REVIEW

MITSUBISHI HEAVY INDUSTRIES LTD

i) **ROOT CAUSE ANALYSIS REPORT FOR TUBE WEAR IDENTIFIED IN THE UNIT 2 AND UNIT 3 STEAM GENERATORS OF SAN ONOFRE NUCLEAR GENERATING STATION - UES-20120254 REV.0 (3/64), *C* OCTOBER 2013**

ii) **SUPPLEMENTAL TECHNICAL EVALUATION REPORT, L5-04GA588(0), *C* JANUARY 2013**

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CLIENT: FRIENDS OF EARTH

LARGE & ASSOCIATES

CONSULTING ENGINEERS
LONDON

This is a review of the redacted MHI Proprietary *Root Cause Report* released by Senator Boxer and Representative Markey on March 8 2013. This Review also considers a second MHI *Supplemental Technical Evaluation Report* released by the NRC on March 8 2013 which also relates to issues arising during the design phase of the replacement steam generators.

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TUBE WEAR IDENTIFIED IN THE SAN ONOFRE REPLACEMENT STEAM GENERATORS

MITSUBISHI REPORTS UES-20120254 REV.0 (3/64) AND L5-04GA588(0)

SUMMARY AND FINDINGS

This is a review of the redacted Mitsubishi Heavy Industries (MHI) Ltd proprietary *Root Cause Analysis* (RCA)[1] report released into the public domain by Senator Boxer and Representative Markey on March 8 2013.

The copy of the MHI RCA report is complete comprising 68 pages of text and tables. The released non-proprietary version has been redacted at a number of locations, namely partially at pages 3, 10, 18, 19, 21, 25 and 26 with the majority of the text redactions removing component dimensions and other details of a proprietary nature – singly and overall, the redactions do not detract from the overall RCA narrative and findings.

This review also refers to a second MHI report released by the Nuclear Regulatory Commission (NRC) on March 8 2013. This second report, the *Supplemental Technical Evaluation Report* (STE),[2] adds to the earlier MHI tube wear report included in the Southern California Edison (SCE) Confirmatory Action Letter (CAL) submission. Similarly, the STE report is redacted at locations throughout the 68 pages of text and figures, although *Section 4* considering the joint SCE and MHI involvement during the design stages from early 2005, includes only a few isolated instances of redaction of what are obviously component dimensions and clearances.

For a background of the steam generator tube degradation at the San Onofre Nuclear Generating Station (SONGS) there are a number of chronological narratives of the events leading up to the withdrawal of all 4 RSGs at SONGS, for example United States Nuclear Regulatory Commission Region IV, *San Onofre Nuclear Generating Station – NRC Augmented Inspection Team Report 05000362/2012007*, July 18 2012, SCE, Enclosure 2, *Songs Return to Service Report*, October 3 2012 and the Large & Associates Affidavit *Response to Atomic Safety and Licensing Board's Factual Issues*, January 22 2013.

GENERAL FINDINGS

In the absence of a detailed rebuttal from SCE, the MHI RCA and STE reports claim that (allegedly):

1) SCE was involved in the overall and detailed design of the replacement steam generators (RSG) for the San Onofre Nuclear Generating Station (SONGS) at both specification and early stages of the design process, namely

   i) in September 2004 when SCE issued the *Certified Design Specification* (CDS) spelling out the design strategy of the anti-vibration bar support systems that were to prove crucial in the tube degradation performance of the RSGs, and

   ii) from about May-June 2005 when SCE, along with MHI, formed the *AVB Design Team* charged with investigating, amongst other things, the high local void fraction[3] in the two-phase flow regime predicted by the MHI computer analysis of the then developing RSG detailed design;

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1 *San Onofre Nuclear Generating Station, Unit 2 & 3 Replacement Steam Generators, Root Cause Analysis Report for Tube Wear Identified in the Unit 2 and Unit 3 Steam Generators*, MHI UE-2012025 Rev 0, Non-Proprietary c October 2011, redacted form released by the NRC on March 8 2013 - hereafter the MHI RCA team undertaking the root cause analysis report will be referred to as RCA to avoid confusion with MHI when it was involved in the earlier design and manufacturing activities and, similarly, the MHI Supplemental Technical Report will be referred to as STE – although note that, essentially, RCA and MHI are the same entity and share the same commercial interests - the location of the text referred to in the RCA report is shown page number and paragraph thus [p53,¶6] .

2 Attachment 4, *Supplemental Technical Evaluation Report*, MHI Document L5-04GA564 Tube Wear of Unit-3 RSG – the location of the text referred to in the STE report is shown page number and paragraph thus {p53,¶6} – text cited from other sources and reports are shown thus |p35, ¶5|.

3 *Void Fraction* – is an index of the volume of steam to water in a two-phase fluid, expressed as a fraction of unity, so a Void Fraction of 0.75 comprises 75% vapor phase (ie steam) and 25% liquid (water) by volume. Local Void Fraction is an important contributor to flow induced tube rattling since increasing void is accompanied by decreasing viscosity and the ability of the two-phase fluid to dissipate or damp out any energy input to immersed structures (ie tubes subject to cross flows) from the *pitch* or *dynamic velocity* – the balance of

2) thereafter, through to at least late 2006, as a joint member of the AVB Design Team, SCE was involved in identifying practical means of curtailing the high void fraction, some of which involved evaluation of very substantial design changes to the RSGs, although SCE, jointly with MHI, agreed not to implement any of these because *'unacceptable consequences'* would arise;

3) one difficulty and possible *'unacceptable consequence'* identified by MHI was SCE's CDS constraint clauses, including *Cl 3.6.1* stipulating the intended use of the provisions of 10 CFR §50.59 to minimize the impact of the RSGs on the existing plant licensing basis, and the *Cl 3.9.1* prerequisite to closely match the RSGs to the original Combustion Engineering SGs in '*in form, fit, and function'*; so that

4) any such modifications and/or departures from the original SG design should not impede the ability to justify the final RSG design under the provisions of 10 CFR §50.59, that is whereby SCE had provided the NRC with assurance that the RSG design would not give rise to any detriment to the established SONGS nuclear safety case and, in doing so, there would be no need to apply for a *License Amendment*.

Overall, the unsatisfactory and clearly defective design of the installed RSGs at San Onofre introduced performance uncertainties and, some would claim, added risk of radiological incident at these two nuclear plants. It might be argued that with prior knowledge of a number of these uncertainties before SONGS Units 2 and 3 were returned to service operation, SCE should have taken the opportunity to revisit the 10 CFR §50.59 screening process - if it had done so then, surely, it would have foreseen the need for the RSG design and function to be subject to a License Amendment.

SC EDISON'S KNOWLEDGE OF AND INVOLVEMENT IN THE DESIGN PROBLEMS

SCE's recent response to the FoE 10 CFR 2.206 Petition states that until recently (2012)[4] it had no knowledge of the design inadequacies that resulted in fluid elastic instability (FEI) (and, hence, accelerated tube wear) in the replacement steam generators (RSG) [p11, 2 ¶4]:[5]

> *". . . As a result of its* ***recent evaluations****, SCE has determined that MHI's thermal-hydraulic analysis code did not predict the fluid elastic instability that occurred in the RSGs. That concern, however,* ***was not known*** *during the design and manufacturing of the RSGs. Therefore, those concerns could not have been a basis for a license amendment and do not provide any basis for an allegation that SCE violated 50.59 in 2009-2011."*
>
> my ***emphasis***

More recently, following public release of the RCA and STE reports, SCE stated:[6]

> *". . . At no time was SCE informed that the maximum void fraction or flow velocities estimated by MHI could contribute to the failure of steam generator tubes . . . At the time, the design was considered sound."*

However, the RCA report suggests otherwise, giving account of when and the extent of SCE's involvement in and knowledge of the uncertainties and inadequacies of the RSG design, for example:

[p48, (3) ¶2] the [link] gives the location of the text extract in the RCA and directs to the where the point is considered in greater detail in this Review – my ***emphasis*** throughout this and following text extracts	*Also* ***MHI and SCE recognized*** *that the SONGS RSG steam quality (void fraction) was high and MHI performed feasibility studies of different methods* ***to decrease it****. Several design adjustments were made to reduce the steam quality (void fraction) but the effects were small. Design measures to reduce the steam quality (void fraction) by a greater amount were considered, but these changes had unacceptable consequences and* ***MHI and SCE agreed*** *not to implement them.*

dynamic velocity *vs* damping, with account of the stiffness (ie excitation frequency) of the immersed structure is described by as *fluid elastic instability* or FEI.

4 SCE is reported to have vigorously denied that it was aware of any design flaws in the steam generators during the design stages – LA Times, February 26 2013 *'Cost for troubled San Onofre plant? $400 million and growing'*

5 Docket N° 50-361 and 50-362 Response to Friends of the Earth 10 CFR 2.206 Petition, January 9, 2013

6 Power Engineering *'Southern California Edison Comments on MHI Evaluation of San Onofre Nuclear Plant Steam Generators'*, Business Wire, March 8 2013

Since void fraction[7] is a direct contributory factor of FEI, knowledge of a high void fraction will forewarn of the potential for FEI (and hence the risk of accelerated tube wear), thus MHI's computer modeling prediction of high void fraction directly related the possible presence of damaging levels of FEI in the RSG tube bundles.

Also, SCE's response analysis to FoE's Allegation [p18, Appendix 1][5] states:

"... *At the time the RSGs were designed, MHI performed analysis that demonstrated that the* ***steam*** *{void fraction} in any area of the tube bundles* ***would be low enough to provide the required damping****, and that the quality of the steam in the vast majority of the secondary side of the steam generators would be even less. Furthermore, MHI analyzed the potential for fluid elastic vibration, and determined that conditions were stable SCE's root cause evaluation has determined that FEI did occur. However,* ***SCE had no evidence of that beforehand****.*"

my ***emphasis*** and *{clarification}*

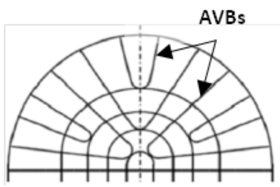
According to the RCA report, not so because SCE was part of the *AVB Design Team* that was charged with investigating the cause(s) of high void fraction (and the associated FEI) and how it could be eliminated from the RSG design:

[p17, ¶2]	*Early in the project,* ***MHI and SCE formed an AVB Design Team*** *with the goal of minimizing U-bend vibration and wear.*
[p22, ¶2]	*However, the AVB Design Team recognized that the design for the SONGS RSGs resulted in* ***higher steam quality (void fraction)*** *than previous designs and had considered making changes to the design* ***to reduce*** *the void fraction (e.g. using a larger downcomer, using large flow slot design for the tube support plates and even removing a TSP). But each of the considered changes had unacceptable consequences and the AVB Design Team agreed not to implement them. Among the difficulties associated with the potential changes was the possibility that making them could* ***impede the ability to justify the RSG design under the provisions of 10 C.F.R §50.59****.*
[p48, (3) ¶2] .	*Design measures to reduce the steam quality (void fraction) by a greater amount were considered, but these changes had unacceptable consequences and* ***MHI and SCE agreed*** *not to implement them.*

The STE report provides further details about the SCE-MHI AVB Design Team {p51, ¶6}:

In ***mid-2005*** *a* ***joint SCE / MHI AVB Design Team*** *was formed for the purpose of minimizing the potential for tube vibration and wear in the SONGS RSGs. For the first six months, video meetings were scheduled every two weeks and technical or design review meetings were held on a two month cycle.*

The primary role of the AVB assembly is to inhibit the onset of tube vibration in the U-bend region of the RSG tube bundle, so the *AVB Design Team* would have been acutely aware of the high void fraction being predicted at the time and, from that, of the need to control and suppress FEI in the U-bend region of the tube bundle - the importance of accounting for and managing FEI in recirculatory steam generators has been established



Location of AVB in U-Bend

7 In gas-liquid two-phase flow, the void fraction is defined as the fraction of the flow volume that is occupied by the gas phase. The void fraction will vary from location to location in the recirculating flow around the SG tube bundle (depending on the two-phase flow pattern), it will fluctuate with time and its value is usually time averaged. In local FEI flow situations the fluid provides the damping or dissipation of the energy entering the situation, so its efficiency in the damping role reduces as the steam content increases (high void fraction) and, with this, is an increase in the two-phase fluid volume and a corresponding raising of the dynamic pressure (*v2*), to the extent that the energy input increases and the situation becomes unstable.

for several decades.[8] Since SCE was a member of the *AVB Design Team* it would have been privy to all of this information, particularly since it had agreed with MHI not to implement certain changes to the RSG design to reduce the void fraction.

Similarly, when questioned by the NRC at the November 30, 2012 Public Meeting, SCE responded specifically on the issue of void fraction,[9] here alluding that it had not known of the high void fraction at the early stages of the design process (ie the *'2005 timeframe'*):[10]

> *". . . Werner {NRC} - "Just so we are clear the underprediction of the velocity by FIT III was not recognised - the problem of the model when it was changed from square pitch to triangular pitch a number of years ago - but the void fraction even under FIT-III while not predicting 99.6% was predicting 95% which was still high and was a matter of concern back in the* ***2005 timeframe*** *– I know that still being looked that was* ***a matter of concern a number of feasibility studies were conducted to try to lower the void fraction before the steam generators were fabricated*** *but apparently it was not - so - we will need to understand that better as we go forward"*
>
> *. . . Palmisano {SCE} - "We have as well – we have asked MHI for a better explanation of that it and we are looking at it ourselves because as you say the void fraction was high it was not predicted as high 99.5% it was high* ***it was questioned ultimately*** *the calculations and the operating experience showed even with that void fraction the system should have been effective it was not – clearly thats a failure several reasons for that failure that have to be dealt with."*
>
> my *{clarification}* and ***emphasis***

Again, according to the RCA report:

[p48, (3)]	*A* ***special AVB team*** *was formed and included industry experts to conduct an extensive design review process in 2005 / 2006 . . . Also* ***MHI and SCE recognized that the SONGS RSG steam quality (void fraction) was high*** *and MHI performed feasibility studies of different methods to decrease it. Several design adjustments were made to reduce the steam quality (void fraction) but the effects were small. Design measures to reduce the steam quality (void fraction) by a greater amount were considered, but these changes had unacceptable consequences and* ***MHI and SCE agreed*** *not to implement them.*

The STE report reiterates this with some additional detail {p56, ¶4.1.3}:

> *In the* ***May 2005*** *Design Review meeting, MHI presented an RSG performance calculation showing* ***high projected void fraction****. It was decided that MHI would perform a parametric analysis to determine* ***how the void fraction could be reduced*** *while maintaining the other design requirements.*

So it seems that the May 2005 Design Review Meeting, attended by both SCE and MHI, recognized undesirable implications (ie tube rattling and wear) of the *'high projected void fraction'* in the then developing RSG design. This most probably motivated the decision *'in mid-2005'* to form *'a joint SCE / MHI AVB Design Team'* and, if so, there is some ambiguity over Palmisano's response to the NRC that the high void fraction *'was questioned ultimately'* because, according to the RCA and STE reports, the AVB Design Team was constituted immediately following the MHI's reporting of the high void fraction result.

These comparisons between the highly confidential RCA report and SCE's published and public recollections provide quite different accounts of how much was known and by whom.

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8 The seminal work in this area is *Fluidelastic Vibration of Heat Exchanger Tube Arrays*, Journal of Mechanical Design – Volume 100 – April 1978, H J Connors although there are earlier references to this topic which is rooted in the *Navier-Stokes Equations*, particularly *Stoke's Law* of the 1850s.

9 At a guess, the design intent for the SONGS RSG steam quality (~void fraction) would have been around a maximum of 90% in the U-bend area of the tube bundle, although value is redacted in the STE {13, Figure 2.2-1}.

10 NRC-Edison exchange at the SONGS CAL Response Public Meeting, November 30 2012 - 0 1hr 52 minutes into session.

Put simply, if the RCA account is to be believed, then with SCE being involved in the design process as part of the *AVB Design Team*, SCE would have known of the design uncertainties (eg unacceptably high void fraction and the direct link to FEI), and it would have had knowledge about this in or about May 2005. Thereafter, with its close involvement in the AVB Design Team, SCE would have been aware of and involved in attempts to modify the design of the RSG internals to reduce FEI contributory factors, including lowering of the high void fraction.

In fact, MHI state in both RCA and STE {p56, ¶4.1.3} reports that the AVB Design Team (comprising both SCE and MHI) recognized a potential requirement to substantially modify the design:

[p22, ¶2]	*However, the AVB Design Team **recognized** that the design for the SONGS RSGs resulted in **higher steam quality (void fraction)** than **previous designs** and had considered making changes to the design to reduce the void fraction (e.g. using a larger downcomer, using large flow slot design for the tube support plates and even removing a TSP). But each of the considered changes had unacceptable consequences and the AVB Design Team agreed not to implement them.*

> *Over the next five months, MHI evaluated alternative design modifications to increase the RSG circulation ratio (and thereby reduce the maximum void fraction). The design alternatives included a larger downcomer, larger TSP flow area, and removing one TSP. None of these alternatives had a large enough effect on the maximum void fraction to justify such a significant change.*

SC Edison's Involvement in the AVB Design Team

a) **Inclusion of SC Edison in the Design Process:** The usual arrangement between the Client (here SCE or its nominee) and the supplier (MHI) was established via the *Certified Design Specification*. Typically this would have involved SCE at arms-length in decisions relating to details of the design, such as the AVBs.

Unusually, however, as the purchasing client, SCE built-in a requirement in the *Certified Design Specification* (reasonably assumed to be part of the contract) whereby it would specify the principal functionality mode of the AVBs. In this respect:

i) SCE required MHI to detail design and incorporate into the RSGs a type of AVB that resulted in a *'zero tube-to-flat bar gap'* - it is important to understand that under this arrangement alone SCE did **not** itself design the AVB, but it did specify what was to be achieved by the AVB that was to be developed and detail designed by MHI.

ii) SCE also specified that the AVB should function specifically in the *out-of-plane* (OOP) direction, but it was tacit on the functioning of the AVB in the *in-plane* (IP) direction.

iii) MHI was also required to submit the a) final design and b) method of manufacturer of the AVB to SCE for its approval.

b) **SCE Involvement in the AVB Design Group**: At some date early in the project, STE states this to be following the May 2005 Design Review meeting, SCE and MHI formed the *AVB Design Team*. This seems to have involved SCE in a much more hands-on role with both the design and manufacturing processes for the AVBs, including attendance at *'numerous technical and review meetings'* {p54, ¶6}:

> *The AVB Design Team **generated many action items** and **answered many questions**, several of which dealt with **high void fraction** and **how to minimize it**. This process **continued through the end of 2006.** The AVB team investigated instances of U-bend tube degradation using the INPO, NPE (Nuclear Power Experience), and NRC databases and studied whatever could be found describing the design of other similarly large SGs.*

Again according to RCA, via the AVB Design Team, SCE would have been instrumental in design decisions on crucial aspects of the AVB design strategy and application, including determining the number of AVBs, the tube and AVB dimensional control to achieve the *'zero-gap'* functionality and, along with this, formulating the strategy to minimize AVB-to-tube preload in order to minimize ding and dent indications.

As described by both RCA and STE reports, SCE's involvement in the overall design strategy, the detailed design of the AVBs and other aspects of the tube bundle, seems to have been within the terms of the *Certified Design Specification* (CDS).**Error! Bookmark not defined.** In fact, the CDS is quite specific in regard to SCE's specification of the AVB design, thereby setting the AVB design strategy of *'zero tube-to-AVB gap-zero force'* - ie no preload in the *in-plane* direction [p**Error! Bookmark not defined.**, figure]:

[p8, ¶3]	*3.10.3.5 . . . The Supplier shall* ***develop*** *and submit for Edison's* ***approval*** *an* ***Engineering*** *and* ***Fabrication*** *Gap Control Methodology describing control of an effective* ***"zero" tube-to-flat bar gap****, gap uniformity and parallelism of the tube bundle in the* ***out-of-plane direction*** *prior to tube fabrication.*

CONSEQUENCES OF SC EDISON'S INVOLVEMENT IN THE DESIGN PROCESS

a) **Cause of Tube Wear:** It is now established that the unacceptable incidence, rates and severity of tube wall thinning (tube wear) extant in the two Unit 3 RSGs arose because of a combination of:

i) the lack of contact or preload force and friction force between the AV bar and individual tubes acting in the IP direction, directly because of the *zero tube-to-flat bar gap* design of the AVB specified and approved by SCE; and

ii) the loss of tube motion restraint at the AVB-to-tube 'contact' points released the free-span sections of the tubes to vibrate, resulting in tube-to-tube wear (TTW); and also

iii) where a degree of pre-load force existed (fortuitously) at some of the AVB-to-tube locations, adjacent tubes that had no pre-load[11] impacted on the restrained tubes, eventually wearing away the AVB points of restraint.

The consequences of ii) and iii) foregoing are the direct result on the inappropriateness of the SCE-MHI jointly specified AVB function and, similarly, the final AVB detailed design.

Similar levels of AVB-to-tube wear have developed in Unit 2 and further TTW is expected to occur if Unit 2 re-enters service.

b) **Other Tube Wear Incidence:** Two other forms of tube wear have been found in both Units 2 and 3 RSGs, these are:

i) the degraded (worn and slackened) AVB-to-tube wear incidences are also most likely to have contributed to the TSP-to-tube wear; whereas

ii) the tube wear found in tubes adjacent to the retainer bar (RB) is not connected to the design and functioning of the AVBs.

MHI identifies the mechanistic causes of the various types of tube wear found in the SONGS Units 2 and 3 RSGs:

[p12, ¶5.3] my added *{explanation}*	*. . . fluid elastic instability {FEI} as the mechanistic cause of the tube to tube {TTW} wear, turbulence induced vibration (often referred to as "random vibration" because the excitation modes over time are unpredictable) as the mechanistic cause of the tube to AVB wear, and turbulence induced vibration of the retainer bar as the mechanistic cause of*

11 No pre-load was the intended design condition – this could also result for tubes where the restraint had been worn away by tube motion in the unrestrained *in-plane* direction,

	the retainer bar to tube wear.

ROLE OF MHI IN THE DESIGN PROCESS

a) **RB-to-Tube Wear:** RCA admits that the design of the small diameter retainer bars was never checked by MHI at the design stage for susceptibility to resonate when subject to random fluid (turbulent flow) excitation.

b) **Thermal Hydraulic Modeling and FIT-III:** Similarly, it was solely MHI who conducted the thermal-hydraulic flow analysis using its FIT-III software, although as a member of the *AVB Design Team* SCE would have been aware of the thermal-hydraulic modeling results. As previously noted, the first results of the FIT-III seemed to have been reported to SCE at the May 2005 Design Review Meeting.

It transpires that MHI not only failed to adequately validate the FIT-III software but, also for the specific SONGS application, MHI incorrectly set up crucial flow modeling parameters[12] as these related to the triangular pitched tube sets of the SONGS RSGs. Even with the triangular pitch error corrected, generally, the FIT-III code under-predicted the tube gap (pitch) velocity by about a factor of x2 when compared to other established methods [TABLE 3].

The involvement of SCE in the thermal-hydraulic modeling of the RSGs, a crucial element in the early stage design process, is specified in the CDS [p**Error! Bookmark not defined.**], the NRC[15] opines that SCE accepted and, it must be assumed, approved the use of the MHI FIT-III thermal-hydraulic code |p35, ¶5|:[13]

> *Mitsubishi's FIT-III thermal-hydraulic code was* ***accepted by SCE*** *for the design of the replacement steam generators.*

In addition, a particular problem with the FIT-III thermal-hydraulic code that '*predicted nonconservative low velocity and low void fraction results'* has been identified by the NRC.[14] In this respect the NRC Augmented Inspection Team reviewed[15] the SCE-MHI cause evaluation for organizational and programmatic factors that might have resulted in the nonconservative low pitch velocity and void fraction results of the thermal-hydraulic model, although at the time of reporting (November 2012) the evaluation was still being finalized and had not then be approved by SCE.

c) **In- and Out-of-Plane FEI:** The FIT-III software could not account for IP FEI that, in the SONGS RSG flow geometry, was subsequently found to dominate the flow regime in the TTW zone of the tube bundle hot-leg to U-bend region.

MHI failed to recognize the dominance of FEI and other fluid flow driven phenomena in the IP direction and, accordingly, it did not modify the AVB design to provide effective (design function) restraint to IP tube motion and wear.

On its part, MHI considers this [p22, ¶4] *'because contemporary knowledge and industry U-tube SG operation experience did not indicate a need to consider in-plane FEI'.* However, it might be construed to be somewhat disingenuous to suggest that *in-plane* FEI is a novel and unresearched phenomenon - it is not, there being a wealth of research papers, guidance notes and standards many of which predate the design of the SONGS RSGs.[8,16] In other words, knowledge of the fluid flow regimes and structural response in both

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12 This appears to a have been a simple arithmetical mistake.

13 San Onofre Nuclear Generating Station – *NRC Augmented Inspection Team Report 05000361/2012007 and 05000362/2012007*, July 18 2012.

14 NRC Inspection Reports 05000361/2012007 and 05000362/2012007 – Augmented Inspection Team, NRC Incident Management Program.

15 San Onofre Nuclear Generating Station – *NRC Augmented Inspection Team Follow-Up Report* 05000361/2012010 and 05000362/2012010, November 2012.

16 Much of the steam generator tubing specific applications work was completed by a Westinghouse employee H J Connors, whose standard work was published as *Flow-Induced Vibration and Wear of Steam Generator Tubes*, Nuclear Technology, V55, November 1981, although interest in this area with SG manufacturers having their own design guidelines, as well as the American Society of Mechanical Engineers (ASME), there are many publications and guides on this topic which predate the SONGS design phase, for

OOP and IP directions is very established and well understood. In this respect, there is no reason why the joint Edison-MHI AVB Design Team should have had any reason to overlook analyzing the potential instability in the IP direction in the tube bundles of the SONGS replacement steam generators.

LICENSE AMENDMENT PROCESS – 10 CFR §50.59

The information provided in the RCA Report strongly hints that because the then FIT-III predicted void ratio was high, the RSG designs were comprehensively reviewed *'in 2005/2006'* – see {DIAGRAM 1}.[17] However, by that date in the design and manufacturing processes, the design should have been largely settled with the purchase of bought-out items, particularly with the vast quantity of customized tubing ordered if not already then in manufacture.

Although RCA admits that SCE and MHI as the *AVB Design Team*, had then jointly considered making some quite substantial changes to the RSG design in order to reduce the higher steam quality (void fraction) - *'using a larger downcomer, using large flow slot design for the tube support plates and even removing a TSP'* – SCE seems to have held sway with its commitment to minimize the *'change'* of the RSG design, over the original Combustion Engineering SGs, in order not to provoke a license amendment under the 10 CFR §50.59 process.

The RCA report specifically identifies SCE's requirement to comply with the 10 CFR §50.59 screening process and therefore circumvent the need for a License Amendment:

[p22, ¶2] my truncation . . .	*However, the AVB Design Team recognized that the design for the SONGS RSGs resulted in higher steam quality (void fraction) than previous designs and had considered making changes to the design to reduce the void fraction . . .* ***Among the difficulties associated with the potential changes was the possibility than making them could impede the ability to justify the RSG design under the provisions of 10 C.F.R §50.59.***

And, similarly, the RCA *'Change Analysis'* concludes:

[p48, ¶(3)] my truncation . . .	*Also MHI and SCE recognized that the SONGS RSG steam quality (void fraction) was high and MHI performed feasibility studies of different methods to decrease it. Several design adjustments were made to reduce the steam quality (void fraction) but the effects were small. Design measures to reduce the steam quality (void fraction) by a greater amount were considered, but these changes had unacceptable consequences and MHI and SCE agreed not to implement them. It was concluded that the final design was optimal based on the overall RSG design requirements and constraints.* ***These included physical and other constraints on the RSG design in order to assure compliance with the provisions of 10 C.F.R. §50.59.***

And, similarly, the STE report sets out the constraint on the design imposed by SCE {p51, ¶4.1.1}:

> *The general design requirements, performance requirements, and design criteria for the SONGS RSGs were set forth in SCE's "Certified Design Specification (CDS), SO23-617-01 (Ref. 8)". Significant features of the CDS were* ***the intended use of the provisions of 10 C.F.R. §50.59 to minimize the impact of the RSGs on the existing plant licensing basis*** *(CDS 3.6.1) and the requirement to closely*

example Au-Yang M K, *Flow Induced Vibration of Power and Process Plant Components*, 2001 ASME. Pettigrew and the others cited in the MHI RCA and STER reports are latecomers to this long established and well understood phenomenon.

17 DIAGRAM 1 is a *'rough-and-ready'* compilation of the revision dates given in the RCA Time Line diagrams [p55 to 59] but which are also interesting in another important respect. This is because many of the revisions referred to would have been raised at the various Design Review and AVB Design Team meetings so, it follows, there must be minuted action lists, or similar, for these meetings – such action lists would provide a greater and more reliable insight into the roles and responsibilities assumed by each of the parties in the overall and detailed design processes.

*match the dimensions and function of the OSGs (CDS 3.9.1). These features meant that the RSGs needed to **"be as close as possible to the existing steam generators in form, fit, and function"** (CDS 3.6.1.1).*

In effect, this 10 CFR §50.59 constraint, that seems to have been imposed solely in order to avoid the need for a license amendment, meant that {p51, ¶3} '*overall RSG had to fit within the size, weight, and volume limits related to those of the OSG, the tube bundle heat transfer area was to be maximized'* – an engineering challenge that SCE and MHI failed to meet, with this being the fundamental root cause of the severe and intolerable levels of tube degradation experienced in the San Onofre Units 2 and 3 replacement steam generators.

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