Public availability of this draft document is intended to inform stakeholders of the current status of this Regulatory Guide (RG), which is being developed to support the NRC staff's preliminary draft final rule package and associated documents for § 50.46c of Title 10 of the Code of Federal Regulations (10 CFR). This preliminary draft document is in support of a March 22, 2016, Advisory Committee on Reactor Safeguards (ACRS) subcommittee meeting.

This draft document has not been subject to all levels of NRC management review. Accordingly, it is incomplete and may be in error in one or more respects. The document may be subject to further revision before the staff issues this RG in final form.

APPENDIX C

PARTITIONING PLANT-WIDE LOCA FREQUENCIES

Cautions, Limitations, and Definitions:

- This appendix refers to the RG 1.174 risk acceptance guidelines in terms of core damage frequency (CDF). It is understood that the large early release frequency (LERF) guidelines must also be met.
- In the context of this appendix, a "critical" break location is one that can produce and transport sufficient debris to cause core damage (e.g., by blocking the ECCS strainer).
- The examples in this appendix involve piping components. LOCA contribution from the failure of non-piping components must also be considered ~~if these~~as stipulated in C.2.a of this RG if breaks in these locations can generate and transport debris.
- ~~Methods 1 and 2 may~~Similarly, site-specific LOCA contributors (e.g., water hammer, seismic) must also be ~~used for both piping and non-piping components; Method 3 may be used for non-piping LOCAs only if a technical justification is provided for non-piping qualitative rupture potential~~considered as stipulated in C.2.g of this RG.

Methodology

When determining the risk attributable to debris, it may be necessary to partition plant-wide LOCA frequency so that it may be allocated to individual break locations. This may be done using ~~one of~~ the following ~~methods~~bounding approach:

~~1. Bounding Approach~~

Analysts should identify the critical break location with the smallest effective break size, D_{min}. As stated in NUREG-1829, Section 3.7, this effective break size corresponds to a partial fracture for pipes with larger diameters than the break size, a complete single-ended rupture in pipes with the same inside diameter~~, D_{min}.~~ (*i.e.*, the effective break size is equal to the inside pipe diameter), or a double-ended guillotine break (DEGB) in pipes with the effective break size equal to 1/√2 times the inside diameter. Assuming that all breaks of this size or larger lead to core damage ~~(even those that are non-critical)~~ provides a bounding estimate of the risk attributable to debris (i.e., ΔCDF). Expressed mathematically:

$$\Delta CDF = f(LOCA\ \sout{X}x \geq D_{min})$$

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If this method yields a ΔCDF that meets the risk acceptance guidelines, then the risk attributable to debris has been shown to be acceptable. Because this is meant to be an upper bound estimate of risk, the mean LOCA frequency values using arithmetic mean (AM) aggregation should be used (NUREG-1829, Table 7.13). ~~Log~~Semi-log interpolation of the NUREG-1829 LOCA frequencies is acceptable~~.~~ because of the overall trend in frequency vs break size

For example, consider a plant where the smallest critical break location has an effective break ~~diameter~~size of 8 inches. Using ~~log~~semi-log interpolation and AM aggregation, the analyst would calculate an exceedance frequency of f(LOCA X ≥ 8 inches) = 7.~~2~~7 E-6 per year.

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~~If the bounding approach produces results that exceed the risk acceptance guidelines, the analyst should move to step 2.~~

~~2. Conservative Partitioning Approach~~

~~If the bounding approach fails to demonstrate that the risk acceptance guidelines are met, a conservative partitioning approach may be applied. This approach assigns 100% of the LOCA frequency for any interval with a critical weld to the smallest (i.e., highest frequency) critical weld in that interval. Put another way, if there is even one critical weld in an interval, the entire interval is assigned a CCDP of 1.0. Therefore, for an interval, I_N, with one or more critical welds:~~

~~$\Delta CDF(I_N) = f(I_N)$~~

~~Where $f(I_N)$ = frequency of LOCA interval N~~

~~Intervals with no critical break locations are assigned a ΔCDF of zero because regardless of how the frequency would be allocated, no breaks in these intervals are expected to lead to core damage (because all locations have CCDP =0).~~

~~The total (plant-wide) ΔCDF is the sum of the ΔCDFs for each interval.~~

~~If the total CDF calculated with this method meets the risk acceptance guidelines, no additional analysis is necessary. If not, the analyst should move to step 3.~~

~~For example, consider the following set of break locations:~~

~~**Table 1**~~

~~Pipe ID (diameter - index)~~	~~Critical?~~	~~CCDP~~	~~Freq for this LOCA interval, (per year)~~
~~8-1~~	~~N~~	~~0~~	-
~~8-2~~	~~Y~~	~~1~~	~~2.20E-06~~
~~8-3~~	~~N~~	~~0~~	~~*Interval 1: [7",8"]*~~
-	-	-	~~***subtotal***~~
~~11-1~~	~~N~~	~~0~~	-
~~11-2~~	~~N~~	~~0~~	~~3.30E-06~~
~~11-3~~	~~N~~	~~0~~	~~*Interval 2: (8",11"]*~~

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11-4	N	0	-
-	-	-	subtotal
12-1	N	0	-
12-2	Y	1	6.00E-07
12-3	Y	1	*Interval 3: (11",12"]*
-	-	-	***subtotal***
13-1	N	0	-
13-2	Y	1	-
13-3	N	0	9.00E-07
13-4	N	0	*Interval 4: (12",14"]*
13-5	N	0	-
-	-	-	subtotal
			Overall total

The frequency for each interval has been determined using the approach described in C.2 of the RG. Note that the total frequency for the interval [7", 14"] matches the NUREG-1829 LOCA frequency calculated by subtracting f(Cat V) from f(Cat IV): 9.4E-6 – 2.4E-6 = 7E-6 per year. It is also important to note that although there are no breaks in the [7",8"] and [13",14"] intervals, this frequency is not discarded but is applied to the nearest break locations.

In this example, an 8 inch break is, again, the smallest critical break location; however, rather than assume that ΔCDF is the frequency of all breaks 8 inches or larger, each frequency interval is considered separately. Any interval containing a critical weld is assigned a CCDP of 1.0. Intervals with no critical welds are assigned a delta CDF of 0.

CDF(interval 1) = 2.2E-6 per year
CDF(interval 2) = 0
CDF(interval 3) = 6E-7 per year
CDF(interval 4) = 0

Total CDF = 2.2E-6 + 6E-7 = 2.8E-6 per year

3. Semi-quantitative partitioning approach

If the bounding and conservative partitioning approaches fail to demonstrate that ΔCDF meets the risk acceptance guidelines, the analyst may partition LOCA frequency by using insights about degradation mechanisms.

Technical basis for approach:

In light of the inherent uncertainties associated with attempting to quantify the impact of degradation mechanisms on break frequency, previous applications (e.g., RI-ISI) have relied upon broad categories of pipe rupture potential. These broad categories (high, medium, low) represent an approximate order of magnitude difference in rupture potential and are intended to account for

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uncertainties and ensure reproducible results between various analysts. As stated in the NRC staff's Safety Evaluation of EPRI TR-112657 (ML013470102), this approach requires an in-depth review of plant and industry databases and plant documents in order to characterize each plant's operating experience with respect to piping degradation. If this requirement is met, the assumption that degradation mechanisms (DMs) can be used to determine the relative likelihood of rupture (to an order of magnitude) has been accepted by the NRC staff for RI-ISI applications.

For the purposes of calculating the risk attributable to debris and allocating LOCA frequency, a similar method may be used. Specifically, each break location should be assigned a qualitative rupture potential (high, medium, or low) based on the DMs at that location. The analyst should develop a list of the DMs assumed to be present at each break location and should document how they were derived (see guidance in previous paragraph). A difference in relative frequency of one order of magnitude between each category may be assumed for the purposes of allocating frequency to individual welds. For example, if two welds have the same inner diameter but one is in the "high" category and one is in the "medium" category, the weld in the high category would be 10 times more likely to rupture.

This is represented mathematically as:

$$N_L \times f_L + N_M \times f_M + N_H \times F_H = f(I)$$

$100 f_L = 10 f_M = f_H$
N = # of break locations in the interval
f = frequency, per break location
H,M,L = high, medium, low

This approach preserves the NUREG-1829 LOCA frequency for each interval but allocates higher portions of that frequency to locations where ruptures are expected to be more likely.

Example:

To illustrate this method, the previous table (Table 1) has been augmented with a Qualitative Rupture Potential for each break location. This represents the *relative* likelihood of rupture (high/medium/low) of a break location compared to other breaks in the same interval. The frequency of a break at each location and the associated ΔCDF are also calculated and included in the table below.

Table 2

Pipe ID (diameter - index)	Critical?	CCDP	Qualitative Rupture Potential	Freq for this LOCA interval, (per year)	Freq for location (per year)	ΔCDF = f • CCDP (per year)
8-1	N	0	H	-	1.98E-06	0.00E+00
8-2	Y	1	M	2.20E-06	1.98E-07	1.98E-07
8-3	N	0	L	*Interval 1: [7",8"]*	1.98E-08	0.00E+00
-	-	-	-	***subtotal***	**2.20E-06**	**1.98E-07**
11-1	N	0	L	-	1.56E-08	0.00E+00
11-2	N	0	M	3.30E-06	1.56E-07	0.00E+00

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11-3	N	0	H	Interval 2: (8",11"]	1.56E-06	0.00E+00
11-4	N	0	H	-	1.56E-06	0.00E+00
-	-	-	-	subtotal	3.30E-06	0.00E+00
12-1	N	0	L	-	2.00E-07	0.00E+00
12-2	Y	1	L	6.00E-07	2.00E-07	2.00E-07
12-3	Y	1	L	Interval 3: (11",12"]	2.00E-07	2.00E-07
-	-	-	-	subtotal	6.00E-07	4.00E-07
13-1	N	0	M	-	4.07E-08	0.00E+00
13-2	Y	1	M	-	4.07E-08	4.07E-08
13-3	N	0	H	9.00E-07	4.07E-07	0.00E+00
13-4	N	0	H	Interval 4: (12",14"]	4.07E-07	0.00E+00
13-5	N	0	L	-	4.07E-09	0.00E+00
-	-	-	-	subtotal	9.00E-07	4.07E-08
				Overall total	7.00E-6	6.39E-7

As in the previous example, intervals 2 and 4 have no critical welds and therefore do not contribute to ΔCDF. They are omitted from Table 3 for brevity. Interval 1 has three welds, each with a different qualitative rupture potential. Note the order of magnitude differences in allocated frequency. Interval 3 has three welds, all with a classification of "L." Note that this does not lower the overall interval frequency; rather, it means that there is not a significant difference in the degradation mechanisms present at each location. Therefore, an equal share of the interval LOCA frequency is allocated to each location. The same result would be observed if all three were classified as medium or high.

Table 3

Pipe ID (diameter -index)	Critical?	CCDP	Qualitative Rupture Potential	Freq for this LOCA interval, (per year)	Freq for this location (per year)	ΔCDF = f * CCDP (per year)
8-1	N	0	H	-	1.98E-06	0.00E+00
8-2	Y	1	M	2.20E-06	1.98E-07	1.98E-07
8-3	N	0	L	Interval 1: [7",8"]	1.98E-08	0.00E+00
-	-	-	-	subtotal	2.20E-06	1.98E-07
12-1	N	0	L	-	2.00E-07	0.00E+00
12-2	Y	1	L	6.00E-07	2.00E-07	2.00E-07
12-3	Y	1	L	Interval 3: (11",12"]	2.00E-07	2.00E+00
-	-	-	-	subtotal	6.00E-07	4.00E-07

The total ΔCDF calculated with this method is the sum of the CDF from intervals 1 and 3:

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1.98E-7 + 4E-7 ~ 6E-7 per year

Analysts using this method should also perform a sensitivity study that classifies all critical break locations as having a high qualitative rupture potential. This provides additional assurance that erroneous or non-conservative classification of welds as "low" or "medium" has not lead to an overly optimistic assessment of the risk attributable to debris.

Consistent with RG 1.174, the intent of this sensitivity study is to demonstrate that the risk acceptance guidelines would be met even if reasonable alternate assumptions related to frequency allocation were made. Therefore, if this sensitivity study produces results that are within the RG 1.174 guidelines, no additional justification with respect to LOCA frequency allocation is necessary.

Example of sensitivity study results:

Table 4

Pipe ID (diameter - index)	Critical?	CCDP	Qualitative Rupture Potential	Freq for this LOCA interval, (per year)	Freq for this location (per year)	ΔCDF = f * CCDP (per year)
8-1	N	0	H	-	1.09E-06	0.00E+00
8-2	Y	1	M H	2.20E-06	1.98E-07 1.09E-06	1.98E-07 1.09E-06
8-3	N	0	L	*Interval 1: [7",8"]*	1.09E-08	0.00E+00
-	-	-	-	***subtotal***	**2.20E-06**	**1.09E-06**
12-1	N	0	L	-	2.99E-09	0.00E+00
12-2	Y	1	L H	6.00E-07	2.00E-07 2.99E-07	2.00E-07 2.99E-07
12-3	Y	1	L H	*Interval 3: (11",12"]*	2.00E-07 2.99E-07	2.00E-07 2.99E-07
-	-	-	-	***subtotal***	**6.00E-07**	**5.97E-07**

Note that all critical break locations (8-2, 12-2, and 12-3) are now classified as having a high qualitative rupture potential. This increases the CDF contribution of these break locations as shown above.

ΔCDF = 1.09E-6 + 5.97E-7 = 1.69E-6 per year

Summary of Results		
Method	**ΔCDF (per year)**	**RG 1.174 Region**

1: Bounding Approach	7.2 E-6	II
2: Conservative Partitioning	2.8 E-6	II
3: Semi-quantitative Partitioning	4.0 E-7	III
3.1: Sensitivity Study	1.7 E-6	II

In this example, the sensitivity study the analysis produces results that meet the RG 1.174 risk acceptance guidelines. If this were not true, the modeling choice for LOCA frequency allocation would have been shown to significantly affect the results of the analysis. This places an additional onus on the analyst toIf the risk acceptance guidelines were not met, the analyst must demonstrate that the risk attributable to debris is small (i.e., meets the RG 1.174 guidelines).) through additional analysis or mitigation. NUREG-1855 contains guidance for performing this step and provides the following options:

- Redefine application
- Refine PRA
- Implement compensatory measures and/or performance monitoring

Licensees should select one or more of these options in accordance with the guidance in NUREG-1855, Stage F.

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