Purpose

To provide a “C” scaling factor for the spurious operation duration estimate, I completed two tasks. First, I used the proposed duration plot that I originally provided to the TI team and compared it to the “C” scaling factor curves provided for AC and DC. I then used a method proposed by Martin Stutzke[1] to evaluate whether the estimated “C” scaling factors were representative. What follows is the process that I followed and the judgment used to arrive at my “C” scaling factor estimation.

Original Proposal

In my initial proposal to the TI team, I developed one CCDF Weibull duration distribution for all cases. This approach was based on pooling various bins of the testing using K-S tests; using the pooled dataset to fit a Weibull distribution; and then use expert judgment to adjust the results to account for differences between test configurations, possibility of spurious operations never clearing, and the typical fire scenarios cable configurations that would be encountered in the plant. The initial pooled data fit is shown in Figure 1.

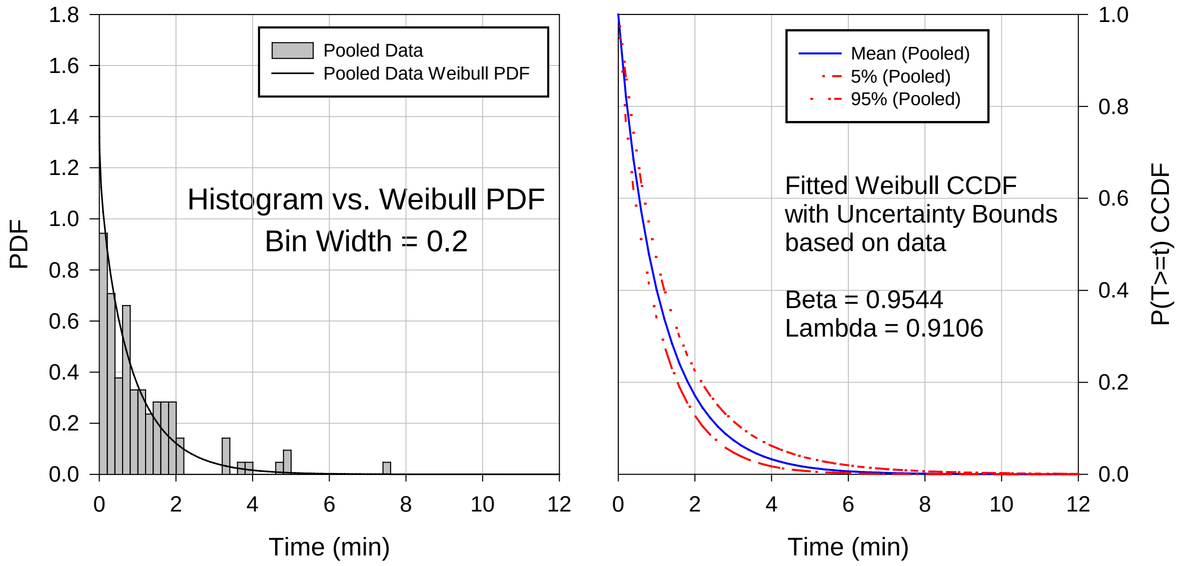

Figure 1. Initial pooled date Weibull Distribution fit

The final pooled data set includes the AC data and DC Data which passed the K-S test. Note that the maximum spurious operation (SO) duration of the pooled data set is 7.6 minutes (456s), while the complete data sets longest SO duration is 1 hour 47 minutes (6417s). There are 5 durations in the complete data set that are longer then the longest in the pooled data set. These duration in seconds are; 811, 1052, 1195, 1427, and 6417.

Next I reviewed the PIRT panel conclusions on the parameters that affect spurious operation duration and examined how these parameters and the differences between the experimental setup and the actual in-plant configurations. Based on this review, I found two parameters that I believe have a first

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[1] See page 8 for Marty’s proposed approach

order effect on duration that indicate to me the experimental data may not fully represent actual plant fire configurations. These are discussed as follows.

First order effect on duration

Thermal Exposure Conditions have an effect on duration. The PIRT panel identified this element as having a “high impact.” For severe thermal exposures, cables quickly cascade through failure modes (insulation resistance is reduced quickly) compared to a less severe thermal exposure where the cable cascade through the failure modes at a less rapid rate (insulation resistance is reduced over a longer time frame). The tests were designed to fail the cables in a reasonable amount of time 10-30 minutes as these were timeframes that were considered risk significant by the test group. To accomplish this objective light cable tray loading were used. Most of the AC tests used 1, 3, 6, or 12 cable bundles, with the 12 bundle configuration being the only one that provides some protection to the cables monitored for electrical response from the thermal conditions. Limited fully loaded cable trays were conducted. Thus, in NPP cables can be exposed to a range of thermal insults. Cables on the bottom of the cable tray may experience severe thermal conditions if the exposure is in the flame or plume region, while cables on the side and top are somewhat shielded from flame/plume exposures and any cable buried in the middle of the cable tray (shielded from direct thermal transport mechanisms radiation, convection) are exposed to the less severe exposure. Unfortunately, the analysis will never know where the cable is located within a fully or even partially full cable tray. Figure 2-6 (AC results, reproduced below, Figure 2) in NUREG-2128 shows the trend thermal exposure has on SO duration, while Figure 4-10 (DC results, on the next page, Figure 3) in NUREG-2128 shows a less substantial trend. Note that the pooled AC data doesn’t include the flame data and the DC data doesn’t include the radiant data. As such, I believe the pooled experimental dataset with respect to duration needs to be increased to account for the experimental protocol was designed to damage the cables in a short (risk significant) timeframe which doesn’t adequately represent the types of thermal exposure cable in NPPs may experience.

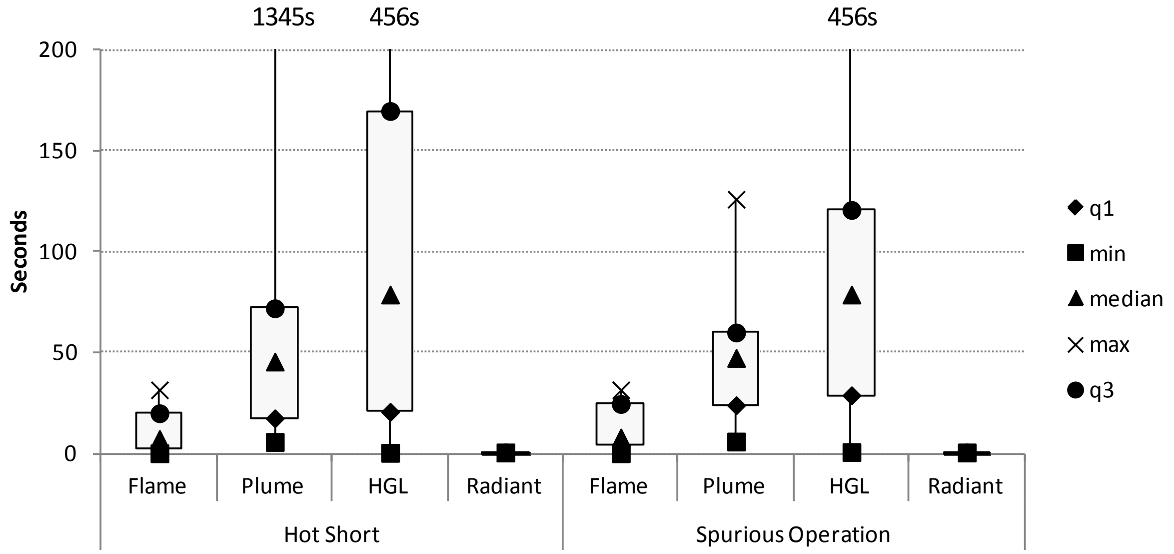

Figure 2. Thermal exposure conditions box plot, duration, AC tests

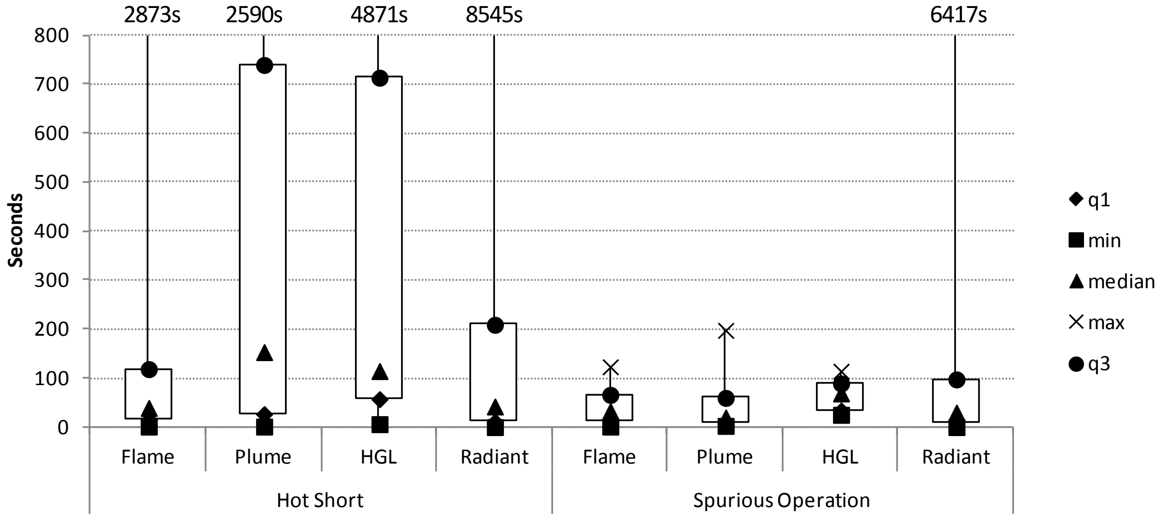

Figure 3. Thermal exposure conditions box plot, duration, DC tests

First order effect on duration

Time-Current Characteristics: the PIRT panel identified that the fuse and breaker size used in the circuit can have “high impact” on the duration of the spurious operation. However, the experimental data doesn’t support a breakdown of spurious operation duration based on fuse sizing because of the circuits used. The PIRT panel suggested there is a threshold possibly around 10A where circuits with larger fuses and typical control cable conductor sizes will take a long time for the fuse/breaker to clear, or they may not clear at all. No meaningful information can be extracted from the data to support any quantitative adjustment to this effect on SO duration because the larger fuses used in testing were associated with a control circuit who’s spurious operation characteristics were instantaneous (i.e., once the spurious operation occurred the circuit changed states and the circuit (not the cable failure) cleared the spurious operation). Some insights of this phenomenon can be obtained from hot short duration plots presented in NUREG-2128 Figure 4-32 (reproduced on the next page, Figure 4). Here you can see that as the fuse sizing is increased the duration of the hot short in increased. Again, because the circuit that used the 35A and 15A fuses don’t have spurious operation durations associated with them, the actual spurious operation duration data presented in the pooled data set are missing this contribution of circuits in the plants that use larger fusing and the circuit can experience spurious operations that are longer than instantaneous.

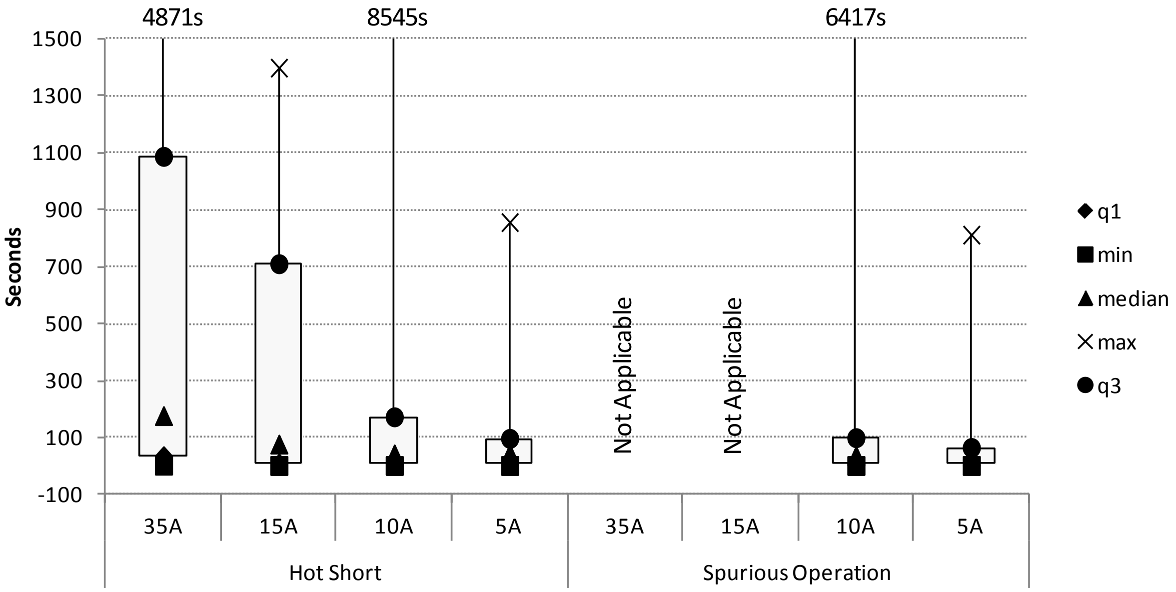

Figure 4. Fuse size, duration, box plot

Given this information, I believe that data represents a lower portion of the actual duration probability distribution curve. This is based on the 1st order effects identified above (thermal exposure conditions, Time-Current Characteristics) applied to the difference between the experimental setup and the in-plant conditions. These differences reflect the limited raceway loading and the severe thermal conditions in testing vs. the range of thermal conditions and typically heavier tray loading found in actual plants configurations.

Additionally, for the DC case, because there were several tests where the fuses didn’t clear, I propose that a minimum duration probability of 0.03 be used to capture these cases. In addition, the AC minimum should be 0.01, consistent with the proposed value of FAQ 51. Give this information I then proposed an adjusted Weibull CCDF curve based on data and expert judgment. My adjustments to the pooled data Weibull distribution account for the 1st order effects described previously and the fact that I believe in-plant conditions will still be dominated by very short SO durations, but for the fraction of spurious operations that are not classified as short in duration, the actual in-plant conditions should cause longer durations than the data represents. These proposed results are shown in Figure 2.

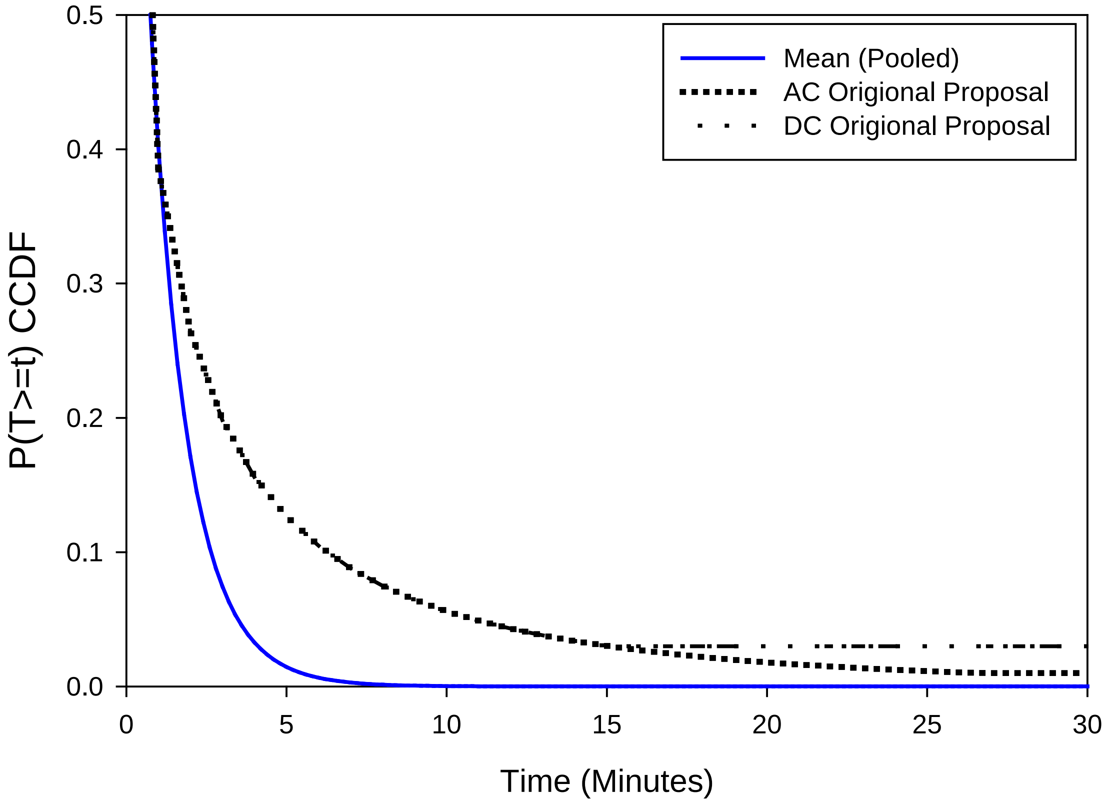

Figure 2. Original proposal

Following the first TI team meeting in January 2013, the TI team requested that I provided uncertainty bounds to the associated distributions I proposed. At this point, I requested assistance from Martin Stutzke[2] of the NRC to support a technically adequate method for assigning uncertainty bounds to my proposal. This resulted in the detailed Weibull analysis, and application of various reliability engineering methods which ultimately resulted in the developing the scaling factor method. During the second TI team meeting in April 2013, Martin presented his approach and the TI team agreed that this was a structured and technically adequate approach to determine the appropriate duration curve and associated uncertainties. However, because there is no physical model currently available to draw conclusions on the adequate "C" scaling factor, the TI team requested the proponents be asked to use their expert judgment to proposed "C" scaling factors for the AC and DC duration plots. The following is in my expert judgment in developing the appropriate "C" scaling factor and associated basis.

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[2] It should be noted that Mr. Stutzke was an original expert proponent on this project but subsequently couldn't commit to this project because of his increased involvement of the development of the Level 3 PRA effort within the NRC. However, experience and support provided alternative approaches to the problem that have technical merit.

Comparison approach

Using the “C” scaling factor plots that were separately provided for AC and DC, I overlayed my original proposed distribution and identified the “C” scaling factor curve which most closely represented my original proposed distribution. This overlay for AC is shown in Figure 3.

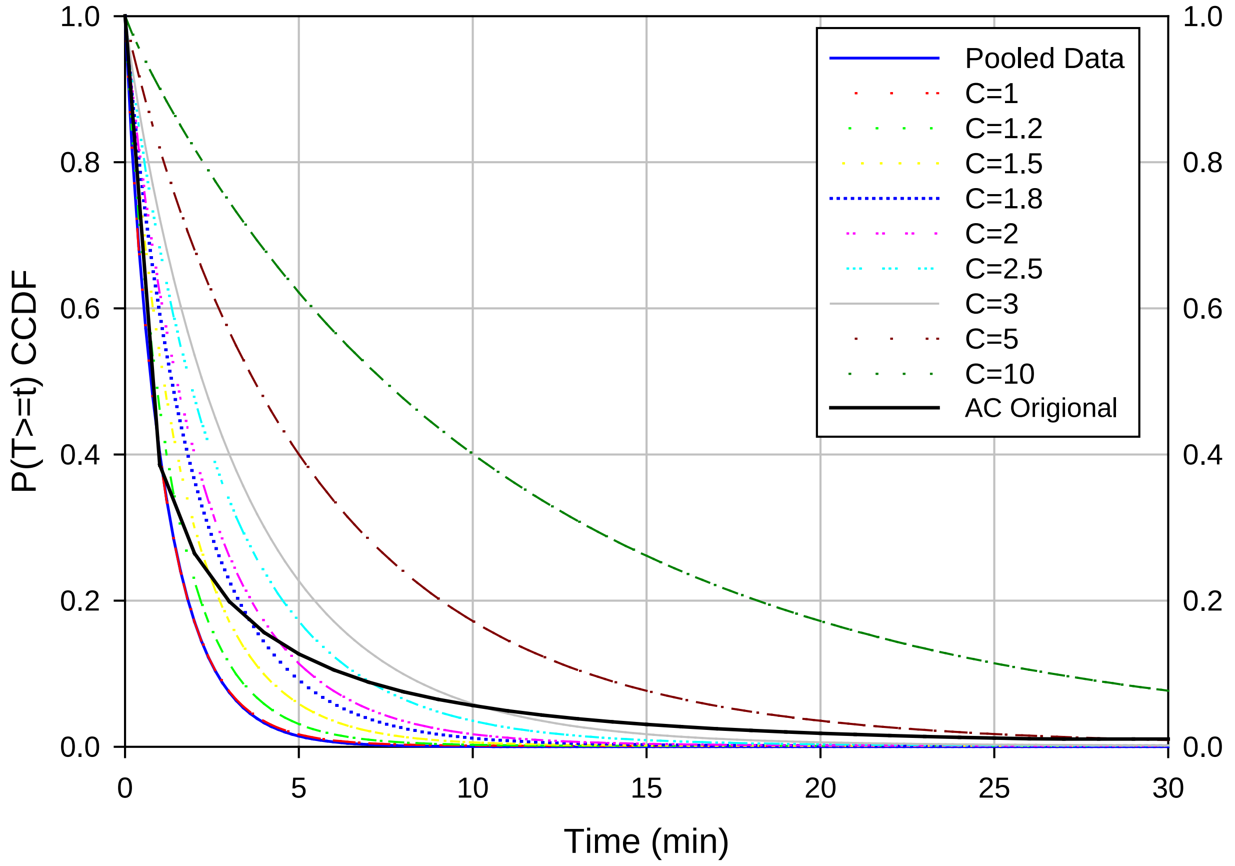

Figure 3. Overlay of AC original Proposal on C scaling factor plot

From a purely graphical comparison of my proposal with the “C” scaling factor curves provided, I would suggested that C = 2.5, based on the fact that from 0 to ~5 minutes it is difficult to make a comparison due to the difference in the shapes of the curves and after 10 minutes the curves C=3 and less are beginning to converge. Thus my proposed distribution falls between C=1.8 and C=5, focusing in on the 5-15 minute range, my proposal matches closes to the C=2.5 curve.

Similarly, for the DC results shown in Figure 4, my proposal falls somewhere between C=1.8 and C=2.5. Focusing on the 5-15 minute range my proposal corresponds to a C=2.2.

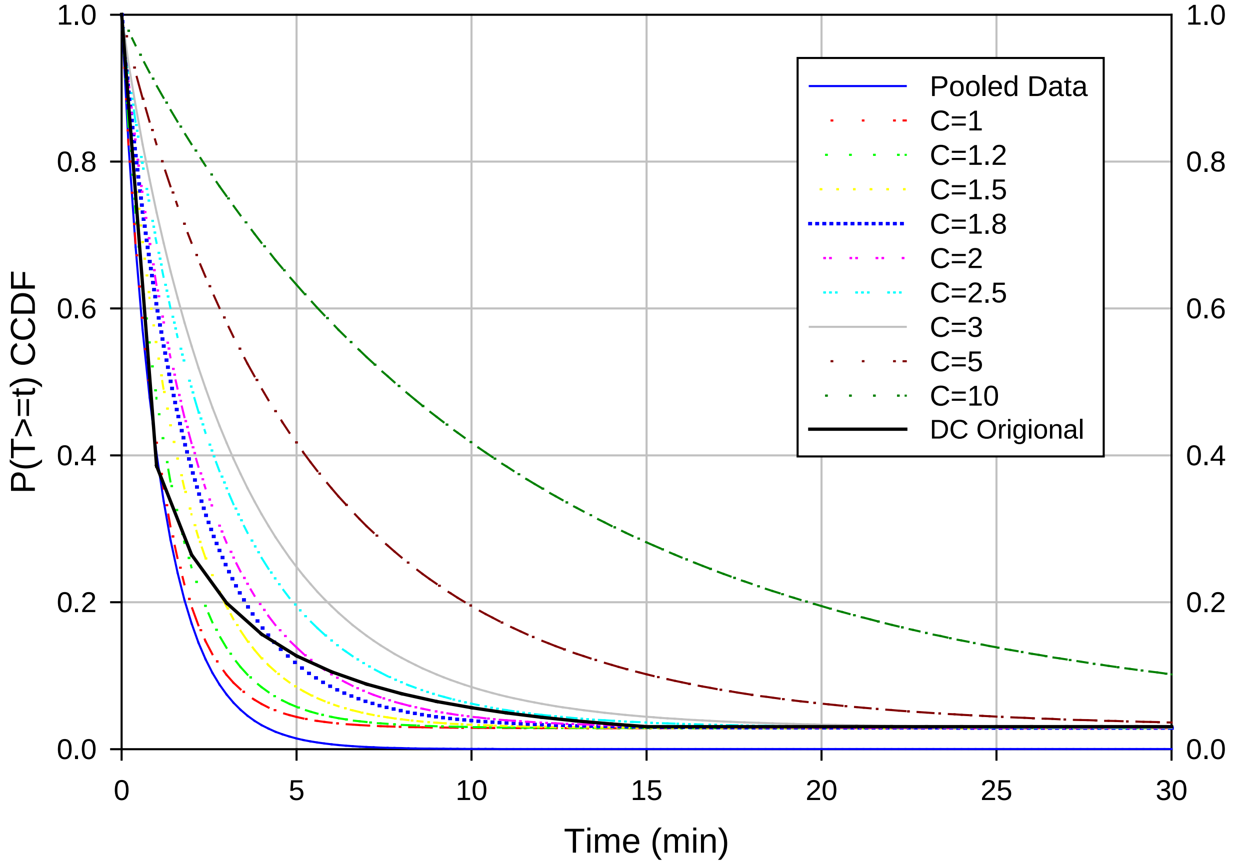

Figure 4. Overlay of DC original Proposal on C scaling factor plot

Martin Stutzke’s suggested approach to selecting the time-scaling factor

Mr. Stutzke had previously proposed an approach to adjusting the results obtained from the analysis of experimental fire-induced hot short durations to account for in-plant conditions. This approach uses a time scaling factor, c, and a floor probability, p_F, which is the probability that a hot short never clears. Parameters λ and β denote that Weibull scale and shape parameters, and were determined from the pooled data set using Bayesian techniques. Note that the team has decided to use two different floor probabilities (0.03 for DC circuits, and 0.001 for AC circuits).

In this approach, the mean probability that the duration of a hot short, T, exceeds a specified value is:

– (1)

The question is how to select the time scaling factor, c.

One possible approach to selecting the time scaling factor is to use expert judgment. Another approach, which is explored below, is to anchor the S(t) curve to known or assumed points. Let t_A denote such a time anchor point, and assume that we want to specify that $S(t_A)$ equals a fixed percentage above its steady-state value of p_F. That is, we want:

— (2)

where f is a small percentage (say 1%, 0.5%, or 0.1%). We can solve the above equation for c in terms of this information:

– – —— (3)

This equation shows that c depends on the floor probability, which in turns depends on the circuit type (DC or AC). As an initial question, we should decide if we should use the same time scaling factor and time anchor points for DC and AC circuits. Table a provides the ratio c/t_A for various values of f and p_F:

Table 1. Ratio c/t_A

β	λ	
0.9521	0.9222	

	floor probability	
	DC	**AC**
f	**0.03**	**0.001**
5.0%	0.129	0.083
1.0%	0.102	0.071
0.5%	0.094	0.066
0.1%	0.079	0.058

There’s a notable difference between the DC and AC circuit types. Moreover, we need to select a time anchor point, t_A, that has a reasonable technical basis. For example, we could assume that the experiments were terminated after 60 minutes, which provides the basis for the floor probabilities (that is, if not cleared in 60 minutes, assume that it will never clear). So, one could argue that $t_A = 60$ minutes. Doing so gives time scaling factors ranging from 4.7 to 7.8 for DC circuits, and ranging from 3.5 to 5.0 for AC circuits.

Another way to set a time anchor is to limit the amount of extrapolation we are willing to accept. In technical terms, the hot short duration curve is a parametric fit to a Weibull complementary cumulative distribution function. We’re interested in extrapolating the curve beyond the range of the observed experimental data so that we can apply it to basic events that appear in a fire PRAs. Although we have a large number of data points (106) that confirm the suitability of the Weibull form, there is some uncertainty involved in using the fitted curve outside of the observed experimental data range on which it is based. The maximum duration in the pooled data set is 7.6 minutes. So, we could establish a time anchor point that is a small multiple of this maximum observation time. For example, if we set $t_A = 30$ minutes (roughly four times the maximum observed time), then we get the following:

Table 2. Ration c/t_A and estimated C for various f values

β	λ			
0.9521	0.9222			
	floor probability		t_anchor	30
	DC	**AC**	**DC**	**AC**
f	**0.03**	**0.001**	**0.03**	**0.001**
5.0%	0.129	0.083	3.9	2.5
1.0%	0.102	0.071	3.1	2.1
0.5%	0.094	0.066	2.8	2.0
0.1%	0.079	0.058	2.4	1.7

This table indicates that if we select a time scaling factor, c, equal to 2, then we know that the S(t) curve will be no more than 0.5% above the floor probability for both DC and AC circuits when t = 30 minutes. The problem with the anchor point approach is that it is not related to a failure of physics model. But, it is consistent with the observed experimental data and the TI team’s expert judgment about the floor probabilities

Gabriel Taylor’s application of Martin Stutzke’s framework:

Since the floors take into consideration the fact that some shorts may not clear, and the basis of the Weibull distribution is the pooled AC and DC datasets, I decided to select an anchor (t_A) representing the maximum duration of the data that exists. Excluding the one case where the short lasted for a significant duration. I found that no spurious operation lasted longer than 25 minutes. Thus, using t_A=25 minutes for both AC and DC, and using the equation above the following C-factors were calculated.

Table 3. Application of Mr. Stutzke’s approach using Mr. Taylors anchor input

	Floor probability		t_A =	25
	AC	DC	AC	DC
f	0.001	0.03	0.001	0.03
5.0%	0.082	0.128	2.1	3.2
1.0%	0.070	0.102	1.8	2.5
0.5%	0.066	0.093	1.6	2.3
0.1%	0.058	0.078	1.4	2.0

Conclusions and Gabe’s final position on scaling factor for AC and DC

Thus, Mr. Stutzke’s approach provides confirmation that my estimates previously are within range. Therefore, I’m proposing a C=2.5 for the AC duration curve and a C=2.2 for the DC duration curve. Figure 5 shows these curves.

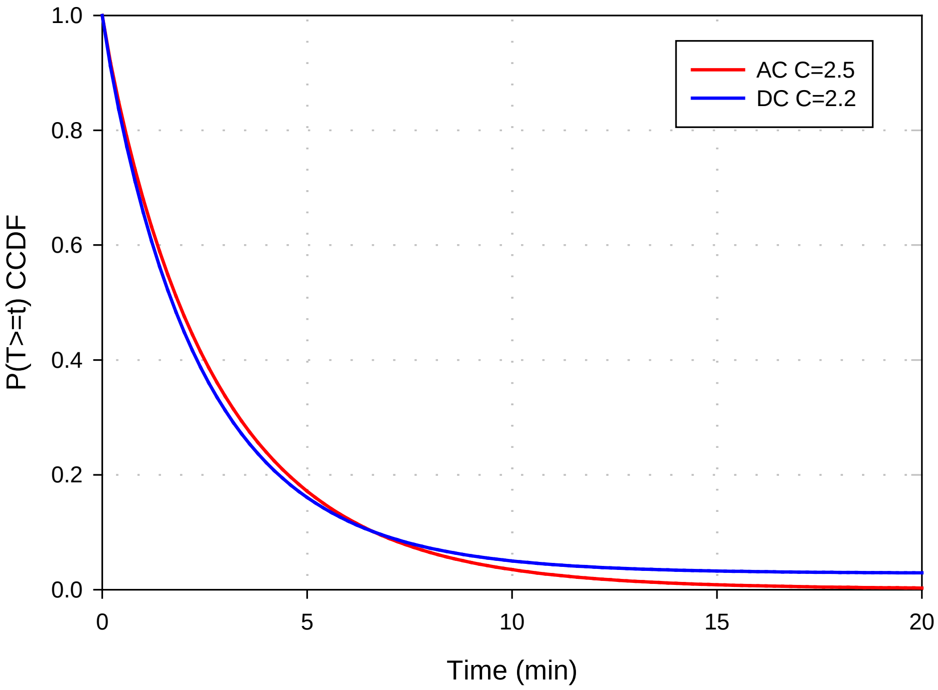

Figure 5. Final Proposal on “C” scaling factor for Gabriel Taylor