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Vogtle Evaluation of DEGB-Only Model versus Continuum Break Model

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1. Purpose and Scope

NUREG-1829 provides a table of LOCA frequencies as a function of break size. Although there is no explicit guidance related to the difference in partial breaks and double ended guillotine breaks (DEGBs) in the NUREG, there has been a lot of discussion around a statement in NUREG-1829 that a break of a given size is more likely to result from a complete rupture of a small pipe than a partial rupture of a larger pipe. Two different positions have been postulated for the types of breaks that could occur:

- DEGB-only model – If a pipe starts to break, the forces from the system operating pressure would cause the crack to propagate into a full DEGB and therefore partial breaks do not need to be evaluated. In this model, the higher frequency associated with small breaks is attributed to a greater likelihood of DEGBs on small diameter pipes.
- Continuum break model – A break of any size up to and including a DEGB can occur on any pipe. In this model, the higher frequency associated with small breaks is attributed to the combination of DEGBs on small diameter pipes and small breaks on large pipes.

Draft Regulatory Guide 1.229 requires that both models be evaluated as a sensitivity. During the NARWHAL NRC audit, the staff clarified that the two models that have been debated represent bounding assumptions regarding the frequency allocation. The DEGB-only model assumes that the frequency associated with a partial break is so low that it is negligible; the continuum break model assumes that the frequency of partial breaks is essentially the same as equivalent size DEGBs. The reality is likely somewhere between these two extremes. Therefore, by evaluating both models with their associated frequency allocations, the sensitivity of the risk quantification to the choice of break models can be determined.

This white paper describes the methodology for evaluating risk using the two break models and provides results for Vogtle based on the current NARWHAL model.

2. General Methodology

If a licensee is using the threshold break approach for quantifying risk (where a bounding break size is determined and all larger breaks are assumed to fail), the DEGB-only model will by definition result in a risk (ΔCDF and ΔLERF) result that is less than or equal to the continuum break model. Since the continuum break model evaluates the range of possible break sizes up to and including a DEGB at every weld, the smallest break that fails could be either a partial break or a DEGB. If it is a DEGB, the smallest break that fails with the DEGB-only model would not change and the calculated risk would be the same. If the smallest break that fails in the continuum model is a partial break, the DEGB-only model would skip over that break size and predict that a larger DEGB is the smallest break that fails. This would result in a lower threshold break frequency and a lower overall risk. Therefore, if the threshold break methodology is being used, the continuum break model can be used without performing a sensitivity analysis for the DEGB-only model.

If a licensee is using the conditional failure probability (CFP) approach for quantifying risk, it is necessary to consider both the continuum break model and the DEGB-only model. The general methodology for doing this is described below:

1. The overall plant-wide LOCA frequencies must be allocated to individual welds and break sizes using an acceptable allocation methodology (e.g., some form of a top-down or hybrid LOCA frequency allocation).
2. GSI-191 failures (strainer, pump, and and/or core failures due to the effects of debris) must be evaluated for each break.
3. The PRA model categories (e.g., large breaks) should be broken up into size ranges where breaks within a given size range are assumed to have an equal probability. Note that every size range must include breaks that fall within the size range.
4. The CFP for a PRA category is calculated based on the combined CFPs for each size range along with the corresponding LOCA frequency weight associated with each category. For example, given a large break PRA category defined as breaks larger than or equal to 6 inches, the size ranges could be 6”-15”, 15”-25”, and >25”. Although the >25” category is most likely to experience GSI-191 failures (due to the greater quantity of debris generated by the larger breaks), most of the frequency weight is associated with the smaller breaks in the 6”-15” category.
5. The CFP values can then be used with the plant PRA model to calculate the risk associated with GSI-191.

These steps can be used to evaluate either the continuum break model or the DEGB-only model. However, as noted in Step 3, every size range must include breaks that fall within the size range. Most plants have a surge line that is 12 to 14 inches in diameter and primary loop piping that is 27.5 inches or larger in diameter with no intermediate pipe sizes. Therefore, using a size range of 15”-25” may be perfectly acceptable for evaluating the continuum break model, but it would not be acceptable for the DEGB-only model since there are no DEGBs between 15 and 25 inches. This raises the question of how to distribute the frequency associated with breaks between the DEGB sizes if these break sizes are assumed to be impossible (as done in the DEGB-only model). If the size range is cut off right below the larger DEGB size, the frequency associated with the gap between the DEGB sizes will be attributed to the smaller beak size, which is generally less likely to fail (skewing the risk lower). If the size range is cut off right above the smaller DEGB size, the frequency associated with the gap between the DEGB sizes will be attributed to the larger break size, which is generally more likely to fail (skewing the risk higher). In general, the recommended approach is to select the midpoint between the DEGB sizes to avoid biasing the results in either direction.

3. NARWHAL Analysis of Continuum Breaks vs. DEGB-only Breaks for Vogtle

As an example calculation, two NARWHAL simulations were run using the current Vogtle model. The simulations evaluated the whole range of continuum break sizes for two equipment configurations (all pumps available and single train failure). To compare the DEGB-only model to the continuum model, the partial breaks were simply filtered out of the results.

Figure 1 shows the fiber accumulated on the RHR A and CS A strainers when all pumps are available. The graph on the left shows the data for the full set of breaks evaluated with the continuum model, and the graph on the right shows the results from just the DEGBs. Note the wide gap between the 12.8-inch surge line breaks and the 27.5-inch cold leg breaks.

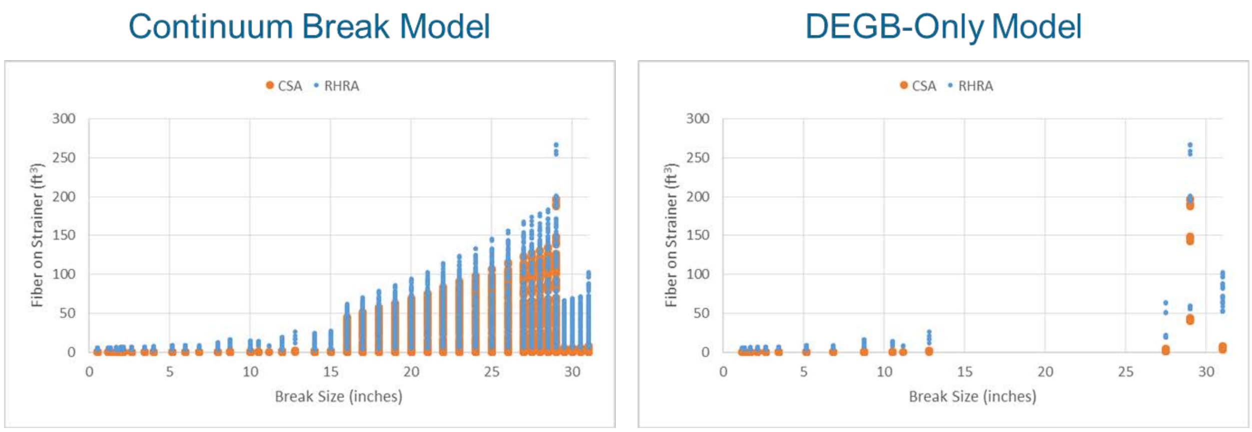

Figure 1 – Fiber Load on RHR A and CS A Strainers (all pumps available)

Figure 2 shows the CFP value as a function of break size for the various failure mechanisms. The only failures observed were flashing failures and strainer debris limit failures. The CFP values in this figure were simply calculated as the number of breaks that failed divided by the number of total breaks evaluated for a given break size. For the continuum break model, the 27.5-inch break size includes cold leg pipe DEGBs, as well as partial breaks on the hot leg and crossover leg piping (i.e., all pipes that can experience a 27.5-inch break). This comparison shows that in general, the CFP value for the large break sizes is higher with the DEGB-only model, which makes sense since DEGBs have a larger (spherical) ZOI volume compared to the partial break (hemispherical) ZOIs.

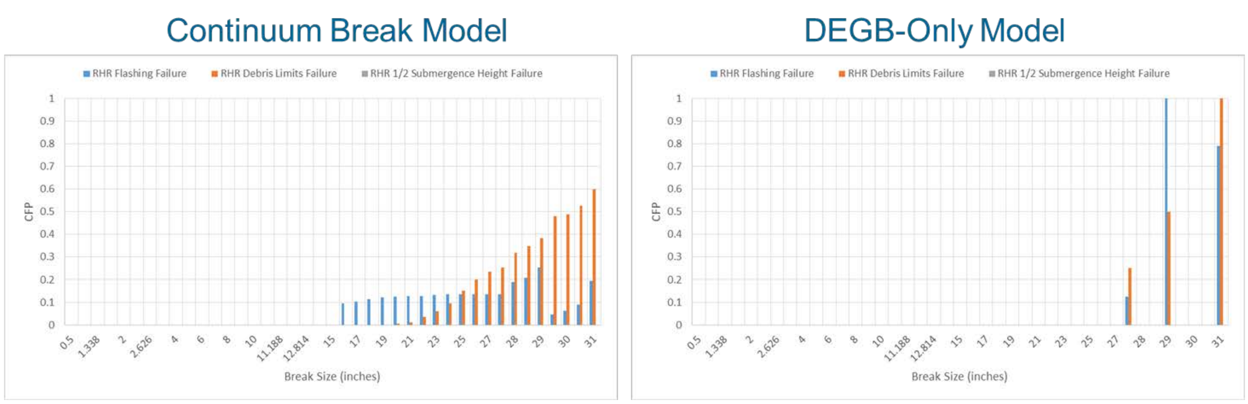

Figure 2 – Break Size-Dependent CFPs (all pumps available)

Figure 3 and Figure 4 show similar results for the case with single train failure.

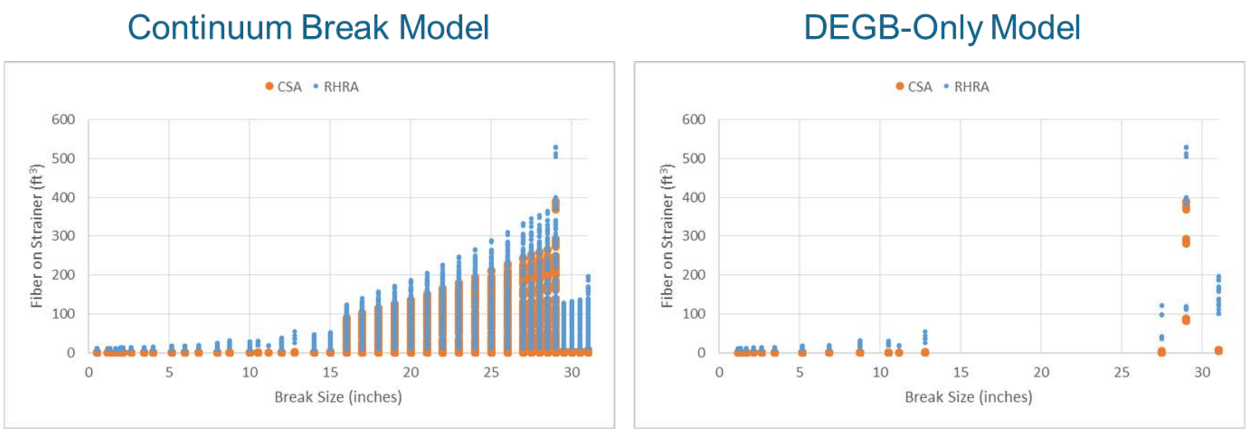

Figure 3 – Fiber Load on RHR A and CS A Strainers (single train failure)

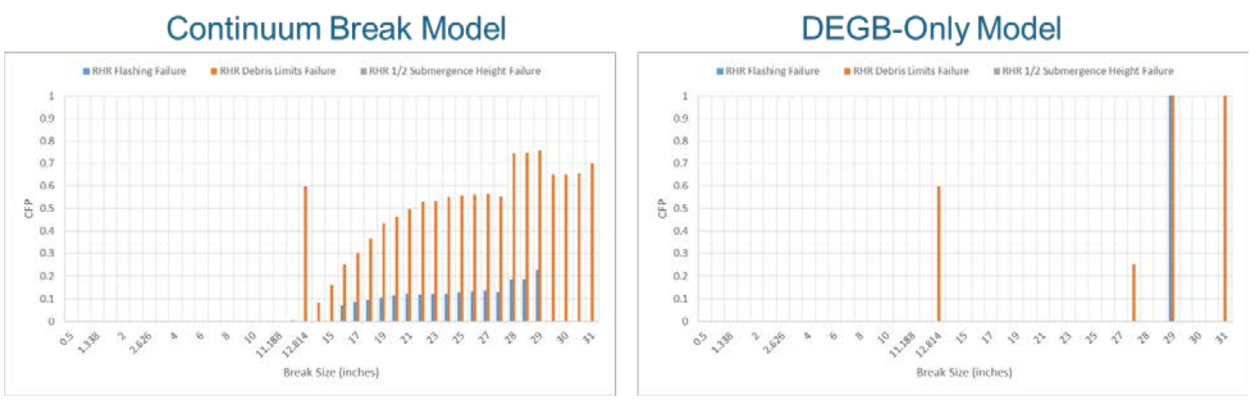

Figure 4 – Break Size-Dependent CFPs (single train failure)

The CFP values corresponding to the Vogtle PRA categories (small, medium, and large LOCAs) were calculated using the built-in CFP calculator in NARWHAL Version 1.0. The required inputs are shown in Table 1 for LOCA frequency values, Table 2 for the PRA categories, and Table 3 for the size ranges within the PRA categories. Note that three separate size ranges are used for the DEGB-only model. The first size range biases the results by assigning the frequency for break sizes between the surge line diameter (12.8 inches) and the cold leg diameter (27.5 inches) to the larger break sizes. Since the larger breaks are more likely to fail, this should generally result in a higher CFP value. The second size range biases the results to a lower CFP value by assigning the intermediate break range to the smaller break sizes. The third size range uses the approximate midpoint of 20 inches to provide an unbiased allocation of the intermediate frequencies to both the smaller and larger breaks sizes. The unbiased results are most appropriate for analyzing risk associated with the DEGB-only model.

Table 1 – LOCA Frequency Inputs for NARWHAL CFP Calculator

Break Size	Mean NUREG-1829 Frequencies (yr^{-1})
0.5	1.9E-03
1.625	4.2E-04
3	1.6E-05
7	1.6E-06
14	2.0E-07
31	2.9E-08

Table 2 – PRA Category Inputs for NARWHAL CFP Calculator

LOCA Category	Break Size Range (in)
Small	0.5 - 2
Medium	2 - 6
Large	6 - 43.84

Table 3 – Size Range Inputs for NARWHAL CFP Calculator

Size Range	Sizes (in)			
	Continuum	DEGB (Bias Max)	DEGB (Bias Min)	DEGB (Unbiased)
Small	0.5 - 2	0.5 - 2	0.5 - 2	0.5 - 2
Medium	2 - 6	2 - 6	2 - 6	2 - 6
Large(1)	6 - 15	6 - 12	6 - 12	6 - 12
Large(2)	15 - 25	12 - 13	12 – 27	12 - 20
Large(3)	25 - 43.84	13 - 43.84	27 - 43.84	20 - 43.84

Table 4 – CFP Using Log Interpolation and Mean Quantile

Case	PRA Category	Continuum CFP	DEGB (Bias Max) CFP	DEGB (Bias Min) CFP	DEGB (Unbiased) CFP
Two ECCS/CS Trains	Small	0	0	0	0
	Medium	0	0	0	0
	Large	0.0118	0.0780	0.0101	0.0243
Single ECCS/CS Train	Small	0	0	0	0
	Medium	0	0	0	0
	Large	0.0353	0.0816	0.0145	0.0286

Based on NUREG-1829, the mean exceedance frequency for 6-inch breaks is 5.2E-06/year. The equipment configuration probabilities for large LOCAs at Vogtle are approximately 91% for no pump failures, 7% for one or two containment spray (CS) pump failures, and 2% for 1 residual heat removal (RHR) pump or 1 train failure. Assuming the CFP values for the single train case are applicable to both the CS pump failures and the RHR pump failures, the overall ΔCDF can be estimated as shown below:

$$\Delta CDF_{continuum} = 5.2 \cdot 10^{-6} \cdot (0.91 \cdot 0.0118 + 0.09 \cdot 0.0353) = 7.2 \cdot 10^{-8}$$

$$\Delta CDF_{DEGB\ (unbiased)} = 5.2 \cdot 10^{-6} \cdot (0.91 \cdot 0.0243 + 0.09 \cdot 0.0286) = 1.3 \cdot 10^{-7}$$

In this example, the DEGB-only model results in a slightly higher ΔCDF value. However, this could be different depending on plant-specific conditions and assumptions.

4. Conclusions

The continuum break model is bounding compared to the DEGB-only model for licensees implementing the threshold break approach, and therefore the DEGB-only model does not need to be explicitly evaluated for those plants.

Licensees implementing the CFP approach must evaluate both the continuum break model and the DEGB-only model to determine the risk sensitivity. Based on preliminary results for Vogtle, the difference in risk calculated from the two break models is relatively small.

It is important to note that the DEGB-only results can be significantly biased depending on how the intermediate frequencies between DEGB sizes are allocated. A reasonable approach to get an unbiased value is to simply pick the midpoint between DEGB sizes.