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October 29, 1992

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: McGuire Nuclear Station
Docket Nos: 50-369 and 370

Dear Sir:

On September 23, 1992, representatives from Duke Power Company and Westinghouse Electric Corporation met with the NRC Staff at the NRC's office in Rockville, Maryland. The purpose of the meeting was to present the results of the inspections and analyses that had been performed on the McGuire Units 1 and 2 steam generators. As a follow up to this meeting and subsequent conference calls, additional evaluations and analyses were performed in order to characterize the probability of occurrence of large differential pressure events and the likelihood of a tube burst concurrent with such events. A discussion of these evaluations and analyses are provided in the attached pages.

It is concluded from the information presented herein and on September 23, 1992, that operation of McGuire Units 1 and 2 until the end of their respective fuel cycles does not present an undue risk to the health and safety of the public.

Very truly yours,

foR

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End of Cycle Steam Generator Tube Integrity McGuire Units

1 Introduction

Information is provided herein for the support of the continued operation of McGuire Units 1 & 2 through the end of their respective fuel cycles, representing periods of operation of 8.5 and 12 months respectively. An integrity analysis of the tubes was performed based on expected conservative assumptions relative to the configuration of cracks which may be postulated to exist in a very limited number of tubes in the steam generators (SG). A probabilistic analysis was also performed.

2 Background

Results of tube integrity evaluations were presented to the NRC in a meeting held on September 23, 1992, in Rockville, Maryland. The information presented supported the operation of Units 1 & 2 until the end of their respective fuel cycles. This was based on 100% detection of free-span cracking at a 50% penetration level, a 2.5% per month growth rate, and an allowable depth of 81% based on the limits of RG 1.121 (draft).

Subsequent discussions with the NRC were held via telephone on October 9, and October 15, 1992. Of specific interest was the probability of occurrence of large differential pressure (ΔP) events, and the associated likelihood of a tube burst concurrent with such events. The second discussion was held to appraise the NRC of the results of performing additional analyses. Information was provided on the results of probability and risk assessment (PRA) analyses for the McGuire Units, see Attachment 1, and the results of statistical simulations (Monte Carlo) of the integrity of the steam generator (SG) tubes. The Monte Carlo analyses were based on statistically sampling the crack depths, crack growth rates, end of cycle (EOC) crack morphologies, tube material properties, and the results of burst testing.

The purpose of this document is to provide a summary review of the information presented and the analyses performed.

3 Deterministic Analysis of EOC Tube Integrity

The deterministic analysis of tube integrity was based on postulating the existence of cracks in the SG tubes at a detection threshold depth. The detection threshold is that depth for which a very high level of confidence exists that such cracks would be detected by eddy current examination (ECT). This was followed by establishing a conservative value for crack growth rate into the wall of the tube, projecting that growth to the end of the fuel cycle, and then determining the burst pressure.

3.1 Detection Threshold

Information was presented based on the non-destructive and destructive examination of eleven tubes which had been removed from the SG's of the two McGuire Units. The results demonstrated that 100% of cracks were detected when the depth was 50% or greater. For cracks in the range of 40% to 49% deep the detection rate was 42%, and for cracks in the range of 26% to 39% deep the detection range was 27%.

3.2 Crack Growth Rate

For the determination of growth rate the available data were segregated into three categories consisting of Units 1 & 2 known grooved and cracked tubes, Units 1 & 2 known cracked tubes, and Units 1 & 2 cracked tubes based on the ECT evaluations that had been performed. For most of the cracked tubes very little information was available in terms of previous ECT magnitudes upon which to base previous depths. Information was available from expert ECT analyst review of previous outage data to determine when a crack's initial presence was indicated by the data. For the cracks found in the pulled tubes a scheme for estimating crack depth at a previous cycle was adopted based on the final depth of the indication. Specifically, if the indication had a final depth of less than 50% it was assumed to be of zero depth at the beginning of the cycle prior to its' initial presence being apparent. If the final depth was greater than 50% it was assumed to be at one-half of its' final depth at the beginning of the previous cycle. For the one month of operation of Unit 1 in December, 1991 and January, 1992 growth rates were not calculated. Over such a short time period such calculations would be subject to significant error since the length of time in the denominator of the rate determination would be so small. This short time period was considered, however, as an end point from the beginning of a previous cycle.

The average growth rate from the **confirmed grooved and cracked** tubes was found to be in the range of 2.3%/mo to 2.5%/mo with a standard deviation (SD) of 0.5%/mo. The maximum value was 3.1%/mo for one cycle of operation. For **all confirmed cracks** the average growth rate was found to be from 2.3%/mo to 2.4%/mo with a SD of 0.7%/mo. Inclusion of the ECT results with the confirmed cracks data base resulted in a mean of 2%/mo with a SD of about 1.6%/mo. For the deterministic analysis it was decided to use the largest average crack growth rate since lower bound material properties would be used in determining the burst pressure.

A comparison of the value selected for the growth rate with available published data, extrapolated to the cold leg operating temperature, was made to verify that the rate was not in disagreement with test data. The selected value was found to lie in the middle of the extrapolated band.

3.3 End of Cycle Crack Morphology

Initial analysis concentrated on a single crack morphology, i.e., that present in section 5 of the tube removed from R18C5 of SG A of McGuire Unit 2. The selection was based on the fact that this was the largest crack that had not been called during the ECT of the tubes prior to removal of the tube for destructive examination. The crack was found to have a maximum depth of 73%, an average depth of 54%, and was 1.1" long. A series of tests were performed to determine the burst pressure of the crack profile as a function of depth. For a tube with the lower bound material properties it was found that the maximum depth of the crack could be 81.5% and still retain a factor of safety of three relative to burst during normal operation and a factor of 1.4 relative to postulated accident conditions. It was also found that the maximum depth that would result in a burst pressure equal to a postulated SLB differential pressure (2560 psi was used for conservatism) was 89.7%.

A second series of tests was subsequently performed using the morphology of the crack found in section 10 of the same tube. This crack had a maximum depth of 100% and was found to be 1.4" long. The purpose of the second testing program was to determine the sensitivity of the results of the evaluation to the length of the crack. For the R18C5-10 crack morphology the burst depth values for normal operation and SLB were found to be 79.8% and 89.2% respectively.

3.4 Lower Bound of Material Properties

Burst pressure determinations are usually performed considering a 95%/95% lower tolerance limit on the flow stress (one-half of the sum of the yield stress and the ultimate stress) for a general population of tubes encompassing the heats of tubing used in the SG's for several plants. However, information relative to heats used in the fabrication of the McGuire Units' SG's was available. Using this information, a 98.6% lower bound for the flow stress of the tubes in the McGuire Units was selected for the burst pressure evaluations. The value was adjusted to a cold leg operating temperature value of 140.3 ksi based on the results of an extensive testing data base comparing values at room temperature and at 650°F.

3.5 Margin for Operation

To determine the margin for operation the burst pressure of the R18C5-5 and R18C5-10 type cracks was plotted as a function of time of operation considering the growth rate reported previously. Using the results of the burst testing, a tube with lower bound material properties, an initial crack depth of 49%, and a crack growth rate of 2.5%/mo would be expected to have a burst pressure greater than the RG 1.121 (draft) limit for 13 months of operation for the R18C5-5 type of crack morphology, and slightly more than 12 months for the R18C5-10 type morphology. For both types of cracks the burst pressure would not be expected to be less than the postulated SLB differential pressure for a period in excess of 16 months. Neither type of crack would be expected to result in a rupture at normal operating conditions at any depth, e.g., through-wall.

Additional considerations indicated that the growth rate would have to be on the order of 3.4%/mo for a R18C5-5 type of crack for the tube to have a burst pressure less that the postulated SLB pressure at the end of 12 months of operation. This growth value is greater than the maximum value considered for the determination of the crack growth rate to be used in the analysis.

4 EOC Probabilistic Analysis (Monte Carlo Simulation)

4.1 Beginning of Cycle Crack Depth

For each simulated tube a beginning of cycle (BOC) crack depth was selected as the sum of the mean BOC crack depth plus the product of the standard deviation (SD) of the crack depths and a random variate distributed as a Student's t-distribution for the number of degrees of freedom (dof) used in determining the standard deviation.

The mean and standard deviation for cracks less than 50% deep (the detection threshold) was determined from the crack population present in the tubes removed from the McGuire Units. Examination of the data shows them to be normally distributed with a mean depth of ~39% and having a SD of ~6%. A total of 18 cracks were found at a depth of less than 50%, thus the t-variate was based on 17 dof's.

The performance of the simulation included rules for eliminating mathematically possible, but unrealistic, random initial depths of less than zero.

4.2 Crack Growth Rates

The same data base for the evaluation of crack growth rates was available for the probabilistic analysis as for the deterministic analysis. Once a mean and standard deviation are determined the crack growth rate for each simulated tube was determined as the sum of the mean and the product of a Student's t-distribution random variate and the standard deviation. The t-variate was based on the degrees of freedom (dof) used for the determination of the standard deviation.

The mean and standard deviation from the largest amount of available data were selected for inclusion in the simulations. Approximately forty-one (41) data points from the non-destructive and destruction examinations of tubes from both units were available for use in the simulation. The data were subjected to a robust estimation of location test with the result that four (4) data points were identified as outliers based on having residual to dispersion scale ratios ranging from 3.15 to 13. The associated probability of occurrence of such values on a random basis ranges from $8.2 \cdot 10^{-4}$ to $8 \cdot 10^{-13}$. The three largest deviations occurred for values based on only three months of operation. Determination of mean and standard deviation values for use in the analysis was therefore performed for two cases: the first being with the exclusion of the outliers, and the second being with the exclusion of all values for which the operating time was on the order of three months. For the first evaluation the mean growth rate was found to be 1.7% per month with a SD of 1.1% per month. For the second case the mean growth rate was found to be 1.8% per month with a SD of 1.2% per month. Both rates were simulated in independent Monte Carlo evaluations.

4.3 End of Cycle Crack Depth

The EOC crack depth was determined simply as the sum of the BOC crack depth plus the product of the growth rate and the number of months of operation being simulated.

4.4 Crack Morphology

Crack morphologies for the Monte Carlo analyses were the same as considered for the deterministic analysis, i.e., Unit 2, SG A, R18C sections 5 and 10. The crack in R18C5-5 was found to be 1.1" long, and in the R18C5-10 the crack was 1.4" long. Both configurations are considered to be representative of the more severe morphologies that can occur. For analysis purposes the basic profile of each crack was considered to only vary in depth, thus the EOC profiles for the simulated tubes matches significant crack profiles observed on the removed tubes. The Monte Carlo analysis considered the probability of occurrence of each morphology to be equally likely. Thus, approximately half of the simulated cracks were 1.1" long and the other half were 1.4" long.

4.5 Material Properties

The calculation of a burst pressure for a tube utilizes the sum of the yield stress and the ultimate tensile stress (twice the flow stress). The material properties simulated were based on the actual plant distribution of mill reported properties. The yield stress and ultimate tensile stress for about 90% to 95% of the tubes in each generator was available based on a data base of the material heat used for each tube. The distribution of mill reported properties had a mean of 162.7 ksi with a SD of 6.1 ksi. Random deviates based on Student's t-distribution based on 100 dof's were used for the simulations. The actual number of different heats is more on the order of 200. The sampling also considered the actual material properties of the tubes removed from the McGuire Unit's SG's. It was found that all of the removed tubes exhibited material properties in excess of those reported on the mill data sheets. The variation was found to have a mean of 1.07 with a SD of 0.06. This distribution was also simulated. Thus, the tubes simulated would on average have a higher value for the sum of the yield plus ultimate than the mill reported values. Given the magnitude of the SD approximately 17% of the tubes would also be considered to have a flow strength less than the mill reported values. Each distribution was sampled independently to arrive at a final value of the flow stress to be used for the burst pressure calculation.

A final adjustment to the sum of the yield plus ultimate properties was made to determine a value corresponding to the operating temperature of the SG. Previous testing on a large number of tube specimens has shown that the 3/4" diameter mill annealed tubing has a decrease in flow strength of 7% in going from room temperature to hot leg operating conditions. For cold leg operating conditions the reduction is 6%. Since the SD of material properties at cold leg conditions is generally less than the SD at room temperature conditions no simulation of any variation of the strength reduction factor was necessary.

4.6 Burst Pressure Determination

A series of tube burst tests was performed for each of the crack morphologies considered. In general the tests considered maximum depths ranging from 50% to 100% through the tube wall. There is essentially no change in burst resistance for these types of morphologies once the crack depth reaches 93% through the tube wall. This is due to the burst mode changing from plastic instability to crack opening displacement (COD) dominated fracture. For each crack morphology a second order regression equation was fitted to the burst data for cracks up to 93% deep. Having the crack depth and the flow strength for the material a determination of the burst pressure was made. More extensive burst testing programs have shown that the SD of burst pressure about the burst curve is ~8%. For the Monte Carlo simulations a value of 24% was selected as representing three SD's. Since the total number of burst tests used to establish the SD value was high, variation about the burst curve was simulated using random Normal deviates. This results in a difference in the final burst pressure of about 0.1% relative to the use of variates based on Student's t-distribution.

4.7 Comparison of Burst Pressure to Steam Line Break Pressure

The calculated burst pressure for each simulated tube was then compared to the differential pressure that would be expected during a steam line break (SLB). Specific analyses performed established that two variations of SLB could be considered. The first terminating in a differential pressure of 2335 psi, and the second terminating in a differential pressure of 2485 psi, see Attachment 1, Table 2. Burst pressure sorting from the Monte Carlo analyses indicate that the probability of burst is slightly higher for the higher pressure, however the frequency of occurrence of the second event is several orders of magnitude less than for the first event. Thus, the joint probability of occurrence of burst coupled with a SLB event is significantly lower for the higher pressure event, and only the lower pressure event probabilities are considered significant for evaluation.

For the growth rate and SD corresponding to the exclusion of outliers from the data base, the probability of a single tube having a burst pressure greater that the SLB differential pressure (2335 psi) at the end of 12 months of operation was found to be 99.9%. For the growth rate and SD corresponding to the use of all data for which the operating time period was in excess of ~3 months the corresponding probability was found to be 99.5%.

During the last outages for both units a total of ten tubes (five per unit) were plugged for free-span indications believed to be similar to those found on the tubes removed from Units 1 & 2, i.e., R18C25 from SG B of Unit 1, R46C47 from SG D of Unit 1, and R18C5 from SG A of Unit 2. A like number of tubes remaining following the inspection outages may be postulated. Postulating the existence of two susceptible tubes in one generator, the probability of them both having burst pressures exceeding the SLB differential pressure at the end of the operating cycle would be 99.8%. For three postulated tubes this value becomes 99.6%. Postulating all ten tubes to be in a single SG, which would have a probability of $7.5 \cdot 10^{-9}$, results in a value of slightly less than 99%. Using the growth rate and SD based on all data for operating times in excess of ~3 months results in the above probabilities being 99.8%, 98.5%, and 95.0% respectively.

5 Conclusions

A deterministic evaluation of the integrity of the McGuire Units' SG tubes, paragraph 3., was performed which concluded that tube cracking would not be expected to progress to a depth such that the burst pressure of the cracked tube(s) would be less than the limits of RG 1.121 (draft) for twelve months of operation of the units. In addition, it would be expected that the burst pressure would be greater than the differential pressure associated with a SLB if the crack growth rate was significantly in excess of that used in the analysis (3.4%/mo versus 2.5%/mo).

A PRA was performed to quantify the likelihood of high ΔP events, see Attachment 1. A probabilistic analysis of the integrity of the SG tubes was also performed, paragraph 4., which concluded that the probability of tube burst during a postulated SLB event is unlikely through the end of the units' respective operating cycles. Thus, we conclude that the combined probability of a tube burst and a SLB event is extremely unlikely.

It is noted that the end of the current cycle for Unit 1 will occur at approximately 8.5 months of operation following the last inspection outage. Unit 1 inspection results will be available after 10 months of unit 2 operation, and alternate actions could be taken if deemed necessary.

It is concluded that the information provided herein supports the continued operation of McGuire Units 1 & 2 through the end of their respective fuel cycles.

ATTACHMENT 1

Probabilistic Risk Perspective of Steam Generator Tube Rupture at McGuire Nuclear Station

Overview

The McGuire PRA study done in response to GL 88-20 estimated the public health risk of tube rupture sequences. The conclusion of the McGuire PRA was that the risk was very low because of the multiple and diverse means of terminating the accident prior to core damage. NUREG-0844 also analyzed the public health risk of SGTR and concluded that, "risk from steam generator tube rupture events is not a significant contributor to total risk at a given site, nor to the total risk to which the general public is routinely exposed." Although the conclusion of both these studies was the same, the actual results show that there are differences in the calculated results. For example, the NUREG estimated the total core damage frequency to be approx. 4E-6/RY while the McGuire PRA estimate was approx. 1E-8/RY. A comparison of the McGuire PRA to the NUREG revealed that there were many similarities but also some differences between the two reports. A summary of this comparison is included in Attachment 1.1.

One of the major differences between the NUREG and the McGuire PRA is that the NUREG evaluated the potential for transients to induce a tube rupture, while the McGuire PRA study did not evaluate this possibility. To determine the effect of this type sequence at McGuire, a screening study was performed to determine if the NUREG analysis bounds the McGuire plant. The conclusion of this review is that the likelihood of a transient induced challenge to the SG tubes for McGuire is either comparable to or less likely than the NUREG-0844 analysis. Additionally, the differential pressures for these transients would be less severe for the McGuire plant. The frequency of transient induced tube challenges for McGuire and resulting pressures are discussed in more detail below.

Another difference between the NUREG and the McGuire PRA is the likelihood that a tube rupture sequence will lead to core melt. The NUREG estimated that for a single tube rupture with a stuck open main steam safety valve, the probability of core melt was 1E-3. For a similar sequence the McGuire PRA estimated a probability of 1E-6. The NUREG appears to have only given credit for depressurizing the primary system using the other steam generators. At McGuire there is also the capability of opening the primary system PORVs as a means of reducing pressure. Both secondary depressurization and primary depressurization are very reliable actions given the long time available before core damage would occur. The NUREG appears to use conservative estimates for the likelihood that a tube rupture sequence will lead to core damage.

Conclusion - The following conclusions can be drawn from the combination of the McGuire PPA and NUREG-0844 analysis of SGTR risk:

1) Considering the design basis transients and accidents, the frequency of events which are expected to induce large stresses (from DP loadings) is small (1E-4/RY for DP= 2485psid and 1E-3 for DP= 2335 psid). It should also be noted that the consequences of a high energy line break inside containment with a tube rupture are expected to be much less severe than if the break is outside containment.

2) For anticipated transients with a frequency of 0.1/RY - 2.0 /RY, the pressure loadings are in the range of normal operating pressure loadings.

3) For McGuire, the plant features of 3 PORVs and 3 safety relief valves on the pressurizer limit the severity of pressure loadings.

4) For accident sequences leading to a core melt condition, both the frequency and risk from a single SGTR event are very small.

5) The consequence results of NUREG-0844 have been compared to results for McGuire for two sequences. The fission product release fractions and consequence results are a factor of 5 to 10 less than those presented in the NUREG, when water is assumed available to cover the rupture as was done for the NUREG analysis. The risk contribution from these sequences is relatively small fraction of the risk calculated in the McGuire IPE.

6) For the complete spectrum of SGTR related core melt sequences, NUREG-0844 estimated a latent fatality risk of approx. 2E-3/RY. This is equivalent to approx. 25 person-rem / RY exposure to the public. If this value is reduced by the factor of 5-10 for more realistic values for McGuire, the risk is 2.5- 5 person-rem/ RY exposure to the public. In contrast, an additional steam generator tube inspection would result in plant personnel exposure of approx. 30 person-rem. The SGTR risk is a conservatively calculated number while the worker exposure during the outage is virtually certain.

Analysis of Sequences Which Have the Potential to Subject the Steam Generator Tubes to Large Differential Pressures

SGTRs can potentially occur as a result of plant transients or accidents when loadings on the steam generator tubes are increased above normal operating loads. These transients can cause significant pressure differences across the SG tubes by either decreasing the secondary pressure, increasing the primary pressure, or a combination of both. NUREG-0844 identified four types of events which have the potential to create this type of transient. These include ATWS, steamline or feedline breaks, LOCAs and transients which result in a stuck open secondary safety valve. An attempt was made to estimate the frequency of these events and the resulting pressure differentials for the McGuire Nuclear Station.

ATWS - The ATWS sequences analyzed in NUREG-0844 are very similar to the analysis performed for the McGuire PRA. The sequences consist of an initiating transient followed by a failure of the reactor to SCRAM. The McGuire PRA frequency of the initiating transient (1.5/RY) is very similar to that of the NUREG-0844 analysis (1/RY). Also, the probability that the reactor will fail to SCRAM is very similar: 1.5E-5 for McGuire , compared to 3E-5 for the NUREG analysis. The pressures resulting from this sequence depend on the effect of the moderator temperature coefficient (MTC). Since the MTC changes with time during a fuel cycle, the probability of achieving different pressure levels depends on the fraction of time that the MTC is at different levels. For the NUREG analysis, the MTC was divided into three categories which could be called favorable (0.5), moderate (0.49), and unfavorable (0.01). The McGuire PRA analysis only looked at a single MTC category which could be considered unfavorable and which was considered to exist 5% of the time. For the purpose of comparison, the McGuire analysis has been modified using the NUREG values for the pressure associated with the other two categories. The results of this comparison are presented in the Table 1. As can be seen, the estimated frequency of challenge to the steam generator tubes for McGuire from an ATWS sequence is very similar to that calculated for the NUREG-0844 analysis.

Secondary Line Break - The secondary line break sequence analyzed by the NUREG was a steamline break resulting in a 2600 psi differential pressure across the SG tubes. The McGuire PRA considers two secondary system initiating events which have the potential to cause significant differential pressures. These are secondary system high energy pipe breaks inside containment and a steamline break outside containment.

The resulting pressure differential for these events depends on the actions taken by the operators in response to the accident. For both events, primary system shrinkage caused by the overcooling of the primary system will initiate safety injection. The ECCS will refill and repressurize the primary system at the same time as secondary system pressure is decreasing. Emergency procedures require that safety injection be terminated as soon as pressurizer level and subcooling are regained. The resulting pressure differential across the SG tubes will depend on when the operators accomplish this action.

If the operators fail to terminate ECCS prior to the pressurizer going solid, the pressurizer PORVs should prevent the pressure differential from exceeding 2335 psid. The differential pressure across the tubes could only reach the maximum pressure of 2485 psid if the operators fail to terminate ECCS and all three PORVs fail to relieve pressure. For the steam line break outside containment the reliability of the PORVs is expected to be very good. However, the secondary line break inside containment will cause containment isolation which cuts off instrument air to the PORVs. The operators are instructed by the procedures to reestablish air to the PORVs, but the possibility that this action will not be performed reduces somewhat the reliability of the PORVs.

The event sequences described above are presented in the attached figures, and a comparison to the NUREG analysis is presented in the attached table. The analysis for McGuire shows that when operator action is considered, the frequency of a secondary line break resulting in very large differential pressures across the SG tubes is reduced by an order of magnitude.

LOCA - NUREG-0844 considered primary system LOCA to be a potential sequence which could result in a large pressure differential across the SG tubes. For this sequence, the pressure would tend to cause tube collapse rather than burst. The concern identified in the NUREG was related to the effect of steam binding from the tube rupture causing delay in core reflood. This would primarily be a peak cladding temperature concern. Several significant conservatisms were included in the analysis and resulted in an event sequence frequency of 2.5E-7/RY. Comparison to McGuire does not seem to be necessary for this case.

Stuck Open Safety Valve - NUREG-0844 concluded that the frequency of stuck open safety valve sequences for Westinghouse type reactors was low enough that it was bounded by the steam line break analysis. Potential transient initiators were reviewed for McGuire to determine if this statement could be supported. Two sequences were identified that could challenge the safeties with sufficient frequency to be a concern. These initiators are loss of offsite power (LOOP) and loss of instrument air which were estimated by the McGuire PRA to have frequencies of 0.07/RY and 0.33/RY respectively. The probability that a safety valve will stick open upon demand is in the range of 1E-2 so that the frequency of this sequence is on the order of 4E-3/RY.

The plant response following the stuck open safety valve would be very similar to the secondary line break inside containment sequence discussed above. This is because both the LOOP and the loss of air would result in failure of air to the pressurizer PORVs and would require the operators to align nitrogen from the accumulators to the PORVs. This action is considered to be as reliable as the one for restoring instrument air following the secondary line break inside containment.

Although the stuck open safety valve sequence may have a frequency comparable to the secondary line break sequence, it is less likely to result in large differential pressures across the SG tubes. The rate of pressure drop on the secondary side of the tubes for a stuck open safety would be slower than for a pipe break, such that even if the primary system goes water solid the secondary pressure will probably be greater than atmospheric pressure. Since the primary system pressure can not exceed the pressurizer safety valves' set point pressure of 2485 psig, the differential pressure would be 2485 less the secondary pressure. Since the likelihood of this sequence is comparable to the secondary line break frequency and the differential pressures are expected to be less, we agree with the NUREG conclusion that the stuck open secondary safety valve sequence is bounded by the secondary line break analysis.

Additional Transients - In addition to the transient discussed above, the McGuire FSAR Chapter 15 analysis was reviewed to determine if any other transients had the potential to cause significant differential pressures across the SG tubes. Table 3 presents the estimated pressure loads and frequency of the Chapter 15 transients. As can be seen, the sequences discussed above bound all other transients by either pressures or frequencies.

The analyses presented here have demonstrated that the frequency of transients which cause large differential pressures across the McGuire steam generator tubes is either lower than or comparable to the analyses presented in NUREG-0844.

Table 1 - Sequences Which May Result in Substantial Pressure Differentials Across the Steam Generator Tubes (ATWS)

	NUREG-0844 Sequence 1	**NUREG-0844 Sequence 2**	**NUREG-0844 Sequence 3**	**McGuire Sequence 1**	**McGuire Sequence 2**	**McGuire Sequence 3**
Sequence Initiator	Loss of Main Feedwater = 1/RY	Loss of Main Feedwater = 1/RY	Loss of Main Feedwater = 1/RY	LOFW or Turbine Trip = 1.5/RY	LOFW or Turbine Trip = 1.5/RY	LOFW or Turbine Trip = 1.5/RY
Action 1	Failure to SCRAM = 3E-5	Failure to SCRAM = 3E-5	Failure to SCRAM = 3E-5	Failure to SCRAM = 1.5E-5	Failure to SCRAM = 1.5E-5	Failure to SCRAM = 1.5E-5
Action 2	Favorable MTC = 0.5	Moderate MTC = 0.49	Unfavorable MTC = 0.01	Favorable MTC = 0.48	Moderate MTC = 0.47	Unfavorable MTC = 0.05
Total Sequence Frequency	**1.5E-5/RY**	**1.5E-5/RY**	**3.0E-7/RY**	**1.1E-5/RY**	**1.1E-5/RY**	**1.1E-6/RY**
Pressure Across Tubes	**1800 psid**	**2150 psid**	**2650 psid**	**1800 psid**	**2150 psid**	**2350 psid**

Table 2 - Sequences Which May Result in Substantial Pressure Differentials Across the Steam Generator Tubes (Secondary System Failures)

	NUREG-6844	McGuire Sequence 1	McGuire Sequence 2	McGuire Sequence 3	McGuire Sequence 4	McGuire Sequence 5	McGuire Sequence 6	McGuire Sequence 7
Sequence Initiator	Secondary Line Break - 1E-3/RY	Secondary Line Break Outside Containment = 1E-3/RY	Secondary Line Break Outside Containment = 1E-3/RY	Secondary Line Break Outside Containment = 1E-3/RY	Secondary Line Break Inside Containment = 3E-3/RY	Secondary Line Break Inside Containment = 3E-3/RY	Secondary Line Break Inside Containment = 3E-3/RY	Secondary Line Break Inside Containment = 3E-3/RY
Action 1	NA	Operators Terminate SI = 0.67	Operators Fail to Terminate SI = 0.33	Operators Fail to Terminate SI = 0.33	Operators Terminate SI = 0.67	Operators Fail to Terminate SI = 0.33	Operators Fail to Terminate SI = 0.33	Operators Fail to Terminate SI = 0.33
Action 2	NA	NA	Pressurizer PORV Relieves Pressure = 1.0	Pressurizer PORV Fails to Relieve Pressure = 1.3E-4	NA	Operators Restore Instrument Air to Pressurizer PORVs = 0.9	Operators Restore Instrument Air to Pressurizer PORVs = 0.9	Operators Fail to Restore Instrument Air to Pressurizer PORVs = 0.1
Action 3	NA	NA	NA	NA	NA	Pressurizer PORV Relieves Pressure = 1.0	Pressurizer PORV Fails to Relieve Pressure = 1.3E-4	NA
Total Sequence Frequency	**1E-3/RY**	**6.7E-4/RY**	**3.3E-4/RY**	**4.3E-8/RY**	**2.0E-3/RY**	**8.9E-4/RY**	**1.2E-7/RY**	**9.9E-5/RY**
Pressure Across Tubes	**2600 psid**	**<2335 psid**	**2335 psid**	**2485 psid**	**<2335 psid**	**2335 psid**	**2485 psid**	**2485 psid**

Table 3 - Sequences Which May Result in Substantial Pressure Differentials Across the Steam Generator Tubes (Chapter 15 Sequences)

Differential Pressure Across SG Tubes	FSAR Chapter 15 Sequence Description	Estimated Sequence Frequency
2485 psid (pressure is limited by the three pressurizer safety valves)	15.1.5 Steamline Break and 15.2.8 Feedline Break	1E-4/RY (See Table 2)
	15.1.4 Spurious Secondary System Valve Opening	Bounded by SLB Frequency
	Total Category	**1E-4/RY**
2335 psid (pressure is limited by the three pressurizer PORVs)	15.1.5 Steamline Break and 15.2.8 Feedline Break	1.2E-3/RY (See Table 2)
	15.1.4 Spurious Secondary System Valve Opening	Bounded by SLB Frequency
	Total Category	**1.2E-03/RY**
2150 - 2335 psid (pressure dependent on time of SI termination)	15.1.5 Steamline Break and 15.2.8 Feedline Break	2.7E-3/RY (See Table 2)
	15.1.4 Spurious Secondary System Valve Opening	Bounded by SLB Frequency
	15.8 ATWS	Does not apply to period under consideration.
	Total Category	**2.7E-3/RY**
1800 - 2150 psid	15.8 ATWS	Does not apply to period under consideration.
1450 - 1800 psid	15.8 ATWS	**1.1E-5/RY**
1400 - 1450 psid	15.4.1 Zero Power Control Bank Withdrawal	Screening value 1E-2/RY
	15.4.2 Control Bank Withdrawal at Power	Screening value 1E-2/RY
	15.4.8 Rod Ejection	Some very low value - e
	Total Category	**2E-2/RY**
1335 - 1400 psid	15.1.3 Excessive Load Increase	Bounded by spurious SI frequency
	15.5.1 Spurious Safety Injection	0.2/RY
	Total Category	**0.2/RY**

Differential Pressure Across SG Tubes	FSAR Chapter 15 Sequence Description	Estimated Sequence Frequency
Less Than Normal Operating DP	15.1.1 Feedwater Temp. Reduction 15.1.2 Increase in Feed Flow 15.2.2 Loss of Load 15.2.3 Turbine Trip 15.2.4 MSIV Closure 15.2.5 Loss of Condenser Vacuum 15.2.6 Loss of 6900 v Buses 15.2.7 Loss of Feedwater 15.3.1 Single RCP Trip 15.3.2 Complete Loss of Flow 15.3.3 Locked RCP Rotor 15.3.4 RCP Shaft Break 15.4.3 Control Rod Errors 15.4.4 Start Up on Inactive RCP 15.4.6 Boron Dilution 15.6.1 Stuck Open Pressurizer PORV or Safety 15.6.2 Instrumentation Line Break 15.6.3 SGTR 15.6.5 LOCA	Frequencies for this group were not estimated since the pressures are bounded by the normal pressures Transients 15.2.4 through 15.2.6 have the potential to cause a stuck open secondary safety valve. These sequences should be bounded by the SLB as discussed earlier.

PRA Evaluation of McGuire Steam Generator Tube Integrity Issue for End-of-Cycle Operation

NUREG-0844 is a comprehensive, state-of-the-art analysis of the probabilities, consequences and risks for steam generator tube rupture (SGTR) events. The report contains analyses of core melt and non-core melt events.

We agree that the NUREG analysis is a conservative analysis of the probabilities and consequences of SGTR-related accident sequences.

Duke's MNS (McGuire Nuclear Station) IPE/PRA contains the analysis of SGTR event sequences leading to core melt conditions

There are similarities and differences between the Duke analysis and the NUREG analysis.

We have attempted in the last few days to evaluate the frequencies of the transient-induced high delta P SG tube stress scenarios, which have a probability of leading to SGTR. (See attached event trees.)

For the *non-core melt sequences*, the similarities and differences are as follows:

> The initiating event frequency for most of the events are about the same. (For example, Duke uses $3x10^{-3}$ for a high energy line break inside containment while the NUREG uses $1x10^{-3}$.)
>
> The type of events of interest are about the same, except perhaps the LOCA + SGTR combination. (The 100°F or so adverse impact on cladding peak clad temperature calculations arising from a small impact -- on post-LOCA refill/reflood phenomenon due to multiple SGTR condition -- should not be considered a significant contributor to core melt.)
>
> For overcooling events (such a SLB), operator action to control primary side repressurization could be considered as a mitigating factor. Also, the PORVs limit the pressure to 2350 psi instead of 2600 psi.
>
> Even with operator failure. the maximum realistic delta P during a SLB is approximately 2500 psi. instead of the 2600 psi used in the NUREG.
>
> For ATWS events, the fractions of the time the delta P is greater than or equal to 2500 psi are less than those estimated in the NUREG because of the presence of three pressurizer SVs and three pressurizer PORVs at MNS.

Duke's PRA assessment does not have a number for the conditional probability of tube failure during a SLB or for the probability of multiple tube failures.

The conditional probability of 0.25 for SG overfill during a SGTR event is very conservative.

Using realistic source terms (the MNS coolant activity is very low), the consequences of these non-core melt sequences is expected to be much less severe than those calculated in the NUREG.

For *core melt sequences*, the similarities and differences are as follows:

The initiating event frequency for a single SGTR is about the same.

Duke does not have a number for the frequency of a multiple SGTR event.

The core damage frequency for a single SGTR initiator is two orders of magnitude lower in the Duke MNS PRA analysis versus the NUREG analysis. The ability to depressurize the primary side and the plant-specific reliability of DHR systems are probably the major causes for this difference.

The sequences modeled in the NUREG which result in depleting the RWST after long periods of time were modeled as part of the MNS PRA event tree. However, they were not quantified because it was decided that if credit is given for throttling ECCS flow to match decay heat, or refilling the RWST, then this sequence would not result in core damage.

In the consequence analysis, the MNS-specific fission product release fractions and site consequence results are similar to NUREG analysis results.

The results imply that frequencies of accident sequences are low and that the risk from SGTR-related sequences is also acceptably low.