Comparison of Approaches for Calculating a Jocassee Dam Failure Frequency

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Objective

The objective of this memo is to explain how the probabilistic risk assessments (PRA) that Duke is preparing will fit into the Oconee Nuclear Site's (ONS) flooding issue and what insights it contributes to our understanding of the issue. Also what are the relative pros and cons to the dam failure probability we have calculated from the Stanford dam failure database?

Introduction and Background

In late 2007, the NRC and Duke Energy Carolinas, LLC (Duke), resolved a Reactor Oversight Process (ROP) finding related to the risk of external flooding (ML063260154). During the evaluation of the risk of this finding as part of the NRC's Significance Determination Process (SDP), the NRC staff discovered that the licensee had used a non-conservative dam rupture frequency in its site external flooding analysis performed pursuant to the Generic Letter 88-20, Supplement 4, Individual Plant Examination of External Events for Severe Accident Vulnerabilities (IPEEE).

During review of the Jocassee dam failure frequency as part of a Reactor Oversight Process (ROP) issue, the staff discovered non-conservative values. These values were also underlying the dam failure frequency contained in NSAC/60, "Oconee PRA a Probabilistic Risk Assessment of Oconee Unit 3," and which were then subsequently incorporated into NUREG/CR-5042, "Evaluation of External Hazards to Nuclear Power Plant in the United States."

A second important piece of information from this ROP analysis was that Duke conducted an inundation study at FERC's direction on the failure of the Jocassee Dam. This study projected an inundation level at the ONS of 18 feet. A flood at this level would flood the safe shutdown facility (SSF).

Jocassee Dam Failure Probability

The calculated dam failure rate used in the ROP issue incorrectly mismatched the failure population (the numerator) and the number of operating dam-years (the denominator).

The Jocassee dam is a rockfill dam consisting of a central earth core and transition filters supported by zoned rockfill shells. Specifically, the calculation

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error identified was that the failed dams included only a small subset of the total population of failed earthen dams, excluding rockfill dams entirely, for a total of two dam failures considered. To have only a resulting two dam failures means that the licensee misapplied its failure exclusion criteria stated in its analysis and/or did not consider the total applicable dam failure population. These errors resulted in a dam failure frequency of 10^{-5} per dam-year. These errors resulted in a lower failure frequency than obtained when correctly performing the calculation.

The NRC would expect that the failure frequency calculation for a rockfill dam such as Jocassee would include as its failed population either rockfill, or both earthen and rockfill, dam failures and as its total population operating dam-years for the matching set of dams.

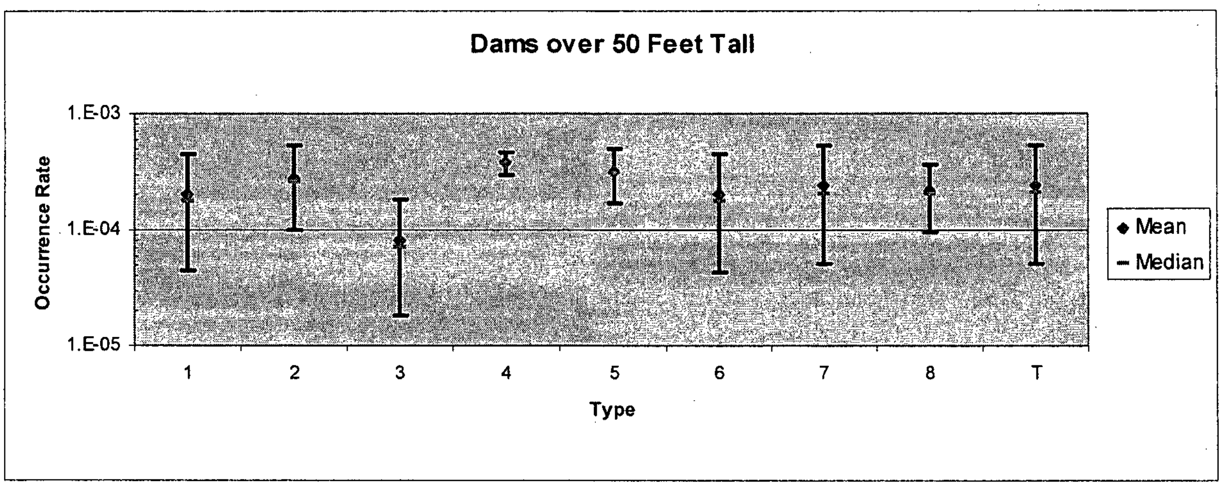
To understand the magnitude of this error for Jocassee, the NRC staff recalculated the Jocassee dam failure frequency using failure data from the National Performance of Dams Program and the dam descriptions and population from the National Inventory of Dams. In order to approach the selection criteria used for NSAC/60, the NRC staff calculation eliminated certain dams from consideration that would affect failure data including those less than 50 feet high due to different construction practices and low head, dams constructed before 1940 due to improved design and construction techniques post-1940, and dams that failed shortly after construction. In doing so, the staff accounted for 34 dam failures (2 rockfill and 32 earthen dams). The corresponding population experience value was 162,569 operating dam-years. The resulting dam failure frequency with this population was 2×10^{-4} failures per dam-year.

The staff notes that any correct correspondence of failed population to total population operating dam-years results in a similar $>10^{-4}$ magnitude dam failure frequency (e.g., rockfill dam failures to rockfill operating dam-years, earthen dam failures to earthen dam operating dam-years, and gravity dam failures to gravity dam operating dam-years). Similar international dam failure results have been 2×10^{-4} to 4×10^{-4} per dam-year (Baecher, Gregory, M.E. Pate and R. Neuville. "Risk of Dam Failure in Benefit-Cost Analysis." Water Research. 16(3):449-456. 1980).

The NRC estimates of dam failure frequencies by type of dam are 10 to 20 times higher than the estimate in NSAC/60 and by extension, NUREG/CR-5042. Illustrative examples of the dam failure probability results are presented in the below table and figure.

Dam Failure Frequencies for Dam Sizes Over than 50 Feet

		Failures	Dam-years	Mean	5%	50%	95%
1	Buttress Dams Over 50 Feet High	0	1876	2.0E-04	4.4E-05	1.7E-04	4.5E-04
2	Arch Dams Over 50 Feet High	2	5667	2.8E-04	1.0E-04	2.6E-04	5.3E-04
3	Concrete Dams Over 50 Feet High	0	19215	8.2E-05	1.8E-05	7.1E-05	1.8E-04
4	Earth Dams Over 50 Feet High	56	144810	3.8E-04	3.0E-04	3.7E-04	4.6E-04
5	Gravity Dams Over 50 Feet High	7	19542	3.2E-04	1.7E-04	3.1E-04	5.0E-04
6	Masonry Dams Over 50 Feet High	0	1987	2.0E-04	4.4E-05	1.7E-04	4.5E-04
7	Multi-Arch Dams Over 50 Feet High	0	77	2.4E-04	5.2E-05	2.0E-04	5.3E-04
8	Rockfill Dams Over 50 feet high	4	19900	2.1E-04	9.6E-05	2.0E-04	3.7E-04
T	Total	69	213074	2.4E-04	5.2E-05	2.1E-04	5.3E-04



Oconee Conditional Core Damage Probability Given a Jocassee Dam Failure

After reviewing the Oconee SPAR model it became evident that if a flood at ONS large enough to inundate the SSF occurs, all three Oconee units would go to core damage. That is that the conditional core damage probability (CCDP) of a flood that inundates the site and the SSF is 1.0. In Duke's letter dated September 26, 2008 to the NRC in response to question three (Attachment 3 page 9), they acknowledge and agree with this understanding when they state: "The failure of both SSDHR and HPI leads to early core damage. Currently, the effects of flooding events resulting in ONS inundation depths greater than 5 ft fall into this category."

The last step in this approach is to calculate the core damage frequency (CDF) from a Jocassee Dam failure. From PRA methods we know that:

CDF = IEF * CCDP

Where:

IEF = Initiating event frequency

For the dam failure case the equations become:

$CDF_{DF} = IEF_{DF} * CCDP_{DF}$

Using the IEF of 1E-4 per dam year and the CCDP of 1.0 values derived above yields:

CDF_{DF} = 1E-4 * 1.0
= 1E-4 per dam year

Jocassee Dam Failure Calculated Via a PRA

The only way to reduce this CDF is to lower the IEF of a dam failure as Duke has acknowledged that the CCDF is equal to 1.0 if the dam fails in a way that inundates the ONS and the SSF. There are two approaches to dealing with this high CDF from dam failure.

The first approach is to scrutinize the dam failure probability derived from the dam failure databases (call it the holistic approach). Without acknowledging that the databases support the above NRC derived IEF, Duke has abandoned this approach. One of their stated reasons is that there is insufficient historical data to support this method. The staff disagrees with this conclusion. While the data is not extensive, it is sufficient to give failure frequencies with 90 percent confidence intervals of about an order of magnitude. This can be illustrated from the above table where the mean failure frequency for a rockfill dam over 50 feet in height is 2.4E-4 with a 90 confidence interval of 5.2E-5 (5%) and 5.3E-4 (95%). These are good statistic in the perspective of internal event PRAs.

Their second and current approach is to develop a Jocassee Dam PRA. This PRA will use standard sequence IEF, event tree (ET), fault tree (FT), and component failures probability, and human reliability analysis (HRA) methods. The end result will supply an overall Jocassee Dam failure frequency as well as individual failure mode frequencies. These individual dam failure mode frequencies will then be used in updating their ONS inundation study. Duke's expectation is two fold. First, that a lower dam IEF will be derived. Their claim is that a detailed model will yield a more accurate – and presumably lower –dam failure frequency. Second. it can be anticipated that Duke will claim that a large percentage of the total frequency will come from sequences that cause ONS inundations at a level that will not flood the site and cause failure of the SSF, in other words within or near the current ONS flood protection capability. To summarize we expect that Duke will come up with a lower dam failure frequency of which only a fraction of the sequences will lead to core damage.

There is an inherent advantage to the PRA approach; it will yield significant insights into the relative strengths and weakness of the various Jocassee Dam systems. This advantage is the traditional strength of the PRA approach. It will allow Duke to focus on those systems and/or components that contribute the most to the overall failure frequency and allow them to potentially strengthen those systems and/or components. This could be accomplished for example by focusing dam surveillance testing and preventative maintenance on those components that contribute most to the dam failure frequency.

However, there are significant weaknesses in this case to the PRA approach. First, the beginning of every ET sequence begins with a corresponding IEF. As stated above, there is not extensive dam failure probability data. This approach will require the analyst to parse this limited data into several and potentially many failure modes and then derive corresponding IEF for each of these failure modes. Duke's stated reason for abandoning this holistic approach is that there is insufficient data to derive realistic dam failure frequencies. From our perspective, this is faulty logic: If there is insufficient data to use the holistic approach there will be significantly worse results from this parsed data. It is the staff's belief that there is sufficient data to use the holistic approach as previously discussed. However, parsing the data will lead to highly questionable results. The standard PRA method to overcome limited data is to substitute expert judgment. It is our expectation that Duke will rely heavily on expert judgment. In this issue, it is not required because of the previously stated understanding of and adequacy of the existing failure data.

The second weakness to the PRA approach is also a data issue. At the bottom of every system FT there are basic events which characterize the failure probability of each of the relevant components which comprise the system. It is our expectation that for some, if not many, of these basic events there will be limited data to support derivation of realistic failure probabilities. As with IEF analysis, the analyst can compensate for this with expert judgment. But this is compromised by the same limits as the IEF data issue.

Conclusions

There is a significant advantage to a dam PRA as it can potentially identify vulnerabilities to the dam that can then be addressed by Duke. This is the inherent strength of PRAs. However, the staff believes that because of the limited failure data, parsing the data will yield less defendable and potentially less realistic dam failure frequencies.