

Common Cause Failure Data and Alpha Factor Modeling

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Common Cause Failure (CCF) Modeling

- Attempt to model simultaneous failures of multiple components due to a single cause
 - Data collection & reduction: Marshall, Mosleh, and Rasmuson, Common-Cause Failure Database and Analysis System, NUREG/CR-6268, Volumes 1-4.
 - Modeling methods: Mosleh, Rasmuson, and Marshall, Guidelines on Modeling Common-Cause Failures in Probabilistic Risk Assessment, NUREG/CR-5485

CCF Model Parameter Estimation

- INL reviews licensee event reports (LERs) and INPO Consolidated Events System (ICES) failure records to identify candidate common cause failure events.
 - Data coder identifies candidate event, creating an event impact vector that characterizes uncertainty about the event.
 - Degraded state
 - Failures close in time but not simultaneous
 - Shared cause cannot be established with certainty
 - Candidate events receive independent review at INL.
 - Periodically candidate events are sent to the Westinghouse Owners Group (WOG) for review
- CCF parameters are computed from database of quality-assured CCF event records.
 - Stand-alone code CCF package
 - Web version on the NROD web site

CCF Model Parameter Estimation (cont.)

- The CCF software (both stand-alone and web versions) provides:
 - Impact vector summaries,
 - Parameter estimates for alpha factors,
 - Parameter estimates for Multiple Greek Letter (MGL) parameters,
 - Parameter estimates scaled to CCF group sizes of up to 16.
- The CCF software implements computational procedures detailed in NUREG/CR-5485.
- Parameter estimates are published on the NRC web site.
- Parameter estimates are used to estimate CCF probabilities in the SPAR models.

Selection of CCF Groups

- Identify components that share one or more coupling mechanisms
 - Same design
 - Same hardware
 - Same function
 - Same installation, maintenance, or operation staff
 - Same procedures
 - Same system
 - Same location
 - Same environment

Selection of CCF Groups (cont.)

- Identical, functionally non-diverse, active components.
- Diverse components that have identical piece parts.
- Passive components omitted, with exception of debris blockage of redundant or diverse strainers.
- Review of operating experience
 - System studies
 - Generally stay within bounds of NRC data collection (CCF database)
 - Generally assume common failure rate
- Generally do not cross system boundaries.

Representation in the SPAR models

- Method follows NUREG/CR-5485, Section 5.3
- $Q_k^{(m)}$ is the probability of k specific components failing in a group of size m .
- $Q_k^{(m)}$ is estimated using the alpha factor method.
 - Rigorous estimators for beta factor and MGL models parameters are difficult to obtain.
 - Alpha factors can be estimated from observable data and a known sampling scheme.
 - MGL parameters can be estimated from alpha factors.
 - Details are provided in Appendices to NUREG/CR-5485.

Representation (cont.)

- The cut sets for a two train system are

$$\{A_I, B_I\}; \{CCF_{AB}\}$$

- The failure probability for the system (using a staggered testing formulation) is

$$P(S) = P(A_I * B_I) + P(CCF_{AB}) = Q_I Q_I + Q_2 = (\alpha_I Q_T)^2 + \alpha_2 Q_T$$

where

Q_I = probability of independent component failure

Q_2 = probability of two components failing from common cause

Q_T = probability of component failure from all causes

α_I = alpha factor for independent failure

α_2 = alpha factor for two components failing from common cause

Representation (cont.)

- There are two formulations relating alpha factor estimates to CCF probability based on the testing scheme that produced the data:
 - Staggered Testing – Equation (5.6) of NUREG/CR-5485
 - Non-Staggered Testing – Equation (5.7) of NUREG/CR-5485
- SPAR models assume all data was collected as a result of staggered component testing.
- Templates are provided for all alpha factors used in the SPAR models
- SPAR model templates are periodically updated with data from the website.
- SAPHIRE does all CCF calculations internally using a compound event plug-in module.

SAPHIRE CCF Calculation Types

- R-type: The standard CCF calculation type for mitigating system failures. Allows for expansion of CCF terms or roll-up into a single basic event.
- Q-type: New CCF calculation type introduced to support SSIE modeling.
- Compound event: Historical event type used for CCF modeling in SPAR. All CCF terms are rolled up into a single basic event. This calculation type will eventually be replaced with R-type.

SAPHIRE Workspace Options for CCF Adjustments

- When adjusting individual failure basic events, SAPHIRE Workspace will make implied changes to the associated CCF basic event. The options are:
 - New probability / frequency
 - CCF is recalculated conditioned on the *individual* failure of component and the multiple failure terms default to the lowest¹ failure probability in the group.
 - Single Failure (with potential shared cause)
 - CCF is recalculated conditioned on the *total* failure of component.
 - Single Failure (without potential shared cause)
 - CCF is recalculated conditioned on the *individual* failure of component.

¹Note that for Compound Events, SAPHIRE now defaults to the highest failure probability in the group. Current SPAR models include a mix of Compound events and R-type events.

SAPHIRE Workspace Options (cont.)

- The conditional CCF probability for observed failures with potential shared cause is triggered when an input is specified as TRUE.
- The conditional CCF probability without potential shared cause is triggered when an input is specified as 1.0.
- Calculations based on NUREG/CR-5485, Appendix E.
- Review of SAPHIRE calculation results provided by basic event modification dialog.

SAPHIRE CCF Calculation Types, R, Q

Edit Basic Event - EPS-DGN-CF-START

Name: EPS-DGN-CF-START Probability = 1.895E-05

Description: DIESEL GENERATORS FAIL FROM COMMON CAUSE TO START

☐ Template Event Default Template: Not Assigned

Failure Model	Attributes	Applicability	Notes	Summary	Model Data
Item	Value				
ModelType	RANDOM				
Phase	CD				
Uses Template	Not Assigned				
Description					
Calculated Probability	1.895E-05				
Process Flag	Failure=> System Logic Success=> Delete Term				
Failure Model	Common Cause Failure (R)				
Edit Properties	Edit				
Correlation Class					

☐ Save As New OK Apply Cancel

SAPHIRE CCF Calculation Types, R, Q (cont.)

Edit Basic Event - EPS-DGN-CF-START

Name: EPS-DGN-CF-START Probability = 1.895E-05

Description: DIESEL GENERATORS FAIL FROM COMMON CAUSE TO START

☐ Template Event Default Template: Not Assigned

Failure Model | Attributes | Applicability | Notes | Summary | Model Data

Model Type: RANDOM Phase: CD Full Detail Events are referenced. Changes made here have ramifications

CCF Data | CCF Results | CCF Calculator

Model: Alpha Factors Results Detail Level: Full Detail

Testing Scheme: Non-Staggered Separator: - Failure Criteria: 4

Independent Failure Events			Factors	
ID		Name	Parameter	Name
1	A	1-EPS-DGN-FS-G4001__	Alpha 1	ZA-DGN-FS-04A01
2	B	1-EPS-DGN-FS-G4002__	Alpha 2	ZA-DGN-FS-04A02
3	C	2-EPS-DGN-FS-G4001__	Alpha 3	ZA-DGN-FS-04A03
4	D	2-EPS-DGN-FS-G4002__	Alpha 4	ZA-DGN-FS-04A04

Remove Remove

☐ Save As New OK Apply Cancel

SAPHIRE CCF Calculation Types, R, Q (cont.)

Edit Basic Event - EPS-DGN-CF-START

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Description: DIESEL GENERATORS FAIL FROM COMMON CAUSE TO START

☐ Template Event Default Template: Not Assigned

Failure Model: Attributes Applicability Notes Summary Model Data

Model Type: RANDOM Phase: CD Detail Events are referenced. Changes made here have ramifications

CCF Data CCF Results CCF Calculator

Probability: 1.895E-5

CCF Event Report

Summary

1.8948E-05 total failure value.
14 permutations.
4 inputs out of 4 possible must fail - All independent only groups are not counted.

Nominal Q Values

Factors
[1] - 9.8900E-01, [2] - 6.0700E-03, [3] - 3.3200E-03, [4] - 1.6300E-03
Events 1-EPS-DGN-FS-G4001..., 1-EPS-DGN-FS-G4002..., 2-EPS-DGN-FS-G4001..., 2-EPS-DGN-FS-G4002...,
Q1 = 2.8573E-03, 2.8573E-03, 2.8573E-03, 2.8573E-03
Q2 = 1.1691E-05, 1.1691E-05, 1.1691E-05, 1.1691E-05
Q3 = 9.5918E-06, 9.5918E-06, 9.5918E-06, 9.5918E-06
Q4 = 1.8837E-05, 1.8837E-05, 1.8837E-05, 1.8837E-05

CCF Terms

1 * Q4 +
3 * Q2^2 +
4 * Q1 * Q3 +
6 * Q1^2 * Q2

CCF Sub-elements

Element #	Terms	Nominal Value
# 1	2-EPS-DGN-FS-G4001..., 2-EPS-DGN-FS-G4002..., EPS-DGN-CF-START-AB	9.5450E-11
# 2	1-EPS-DGN-FS-G4001..., 2-EPS-DGN-FS-G4002..., EPS-DGN-CF-START-AC	9.5450E-11
# 3	1-EPS-DGN-FS-G4001..., 2-EPS-DGN-FS-G4002..., EPS-DGN-CF-START-BC	9.5450E-11
# 4	2-EPS-DGN-FS-G4002..., EPS-DGN-CF-START-ABC	2.7407E-08
# 5	1-EPS-DGN-FS-G4002..., 2-EPS-DGN-FS-G4001..., EPS-DGN-CF-START-AD	9.5450E-11
# 6	1-EPS-DGN-FS-G4001..., 2-EPS-DGN-FS-G4001..., EPS-DGN-CF-START-BD	9.5450E-11
# 7	2-EPS-DGN-FS-G4001..., EPS-DGN-CF-START-ABD	2.7407E-08
# 8	1-EPS-DGN-FS-G4001..., 1-EPS-DGN-FS-G4002..., EPS-DGN-CF-START-CD	9.5450E-11
# 9	1-EPS-DGN-FS-G4002..., EPS-DGN-CF-START-ACD	2.7407E-08
# 10	1-EPS-DGN-FS-G4001..., EPS-DGN-CF-START-BCD	2.7407E-08
# 11	EPS-DGN-CF-START-ABCD	1.8837E-05
# 12	EPS-DGN-CF-START-AB, EPS-DGN-CF-START-CD	1.3668E-10
# 13	EPS-DGN-CF-START-AC, EPS-DGN-CF-START-BD	1.3668E-10
# 14	EPS-DGN-CF-START-BC, EPS-DGN-CF-START-AD	1.3668E-10

☐ Save As New OK Apply Cancel

SAPHIRE CCF Calculation Types, R, Q (cont.)

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Failure Model | Attributes | Applicability | Notes | Summary | Model Data

Model Type: RANDOM Phase: CD Full Detail Events are referenced. Changes made here have ramifications

CCF Data | CCF Results | CCF Calculator

This is for testing only!! Any modifications are not saved or used in other areas!

Independent Failure Events			
ID	Name	Failure Type	Value
A	1-EPS-DGN-FS-G4001__	Nominal	2.940E-3
B	1-EPS-DGN-FS-G4002__	Nominal	2.940E-3
C	2-EPS-DGN-FS-G4001__	Nominal	2.940E-3
D	2-EPS-DGN-FS-G4002__	Nominal	2.940E-3

Factors		
Parameter	Name	Value
Alpha 1	ZA-DGN-FS-04A01	9.890E-1
Alpha 2	ZA-DGN-FS-04A02	6.070E-3
Alpha 3	ZA-DGN-FS-04A03	3.320E-3
Alpha 4	ZA-DGN-FS-04A04	1.630E-3

Probability: 1.895E-5

CCF Event Report

Summary

1.8948E-05 total failure value.
14 permutations.
4 inputs out of 4 possible must fail - All independent only groups are not counted.

Nominal Q Values

Factors
[1] - 9.8900E-01, [2] - 6.0700E-03, [3] - 3.3200E-03, [4] - 1.6300E-03
Events 1-EPS-DGN-FS-G4001____, 1-EPS-DGN-FS-G4002____, 2-EPS-DGN-FS-G4001____, 2-EPS-DGN-FS-G4002____
Qt = 2.9400E-03, 2.9400E-03, 2.9400E-03, 2.9400E-03
Q1 = 2.8573E-03, 2.8573E-03, 2.8573E-03, 2.8573E-03
Q2 = 1.1691E-05, 1.1691E-05, 1.1691E-05, 1.1691E-05
Q3 = 9.5918E-06, 9.5918E-06, 9.5918E-06, 9.5918E-06
Q4 = 1.8837E-05, 1.8837E-05, 1.8837E-05, 1.8837E-05

Save As New OK Apply Cancel