 2008.
14 tubes plugged during first ISI.

5,994 wear indications on 2,174 tubes. See 2009 tube inspection ML093230226, pg 13-115 of PDF/pgs 2-64 of attachment 1, pgs 2-40 of attachment 2.

Only 2 indications exceeded 30% wear, no indications over 35%; 2009 tube inspection ML093230226, pg 14 of PDF/pg 3 of Attachment 1, pg 78 of PDF/pg 3 of Attachment 2

Steam generators are Areva-NP Model 86/19TIs, 2009 tube inspection ML093230226, pg 2 of PDF/pg 1 of enclosure and have 8999 tubes each, according to the NRC review of 2009 tube inspection ML03340040, pg 2 of PDF/pg 1 of enclosure.

Salem, Unit 2 in New Jersey: 4 replacement steam generators in 2008.
10 tubes plugged during first ISI.

1,567 wear indications on 591 tubes, see 2009 steam generator tube inspection report ML101250176, pg 10 of PDF/pg 1 of attachment 3.

The steam generators are Areva Mod 61/19Ts with 5,048 tubes per steam generator, 2009 tube inspection ML101250176, pg 4 of PDF/pg 1 of attachment 1.

San Onofre 2 in California: 2 replacement steam generators in 2010.
510 tubes plugged during first ISI.

4721 wear indications on 1,595 tubes. See NRC tables in main body of report.

Mitsubishi steam generators with 9,727 tubes per generator. See Southern California Edison, "San Onofre Nuclear Generating Station Confirmatory Action Letter Fact Sheet," last updated on 6/13/2012

San Onofre 3 in California; 2 replacement steam generators in 2011.
807 tubes plugged within one year of installation (tube failure during operation led to shutdown and inspection prior to normal ISI.)

10,284 wear indications on 1806 tubes.

Mitsubishi steam generators with 9,727 tubes per generator, same as Unit 2.

Sequoyah, Unit 1 in Tennessee: 4 replacement steam generators in 2003.
11 tubes plugged during first ISI, 20 plugged prior to service.

11 wear indications on 11 tubes; see 2004 ISI report ML050550413, pg 55 of PDF/unnumbered Appendix A.

All 11 tubes plugged as a result of this inspection were preventively plugged with TW% ranging from 8-17% according to Sequoyah 1 steam generator inspection ML053050386, pg 3 of PDF/unnumbered in report.

Model 57AG steam generators by Doosan, 4,983 tubes per SG. 2006 NRC review ML060950510, p. 4 of PDF/unnumbered in review.

Shearon Harris in North Carolina: 3 replacement steam generators in 2001
0 tubes plugged during first ISI, 2 tubes plugged during manufacture.

0 wear indications, 2003 ISI ML032680868, pg 7 of PDF/unnumbered report supplemental information ML041120371 pg 4 of PDF/pg 2 of attachment, pg 7 of PDF/pg 5 of attachment, 2003 tube test ML041320496 pg 5 of PDF/pg 2 of attachment 1.

Westinghouse Model Delta 75 replacement steam generators, 6,307 tubes in each steam generator, 2003 tube test ML041320496, pg 4 of PDF/pg 1 of attachment 1, and pg 3 of PDF, pg 1 of attachment,, ML042360545.

South Texas Project, Unit 1: 4 replacement steam generators in 2000.
0 tubes plugged during first ISI, 108 tubes pre-service.

0 wear indications, see 2001 ISI ML020390361, pg 12 of PDF/pg 7 of report.

Steam generators are Westinghouse Model Delta 94s with 7,885 tubes per steam generator, pg 6 of PDF/pg 1 of above report.

South Texas Project, Unit 2: 4 replacement steam generators in 2002.
0 tubes plugged during first ISI, 6 tubes plugged pre-service.

0 wear indications, 2004 ISI ML041730355, pg 13 of PDF/pg 8 of report, pg 14 of PDF/pg 9 of report.

Steam generators are Westinghouse Delta 94s with 7,585 tubes each, see South Texas Project 2 pre-service inspection ML030710429 pg 6 of PDF/pg 1 of report

Watts Bar, Unit 1 in Tennessee: 4 replacement steam generators in 2006.
7 tubes plugged during first ISI, 2 plugged prior to service.

9 wear indications on 6 tubes. All the tubes with any wear indications were plugged preventively. One tube with a tube sheet bulge detected prior to service was also preventively plugged which is why there were 7 tubes plugged and only 6 tubes with wear indications. The TW% detected ranged from 7% to 13%, well under the plugging limit of 40% TW. Source is 2008 tube inspection ML082600068, pg 5 of PDF/pg E-3 of report, pg 6 of PDF/pg E-4 of report.

Westinghouse designed the replacement steam generators, and Doosan Heavy Industry and Construction manufactured them. There are 5,128 tubes per steam generator, supplemental information ML090960558, pgs 4 and 9 of PDF/pgs 2 and 7 of enclosure.

APPENDIX B

NOTES ON SOURCES AND METHODS

NOTES ON SOURCES AND METHODS

Licensees are generally required to conduct, at the first shutdown for reactor refueling after installation of replacement steam generators, inspection of 100% of the steam generator tubes. That inspection is typically performed using eddy current testing (ECT). If signals from the ECT suggest a potential problem, frequently follow-on tests are performed to ascertain if indeed there is wear.

The licensee is required to submit to the NRC within a set period after completion a report on the results of the steam generator inspection conducted during the In-Service Inspection (ISI). NRC staff review the ISI report, and will occasionally submit requests for additional information to the licensee. Thus, the primary records related to the number of wear indications found during an ISI, the number of tubes experiencing wear, and the number of tubes plugged during the ISI, are: the ISI report itself, requests for additional information by NRC and responses thereto by the licensee, and correspondence by NRC concluding its review. When there is a significant problem identified, NRC may initiate a meeting or conference call with the licensee and a memorandum may result therefrom. Lastly, the pre-service inspection report—after installation but before operation with replacement steam generators—may also provide useful information about steam generator design and dings, dents, and manufacturing burnishing marks that pre-date operation and thus, if noted thereafter, are not due to operational wear.

Unfortunately, the ISI reports are not always entirely consistent in form and content from one licensee to another. Sometimes a summary is provided quantifying the total numbers of tubes and indications of wear that observed; other times one has to tabulate the figures by hand. Additionally, definitions are not always clear or consistent. For example, guidance from the Electric Power Research Institute (EPRI) defines wear as "the loss of tube material caused by excessive rubbing of the tube against its support structure, a loose part, or another tube," but also uses the term "degradation" as wear of greater than 20% or greater through wall (TW). ML ML080450582. NRC draft guidance on steam generator tube integrity, by contrast, defines a degraded tube as a tube showing any wear below the applicable plugging limit. ML003739223. To avoid any question, data for wear rather than degradation were relied upon for this report.

Furthermore, the raw data were reviewed to confirm, for example, that all measurable wear was in fact reported, not just wear below a threshold such as 20% TW. This was readily determinable for virtually all of the plants, as they reported wear down to a few % TW, and for those that reported zero wear, statements in the ISI or NRC communications generally made clear that this indeed meant no measurable wear.

In some cases, a few tubes were identified in the ISI reports as being involved with possible loose parts in the steam generators. Where damage to the tubes was indicated by %TW wear indications, they were generally included; where it appears that subsequent evaluation had determined no TW damage, they were not.

In some cases, tubes were plugged by the manufacturer or otherwise prior to operation. In Appendix A, tubes plugged prior to operation and tubes plugged thereafter at the time of the first ISI are both identified. Table 3 and Figures 3-5 of the main body of the report, however, are worn tubes, i.e., those damaged by steam generator operation. The reports also generally identified dents, dings, manufacturing burnishing marks and the like that pre-dated operation. These also were not included here, as the analysis is on wear due to operations.

It is possible that ambiguities remain in the ISI reports that were not fully resolvable by reviewing associated documents such as correspondence with NRC, but it appears that they would not have any substantive effect on the fundamental conclusions of this report. One take-away suggestion from this analysis, however, is that greater uniformity and clarity in ISI reports would be helpful in analyzing national trends.

APPENDIX C

BIBLIOGRAPHY

BIBLIOGRAPHY

Arkansas Nuclear One, Unit 2
April 2002 tubing inspection ML031080421
2003 NRC review ML031820241

Beaver Valley, Unit 1
2006 preservice inspection report (check of replacement steam generators before they go on-line) ML061990398
2007 steam generator inspection report ML080800448
supplemental information to steam generator inspection report ML082900489

Braidwood 1
2000 15 day report on tubing inspection ML003701661
2000 tubing inspection report ML010930262

Callaway 1
2007 inservice inspection report ML073050323

Calvert Cliffs 1
2004 tubing inspection report ML050610714
2005 NRC review ML051440076

Calvert Cliffs 2
2005 tubing inspection report ML060610081
2005 review of inservice inspection of tubing ML063380188
2005 teleconference on preventive plugging ML052410150

Comanche Peak 1
2008 tubing inspection report M090300118
2008 supplemental information to tubing inspection report ML091180326

Diablo Canyon 1
2010 steam generator inspection report ML111160101
2012 NRC review ML120740373

Diablo Canyon 2
2009 steam generator inspection report ML101330269
2009 steam generator eddy current testing report ML063380449
2009 supplemental information to steam generator inspection report ML103300051

Farley 1
Fall 2001 inservice inspection report ML020300072
2002 supplemental information to request for technical specifications change ML021960109
Farley 1 2003 NRC Review ML031110259

Farley 2
Fall 2002 inservice inspection report ML030300235
2002 supplemental information ML043570226
Farley 2 2008 NRC review ML083100232

Fort Calhoun 1
2008 steam generator tubing inspection ML093000157
2008 eddy current test report ML083440629

Kewaunee
2003 inservice inspection report ML032250165
2003 annual report ML040650370

Palo Verde 1
2007 tubing inspection report ML080090193

Palo Verde 2
2005 tubing inspection report ML0513130156
2005 supplemental information to tubing inspection report ML060890657

Palo Verde 3
2009 inservice inspection report ML093310442
2011 NRC review ML112060490

Prairie Island 1
2006 inservice inspection ML062550530
2006 revision to inservice inspection report ML101530111
2006 NRC letter ML061680005

St. Lucie 1
1999 inservice inspection report ML003684169
2008 inservice inspection report ML091120207
2008 NRC review ML100960626

St Lucie 2
2006 tubing inservice inspection ML071350383
2009 tubing inspection report ML093230226
2009 request for supplemental information ML102360491
2009 supplement to tubing inspection report ML102870115
2009 NRC review ML103340040

Salem 2
2009 tubing inspection report ML101250176
2009 NRC review ML103340348

Sequoyah 1
2004 inservice inspection report ML050550413
2003 90 day inspection report ML032660885
2004 steam generator inspection ML053050386
2006 NRC review ML060950510

Shearon Harris 1
2003 tubing inspection report ML041320496
2003 supplemental information ML041120371
2003 inservice inspection report ML032680868

South Texas Project 1
2001 inservice inspection report ML020390361

South Texas Project 2
2004 inservice inspection report ML041730355
2002 preservice steam generator inspection report ML030710429

Watts Bar 1
2008 tubing inspection report ML082600068
2008 supplemental informationML090960558

Electric Power Research Institute (EPRI) Steam Generator Management Program: Steam Generator Integrity Assessment Guidelines, Revision 3, final report October 2008, non-proprietary version ML100480243

EPRI Steam Generator Management Program: Pressurized Water Reactor Steam Generator Examination Guidelines: Revision 7, final report October 2007, non-proprietary version ML080450582

Nuclear Energy Institute (NEI) 97-06 Steam Generator Program Guidelines, Revision 2, 2005
ML052710007

Nuclear Regulatory Commission Guide DG-1074, draft of Steam Generator Tube Integrity for Public Comment (1998)
ML003739223

APPENDIX D

ABOUT THE AUTHORS

DANIEL HIRSCH is President of the Committee to Bridge the Gap and has been associated with it since 1970. He is also a Lecturer at the University of California, Santa Cruz, where he teaches courses on Nuclear Policy and Environment Policy. He is the former Director of the Adlai E. Stevenson Program on Nuclear Policy at UCSC.

DORAH ROSEN is a Research Associate with the Committee to Bridge the Gap. She had primary responsibility for acquiring and compiling the steam generator tube data from licensee ISI reports and related documentation.

DALE BRIDENBAUGH is a retired Nuclear Engineer with forty years experience with the commercial nuclear industry. He was a nuclear engineer and manager for General Electric's Nuclear Division, spending twenty years with GE. In 1976, he and two colleagues resigned from GE and testified before Congress regarding their concerns that safety issues with the GE Mark I containment structures were being ignored. The subsequent Fukushima nuclear accident tragically proved them correct. After their resignation from GE, the three nuclear engineers formed MHB Associates, which for more than twenty years performed studies on the operation, safety and costs of nuclear plants for state agencies and foreign countries.

THE COMMITTEE TO BRIDGE THE GAP is a forty-two-year-old non-profit public policy organization focused on issues of nuclear safety, proliferation, waste disposal, and terrorism.

www.committeetobridgethegap.org

(831) 336-8003