Common-Cause Failure (CCF) Work Summary and Conclusions

1 Introduction

The paper provides a summary of the CCF work completed by the Office of Nuclear Regulatory Research (RES) with support from Idaho National Laboratory (INL) associated with Office of Nuclear Reactor Regulation (NRR) User Need NRR-2015-009. Specifically, NRR requested that RES explore the use of causal alpha factor method (CAFM) and existing CCF parameters to:

1. Determine whether causal alpha factors more appropriately characterize the risk associated with a licensee performance deficiency (PD) in Significance Determination Process (SDP) risk assessments (addressed in Section 2.1).
2. Identify if any data gaps exist for CAFM implementation, including any resource implications (addressed in Section 2.2).
3. Develop guidance on how to apply the CAFM in event and condition assessment (ECA) (addressed in Section 2.3).
4. Investigate the practice of common-cause component groups (CCCGs) within the Standardized Plant Analysis Risk (SPAR) models (addressed in Section 3).
5. Evaluate the existing alpha factors used in the SPAR models to determine if they accurately reflect existing industry performance, including more recent practices designed to prevent CCFs (addressed in Section 4).

The complete work plan is provided in Appendix A. A brief summary of the main tasks, along with key observations, questions, and conclusions are provided in the following sections.

2 Application of the CAFM

RES was tasked to continue the development of the CAFM and perform feasibility tests to improve the current state-of-practice.[1] As part of this effort, RES was tasked with the following:

- Calculate causal alpha factors for all CCF modeled components in the SPAR models.
- Review of the causal alpha factors to identify any data gaps and/or if resource implications existing in applying the CAFM in ECA.
- Determine whether causal alpha factors more appropriately characterize the risk associated with a licensee PD in SDP risk assessments.
- Develop guidance on the how to apply the CAFM in ECA.

[1] Initial development of the CAFM was performed by University of Maryland as part of NRC collaborative research grant NRC-04-10-164 as documented in “An Extension of the Alpha Factor Model for Cause-Based Treatment of Common-Cause Failure Events in PRA and Event Assessment,” (ADAMS Accession No. ML13322B210). Follow-up development activities conducted by INL included a feasibility study of alternative CCF models as a part of NRC contract NRC-HQ-60-13-D-0006 and the calculation of Bayesian priors for each of the five cause groups (design, component, environment, human, and other/unknown) as a part of NRC contract NRC-HQ-60-14-D-0018. See INL/LTD-14-33376, “Feasibility Study of Developing Alternative Common-Cause Failure Model for Event Assessment,” (ADAMS Accession No. ML20279A410) and INL/LTD 17-43723, “Developing Generic Prior Distributions for Common Cause Failure Alpha Factors and Causal Alpha Factors,” (ADAMS Accession No. ML20279A420) for additional information.

The following sections summarize the key observations from these CAFM development activities.

2.1 CCF Cause Grouping Scheme

The initial plan for the CCF cause grouping scheme was to adopt the existing CCF data classification cause groups (see Table 1 below). Adopting the existing classification cause groups provides two benefits. First, the five existing groups (component, design, environment, human, and other/unknown) have cause-specific Bayesian priors that were calculated as part of previous work. Second, no changes were required to be made in the CCF data classification process. However, further review of the existing cause grouping scheme indicated that the grouping scheme is not optimal when considering risk evaluations of the licensee PD. Specifically, many of the failure causes currently used are not likely to result in PDs. In addition, many of the failure causes likely to result in a licensee PD are currently grouped in the human CCF cause group. Therefore, use of the grouping scheme would not differentiate between causes within this groups that are due to different underlying conditions (e.g., procedure deficiency vs. inadequate maintenance).

Table 1. Existing CCF Cause Grouping Scheme

CCF Cause Group	Failure Cause
Component	Internal to component; piece-part
	Setpoint drift
	Age or wear
Design	Construction installation error or inadequacy
	Design error or inadequacy
	Manufacturing error or inadequacy
Environment	Ambient environmental stress
	Extreme environmental stress
	Internal environment
Human	Accidental human action
	Inadequate maintenance
	Human action procedure
	Inadequate procedure
Other/Unknown	State of other component
	Other
	Unknown

Due to the level of effort to change the existing CCF cause grouping RES continues to use the existing scheme in the application of the CAFM. If future user experience indicates that modifications may be beneficial, CCF cause grouping will be revisited in future work. Table 2 below shows likely PD categories mapped to existing CCF cause groups. Risk analysts may seek RES assistance in ensuring the most appropriate CCF cause group is chosen for a specific ECA.

Table 2. Likely PD Categories for Existing CCF Cause Groups

CCF Cause Group	Failure Cause	Likely PD Category
Component	Internal to component; piece-part	[redacted]
	Setpoint drift	
	Age or wear	

CCF Cause Group	Failure Cause	Likely PD Category
Design	Construction installation error or inadequacy	Design and Engineering
	Design error or inadequacy	
	Manufacturing error or inadequacy	
Environment	Ambient environmental stress	
	Extreme environmental stress	
	Internal environment	
Human	Accidental human action	Corrective Action Program Maintenance Management Oversight Operations Procedures
	Inadequate maintenance	
	Human action procedure	
	Inadequate procedure	
Other/Unknown	State of other component	
	Other	

Although the existing CCF cause groups do not align perfectly with typical PD categories, the use CAFM best characterizes the CCF risk impact within SDP risk assessments by focusing on a specific failure causes that result in the licensee PDs. The existing alpha factors consider all failure causes and, therefore, likely result in greater uncertainties if used in ECA.

2.2 Evaluation of Causal Alpha Factors

INL completed preliminary calculations of causal alpha factors for CCF-modeled components currently included in the SPAR models. Although some minor issues (e.g., rule name errors, inconsistency in data range selections, and discrepancies in the number of independent events and CCF events) were identified in the calculated causal alpha factors, there does not appear to be any data gaps in causal alpha factors for the various causes, components, failure modes, or CCCG sizes that would cause issues in applying the CAFM in ECA.

Larger causal alpha factors (when compared to existing alpha factors with updated prior) were observed for the design and environment CCF cause groups for most components and failure modes. The other three cause groups (component, human, and other/unknown) have smaller causal alpha factors, although the human cause group does have larger causal alpha factors for emergency diesel generators (EDGs) and turbine-driven pumps (TDPs). Therefore, the CCF risk impact would increase when applying the CAFM for the following cases:

- Design issues for almost all components and failure modes;
- Environment issues for all components and failure modes; and
- Human issues (inadequate maintenance, procedure, or operator performance) for EDGs and TDPs.

The CCF impact will likely decrease when applying the CAFM for other CCF cause groups for most components and failure modes. Since the design and human CCF cause groups will be the most often used in SDP risk assessments, analysts can expect the CCF impact to increase in many SDP assessments if CAFM is used.

2.3 Guidance for CAFM Application in ECA

Although the CAFM could be applied either in the base SPAR models or in ECA, inclusion of CAFM in the SPAR models is not implemented at this time because such inclusion would require significant effort while practical benefits can be more easily achieved by application within ECA. Application of the CAFM in ECA is relatively straight forward via the ECA module or using a change set in the normal SAPHIRE platform. An analyst can modify the applicable alpha factor template events in a change case by setting them to the values of the applicable causal alpha factors. The calculated causal alpha factors will be stored on the RASP toolbox webpage. In addition, technical support from RES will be available for the selection of the appropriate failure cause, if needed. Appendix B provides detailed guidance of applying the CAFM in ECA.

3 CCCG Modeling in the SPAR Models

Some SPAR models have multiple CCCGs for the same components (up to five or more for some components). This issue is largely affected by the modeling of redundant components in multi-unit sites. The modeling of components in multiple CCCGs could lead to potential overestimation of CCF. INL was tasked to investigate CCCGs in the SPAR models to determine issues associated with the current approach and recommend a consistent approach to CCCG modeling in the SPAR models. The following are key observations from the investigation of identified issues and plans to address these issues:

- *CCCG Consistency and CCF Probability Overestimation*. Currently there are no guidelines on whether components should be modeled in only single CCCG or can be included in multiple CCCGs. The CCCG modeling is by discretion of the SPAR model developer, which leads to inconsistences in CCCGs for similar SPAR models. Including more than one CCF event for a single component/failure mode in the same fault tree without special treatment artificially overestimates the component and system unreliability. A recent SAPHIRE enhancement, in conjunction with another planned enhancement, provides the tools necessary to address this issue and ensure the CCF impact is appropriately calculated. The recently completed enhancement involves the ability to expand existing CCF basic events to generate subgroup events, which can then be placed in the appropriate fault tree locations. A manual step of incorporating these subgroup events into the appropriate fault tree locations is then required. The logic structure of the fault trees, in conjunction with existing SAPHIRE post-processing functions, eliminate illogical combinations of subgroups yielding a more appropriate CCF impact. The pending enhancement involves the application of convolution factors in cut sets containing EDG failure to run CCF subgroup events. Currently, SAPHIRE does not recognize these autogenerated subgroup events as normal basic events. An existing SAPHIRE feature of convolution event mapping needs to be modified to recognize the subgroup events to ensure the proper application of convolution factors to cut sets containing these subgroup events. These enhancements will yield more accurate CCF impacts as well as reduce the current overestimates associated with CCF modeling. A few notes regarding this approach are presented below:
  - There may still be potential issues with cross products between trains and support systems that must be worked out by SPAR model developers. Another pending SAPHIRE enhancement (train level identification), in conjunction with test cases using high importance CCCGs (e.g. EDGs), should provide key insights prior to performing global modeling changes.
  - It should be noted that the application of this new approach will likely result in differences in the calculated CCF probabilities when compared to the existing approach. For example, a CCF group of 2 components could now be a subgroup of a CCCG with 3 or more components. For a CCCG size of 2, the CCF probability of

both components is determined by α_2 using the equation $Q_2^{(2)} = \alpha_2 * Q_t$. However, as a subgroup of CCCG size of 3, the CCF probability of 2 components is determined by equation of $Q_2^{(3)} = \frac{1}{2}\alpha_2 * Q_t$. Sine the α_2 in CCCG of 2 could be very different from one half of α_2 in CCCG of 3, the CCF probability of two components from the new approach could be significantly different from the existing value.

– While these enhancements are planned to be implemented, a completion date has not been scheduled. RES and NRR will need to determine the priority of these enhancements given existing and other planned work at INL.

- *CCF Data Classification Limitations*. It is generally considered beyond the state-of-practice to consider inter-system and multi-unit CCFs.[2] However, the SPAR models currently include some multi-unit CCF events for shared systems (e.g., EDGs, service water) using the same alpha factors used in intra-system CCF modeling. However, this presents an issue because the characterization of CCF failure data is normally limited to intra system CCFs. Therefore, inter-system and multi-unit CCFs are not considered in the CCF data process and are not reflected in the existing alpha factors. Using the existing CCF parameters for inter-system or multi-unit CCF may overestimate or underestimate the risk impact. Given the data limitations on shared systems at multiple units and inter-system CCF, CCCGs in the SPAR models, limiting CCCGs single unit, intra-system may be the best option. However, some latitude may be warranted for modeling CCF for multi-unit, shared systems such as EDGs and service water. Model developers should note that applying single unit, intra-system based CCF parameters to these CCF events adds additional parameter uncertainties to the model.

4 Evaluation of Existing CCF Parameters and Data

Whether the existing CCF parameters (i.e., alpha factors) are representative of current licensee performance has been questioned by both internal and external stakeholders in the past few years. To shed light on this matter, RES examined a few key areas to glean potential insights on whether the existing CCF parameters are representative of current licensee performance. The following sections describe key areas and observations from a systematic investigation of how CCF data would affect the calculation of alpha factors. Note that industry stakeholders have mentioned in various forums that new practices to prevent or minimize CCFs are not reflected in much of the existing data. However, industry has not provided specific examples of these new measures. The staff believes that the effects of measures such as staggered maintenance are already reflected in the existing CCF data.

4.1 Effect of Partial CCF Events

Partial CCFs are events that only result in a CCF of some number of components within a CCCG (e.g., 2 out of 4 EDGs fail from a common cause) or events that are weighted by factors (e.g., timing, coupling factor, etc.), which do not constitute a complete CCF (e.g., 2 out of 2 EDGs fail but failures were separated by more than one surveillance period). To evaluate the effect of partial CCF events on the current alpha factor parameter estimations, existing CCF events were reviewed for three test cases [EDG failure to start (FTS), EDG failure to run (FTR),

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[2] SPAR models typically only model multi-unit CCFs for a few risk significant shared systems (e.g., EDGs and safety related service water systems). A few SPAR models include inter system CCFs (e.g., reactor core isolation cooling and high-pressure coolant injection TDPs and residual heat removal and containment spray MDPs).

and motor-driven pump (MDP) FTS]. These test cases were selected because they represent components and failure modes where CCF potential has shown to have a significant impact in ECA. In addition, the recent data review performed by the Pressurized Water Reactor Owners Group (PWROG) focused on these three cases. Firstly, staff determined if the CCF events for those test cases are complete or partial CCF events. Alpha factors were then recalculated for these three test cases using only complete CCF events and then compared to the existing alpha factors.

The assessment indicates that the impact of partial CCF events on the alpha factors varies from a minimum to significant impact. For α_2 in CCCG of 2, using only complete CCF events reduces the alpha factor from 6 to 27 percent for the three cases (MDP-FTS, EDG-FTS, EDG-FTR). For α_3 in CCCG of 3 and α_4 in CCCG of 4, the three cases have a smaller impact (less than 10 percent) when partial CCF events are removed. However, for α_2 in CCCG of 3 or CCCG of 4, the impact is more significant (approximately 20 to 80 percent). The impact of removing partial CCF events appears to be proportional to the number of partial CCF events versus complete CCF events in the specific impact vectors of various cases.

4.2 Effect of Upward Mapping of CCF Events

The majority of complete CCF events in the CCF database are for smaller (i.e., 2 or 3) CCCGs. Therefore, to convert these events to larger (4 or more) CCCGs, they must be mapped up. There is some concern that the current mapping technique is potentially overestimating potential CCF for larger CCCGs. To evaluate the effect of upward mapping of CCF events, the CCF events in same three test cases (EDG FTS, EDG FTR, MDP FTS) were categorized according to their CCCG size. Alpha factors were then recalculated for these three test cases without upward mapping and then comparted to the existing alpha factors. This assessment indicated that the upward mapping of CCF events for the three test cases significantly increase the alpha factors (between 65 to 88 percent) for the most common CCCG sizes.

4.3 Effect of Prior Date Range

There is currently one CCF Bayesian prior used for the calculation of all alpha factors in the SPAR models, which uses all CCF events from 1991–2005. It is important to know the sensitivity of the current alpha factors to the use of this prior (i.e., whether the current alpha factors are dominated by the prior and, therefore, insensitive to the Bayesian updating with component specific data). Sensitivity analyses using the updated (1997–2015) Bayesian prior for the same three test cases were performed.

Although significant reductions (approximately 50 percent) were observed in the number of failures between the two priors, the calculated alpha factors did not show significant differences for the three test cases. Specifically, alpha factors were reduced by 3 to 10 percent when the updated Bayesian prior was used. When reviewing the '*a*' shape parameter for alpha factors α_2, α_3, α_4 in the original (1991–2005) and update (1997–2015) priors, differences between the '*a*' shape parameters are quite small (e.g., for CCCG of 2, the shape parameters '*a*' for α_2 are 0.435 and 0.469, respectively). The '*b*' shape parameter for alpha factors α_2 has larger differences between the two priors (10.2 vs. 22.4), but the values of these prior distribution parameters are much smaller when compared to other parameters in the Bayesian update equation (e.g., the observed independent failures), which is in the range of 100 or more in the case studies. Therefore, the priors have much less impact on the posterior mean value in these three examples. The priors would have more impact in cases where there are fewer independent failures and CCFs in the observed data.

4.4 Effect of CCF Data Date Range

A review of CCF data for different date ranges was performed to determine the effect of the CCF data date range on the current alpha factors. It should be noted that the assessment discussed above showed that although the use of older data has a significant effect on the prior, the corresponding alpha factors were not significantly affected. The 2015 CCF parameter estimations used a date range from 1997 to 2015 in its alpha factor calculations. Whether this date range should be changed (e.g., latest 10 or 15 years) to reflect the most recent industry performance is a valid question; however, the choice of the data range is likely a very subjective decision. A breakdown of the CCF events for three discrete periods for three test cases is shown in Table 3 below.

Table 3. Breakdown of CCF Events for Three Different Periods

Component/Failure Mode	1997–2015	1997–2005	2006–2015
ALL-MDP-FS	21	19	2
EPS-EDG-FS	4	3	1
EPS-EDG-FR	6	3	3

A snapshot of total number of CCF events and independent failure for the three different periods is shown in Table 4 below. The overall period from 1997 to 2018 was chosen to evaluate the impact of time periods on the most recent data.

Table 4. Total Number of CCFs and Independent Failures for Three Different Periods

Failure Type	1997–2018		1997–2008		2009–2018	
	Counts	Counts/Year	Counts	Counts/Year	Counts	Counts/Year
CCF	382	17.4	297	24.8	85	8.5
Independent	8365	380	5092	424	3273	327

Revised alpha factor calculation examples were not performed due to the lack of appropriate priors for the different periods. However, one can see from the counts in the tables above that the most-recent 10-year period has fewer CCF events and independent failures, which could create the following issues: (1) the developing of CCF priors would be a challenge with the current methodology due to more zero data points; (2) the posterior CCF parameters would be dominated by priors due to scarce data; and (3) the double use of CCF data in the Bayesian update process (in both priors and observed data) would become more significant and problematic.

As stated earlier, industry stakeholders have not provided examples of new practices that were put in place in the past 10 to 15 years to reduce CCFs (e.g., unique CCF defenses) and, consequently, have not demonstrated that the older data (late 1990s and early mid-2000s) may not be representative of current licensee performance. Without evidence of new practices, the decision regarding the appropriate data period is subjective and requires a balance between eliminating representative data and having some level of sensitivity to potential changes in new data and trends.

Selection of the CCF data period is part of the overarching issue that exists for all SPAR model parameters that is being discussed with the PWROG. The staff will use data periods consistent with those of other parameters. The recurring data update performed by INL is expected to adopt a 10-year rolling window date range for most parameters including CCFs. This next data update is expected to be completed in 2021.

4.5 Use of Component-Specific Bayesian Priors

The use of generic CCF prior is considered a potential uncertainty in CCF parameter estimates because all CCFs from all components and failure modes are considered. Therefore, the existing alpha factors could be influenced by other component types and failure modes. No test cases have been performed using component-specific Bayesian priors due to the additional level of development effort needed. Note that the component-specific CCF priors may not have significant impact on the CCF parameter results as shown by previous investigation of the effect of priors calculated from different date ranges. Use of component-specific CCF priors would also encounter the same challenges as the above when discussing the using of more recent date range for CCF data.

Once this year's data updates are completed, a case study will be completed that includes the following

- Determine the specific component types and failure modes for the case study. Appendix D of INL/LTD-17-43723 suggests the five following component types:
  - Diesel Generators
  - Pumps
  - Valves
  - Strainers
  - Other
- Develop component-specific priors for the selected component types.
- Estimate CCF parameters for the selected component-failure mode using the new component-specific priors.
- Compare the CCF parameters using component-specific priors and those using generic priors.

Based on the case study, RES will evaluate the level of effort and potential benefits/issues and make a subsequent recommendation on whether component-specific priors are implemented.

5 Conclusions

The following conclusions are provided for the five topics that NRR asked RES to explore regarding CCF modeling and treatment within ECA:

- ***Determine whether causal alpha factors more appropriately characterize the risk associated with a licensee PD in SDP risk assessments.*** The use CAFM best characterizes CCF risk impact within SDP risk assessments by focusing on a specific failure causes that resulted in licensee PDs. The existing alpha factors consider all failure causes and, therefore, likely result in greater uncertainties if used in ECA.
- ***Identify if any data gaps exist for CAFM implementation, including any resource implications.*** There does not appear to be any data gaps in causal alpha factors for the various causes, components, failure modes, or CCCG sizes that would cause issues in applying the CAFM in ECA.
- ***Develop guidance on how to apply the CAFM in ECA.*** Appendix B provides detailed guidance of applying the CAFM in ECA.

- ***Investigate the practice of CCCGs within the SPAR models.*** Completed and planned SAPHIRE enhancements provide the necessary tool to address the issue of inconsistent/multiple CCCGs and to ensure the CCF impact is appropriately calculated. The remaining SAPHIRE enhancement is expected to be implemented within the next 6 months to a year. The SPAR models changes will follow, and the completion schedule will depend on the level of effort (TBD) and the priority of other modeling changes.

- ***Evaluate the existing alpha factors used in the SPAR models to determine if they accurately reflect existing industry performance, including more recent practices designed to prevent CCFs.*** Based on the review of the existing CCF data and various elements of the alpha factor calculations, the staff determined that using a more recent prior (1997–2015) and performing Bayesian updates with more recent data from a shorter time period (e.g., the last 10 years) will acceptability reflect the existing industry performance.

  A clear justification for changing the range for CCF prior date (beyond the use of the 1997–2015 prior, which is the most recent prior data) was not identified because no explicit information indicates that failure data (including CCF data) from the late 1990s and early 2000s should be excluded from the CCF prior data. To perform Bayesian updates of the prior with most recent data, the recurring data update performed by INL is expected to adopt a 10-year rolling window date range for most parameters including CCFs.

  The consideration of partial CCF events and mapping of CCF events to other CCCGs sizes is integral to the alpha factor method. However, these two areas are sources of uncertainty in the calculation of the existing alpha factors and can be evaluated qualitatively in ECA. Those uncertainties likely increase for CCCGs of 4 or more components. The use of generic priors is also a source of uncertainty. Future work discussed in Section 4.5 to determine if component-specific prior would allow better characterization of these uncertainties and perhaps serve as a replacement for the generic prior to reduce this uncertainty.

Appendix A: CCF Work Plan

Below is the CCF data work plan as part of the existing data contract with INL. The highlighted text pertains to tasks that are a part of normal recurring data analysis activities and are not included in the work documented in this report.

Task 2, Common-Cause Failure (CCF) Analysis

This task provides for CCF support and maintenance of the current alpha factor method and it also provides support for the transition to the evolutionary causal alpha factor methodology. The following tasks will be performed by INL:

1. *Current Practice Activities Regarding the Current Alpha-Factor CCF Method and Existing Data*

    - *CCF Data Review.* INL will provide existing CCF data collected to the Pressurized Water Reactor Owners Group (PWROG) or other nuclear industry peer-reviewers for their review, if available. INL will resolve any comments from PWROG and coordinate them through the COR.
    - *Verifying CCF Events in CCF database.* INL will verify final, screened CCF events in the CCF Database.
    - *CCF Parameter Estimates.* INL will update the CCF parameter estimates periodically as directed by the COR. The results will be placed on the NRCOE web pages (http://nrcoe.inl.gov/resultsdb/) and incorporated into the SPAR models as part of the periodic parameter update process.
    - *CCF Insights.* INL will provide high level CCF insights periodically and post them on the NRCOE web pages. This will be coordinated with the update of the CCF parameter estimates.
    - *CCCG Modeling in the SPAR Models.* Some SPAR models have multiple CCCGs for the same components (up to 5 or more for some components). This issue is largely affected by the modeling of redundant components in multi-unit sites. INL will write a white paper investigating and defining a systematic approach for making this effect consistent across the SPAR model universe.

2. *Critical Evaluation of Current Alpha Factor CCF Method*

    - *Determination of the effect of the generic prior has on the current alpha factors*. There is currently one CCF prior used for the calculation of all alpha factors used in the SPAR models. This prior uses all CCF events from 1991–2005. It is important to know how sensitive the current alpha factors are to the use of this prior (i.e., whether the current alpha factors are dominated by the prior and, therefore, insensitive to the Bayesian updating with component specific data). Sensitivity analyses using the updated (1997–2015) Bayesian prior for key components (e.g., EDGs) should be performed.

    - *Determination if the older CCF data is significantly affecting the current alpha factors*. A sensitivity analysis using the updated prior will provide insight into whether older data (early-to-mid 1990s) is significantly affecting current alpha factors. In addition, a trend analysis could be performed to identify if a significant number of CCF events occurred in years that could be argued are not representative of current industry performance and practices. The trend analysis should determine the year to year variability and determine if there is an identifiable demarcation point that could be the result of industry action (i.e., implemented new CCF defenses).

- *Determination of the effect of partial CCF events have on the current alpha factors*. Partial CCFs are events that only result in a CCF of some number of components within a CCCG (e.g., 2 out of 4 EDGs fail from common cause) or events that are weighted by factors (timing, coupling factor, etc.), which do not constitute a complete CCF (e.g., 2 out of 2 EDGs fail but failures were separated by more than one surveillance period). It would be beneficial to determine the effect that these partial CCF events are significantly affecting the current alpha factors.

- *Determination of the effect of the upward mapping of CCF events*. Most of the complete CCF events in the CCF database are for smaller CCCG sizes (2 or 3 components). If there are a very limited number of complete CCFs for CCCGs of 4 or more, will the current mapping technique overestimate potential CCF for larger groups (4 or more)? Is there causal exception for complete CCFs for larger groups (e.g., environmental events—grass intrusion into service water bay failing all pumps or clogging strainer)?

- *Determination of the effect of component type based generic priors*. Appendix D of INL/LTD-17-43723, which develops updated generic prior distributions for CCF alpha factor and causal alpha factors with 1997–2015 data, discusses the potential to develop different priors for different component types. An evaluation could be performed to determine the effect of component type based generic priors in PRA models.

3. *Evolution of the CCF Methodology to Causal Alpha Factor Method*

- *Calculation of causal alpha factors.* As directed by the NRC COR, INL will help develop the new causal alpha factor method (CAFM) and perform feasibility tests on CCF data using the new method to assess its capability to improve the current state-of-practice. This subtask will be performed in accordance with the approved annual work plan.

  INL will calculate causal alpha factors for all CCF modeled components in the SPAR models. Bayesian priors for each of the five causes (design, component, environment, human, and other) using data from the 1997–2015 period was completed as part of previous CAFM development work and are already incorporated into the Reliability and Data System (RADS) maintained by INL. A report is expected similar to CCF parameter estimation reports produced by INL during scheduled data updates which will integrate results of Task I, II and III, below.

- *Evaluation of the application of the CAFM for NRC risk assessments.* The causal alpha factors will be evaluated to:

  a) Investigate how to align common-cause failure cause groups (or whether potential new categorizations for CCCGs should be developed) with the licensee performance deficiencies most often cited as part of the Reactor Oversight Process.

  b) Determine if there are any specific components, CCCG sizes, and/or causes for which the data will not support applying the CAFM in NRC risk assessments.

c) Determine to what degree the causal alpha factors are affected by the Bayesian prior per cause (i.e., causal alpha factors are nearly the same regardless of component type given the same cause).

d) Develop high level conclusions from an evaluation of the calculated causal alpha factors (e.g., specific causes dominating CCF events, specific causes likely to lead to complete CCFs or partial CCFs).

4. *Guidance on Application of the CAFM in NRC Risk Assessments*

- INL will support the development of written guidance on the steps analysts must complete in order to apply the CAFM in NRC risk assessments. This guidance may be incorporated into a future update of Volume 1 of the RASP Handbook.

5. *International Common Cause Data Exchange (ICDE) Support*

- *CCF Data*. INL will prepare CCF data from the CCF database in the ICDE exchange format so that it can be provided to the ICDE Operating Agent (formerly called the Clearinghouse). The specific data to be prepared (e.g., CCF data on centrifugal pumps, MOVs) will be specified by the COR. It is anticipated that a maximum of two exchange packages shall be prepared per fiscal year.

- *Maintain ICDE CCF Data of other Countries*. INL will maintain ICDE CCF data of other countries provided to the NRC through the ICDE Operating Agent. There will likely be several exchange packages converted to NRC CCF database format and loaded into the NRC CCF database format during each fiscal year of the project. INL will perform qualitative and quantitative assessments of each exchange package in accordance with the approved project plan and compare the results to the NRC CCF component data.

- *Continued Support*. INL will continue to support RES for the ICDE. Anticipated tasks include reviewing draft coding guidelines for approximately four additional components, reviewing three draft summary reports and preparing two data exchange packages. Anticipated tasks also include reviewing coding guidelines developed by other countries and preparing coding guidelines for one or two additional components to be identified.

This task also funds a subcontract with Professor Ali Mosleh for expert assistance on the CCF tasks in this Work Plan.

2.1 Work Breakdown Structure

2.1.1 CCF Database and ICDE Support

Provide support as directed by the NRC COR. Review and verify CCF events in CCF database. Provide CCF data to PWROG or other reviewers for peer review. Resolve any comments from peer-reviewers.

Provide continuing support to RES for the ICDE project. Prepare CCF data from the CCF database in the ICDE exchange format. Maintain ICDE CCF data of other countries provided to the NRC. Provide other supports as instructed by the COR, such as reviewing coding guidelines and draft summary reports.

2.1.2 CCF Parameter Estimates and Insights

Update the CCF parameter estimates and provide high level CCF insights periodically as directed by the COR. Update the CCF parameter estimation report and the CCF insights report. The CCF parameter estimation report presents the CCF parameter estimation results for users that are not allowed to use the CCF database. In addition, this document presents the CCF parameters used in the SPAR models. The CCF insights report uses the CCF database to identify trends in the data, distributions of CCF causes, and coupling factors.

Place the results on the NRCOE web pages (http://nrcoe.inl.gov/resultsdb/) as PDF files. Incorporate the results into the SPAR models as part of the periodic parameter update process.

2.1.3 Evaluation of Current CCF Method

Critically evaluate the current CCF method, i.e., alpha factor method. For example, evaluate the effects of the generic prior, the older CCF data, the partial CCF events, the upward mapping method, and the component types might have on the current alpha factors.

2.1.4 Evolution of the CCF methodology to CAFM

Develop the new CAFM and perform feasibility tests on CCF data using the new method. Calculate causal alpha factors for all CCF modeled components in the SPAR models. Prepare a report for causal alpha factor parameters that is similar to CCF parameter estimation reports produced by INL during scheduled data updates.

Evaluate how to align common-cause failure cause groups (or whether potential new categorizations for CCCGs should be developed) with the licensee performance deficiencies most often cited as part of the Reactor Oversight Process.

Evaluate the application of the CAFM for NRC risk assessments. Develop guidance for analyst to apply the CAFM in risk assessments.

2.2 Deliverables

1. A draft white paper on CCCG modeling in SPAR models is due December 31, 2019.
2. A draft report for the critical evaluation of current alpha factor method is due January 31, 2020.
3. A draft progress report on the development of new CAFM is due February 28, 2020.
4. A draft guidance document evaluating application of CAFM to NRC risk assessment is due March 31, 2020.
5. Update CCF database through CY 2019 data is due April 30, 2020.
6. Prepare a peer review package consisting of CCF events for PWROG is due June 30, 2020.
7. A draft CCF parameter estimate update report is due October 30, 2020.
8. A draft report on CCF insights is due November 15, 2020.

9. The final reports for the above draft reports will be determined after the COR review and approval.

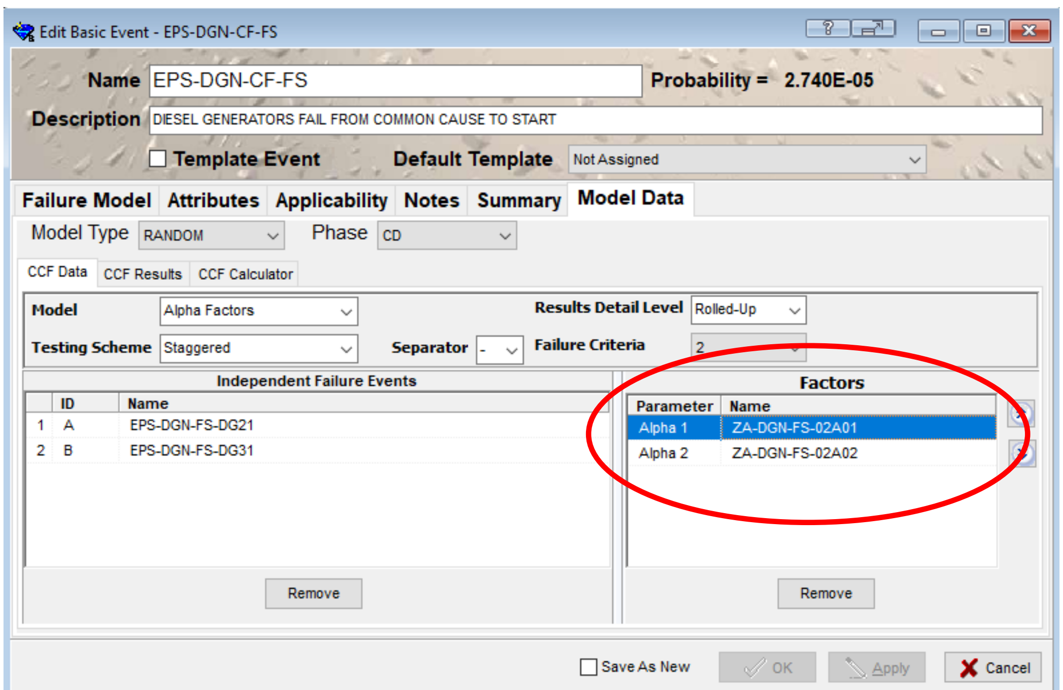
FY 2020 Estimated Level of Effort:	960 hours
Key INL Staff:	Zhegang Ma
Estimated Completion:	September 30, 2020

Appendix B: CAFM Guidance for ECA

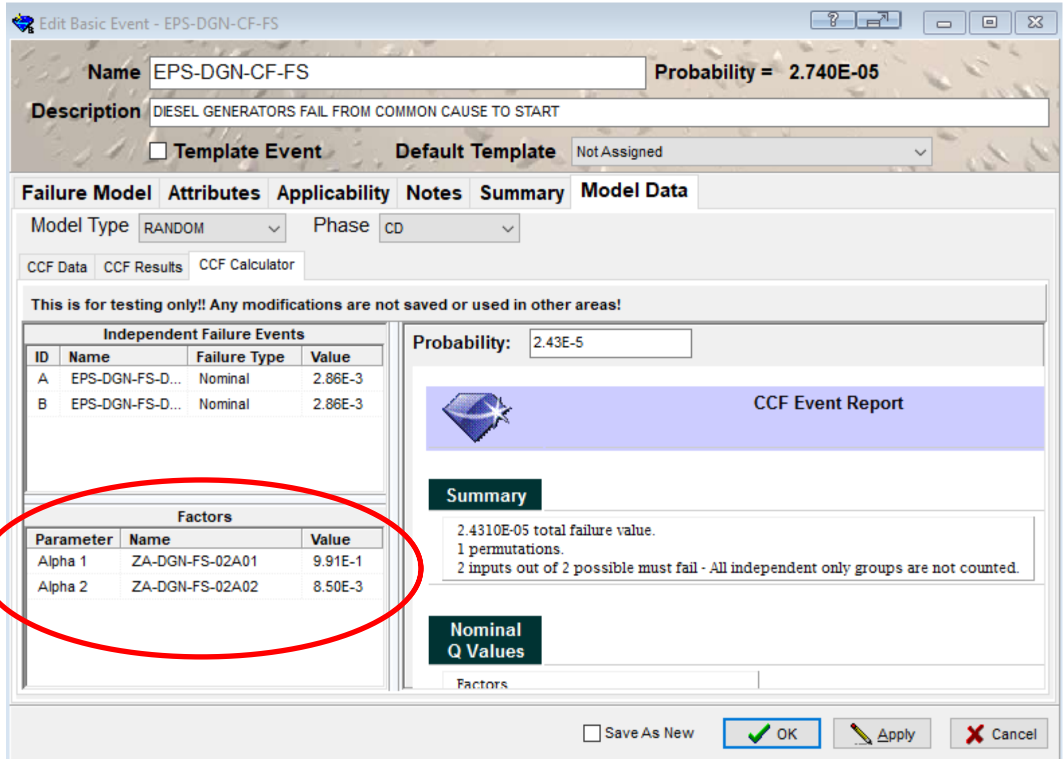
The process to apply the causal alpha factor method (CAFM) is relatively straight forward and doesn't require any SPAR model logic changes. The steps shown below will allow an analyst to apply the CAFM for both condition and initiating events assessments where the common-cause failure (CCF) potential is a significant risk contributor. Note that these steps will use an example for emergency diesel generator (EDG) failure to start (FTS) for a common-cause component groups (CCCG) size of two. As part of the example, it is assumed that the observed failure of one of the EDGs was the result of a failure in the licensee's design control process.

Step 1. Identify Applicable CCF Basis Event and the Associated Alpha Factors

In the SPAR model, locate the applicable CCF basic event to identify the alpha factors that need to be modified. In this example, the basic event of interest is EPS-DGN-CF-FS (*diesel generators fail from common cause to start*). Open the basic event to identify the existing alpha factor basic events (see screen shot shown below). For basic event EPS-DGN-CF-FS, the two alpha factors are ZA-DGN-FS-02A01 (*alpha factor 2 in group size 2 for component DGN with failure mode FS*) and ZA-DGN-FS-02A02 (*alpha factor 2 in group size 2 for component DGN with failure mode FS*).



The values for the existing alpha factors are 0.991 (α_1) and 8.5×10^{-3} (α_2), as shown below.



Step 2. Identify the Applicable Causal Alpha Factors

In this example, a failure in the licensee design control process resulted in FTS of 1 of the 2 EDGs.[3] The analyst should locate the causal alpha factors associate with the design failure cause group for EDG CCCG size of two. The plan is to have the causal alpha factors for all components and failure modes included in the SPAR models on the RASP Toolbox Webpage. The causal alpha factors will be in separate reports for each failure cause group. For this example, the applicable section of the design causal alpha factor report will look like the following:

EPS-EDG-FS-GD EMERGENCY DIESEL GENERATOR SPAR: DGN-FS

Systems/Electrical/Emergency power supply
Components/Emergency Power/Generator/Emergency Diesel Generator
Failure Modes/Fail to Start
CCF Categories/Cause/Design
Date Range: 1998 through 2019

Total Number of Independent Failure Events: 45.0
Total Number of Common-Cause Failure Events: 1

ALPHA FACTOR DISTRIBUTIONS

CCCG = 2

α	5th%	Mean	Median	95th%	MLE	a	b
α_1	0.9666740	**0.9909883**	0.9955115	0.9999451	0.9978678	6.046E+01	5.498E-01
α_2	5.78E-05	**9.01E-03**	4.49E-03	3.33E-02	2.13E-03	5.498E-01	6.046E+01

[3] If needed, analysts should seek Office of Nuclear Regulatory Research (RES) assistance in identifying the most appropriate failure cause group.

CCCG = 3

α	5th%	Mean	Median	95th%	MLE	a	b
α_1	0.9640427	0.9862370	0.9891540	0.9984458	0.9960120	1.045E+02	1.458E+00
α_2	9.08E-04	1.14E-02	8.51E-03	3.18E-02	3.85E-03	1.209E+00	1.047E+02
α_3	3.93E-08	2.36E-03	4.13E-04	1.14E-02	1.42E-04	2.496E-01	1.057E+02

CCCG = 4

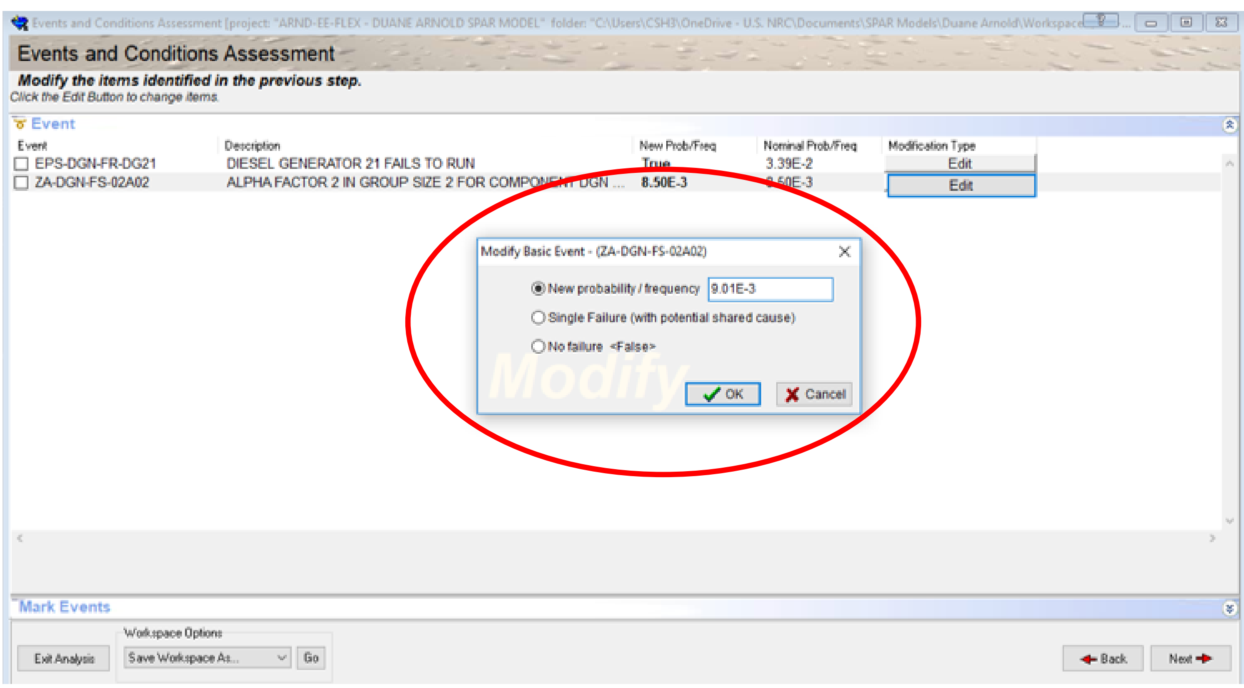
α	5th%	Mean	Median	95th%	MLE	a	b
α_1	0.9630875	0.9833726	0.9855340	0.9962818	0.9944028	1.432E+02	2.421E+00
α_2	1.85E-03	1.22E-02	1.00E-02	2.98E-02	5.20E-03	1.771E+00	1.439E+02
α_3	4.81E-06	2.94E-03	1.16E-03	1.19E-02	3.85E-04	4.287E-01	1.452E+02
α_4	6.18E-09	1.52E-03	2.05E-04	7.63E-03	1.07E-05	2.217E-01	1.454E+02

The design causal alpha factors for EDG FTS for CCCG size of two are highlighted in yellow (0.991 for α_1 and 9.01×10^{-3} for α_2). When compared to the existing alpha factors (identified in the previous step), α_2 for the design issues is slightly higher. Therefore, we would expect the CCF risk impact to increase.

Step 3. Substitute Causal Alpha Factors in ECA

Once the applicable causal alpha factors for the specific failure cause group are identified, the analyst will make the change either in the ECA module or via a change set in the base SAPHIRE platform. The alpha factor changes should not be made in the base SPAR model (also known as the nominal case with SAPHIRE) for condition assessments.

For this example, the causal alpha factors for design issues are 0.991 and 9.01×10^{-3} were identified in the previous step. The value for α_1 remained at 0.991 and, therefore, no changes are needed for basic event ZA-DGN-FS-02A01. The probability for basic event ZA-DGN-FS-02A02 will be changed to 9.01×10^{-3} in either the ECA module (shown below) or change set.



The conditional CCF probability with an FTS of 1 of 2 EDGs in this example increases from 8.5×10^{-3} to 9.01×10^{-3}.