Enclosure 5

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Engineered Safety Features

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NEDO-33572 Revision 1, "ESBWR ICS and PCCS Condenser Combustible Gas Mitigation and Structural Evaluation," May 2010

Public Version

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GE Hitachi Nuclear Energy

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May 2010

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ESBWR ICS AND PCCS CONDENSER COMBUSTIBLE GAS MITIGATION AND STRUCTURAL EVALUATION

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ILLUSTRATIONS

1.0 SCOPE

The design of the Isolation Condenser System (ICS) and Passive Containment Cooling System (PCCS) as described in Revision 6 of the ESBWR Design Control Document (DCD) are being modified to improve their ability to mitigate the loads resulting from the buildup and possible detonation of radiolytically generated combustible gases. This report describes these changes and the conservative methodology by which the detonation loads are calculated as well as the design philosophy used to ensure the ICS and PCCS have been designed robustly to withstand the most bounding loads while not affecting their heat transfer capability.

2.0 PCCS METHODOLOGY

The PCCS components are first evaluated for accumulation of radiolytically generated hydrogen and oxygen and then the possible range of mixture concentrations is determined. A bounding detonation pressure for a pure stoichiometric mixture of hydrogen and oxygen is calculated using the highest peak pressures during a loss of coolant accident (LOCA). It is then applied statically using dynamic load factors (DLF) in a finite element model for the PCCS condenser using the approved ANSYS computer code. The calculated stresses for the detonation load are combined with those from seismic and LOCA thermal loads. The acceptance criterion for components subject to detonation is based on the ability of those components to retain their pressure integrity without significant plastic deformation following [[ ]] detonation cycles. Two postulated detonation scenarios are analyzed in the finite element model: a detonation in one tube and a detonation in the lower drum.

Inputs are provided for the finite element analysis that describes increased thicknesses for the PCCS tubes and lower drum that are expected to satisfy the acceptance criteria for elastic-plastic analysis. The impact of increased tube thickness on heat removal capacity is estimated and compensated for by adding additional tubes. This configuration is evaluated in Appendix B.

The specific routing and configuration of components downstream of the lower drum is not yet specified. Therefore, the thickness of downstream piping and components will be sized to accommodate the resulting detonation loads. The magnitude of the detonation load on the downstream components will also be minimized by the addition of a safety-related catalyst module at the entrance of the vent pipe in the condenser lower drum. The catalyst module will function to keep hydrogen concentrations in the PCCS vent below levels at which deflagration-to-detonation (DDT) events can occur.

2.1 COMBUSTIBLE GAS GENERATION / CONCENTRATION

The radiolytic generation of combustible gas is a common occurrence in typical power reactors, including ESBWR. The generation of hydrogen and oxygen gas occurs in a stoichiometric ratio at a rate proportional to the core decay heat. During a LOCA, these gases escape into the containment resulting in very dilute concentrations of combustible gas in the drywell (below concentrations that could result in ignition). The PCCS contains six condensers that are designed to receive this mixture of steam and noncondensable gas, condense the steam, and return the condensate back to the drywell. See simplified sketch, Figures 1a, 1b, and 1c, of the PCCS Condenser.

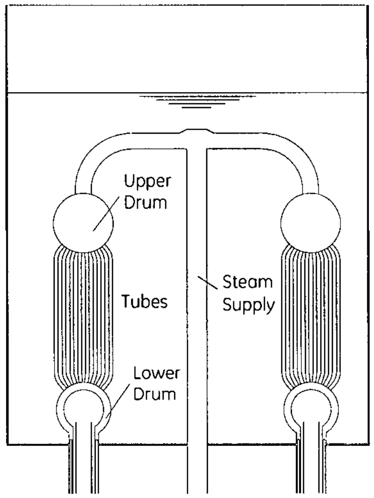

Figure 1a: PCCS Condenser Simplified Sketch

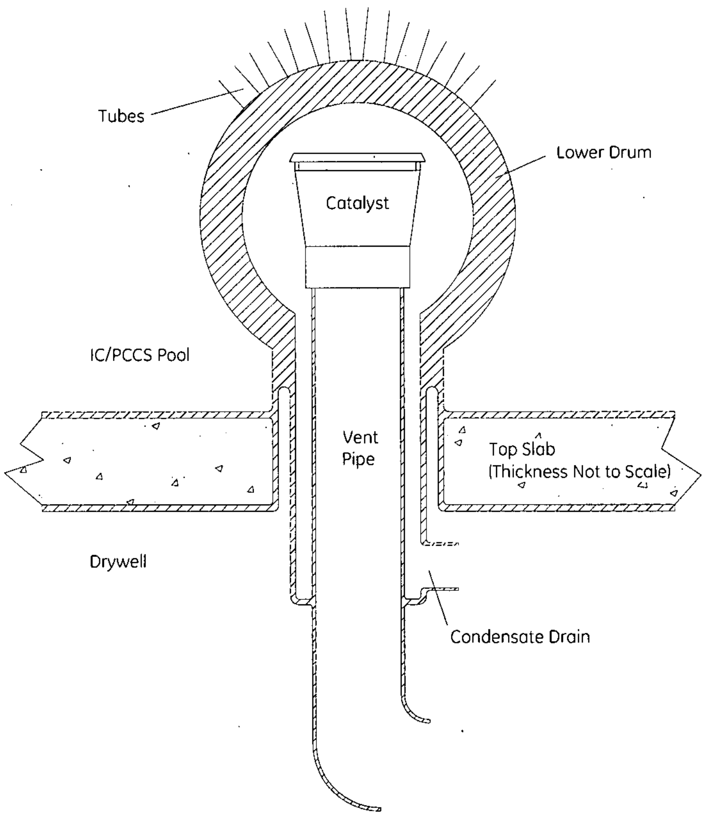

Figure 1b: PCCS Condenser Lower Header Section View (Not to Scale)

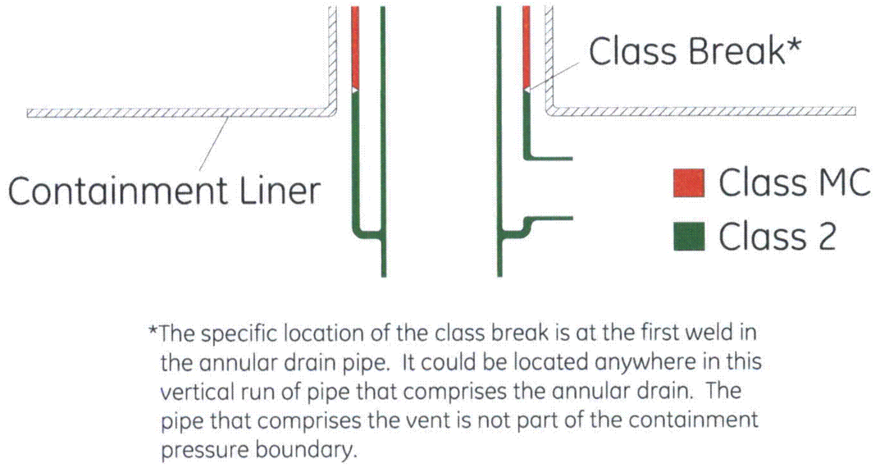

Figure 1c: PCCS Condenser ASME Jurisdictional Boundaries

Each PCCS condenser consists of two modules submerged in a pool of cooling water. Each module contains an upper and lower drum connected by an array of 2-inch diameter tubes. Gas from the drywell passes up a central supply line that feeds both upper drums. The steam component of the gas condenses as it moves downward through the tube array (transferring its heat to the pool water) and condensate collects in the lower drum and drains back to the drywell by gravity. The pool water level drops slowly over the course of the accident as water boils off.

The leftover noncondensable gas can exit the PCCS condenser through a vent line that connects the lower drum to the wetwell. As steam and noncondensables enter, the vent operates passively to bleed gas from the lower drum of the condenser when there is a sufficient pressure differential between the drywell and wetwell. In this way, something close to an equilibrium state is reached in which noncondensables persistently linger in the condenser while small amounts continue to come in with the steam and go out through the vent.

In the initial stage of a LOCA, the majority of the noncondensable gas in the drywell is nitrogen. This gas is eventually forced into the wetwell by the depressurization of the Reactor Pressure Vessel (RPV). Over time, the primary source of noncondensable gas in the drywell is the radiolytically generated hydrogen and oxygen. It has been shown in TRACG that noncondensable gas accumulates in the lower portions of the tubes and lower drum. When this gas transitions from mostly nitrogen to a stoichiometric mixture of hydrogen and oxygen, a combustible concentration may exist.

The relative concentration of steam to hydrogen and oxygen in the PCCS condenser is highly dependent on the conditions in the Isolation Condenser /Passive Containment Cooling System (IC/PCCS) pool subcompartment. Lower pool temperatures will bring down the temperature inside the condenser thereby lowering the steam fraction. The pool level can influence the variation in steam fraction over the height of the condenser tubes. TRACG analyses show that the steam fraction in the upper drum, and upper portion of the PCCS condenser tubes remains above 75%. The steam fraction in the lower portion of the tubes and the lower drum will remain above 30%.

In order to bound the amount of fuel and oxidizer inside the condenser, the atmosphere inside the PCCS is assumed to be 67% hydrogen and 33% oxygen (no steam).

Also, the initial PCCS pressure is assumed equivalent to the peak drywell pressure (407 kPa absolute) for the bounding containment LOCA even though the actual pressure inside the condenser will be significantly lower due to condensation. This approach is conservative because it results in a pure mixture (free from steam diluent) and assumes it is at an initial density greater than it could realistically achieve.

2.2 DETONATION LOADS

The process by which a detonation wave propagates through a medium and imparts stress on its surroundings is a complex subject that has been studied for a variety of applications. References 1 through 9, and 17 are reports that attempt to characterize this phenomenon. Data from these reports have been used to determine a bounding detonation load.

The entire PCCS is considered, but the focus of this report is on the condenser tubes and lower drum because of the complex geometry at the interface between the two and also because of the relatively thin walls of the tubes that make them more vulnerable to internal overpressure. The other portions of the PCCS (vent and drain piping) are considered separately in this report.

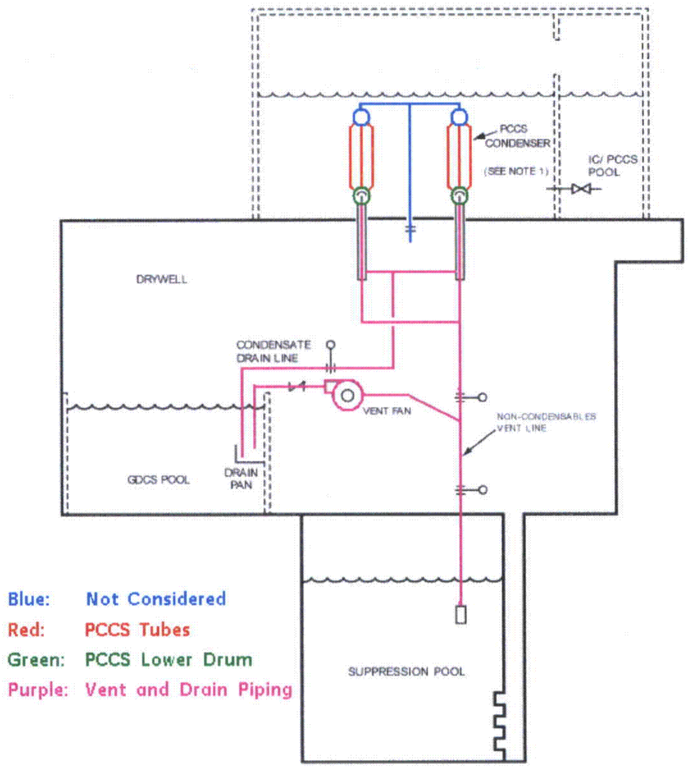

Figure 2: Portions of PCCS Considered for Detonation

The steam supply line and upper drums are not considered in this evaluation because they are constantly being flushed by steam coming from the drywell. The hydrogen and oxygen in this mixture is too dilute to support combustion.

The process used to evaluate the PCCS loads will first estimate the peak pressure resulting from detonation, and then apply this pressure in a finite element model as a static load multiplied by a dynamic load factor.

2.2.1 Peak Pressure Ratio

Many of the studies referenced in Section 6.0 describe the resultant pressure following the passage of a detonation wave, often called the Chapman-Jouguet pressure (or CJ pressure). It has been shown that a correlation can be made between the CJ pressure and the initial pressure prior to detonation. The correlation is dependent on the composition of the fuel-oxidizer mixture, the initial conditions (pressure and temperature), and the geometry of the system.

2.2.1.1 Gas Composition

Reference 3 describes a ratio between CJ pressure and initial pressure for a variety of fuel-oxidizer mixtures. For a stoichiometric mixture of hydrogen and oxygen at an initial temperature of 25°C, this ratio is given as 19:1 (See Table 1 of that report). This ratio is applicable for the PCCS, which also assumes a pure stoichiometric mixture. The assumption of a pure mixture is conservative for the purposes of maximizing the CJ pressure ratio. However, in certain circumstances the presence of steam will be considered as it has the potential to increase pressure loading (explained in Section 2.2.3).

2.2.1.2 Initial Conditions

References 2 and 7 show that lower initial temperatures result in higher peak pressure ratios. Realistic temperatures inside the PCCS at the time of detonation would be approximately 100°C. The assumption of 25°C is considerably lower than the expected temperatures inside the PCCS prior to a detonation and therefore more conservative. Likewise, the initial pressure is assumed to be 407 kPa absolute, which is equivalent to the peak drywell pressure during the most limiting LOCA. Even when the drywell is at this peak pressure, the actual pressure in the PCCS will be considerably lower due to its inherent design (submerged in a pool of cooling water). In this way, the initial conditions for the PCCS are conservatively bounded in the context of the 19:1 peak pressure ratio.

2.2.1.3 PCCS Geometry

Much of the literature cited in Section 6.0 discusses testing using simple straight-tube experiments. These simplified geometries are not necessarily representative of the PCCS condenser, which has a more complex shape with upper and lower drums connected by tubes bending at angles ranging from [[ ]]. The presence of bends, constrictions, and closed ends creates opportunities for reflections that can create localized peak pressures in excess of the

CJ pressure. Reference 9 characterizes this peak pressure for a closed volume as a maximum of 2.5 times the CJ pressure.

The design of the PCCS condenser (in particular the tubes) is more benign in terms of this loading than the tested configuration in Reference 9. Although the condenser tubes do contain bends that are subject to reflection loads, these bends are not as severe as a closed vessel that reflects the full force of the detonation wave. The tube bends range from [[ ]] to a maximum of [[ ]], and all have a bend radius of [[ ]]. Although the presence of bends will introduce some loading due to reflection, the loading will not be to the degree of a closed terminal end. Therefore, the multiplier of 2.5 is a conservative selection for the PCCS to account for effects that could amplify the internal pressure beyond the CJ pressure.

Using the methodology described above, the peak pressure for the PCCS is determined as:

407 kPa (initial pressure) • 19.0 • 2.5 = 19.3 MPa absolute

2.2.2 Dynamic Load Factor (DLF)

The dynamic load factor (DLF) is a multiplier that is factored into the peak static pressure to determine a maximum bounding load that accounts for dynamic effects resulting from a detonation.

2.2.2.1 DLF Dependence on Detonation Velocity

Reference 3 provides guidance on selecting an appropriate DLF. That study correlates the DLF (also called an amplification factor) to the velocity at which the detonation wave propagates. Low wave speeds are shown to have correspondingly low DLFs (approximately 1). As the wave reaches a "resonance" velocity, the DLF is observed to be as high as 4. At velocities above this resonance threshold, the DLF is shown to decrease and plateau around 2.

The resonance velocity is a characteristic of the tube in which the detonation occurs. A formula for calculating the characteristic resonance velocity or critical velocity (V_{c0}) for the PCCS tubes is given in Reference 3 as:

$$V_{c0} = \left[\frac{E^2 h^2}{3\rho^2 R^2 (1 - \nu^2)}\right]^{1/4}$$

where

E = Young's modulus

h = tube thickness

ρ = density

R = mean radius

ν = Poisson's ratio

When these parameters are applied in accordance with the revised PCCS condenser tube design (see Section 2.3), the equation becomes:

[[

]]

2.2.2.2 Determination of a Conservative Detonation Velocity

Reference 1 describes detonation velocities for a pure stoichiometric mixture of hydrogen and oxygen. The velocities reported there (Figure 1 of that report) are in excess of 2800 m/s, which is considerably higher than the V_{c0} value of [[ ]]. However, a pure mixture is not necessarily representative of the mixture in the PCCS (although it has conservatively been assumed so in Section 2.2.1.1), and there is also data to suggest that the presence of steam or other diluents could slow the propagation of the detonation wave. To justify using a DLF of 2, it is important to consider the effects of various diluents to ensure that the most limiting case does not reduce the detonation velocity to a value near V_{c0}.

Reference 10 is a study in which the main focus is on detonation cell widths; however, detonation wave velocity data is also collected and presented with varying dilutions of helium and steam (Figure 2 of that report). The data shows a case with 10% steam and no helium in which there is a small velocity reduction to about 2700 m/s. The data for a dry mixture shows that as helium concentrations approach zero, the velocity approaches a value of approximately 2800 m/s, which is in good agreement with Reference 1. Although this small reduction in velocity is promising, the result of 2700 m/s cannot be considered bounding because steam concentrations in the PCCS can exceed 10%. For the purpose of this evaluation, a steam fraction of 80% is considered bounding because such a mixture lies on the fringe of the lower flammability limits described in Reference 11 (see Figure 1 of that report). However, the studies referenced above do not have data describing detonation velocities at such high steam concentrations.

Because of the lack of experimental data at high steam concentrations, the effects of steam on detonation velocity will be evaluated using a substitute diluent. Reference 6 compares various computational methods for predicting the detonation behavior of various mixtures, including hydrogen and oxygen diluted by argon. Data is presented (Figure 1 of that report) showing that at argon concentrations of 25%, the detonation velocity is in excess of 2200 m/s. At concentrations of 60% argon, this velocity is still above 1800 m/s. Only when argon concentrations reach as high as 80% does the detonation velocities approach the V_{c0} value of [[ ]]. Dilution above 80% results in a mixture outside the flammability limit. Argon is considered a more effective diluent for reducing detonation velocity due to the dependence of such behavior on the molecular weight of the diluent. Argon is considerably heavier than steam - unlike helium, which is actually shown to increase the speed of the detonation wave. The helium data, which is shown plotted along with argon, is in very close agreement with the experimental helium data described above in Reference 10. This agreement provides confidence in the computational methodology and assurance that a mixture of hydrogen and oxygen with 80% steam dilution will remain above the PCCS tube V_{c0}. Because an equivalent amount of argon dilution is just barely sufficient to reduce the velocity to the V_{c0} range, there is adequate assurance that the corresponding velocity for 80% steam dilution will be significantly higher than V_{c0}. These findings justify the use of a DLF of 2.

2.2.2.3 DLF Summary

The PCCS condenser tubes will be evaluated with a DLF of 2 (other portions of the PCCS will be considered separately).

The DLF is shown to be highly dependent on the speed of the detonation wave. For a given geometry, there is a characteristic resonance velocity at which a DLF of 4 should be used. This characteristic velocity for the PCCS condenser tubes is [[ ]]. For velocities sufficiently higher than this resonance value, a DLF of 2 is appropriate.

The detonation velocity is highly dependent on the composition of the gas mixture. For the purpose of estimating a peak static load, it is assumed that the PCCS contains a pure stoichiometric mixture of hydrogen and oxygen. For the purpose of estimating detonation velocities, it is more conservative to assume a high amount of dilution that could bring the velocity down into the resonance range. Although these assumptions are in contradiction with one another, they are both conservative in the context in which they are applied.

A literature review identified several studies that evaluate the velocity of a hydrogen-oxygen detonation wave for a pure mixture and in the presence of diluents. The results show that for a conservatively diluted mixture, the velocity is still in excess of [[ ]]. Thus the DLF of 2 is justified.

The bounding detonation load for the condenser tubes is therefore:

407 kPa (initial pressure) • 19.0 • 2.5 • 2 = 38.7 MPa absolute

Mitigation strategies for other PCCS condenser components are described in 2.2.4.

2.2.3 Deflagration to Detonation Transition (DDT)

In some cases, an additional factor known as delayed deflagration to detonation transition (or delayed DDT) can increase localized pressures to values even higher than those discussed above. The delayed DDT phenomenon can occur when the deflagration front undergoes a substantial acceleration period before transitioning to a detonation. This acceleration compresses the fuel-oxidizer mixture ahead of the wave, and this compression at the onset of detonation has the potential to cause much higher localized pressures loads.

In the case of the PCCS condenser there is potential for delayed DDT when the hydrogen-oxygen mixture is diluted with some significant fraction of inert gas. In other words, the pure mixtures that were described as being conservative in Section 2.2.1.1 are not necessarily conservative for estimating loads from delayed DDT. This is because a pure mixture would transition to a detonation almost instantly and thus avoid the compression resulting from a delayed run-up. Because the PCCS has minimum steam fractions of 30%, the potential for delayed DDT must be addressed.

Delayed DDT is a relatively complicated research area and the phenomenon is dependent on many different variables. Therefore, there is a lack of experimental data that is applicable to the configuration of the PCCS condenser. There are, however, a number of considerations that can be shown to help mitigate the effects of delayed DDT specifically for the PCCS:

- Reference 10 is a report that discusses detonation cell sizes for a range of temperatures, pressures, and diluents. Figure 7 of that report characterizes the cell size for stoichiometric ratios of hydrogen and oxygen with 30% and 40% steam, at a pressure of 106.6 kPa. Those cell sizes are approximately 10 mm and 30 mm respectively. The detonation cell size is inversely proportionate to initial pressure. Therefore, a mixture starting at 407 kPa would have detonation cell sizes of approximately 2.6 and 7.9 mm respectively. These small detonation cell sizes (relative to the tube ID of [[ ]]) are indicative of a sensitive mixture that would transition to detonation prior to accelerating through a long run-up distance. Reference 20 describes a complex correlation of run-up distance to the cell size, tube diameter, tube roughness and burning velocity. Though there is significant uncertainty associated with the reported measurements, typical run-up distances fall in a range of 15-40 times the tubes diameter.

- As stated above, any potential for a delayed DDT event would arise because of substantial steam dilution of the mixture. Such steam dilution would significantly reduce the initial estimate of CJ pressure (the 19:1 ratio described in Section 2.2.1.1). Hypothetically, the reduction in multiplication factor of 19 would offset the increase due to delayed DDT, which should be minimal due to the short run-up distances associated with small detonation cell sizes.

- Reference 17 is a report by the International Radiolytic Gas Combustion project, part of which specifically addresses DDT. The report evaluated the effects of steam concentration and pressure and found that for stoichiometric mixtures of hydrogen and oxygen at initial pressure < 10 bar, the delayed DDT phenomenon need not be considered provided steam concentrations are ≥ 40%. These findings validate the range of detonation cell sizes described in the first bullet, and indicate that the range of potential mixtures that could result in a delayed DDT event is small.

For these reasons, it is assumed that the conservative assumptions used to estimate the pressure load on the condenser bounds the effects of a delayed DDT event.

2.2.4 Other PCCS Components

2.2.4.1 Lower Drum

The lower drum of the PCCS condenser is also subject to the accumulation of hydrogen and oxygen (at similar concentrations as the lower portions of the tubes), however, the combustion of these gases is expected to occur by a different mechanism than that described above for the tubes. Whereas the interior of the tube is a relatively restricted volume with a small diameter and long length, the drum interior is a more spacious and open volume. The top of the lower drum is vented through the tubes, which have a cumulative flow area of [[ ]]. Because of the less constrained geometry and ample pathway for pressure relief, it is expected that the progression of the reaction will be more along the lines of a constant volume combustion rather than a traditional CJ detonation.

Constant volume combustions do not have the same characteristic pressure response as a CJ detonation. However, for conservatism, the same series of pressure multipliers will be assumed for the lower drum as was assumed for the tubes in Section 2.2.2.3.

2.2.4.2 Vent Pipe and Catalyst Recombiner

The PCCS vent line begins with a standpipe in the lower drum, and extends downward to the drywell (routed inside the condensate drain pipe through the top slab) where it separates into an independent line that penetrates the diaphragm floor and terminates at a submerged location in the wetwell. The vent line is designed to conduct noncondensable gases from the PCCS condenser to the wetwell, therefore high concentrations of hydrogen and oxygen would be expected under normal circumstances.

Because of the uncertainties associated with the routing of the PCCS vent line, it is difficult to justify a specific DLF, and even more difficult to make a conclusive statement about the potential for DDT. Therefore, a safety-related catalyst module has been added to the design and will be relied upon to minimize the concentration of noncondensable gas in the vent line.

The catalyst module is bolted to the entrance of the vent pipe in the lower drum so that any gas entering the vent must first pass through the catalyst. The catalyst is composed of an array of platinum or palladium coated plates, arranged in a parallel pattern. A cover is provided on the catalyst that prevents condensate from dripping on the plates. A conceptual sketch is shown in Figure 3 below:

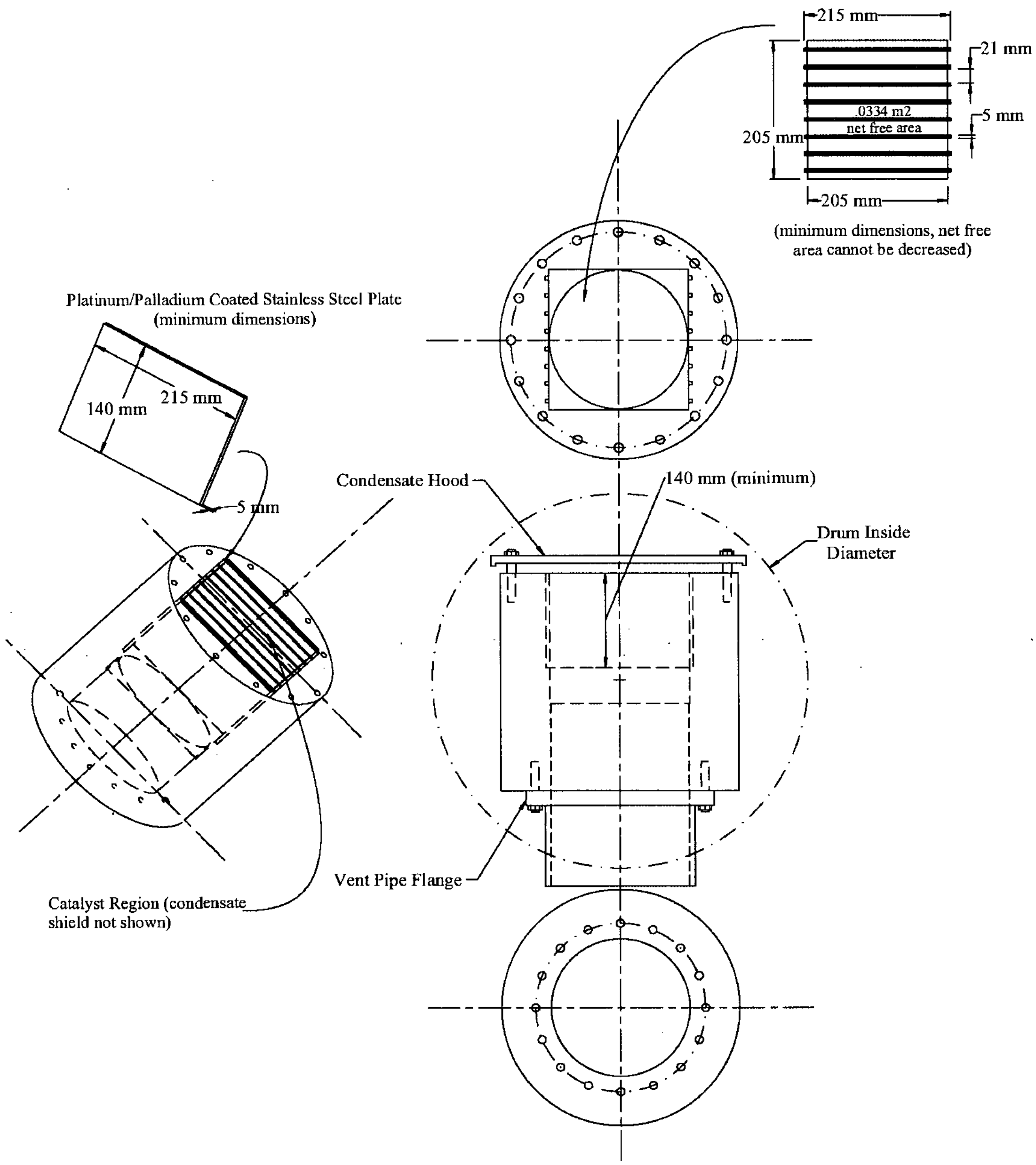

Figure 3: Conceptual Design for In-Line Catalyst

This sketch was based on the dimensions of a similar catalyst that underwent performance testing. The results of these tests (documented in Reference 18) show that for initial hydrogen concentrations of 4%, the catalyst will recombine virtually all of the hydrogen, provided the flow velocity remains below 0.25 m/s. The flow velocity through the vent of the PCCS condenser has been shown to peak at [[ ]] (nominally much lower). Therefore, it is assumed that the fraction of hydrogen and oxygen downstream of the catalyst is insignificant. Once downstream of the catalyst, it is unlikely that hydrogen concentrations will increase to flammable levels due to the lack of condensation in the downstream portions of the vent line. Additionally, the gas that does enter the line will eventually be pushed into the wetwell due to the slow but steady venting process. Therefore, it is assumed that the safety-related catalyst prevents hydrogen and oxygen in the vent line from reaching flammability limits.

The potential for catalyst degradation due to inhibitors and poisons has been evaluated. Reference 19 describes the effects of various aerosols and particulates on the recombination performance in prototypical passive autocatalytic recombiners (PARs). These PARs feature similar geometries and orientations as the in-line catalyst module being proposed in this report (vertically-oriented parallel coated plates). The evaluation considered poisons and inhibitors such as steam, water, smoke, soot, iodine vapor, and carbon monoxide. The evaluation concluded that although some noticeable short-term effects were detected, these diminished as the catalyst reached operating temperatures and the overall performance was not significantly affected. It is also worth noting that many of the poisons considered in the evaluation are not expected to be present during a design basis accident.

An optimization study was performed on the size of the vent line portion leading to the suppression pool downstream of the branch to the vent fan. This line, which had been sized at 10 inches, has been shown to perform sufficiently with flow areas as low as 2 inches. Therefore, in order to provide optimal structural integrity, the vent pipe is reduced to a 3-inch line.

2.2.4.3 Vent Fan Ball Valve

A ball valve is added to the vent fan branch line upstream of the fan as close as possible to the branch from the main vent line to the suppression pool. The ball valve is designed to protect the vent fan from detonations described in 2.2.4.2, and as such shall be designed robustly to remain operational after withstanding a detonation.

The classification of the valve is consistent with the RTNSS function of the vent fans. The valve is nitrogen-operated, normally closed, fail as-is, and provided with an accumulator. It is provided with nonsafety-related power (same power source as the vent fan). While the operation of the ball valve is not safety-related, it is classified as a safety-related component for the purpose of pressure integrity. Because the normally closed ball valve is a safety-related barrier that prevents water redistribution from the GDCS pool to the suppression pool, the safety-related check valve that had been included downstream of the vent fans is no longer required and has been removed from the design. The concern of water transfer from the GDCS pool to the suppression pool only exists in the early stages of an accident when there are large pressure transients in the drywell. After this initial period, the differential pressure between the drywell and wetwell is not large enough to push GDCS pool water back through the vent fan piping, therefore, there are no adverse consequences to the ball valve failing in the open position after the fans have been activated.

2.2.4.4 Drain Pipe

The drain from the PCCS condenser consists of an annular region surrounding the vent pipe. Once the combined vent/drain pipe reaches the drywell, they separate, and the 4" drain pipes from the two lower drums combine and are routed to the GDCS pool. The length of these pipe runs is small compared to the length of the vent line, and the constant liquid flow through them prevents significant concentrations of hydrogen from accumulating.

2.2.5 Post-Detonation Pressure Relief

Following a postulated detonation in the lower drum, the resulting pressurized gas mixture will relieve downward through the vent line, and also upward through the tubes (reverse flow). These relief pathways may briefly be subject to higher pressures as the lower drum equalizes pressure with its surroundings. The pressures seen by the relief pathway will not include the dynamic factors associated with the detonation. If only the CJ pressure is applied, the resulting lower drum pressure is 0.407 MPa • 19.0 = 7.73 MPa. As this gas expands through the relief volume, its pressure is assumed to drop proportionately.

The PCCS vent is [[ ]] pipe made of 304L stainless steel [[ ]]. ASME Section III, Paragraph NC-3324.3 provides a correlation to the minimum wall thickness for a given pressure. The S_m value for 304L pipe at 500°F is 14.7 ksi. Using this information, a conservative allowable pressure for this pipe can be determined as follows:

[[ ]]

The vent pipe, therefore, is capable of relieving the CJ pressure of the lower drum. No dynamic factors are applied for the purpose of pressure relief. Though the margin to the allowable is small, the actual pressure the vent pipe sees will be much less due to preferential venting through the tubes and upper drum (much greater effective flow area), which serve as an additional expansion volume that will ultimately relieve pressure back to the drywell.

2.3 INITIAL SIZING AND STRESS CALCULAITON

The design of the PCCS condenser as described in DCD Revision 6 is not considered robust enough to withstand the very conservative detonation loads postulated in the sections above. This section describes the methodology by which the design has been modified to withstand a detonation.

A seismic and hydrodynamic analysis was performed for the original configuration of the PCCS condenser (See Appendix A) and was described in Revision 6 of the DCD. This analysis has been redone to include detonation loads and the configuration changes described below (analysis is described in Appendix B):

- PCCS condenser tube material changed to SA312 TP XM-19.
- PCCS condenser tube thickness changed to [[ ]].
- Number of tubes for each module increased from 280 to [[ ]] (there are two modules in each PCCS condenser).
- PCCS drum material changed to SA182 FXM-19 (both upper and lower drums).
- Thickness of lower drum increased to [[ ]] (upper drum thickness remains[[ ]]).
- Catalyst module added to the entrance of the vent in the lower drum of the condenser.
- Ball valve is added to the vent fan branch line upstream of the fan. Check valve has been removed from the design.
- Vent line between the branch for the vent fans and the suppression pool is reduced to a nominal size of 3".

2.3.1 Design Criteria

The PCCS condenser is designed to ASME Section III, Subsection NE as a Class MC component. As such it must be designed to accommodate the loads within the acceptance criteria stated in that part of the Code. This report postulates a detonation as a Service Level D event (See Appendix B, Table B-2b), but also evaluates how the detonation loads compare to the Service Level C allowables (See Appendix B.6). For areas in which the detonation loads exceed Service Level C allowables there is an assessment of what additional modifications would be necessary in order for the detonation to be classified as a Service Level C event instead of a Level D event.

2.3.2 Deleted

2.4 EFFECT ON HEAT TRANSFER

The increase in tube thickness and change in material will increase conduction resistance through the tube wall, which will have a negative effect on the overall heat transfer coefficient of the condenser. To compensate for this effect, TRACG evaluations have determined that it is necessary to increase the number of tubes from 280 to [[ ]] per module in order to keep the containment pressure response bounded by the values described in Revision 7 of the DCD.

2.5 POSTULATED DETONATION SCENARIOS

The two detonation scenarios analyzed in Appendix B are for a detonation in one PCCS tube and in the PCCS lower drum. The evaluation considers the cumulative effect of [[ ]]

detonation cycles. Detonations are not assumed to propagate into a component where a detonation has already occurred.

2.5.1 Detonation in Tubes

The detonation wave in a tube travels into the upper and the lower drums with it quenching in upper drum due to high steam fractions and with a possibility of reflecting back into the tube once it reaches the lower drum wall. This reflection is accounted for in the peak pressure ratio of 2.5 times 19.0 used in determining the detonation pressure for the PCCS condenser.

2.5.2 Detonation in Lower Drum

A postulated detonation in the lower drum will vent through the tubes. The potential for the reflected waves at the flanges to amplify the detonation pressure are accounted for by the 2.5 factor.

2.6 DISCUSSION OF UNCERTAINTY AND CONSERVATIVE ASSUMPTIONS

The methodology described in this report relies heavily upon theory from literature and experimental data from scientific reports. Because of the complexity and uncertainty associated with predicting detonation properties, this report has made conservative assumptions as appropriate. These assumptions are summarized below.

2.6.1 Overestimation of Radiolytic Gas Concentration

In Section 2.1, it is stated that the initial gas mixture inside the PCCS is a pure stoichiometric mixture of hydrogen and oxygen with no steam presence. This is not a realistic scenario, especially for the upper drum and upper portion of the tubes in which less condensation will have taken place. By assuming a pure stoichiometric mixture, this methodology maximizes the amount of combustible gas in the condenser.

2.6.2 Overestimation of Initial Pressure

As described in Section 2.2, the initial PCCS pressure prior to a detonation is assumed to be the drywell peak pressure following the most limiting LOCA. Because of the inherent design of the PCCS the pressure in the system will always be lower than the drywell pressure, and will not reach a value as high as 407 kPa. For the majority of the accident, the drywell pressure is actually much lower than this, and slowly increases to a peak value over the course of the first 3 days. This trend is illustrated in Table 6.2-14e11 of the ESBWR DCD. The overestimation of initial pressure is a conservative assumption to address uncertainties associated with the experimentally determined peak pressure ratio of 19.0.

2.6.3 Underestimation of Initial Temperature

As described in Section 2.2, the ratio of peak pressure to initial pressure is also dependent on the initial temperature. The references cited in the section have concluded that a lower initial temperature, which allows for a denser mixture of combustible gas, results in a higher peak pressure ratio.

The ratio of 19.0 used in this report was taken from experimental data in which a stoichiometric mixture of hydrogen and oxygen was detonated at an initial temperature of 25°C. The realistic temperature inside the PCCS remains steady in the range between 90°C - 100°C. The underestimation of initial temperature is a conservative assumption to address uncertainties associated with the experimentally determined peak pressure ratio of 19.0.

2.6.4 Bounding the Effects of Tube Bend Reflections

Section 2.2 discusses the bends associated with the PCCS tubes. The literature referenced in Section 6.0 provides experimental data to account for amplification due to the presence of bends or tees. Reference 9 states that the peak pressures resulting from reflected waves in closed vessels are "approximately 2.5 times higher than the CJ pressure". Because the tubes in the PCCS condenser are bent to angles no greater than [[ ]] with bend radii of [[ ]], they are considered less susceptible to reflections than the case in Reference 9, yet the full 2.5 factor is applied for conservatism prior to the application of a dynamic load factor (which is determined in 2.2.2).

2.6.5 Critical Velocity for Bounding DLF Estimate

Following the guidance of Reference 3, the V_{c0} calculated for the PCCS condenser tubes was [[ ]]., which is considerably less than the detonation velocity 2800 m/s for the assumed stoichiometric mixture of hydrogen and oxygen in the PCCS. Although the assumption of no steam is conservative for estimating peak pressure, is not necessarily conservative for the determination of DLF. Therefore, an assumption of a diluted mixture was used to determine DLF. The lack of velocity data for mixtures rich in steam required the substitution of argon data. Argon, since it is heavier than steam, is considered a more effective diluent in terms of reducing detonation velocity. The theoretical detonation velocities for reasonably diluted mixtures (as much as 60%) show considerable margin still exists above the V_{c0} value. It is also worth noting that such a lean mixture would likely result in much lower peak pressures.

2.6.6 Elastic Range of Material

The design requirements use acceptance criteria that are within the elastic range of the materials used; therefore the material response will be elastic in the range when subjected to a detonation load.

The reported Reference 15 response of a tube with 15 mm ID and 3 mm wall thickness subjected to hydrogen/oxygen detonations with initial pressures up to 20 bar remained within the elastic range. The tube material had comparable yield and ultimate strength to that of SA-312 TP XM-19. The PCCS condenser is analyzed at much lower initial pressure of about 4 bar.

2.6.7 Deleted

3.0 CONSIDERATION FOR OTHER PCCS COMPONENTS

Section 2.0 of this report discussed the methodology for calculating detonation loads for the various portions of the PCCS. This section classifies those components and describes what pressures they are designed to withstand.

3.1 DELETED

3.2 APPLICABLE SUBSECTIONS OF ASME CODE SECTION III

The applicable subsection of ASME Code Section III for each PCCS component is given in Table 3-1.

Table 3-1: PCCS Components Applicable ASME Code III Subsection

Component	ASME Code Section III, Subsection
Steam Supply Piping (drywell)	NE
Steam Supply Piping (pool)	NE
Upper Drum	NE
Tubes	NE
Lower Drum	NE
Vent Pipe (pool)	NC
Vent Pipe (drywell)	NC
Vent Fan Ball Valve (drywell)	NC
Vent Fan Pipe[1] (drywell)	NC
Drain Pipe (pool)	NC
Drain Pipe (drywell)	NC

1) Vent fans and vent fan piping are nonsafety-related components but are conservatively designed to the criteria in Subsection NC.

3.3 PCCS COMPONENT DETONATION LOADS

The following table is a breakdown of the diameters and thicknesses of components of the PCCS components, and a description of the detonation loads assumed, or a summary of the mitigation strategy.

Table 3-2: Evaluation of Other Components of the PCCS

[[

]]

4.0 ICS METHODOLOGY

The Isolation Condenser System (ICS) contains four condensers that are of a tube-and-drum design similar to the PCCS condensers. During a LOCA, these condensers are also vulnerable to the buildup and detonation of combustible gases.

Several design changes have been implemented for the ICS to prevent the accumulation of detonable concentrations of hydrogen.

4.1 ICS OPERATION (HIGH PRESSURE)

During scenarios in which the ICS is credited with heat removal (plant transients, station blackout, etc), the condenser vent function will be modified to keep the unit continuously purged of noncondensable gas.

The ICS vent had previously been designed to open automatically only on high pressure (indicative of a buildup of noncondensable gas). By the time this high pressure is reached, the concentration of hydrogen is expected to have already reached combustible levels (this is shown to occur after approximately 10 hours of ICS operation). In order to prevent this buildup, a logic change is implemented in which the vent valves automatically open 6 hours after the ICS is initiated regardless of the system pressure. Once open, the vent will bleed steam and noncondensables from the condenser to the suppression pool, keeping the steam fraction at high levels throughout the event. The vent valves are designed to fail open on a loss of power to provide additional reliability for this function.

A flow restriction shall be included in the vent line such that the maximum flow area is 0.167 cm^2. This flow restriction is provided to minimize the amount of water inventory lost from the reactor as a result of the constant flow through the vent lines. The flow restriction had been evaluated and shown to provide sufficient flow to keep the condensers purged, and the RPV water level is shown to remain above Level 1 for 72 hours.

4.2 ICS DURING LOCA (LOW PRESSURE)

During a loss of coolant accident (LOCA), the ICS is needed to initiate in order to supply the condensate stored in its drain piping. This additional water is credited with keeping the core covered with margin during a design basis accident. The actual heat removal through the ICS condenser is relatively small and is not credited in this type of event. However, there is potential for condensation to occur, and given enough time it is possible for combustible gases to accumulate in the ICS condenser following a LOCA.

In order to prevent this buildup from occurring, a logic change has been implemented for the ICS containment isolation valves in which the valves now automatically close after receiving an indication that the depressurization valves on the reactor have opened. The sequence of events during a design basis accident show that there is adequate time between ICS initiation and DPV opening for the condensate in the ICS drain lines to transfer to the RPV.

Once isolated from the vessel, the ICS condenser pressure drops below 15 psia within 2,000 seconds. Noncondensable gas partial pressure does not exceed 0.63 following isolation. A detonation under these conditions is highly unlikely, however, if one were to occur the ICS can accommodate the load within its stated design pressure (1250 psig).

The methodology by which the PCCS CJ pressures were calculated can be applied to the ICS, although the conservative CJ multiplication factor of 19.0 is reduced to 13.3. The factor of 13.3 is justified by experimental data contained in Reference 17. Table 5.1.8 of that report contains data that is a good fit with the initial conditions in the ICS (factor of 13.3 is associated with 20% steam and 383°K, which bound the conditions within the ICS condenser).

Beginning with an ICS initial pressure of 15 psia, the final load is:

$15.0 \cdot 13.3 \cdot 2 \cdot 2.5 = 1000$ psia,

which is significantly below the ICS design pressure of 1250 psia.

4.3 APPLICABLE SUBSECTIONS OF ASME CODE SECTION III

The applicable subsection of ASME Code Section III for each ICS component is given in Table 4-1.

Table 4-1: ICS Components Applicable ASME Code III Subsection

Component	ASME Code Section III, Subsection
Steam Supply Pipe (drywell)	NB
Steam Supply Pipe up to Venturi (pool)	NB
Steam Supply Pipe from Venturi to Upper Drum (pool)	NC
Upper Drum	NC
Tubes	NC
Lower Drum	NC
Vent Pipe (pool)	NC
Vent Pipe (drywell + wetwell)	NC
Drain Pipe from Lower Drum to Tee Connection (pool)	NC
Drain Pipe from Tee Connection in Pool to Reactor Pressure Vessel	NB

5.0 PCCS AND ICS INSPECTIONS AND QUALIFICATION

This section defines the nondestructive examination (NDE) and preservice and in-service inspection requirements as they pertain specifically to the welds between the tubes and drums of the ICS and PCCS condensers. Inspection of these welds is described in detail because they are of a unique design and geometry. The other pressure retaining welds are of a more standard design and are assigned standard ASME inspection requirements.

5.1 FABRICATION INSPECTIONS

5.1.1 PCCS

Non-destructive examination for the PCCS is governed by ASME Section III, Subsection NE-5000. Paragraph NE-5200 calls for radiographic examination (RT) for all types of welded joints with the exception of socket welds (which do not apply to the PCCS). However, the requirements of NE-5280 allow for the substitution of ultrasonic (UT) and liquid penetrant (PT) testing in lieu of RT if the joint detail does not permit RT. Because of the close spacing and confined geometry of the tube-to-drum welds, this substitution of UT and PT for RT is considered appropriate.

5.1.2 ICS

Non-destructive examination for the ICS is governed by ASME Section III, Subsection NC-5000. Per NC-5220, radiographic examination is called out for circumferential welded joints; however, these requirements only apply to members that are at least 4.8 mm thick. The ICS will adhere to these rules for conservatism although the tube thickness is only [[ ]].

Like the PCCS, there is a paragraph for special substitutions for RT in which a combination of UT and PT may be used instead (Paragraph NC-5279). This substitution will be credited for the ICS condenser, as its geometry is nearly identical to the PCCS.

5.2 PRE-SERVICE / IN-SERVICE INSPECTIONS

5.2.1 PCCS

The PCCS condenser is a Class MC component that is subject to the requirements of ASME Section XI, Subsection IWE. Because the PCCS resides in a low-pressure low temperature environment, it is not subject to accelerated wear or degradation and therefore does not qualify for augmented visual inspections per the requirements of IWE-1240.

Table IWE-2500-1 defines examination requirements. Item E1.12 calls for "General Visual" inspection of the PCCS condensers. A VT-3 exam is appropriate based on the guidance of Reference 16.

5.2.2 ICS

The ICS condenser is a Class 2 component that is subject to the requirements of ASME Section XI, Subsection IWC. The guidance of paragraph IWC-1221 indicates that the ICS condenser meets the criteria for exemption from surface and volumetric exams due to the [[ ]] diameter of the ICS tubes, per IWC-1221(a)(1). Also, the requirements of IWC-1221(c) indicate that the passive nature of the condenser (statically pressurized, passive with no pumps, safety injection) also meets the exemption criteria. A General Visual inspection requirement with a VT-2 test shall be assigned to the ICS condenser tube welds.

5.3 TUBE BENDS

5.3.1 PCCS

PCCS tubes bent by cold forming shall be annealed after bending. Annealing shall be required. Annealing shall be conducted between 1065°C and 1120°C, followed by a quench to 205°C within 5 minutes. Process includes tube bends + 150 mm on each side. Interior of tubes is purged with a protective atmosphere during the process.

Tube thickness shall be verified post-bending. A qualification sample with smallest bend radius shall be sectioned to confirm wall thickness requirement is met.

The hardness of XM-19 for PCCS tubes is limited to Rockwell C 30 for the final product.

5.3.2 ICS

Induction bending of ICS tubes shall be qualified based on the bend radius and the diameter.

Tubes shall be UT examined before bending according to the requirements of NB-2551. After bending, tubes shall be PT examined according to NB-2556. Section NB requirements are applied here for conservatism.

Tube thickness shall be verified post-bending. A qualification sample with smallest bend radius shall be sectioned to confirm wall thickness requirement is met. Tests shall also be performed to qualify the tubes for tensile, yield, and elongation requirements post-bending.

5.4 WELD AND WELD FILLER MATERIAL

Appropriate weld filler metal for XM-19 shall be 308L. Appropriate weld filler metal for Nb-modified Alloy 600 shall be Nb-modified Alloy 82.

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18. Kelm, Jahn, and Reinecke, "Operational Behavior of Catalytic Recombiners – Experimental Results and Modeling Approaches", Institute for Energy Research, Safety Research and Reactor Terminology (IEF-6), Jülich, Germany

19. "Qualification of Passive Autocatalytic Recombiners for Combustible Gas Control in ALWR Containments," Prepared by the Electric Power Research Institute (EPRI) ALWR Program, April 8, 1993.

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APPENDIX A - SUPERSEDED PCCS STRUCTURAL ANALYSIS

A.1 Description of Model

This Appendix archives the previous configuration of the PCCS that has since been superseded by Appendix B.

A finite element analysis model (FEM) using the approved ANSYS computer code was performed on the PCCS condenser with a supplemental hand calculation. Approved versions of ANSYS are given in ESBWR DCD Tier 2, Table 3D.1-1.

- The FEM models the current geometry of the PCCS condenser and supports described in Figures A-1a, A-1b, and A-2, including all components between the steam inlet passages through the RCCV Top Slab and the condensate drain/vent passages through the RCCV Top Slab.
- The following components of the PCCS condenser were modeled with [[ ]] ANSYS elements:

[[

]]

- The tubes of the PCCS condenser were modeled with [[ ]] ANSYS elements with the following properties:

[[

]]

- The [[ ]] of the dynamic steel frame were modeled with [[ ]] ANSYS elements with the following properties:

  [[

  ]]

A.2 Load Definitions

Consideration of the following loads has been taken into account for the PCCS condenser:

- D (+B) Dead Weight (+ Buoyancy)
- P_t Test Pressure
- P_a Design accident pressure generated by a LOCA
- T_t Thermal effects during tests
- T_a Thermal effects generated by a LOCA
- SSE Safe Shutdown Earthquake
- SRVD Safety Relief Valve Discharge
- LOCA Loss of Coolant Accident

A.3 Load Combinations

Enveloping Load Combinations are described in Table A-1.

Table A-1: PCCS Load Combinations

Service Level (elastic analysis)	Load Combination
Test Condition	$D + P_t + T_t$
Design Condition	$D + P_a + T_a$
Levels A, B	$D + P_a + T_a$ + SRV + LOCA
Levels C, D	$D + P_a + T_a$ + SSE + SRV + LOCA

A.4 Finite Element Model Inputs

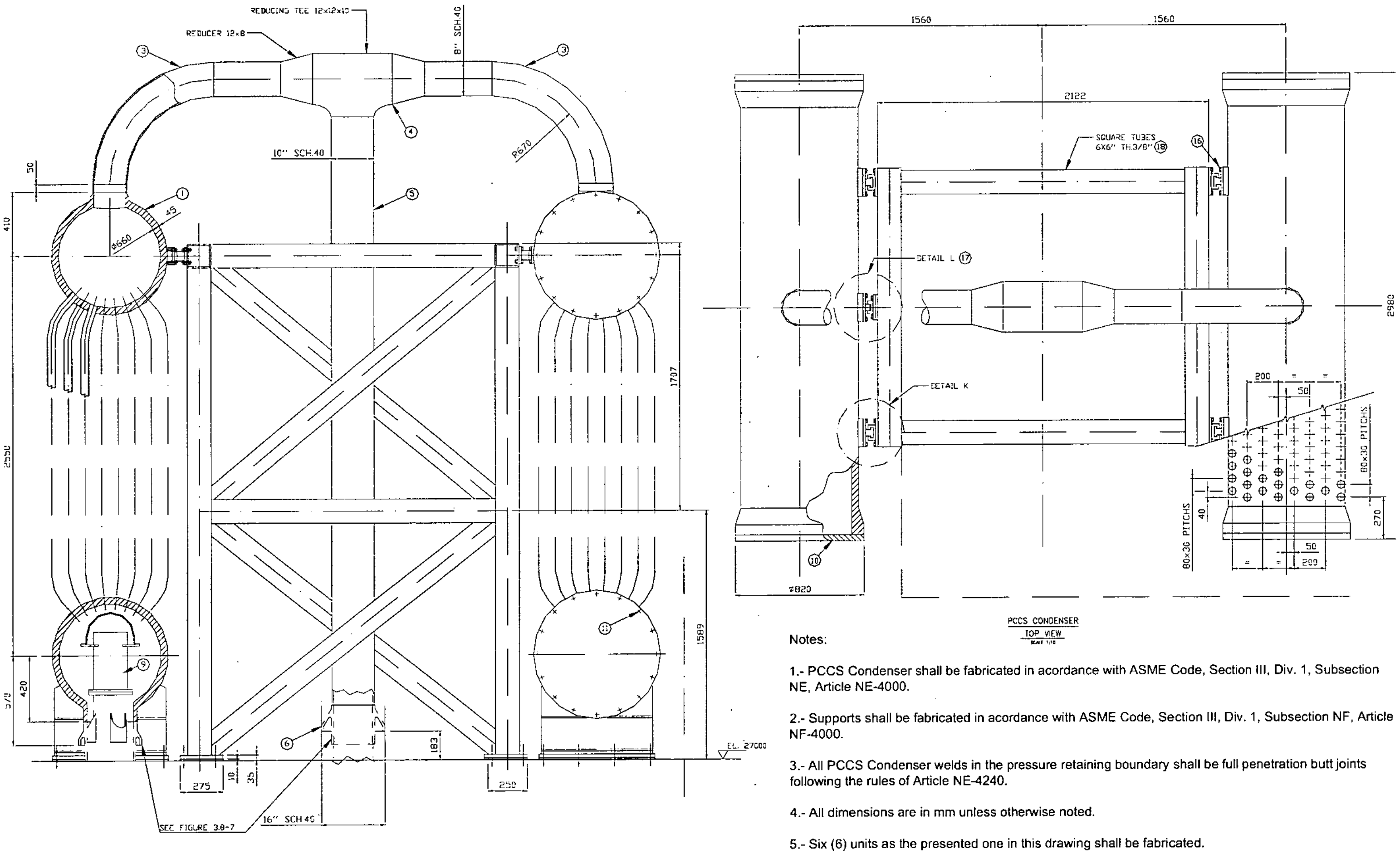
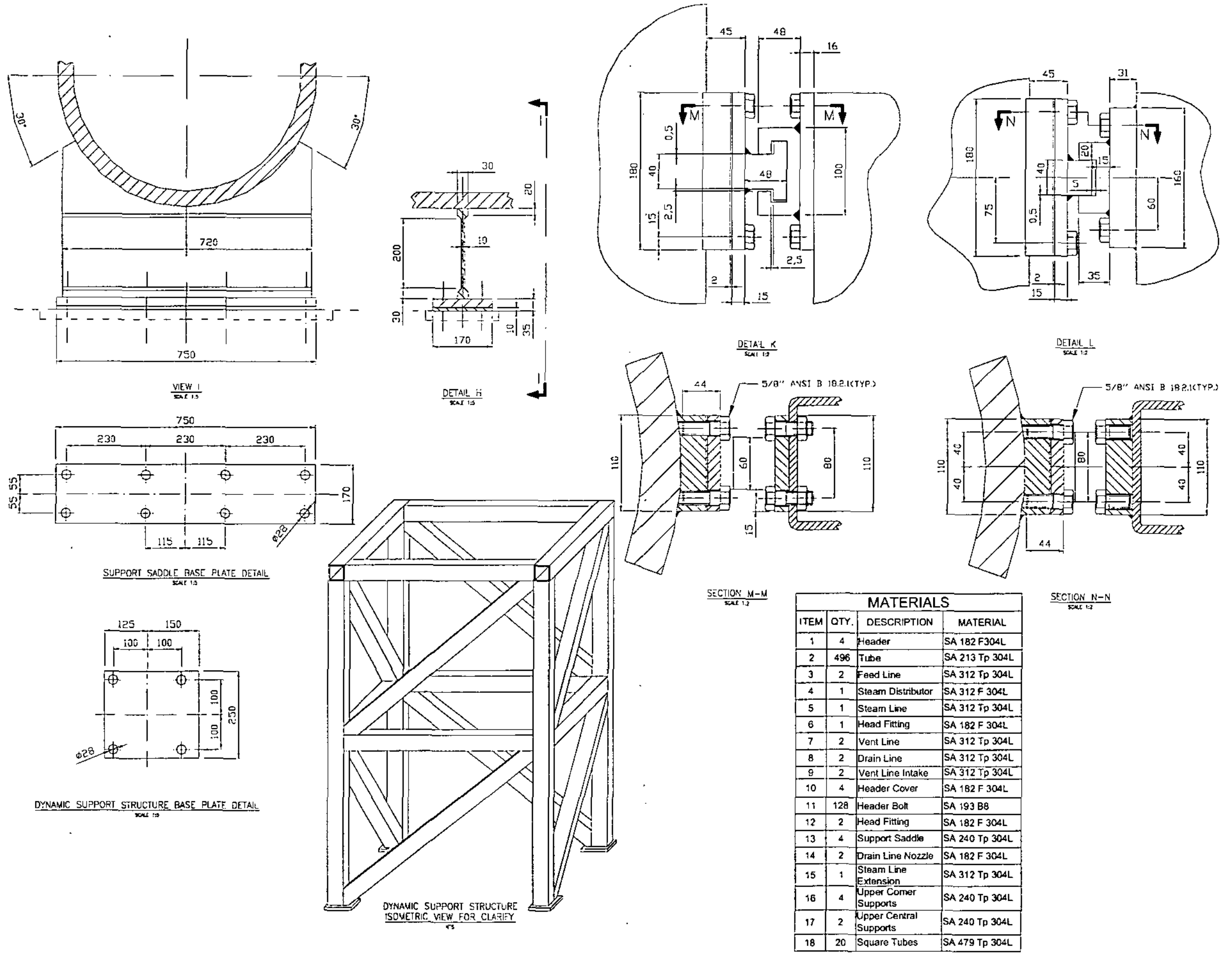


Figure A-1a: PCCS Condenser and Supports



MATERIALS			
ITEM	QTY.	DESCRIPTION	MATERIAL
1	4	Header	SA 182 F304L
2	496	Tube	SA 213 Tp 304L
3	2	Feed Line	SA 312 Tp 304L
4	1	Steam Distributor	SA 312 F 304L
5	1	Steam Line	SA 312 Tp 304L
6	1	Head Fitting	SA 182 F 304L
7	2	Vent Line	SA 312 Tp 304L
8	2	Drain Line	SA 312 Tp 304L
9	2	Vent Line Intake	SA 312 Tp 304L
10	4	Header Cover	SA 182 F 304L
11	128	Header Bolt	SA 193 B8
12	2	Head Fitting	SA 182 F 304L
13	4	Support Saddle	SA 240 Tp 304L
14	2	Drain Line Nozzle	SA 182 F 304L
15	1	Steam Line Extension	SA 312 Tp 304L
16	4	Upper Corner Supports	SA 240 Tp 304L
17	2	Upper Central Supports	SA 240 Tp 304L
18	20	Square Tubes	SA 479 Tp 304L

Figure A-1b: PCCS Condenser and Supports Details

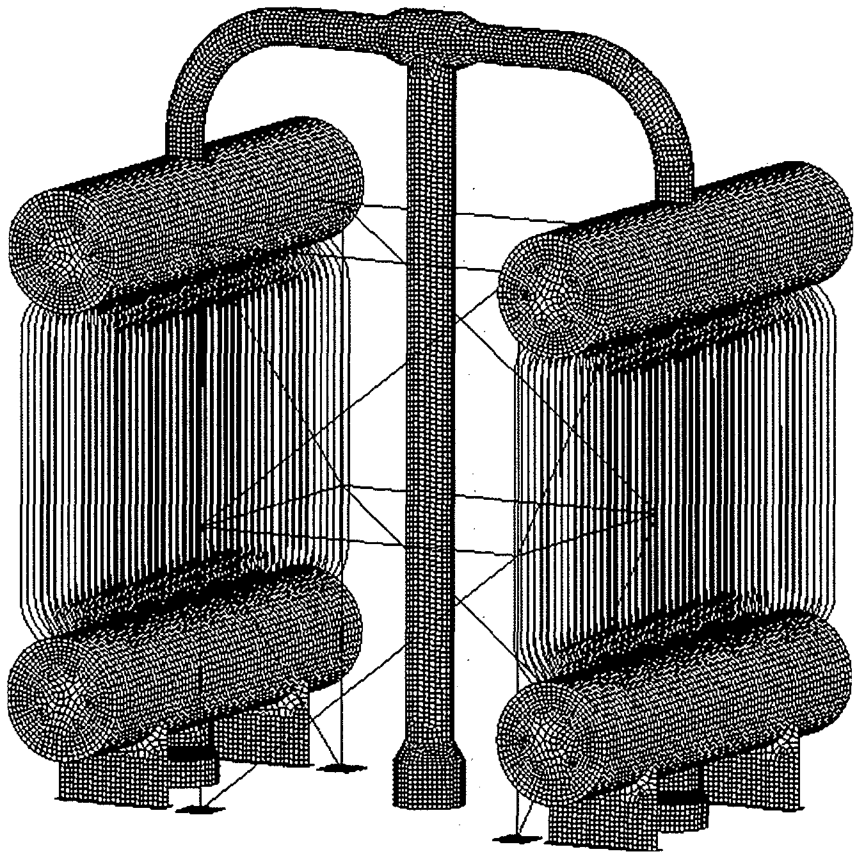


Figure A-2: FEM of PCCS Condenser and Supports

A.5 Stress Results and Margin to Allowable

Table A-2: Stress Summary of the PCCS Condenser and Supports

Component	Stress Category	Test			Design			Service Level A/B			Service Level C/D		
		Calculated Stress (MPa)	Allowable Stress (MPa)	Stress Margin (%)	Calculated Stress (MPa)	Allowable Stress (MPa)	Stress Margin (%)	Calculated Stress (MPa)	Allowable Stress(1) (MPa)	Stress Margin (%)	Calculated Stress (MPa)	Allowable Stress(2) (MPa)	Stress Margin (%)
Upper Header	P_m	11.8	119.8	90	11.8	114.9	90	16.8	114.9	85	37.8	137.9	73
	$P_L + P_b$	11.8	183.7	94	11.8	150.6	92	16.8	150.6	89	39.8	180.7	78
Lower Header	P_m	11.8	119.8	90	11.8	114.9	90	24.8	114.9	78	47.8	137.9	65
	$P_L + P_b$	11.8	183.7	94	11.8	150.6	92	26.8	150.6	82	55.8	180.7	69
Tubes	P_m	11.4	119.8	91	11.4	114.9	90	15.4	114.9	87	19.4	137.9	86
	$P_L + P_b$	11.4	183.7	94	11.4	150.6	92	33.4	150.6	78	66.4	180.7	63
Feed Line	P_m	9.9	119.8	92	9.9	114.9	91	23.9	114.9	79	79.9	137.9	42
	$P_L + P_b$	9.9	183.7	95	9.9	150.6	93	29.9	150.6	80	110.9	180.7	39
Steam line	P_m	10.9	119.8	91	10.9	114.9	91	25.9	114.9	77	80.9	137.9	41
	$P_L + P_b$	10.9	183.7	94	10.9	150.6	93	31.9	150.6	79	112.9	180.7	38
Steam Distributor	P_m	12.6	119.8	89	12.6	114.9	89	24.6	114.9	79	67.6	137.9	51
	$P_L + P_b$	12.6	183.7	93	12.6	150.6	92	26.6	150.6	82	73.6	180.7	59
Condensate Lines	P_m	12.6	119.8	89	12.6	114.9	89	31.6	114.9	73	66.6	137.9	52
	$P_L + P_b$	12.6	183.7	93	12.6	150.6	92	37.6	150.6	75	80.6	180.7	55
Header Cover	P_m	87.0	119.8	27	87.0	114.9	24	89.0	114.9	23	92.0	114.9	20
	$P_L + P_b$	87.0	183.7	53	87.0	150.6	42	89.0	150.6	41	92.0	180.7	49
Header Bolt	Average Stress	70.3	144.7	51	70.3	110.1	36	70.3	220.2	68	70.3	220.2	68
Support Saddle	P_m							29.0	112.6	74	87.0	168.9	48
	$P_L + P_b$							30.0	168.9	82	88.0	253.4	65
	Shear							9.0	67.6	87	26.0	101.3	74
Truss Support Structure	Tension	Negligible						14.0	76.6	82	69.0	114.9	40
	Shear							3.0	51.1	94	12.0	76.6	84
	Compression							14.0	47.9	71	69.0	71.9	4
	Bending							14.0	84.3	83	70.0	126.4	45

1) Allowable stress values correspond to Level A

2) Allowable stress values correspond to Level C

APPENDIX B - PCCS STRUCTURAL ANALYSIS WITH DETONATION LOADING

B.1 Description of Model

This Appendix summarizes the evaluation of the PCCS for detonation loads based on the revised configuration described in this report. The inputs to the modified analysis are as follows:

B.1.1 Tube Analysis Model

A 3-D finite element model (FEM) for the analysis of one tube under hydrogen detonation load is built with ANSYS 10.0. A description of the FEM follows:

- The FEM physically represents the current geometry of [[ ]] tubes and the portion of the headers that join to the tubes.
- The entire model is built with [[ ]] ANSYS elements. The mesh of the tube where the detonation pressure is applied is very refined to get accurate results.
- The detonation load of 19.333 MPa multiplied by the DLF of 2, i.e. 38.7 MPa is applied as internal pressure in one tube and along the tube length, including the hole in the headers.
- Displacement restrictions are applied at the different cut section of the headers as boundary conditions. Boundary conditions far of the analyzed tube, no impact in the results obtained
- Several analysis cases have been executed changing the tube where the detonation occurs, and the maximum resultant stress is not significantly affected.

B.1.2 Lower Header Analysis Model

A 3-D finite element model (FEM) for the analysis of the lower header under hydrogen detonation load is built with ANSYS 10.0. The portion having the condensate nozzle has been selected as the most critical header area. A description of the FEM follows:

- The FEM physically represents the current geometry of a cylindrical section of the lower header, containing the condensate nozzle and the holes corresponding to an [[ ]] array of the tube bank.
- The entire model is built with [[ ]] ANSYS elements.
- The detonation load of 19.333 MPa multiplied by the DLF of 2, i.e. 38.7 MPa is applied as internal pressure on the inner face of the header, including the nozzle opening and the

holes for the tubes. Displacement restrictions or equivalent edge pressures are applied at the different cut sections to account for the edge effects.

B.1.3 PCCS Condenser Analysis Model

A 3-D finite element model (FEM) for the analysis of the PCCS Condenser and support is built with ANSYS 10.0. A description of the FEM follows:

- The FEM physically represents the revised geometry of the PCCS Condenser and support, including all components between the steam inlet passage through the RCCV Top Slab and the condensate drain/vent passages through the RCCV Top Slab.
- The following components of the PCCS Condenser are modeled with SHELL 63 ANSYS elements: upper headers [[ ]], lower headers [[ ]], upper header covers [[ ]], lower header covers [[ ]], steam line [[ ]], feed lines [[ ]], steam distributor [[ ]], steam line sleeve [[ ]], steam line head fitting [[ ]], condensate line [[ ]], condensate line sleeve [[ ]], condensate line head fitting [[ ]], support saddle [[ ]], support saddle base plates [[ ]], and steel frame support structure base plates [[ ]].
- [[
-

]]

- RCCV top slab passages are not represented in detail since they are outside the scope. The vent lines, which run inside condensate lines, are not included in the model, since they do not have any structural influence in the PCCS Condenser behavior.
- The internal and external water masses are introduced in the model by increasing the material density. All components of the PCCS Condenser are cylindrical form. All members of the steel frame support structure are square tubes.
- Displacement restrictions are applied as boundary conditions at the bolt point locations of the base plates and at the lower section of the line passages through the RCCV Top Slab.
- In the node corresponding to the upper support location, the appropriate directional coupling is applied between the upper headers and the steel frame support structure.
- The coordinate system adopted in the FEM is the right hand Cartesian coordinate system. Direction X of the FEM follows the Y-direction (E-W) of the plant, direction Y of the FEM follows the X-direction (N-S) of the plant, and direction Z of the FEM coincides with Z-direction (vertical).

B.2 Load Definitions

Consideration of the following loads has been taken into account for the PCCS condenser:

- D (+B) Deadweight (+ Buoyancy)
- P_t Test pressure
- P_a Design accident pressure generated by a LOCA
- T_t Thermal effects during tests
- T_a Thermal effects generated by a LOCA
- SSE Safe Shutdown Earthquake

- SRVD Safety Relief Valve Discharge
- LOCA Loss of Coolant Accident
- DET Detonation pressure load

B.3 Load Combinations

Enveloping Load Combinations are described in Table B-1.

Table B-1: Modified PCCS Load Combinations

Service Level (elastic analysis)	Load Combination
Test Condition	$D + P_t + T_t$
Design Condition	$D + P_a + T_a$
Levels A, B	$D + P_a + T_a$ + SRV + LOCA
Level C	$D + P_a + T_a$ + SSE + SRV + LOCA
Level D	$D + P_a + T_a$ + SSE + SRV + LOCA D + DET + T_a + SSE

B.4 Finite Element Model Inputs

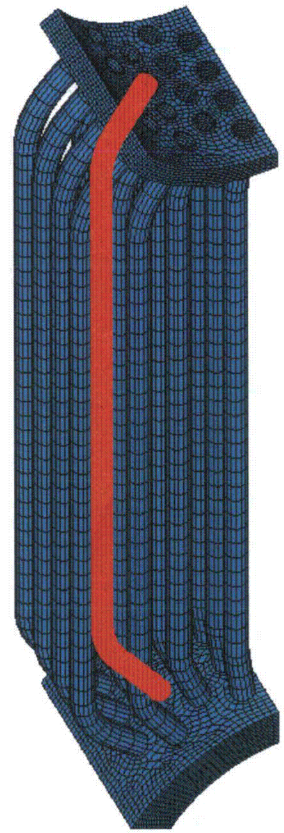


Figure B-1a: Tube FEM of and Pressure Load

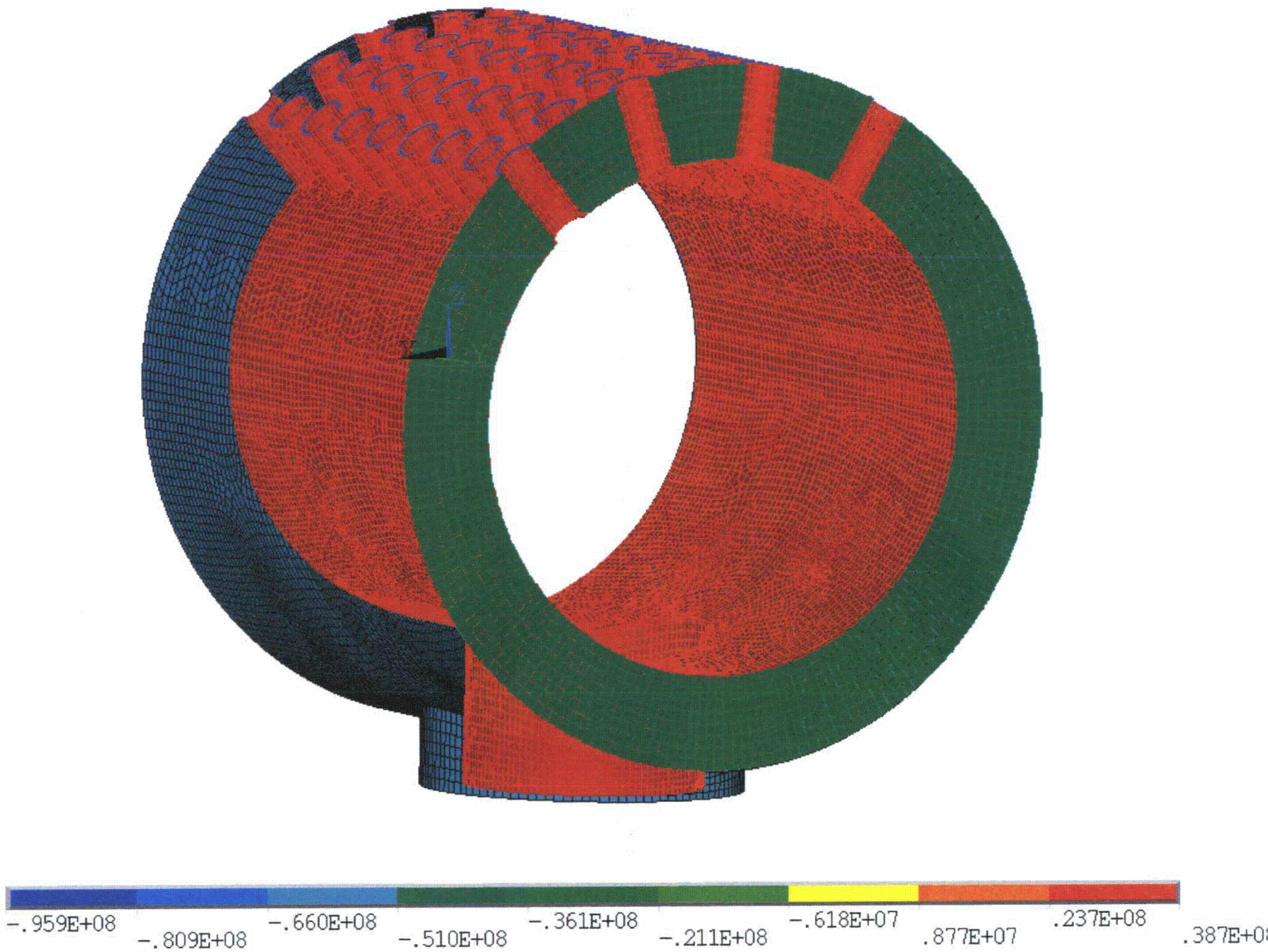


Figure B-1b: Lower Header FEM and Pressure Load

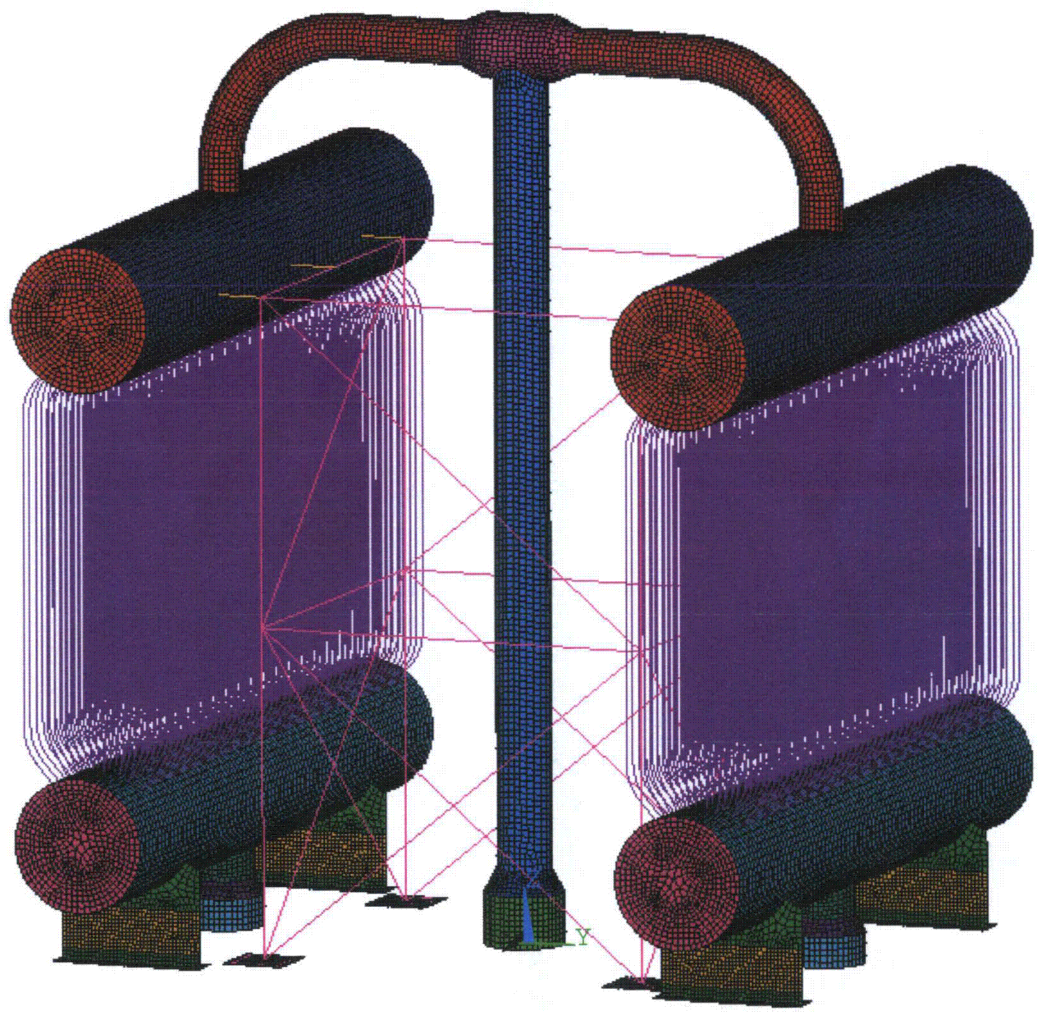


Figure B-1c: PCCS Condenser FEM

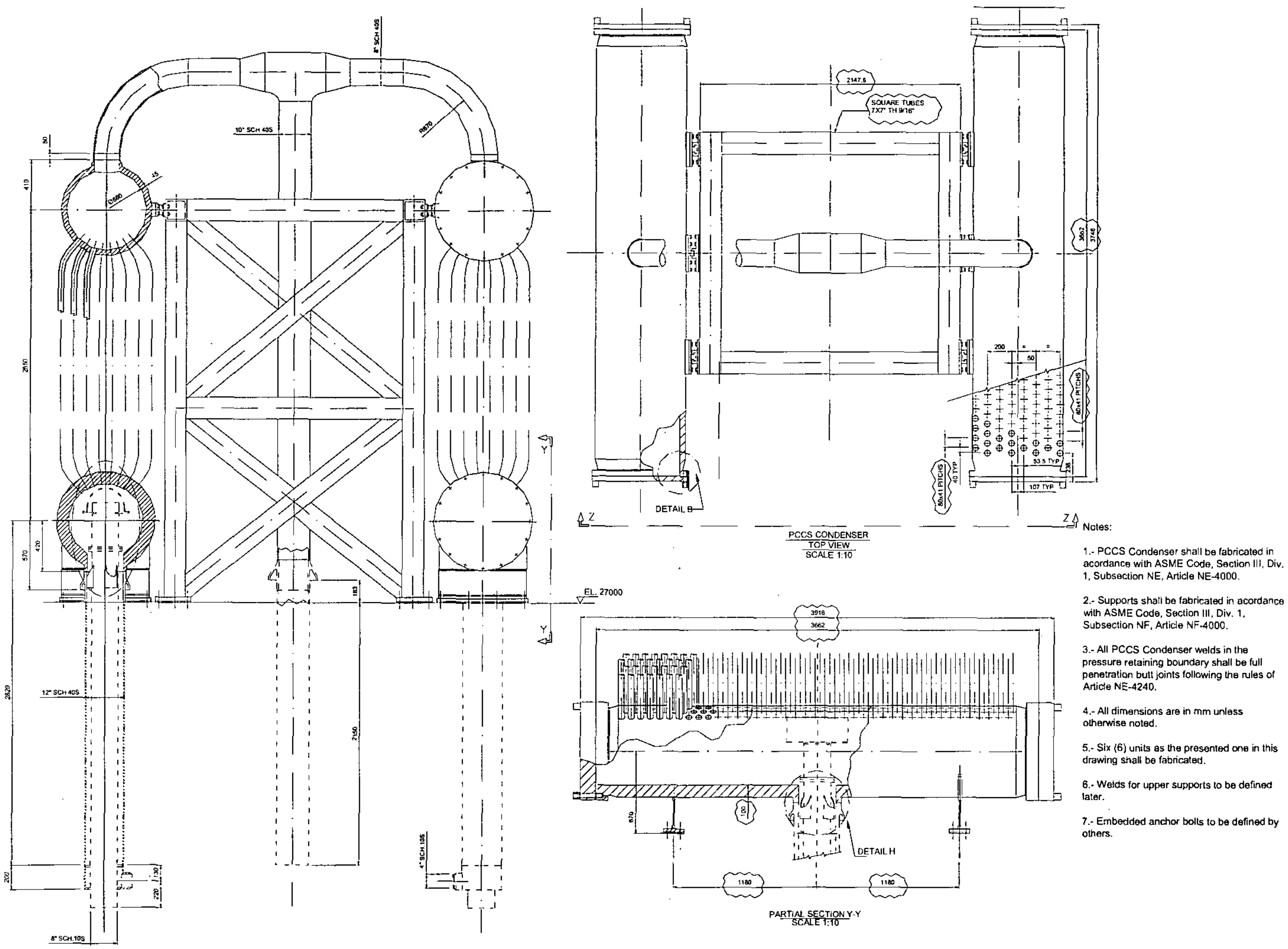


Figure B-2a: PCCS Condenser and Supports Details

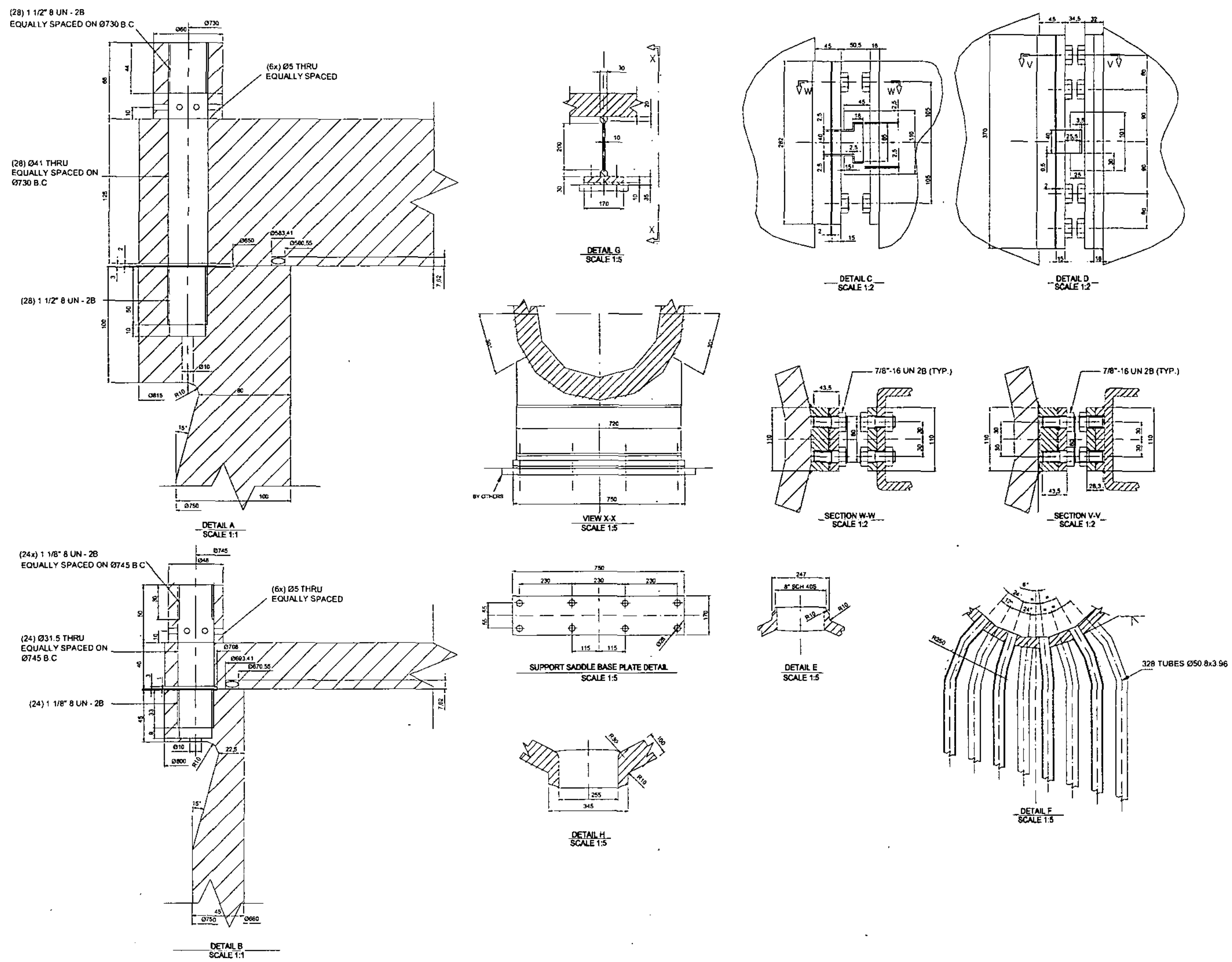


Figure B-2b: FEM of PCCS Condenser and Supports

B.5 Stress Results and Margin to Allowable

Table B-2a: Stress Summary of the PCCS Condenser and Supports

Component	Stress Category	Test			Design			Service Level A/B		
		Calculated Stress (MPa)	Allowable Stress (MPa)	Stress Margin (%)	Calculated Stress (MPa)	Allowable Stress (MPa)	Stress Margin (%)	Calculated Stress (MPa)	Allowable Stress (MPa)	Stress Margin (%)
Upper Header	P_m	11.1	119.8	90.7	11.1	114.9	90.3	13.6	114.9	88.2
	$P_L + P_b$	11.1	183.7	94.0	11.1	150.6	92.6	14.3	150.6	90.5
Lower Header	P_m	4.4	262.9	98.3	4.4	201.3	97.8	5.6	201.3	97.2
	$P_L + P_b$	4.4	403.1	98.9	4.4	263.7	98.3	5.8	263.7	97.8
Tubes	P_m	4.6	262.9	98.3	4.6	201.3	97.7	4.9	201.3	97.6
	$P_L + P_b$	4.6	403.1	98.9	4.6	263.7	98.3	7.3	263.7	97.2
Feed Line	P_m	9.9	119.8	91.7	9.9	114.9	91.4	15.3	114.9	86.7
	$P_L + P_b$	9.9	183.7	94.6	9.9	150.6	93.4	17.6	150.6	88.3
Steam line	P_m	10.9	119.8	90.9	10.9	114.9	90.5	13.2	114.9	88.5
	$P_L + P_b$	10.9	183.7	94.1	10.9	150.6	92.8	13.6	150.6	91.0
Steam Distributor	P_m	12.6	119.8	89.5	12.6	114.9	89.0	15.0	114.9	86.9
	$P_L + P_b$	12.6	183.7	93.1	12.6	150.6	91.6	15.8	150.6	89.5
Condensate Lines	P_m	12.6	119.8	89.5	12.6	114.9	89.0	16.4	114.9	85.7
	$P_L + P_b$	12.6	183.7	93.1	12.6	150.6	91.6	17.7	150.6	88.2
Upper Header Cover	P_m	55.3	119.8	53.8	55.3	114.9	51.9	55.5	114.9	51.7
	$P_L + P_b$	55.3	183.7	69.9	55.3	150.6	63.3	55.5	150.6	63.1
Lower Header Cover	P_m	5.6	262.9	97.9	5.6	201.3	97.2	5.7	201.3	97.2
	$P_L + P_b$	5.6	403.1	98.6	5.6	263.7	97.9	5.7	263.7	97.8
Upper Header Bolt	Average Stress	25.7	144.7	82.2	25.7	110.1	76.7	25.7	220.2	88.3
Lower Header Bolt	Average Stress	8.3	570.7	98.5	8.3	212.3	96.1	8.3	424.6	98.0
Support Saddle	P_m							6.4	112.6	94.3
	$P_L + P_b$							6.4	168.9	96.2
	Shear							1.1	67.6	98.4
Steel Frame Support Structure	Tension	Negligible						2.8	76.6	96.3
	Shear							0.5	51.1	99.0
	Compression							2.8	47.9	94.2
	Bending							3.8	84.3	95.5

Table B-2b: Stress Summary of the PCCS condenser and Supports

Component	Stress Category	Service Level C/D			Service Level D		
		Calculated Stress (MPa)	Allowable Stress (MPa)	Stress Margin (%)	Calculated Stress (MPa)	Allowable Stress (MPa)	Stress Margin (%)
Upper Header	P_m	50.5	137.9	63.4	39.3	229.7	82.9
	$P_L + P_b$	61.0	180.7	66.2	49.8	300.9	83.4
Lower Header	P_m	17.3	291.4	94.1	309.9	381.3	18.7
	$P_L + P_b$	18.0	381.7	95.3	491.5	550.2	10.7
Tubes	P_m	7.6	291.4	97.4	275.0	381.3	27.9
	$P_L + P_b$	41.1	381.7	89.2	308.2	499.5	38.3
Feed Line	P_m	94.1	137.9	31.8	84.0	229.7	63.4
	$P_L + P_b$	130.9	180.7	27.6	121.0	300.9	59.8
Steam line	P_m	42.1	137.9	69.5	31.1	229.7	86.5
	$P_L + P_b$	47.7	180.7	73.6	36.7	300.9	87.8
Steam Distributor	P_m	44.2	137.9	67.9	31.6	229.7	86.2
	$P_L + P_b$	61.5	180.7	66.0	48.8	300.9	83.8
Condensate Lines	P_m	56.0	137.9	59.4	43.3	229.7	81.1
	$P_L + P_b$	67.6	180.7	62.6	54.8	300.9	81.8
Upper Header Cover	P_m	58.0	114.9	49.5	2.7	137.9	98.0
	$P_L + P_b$	58.3	180.7	67.7	3.0	300.9	99.0
Lower Header Cover	P_m	6.2	201.3	96.9	288.1	291.4	1.1
	$P_L + P_b$	6.3	381.7	98.3	288.2	499.5	42.3
Upper Header Bolt	Average Stress	25.7	220.2	88.3	0.1	220.2	100.0
Lower Header Bolt	Average Stress	8.3	424.6	98.0	423.0	424.6	0.4
Support Saddle	P_m	74.2	168.9	56.1	74.0	168.9	56.2
	$P_L + P_b$	75.0	253.4	70.4	74.8	253.4	70.5
	Shear	15.2	101.3	85.0	15.1	174.3	91.3
Steel Frame Support Structure	Tension	42.4	131.0	67.6	42.3	174.7	75.8
	Shear	7.4	87.3	91.5	7.3	104.8	93.0
	Compression	42.4	83.6	49.3	42.3	83.6	49.4
	Bending	60.2	144.1	58.2	60.1	189.2	68.2

B.6 Consideration for Service Level C

The results tabulated in Tables B-2a and B-2b indicate that the PCCS condenser seismic and hydrodynamic loads fall within the allowables, and the detonation load meets the allowables for a Service Level D event.

The detonation loads for the condenser satisfy the Service Level C allowables for all components except the lower header and the lower header cover. The lower header primary membrane stress exceeds Level C by 6.3%, and the local plus bending stresses exceed Level C by 28.8%, and the maximum stress is located at the connection between the inner blend radius of the drain line and the lower drum. The lower header cover primary membrane stress exceeds the Service Level C allowable by 43.1%.

The following are possible strategies to reduce the stresses on these components during a detonation:

- increasing the inner blend radius at the lower header drain pipe connection in conjunction with adding reinforcing material to the outside surface of the drum at the pipe penetration. Additionally, the lower header cover can be redesigned to a torospherical shape to more efficiently reduce the stresses with only minor changes in mass.
- reducing some of the conservative margin (with appropriate justification), for example, by crediting initial temperatures on the order of 110°C instead of 25°C (see Section 2.2.1.2).
- reducing the conservative load combination described in Table B-1, with the understanding that T_a is a secondary stress outside the scope of Service Levels C and D per the requirements of Figure NE-3221-3, or
- a combination of the above

This report has demonstrated that increasing the thickness of certain components is an effective way to increase the amount of internal pressure the component can withstand. Reference 17 considers the effect of changing initial temperature on the CJ pressure ratio. Table 5.1.8 of that report indicates that a pure stoichiometric mixture of hydrogen and oxygen has a characteristic CJ Pressure ratio of 14.5 (as opposed to 19.0). Using this strategy, the PCCS condenser detonation loads can be brought into conformance with the requirements of a Service Level C event. Since the changes described above are readily achievable, these modifications to the PCCS will be made during the detailed design phase and compliance with the ASME acceptance criteria (including the Service Level C criteria) will be demonstrated in the closure of ITAAC item 2a1 in Table 2.15.4-2 of DCD Tier 1.

Enclosure 6

MFN 10-044 Supplement 1

Response to NRC Request for Additional Information Letter No. 411 Related to ESBWR Design Certification Application

Engineered Safety Features

RAI Number 6.2-202 S01

Affidavit

GE-Hitachi Nuclear Energy Americas LLC

AFFIDAVIT

I, **Mark J. Colby,** state as follows:

(1) I am the New Plants Engineering Manager, ESBWR, GE Hitachi Nuclear Energy ("GEH"), and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in enclosures 1 and 4 of GEH's letter, MFN 10-044 Supplement 1, Mr. Richard E. Kingston to U.S. Nuclear Energy Commission, entitled "*Response to NRC Request for Additional Information Letter No. 411 – Related to ESBWR Design Certification Application – Engineered Safety Features – RAI Number 6.2-202 Supplement 1,*" dated May 22, 2010. The proprietary information in enclosure 1, which is entitled "*MFN 10-044 Supplement 1 – Response to NRC Request for Additional Information Letter No. 411 – Related to ESBWR Design Certification Application – Engineered Safety Features – RAI Number 6.2-202 S01 – GEH Proprietary Information,*" and enclosure 4, which is entitled "*MFN 10-044 Supplement 1 – Response to Portion of NRC Request for Additional Information Letter No. 411 – Related to ESBWR Design Certification Application – Engineered Safety Features – RAI Number 6.2-202 S01 – NEDE-33572 Revision 1, "ESBWR ICS and PCCS Condenser Structural Evaluation," May 2010, GEH Proprietary Information,*" is indicated as the content contained between opening double brackets ([[) and closing double brackets (]]), and underlined. [[This sentence is an example {3}]]. Figures and large equation objects are identified with double square brackets before and after the object. In each case, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner or licensee, GEH relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by GEH's competitors without license from GEH constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future GEH customer-funded development plans and programs, resulting in potential products to GEH;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b. above.

(5) To address 10 CFR 2.390(b)(4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GEH, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GEH, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge, or subject to the terms under which it was licensed to GEH. Access to such documents within GEH is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist, or other equivalent authority for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GEH are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2) is classified as proprietary because it contains details of GEH's design and licensing methodology. The development of the methods used in these analyses, along with the testing, development and approval of the supporting methodology was achieved at a significant cost to GEH.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GEH's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GEH's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GEH.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GEH's competitive advantage will be lost if its competitors are able to use the results of the GEH experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GEH would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GEH of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing and obtaining these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 22nd day of May 2010.

Mark J. Colby

Mark J. Colby
GE-Hitachi Nuclear Energy Americas LLC