Cut Set Analysis

Tutorial

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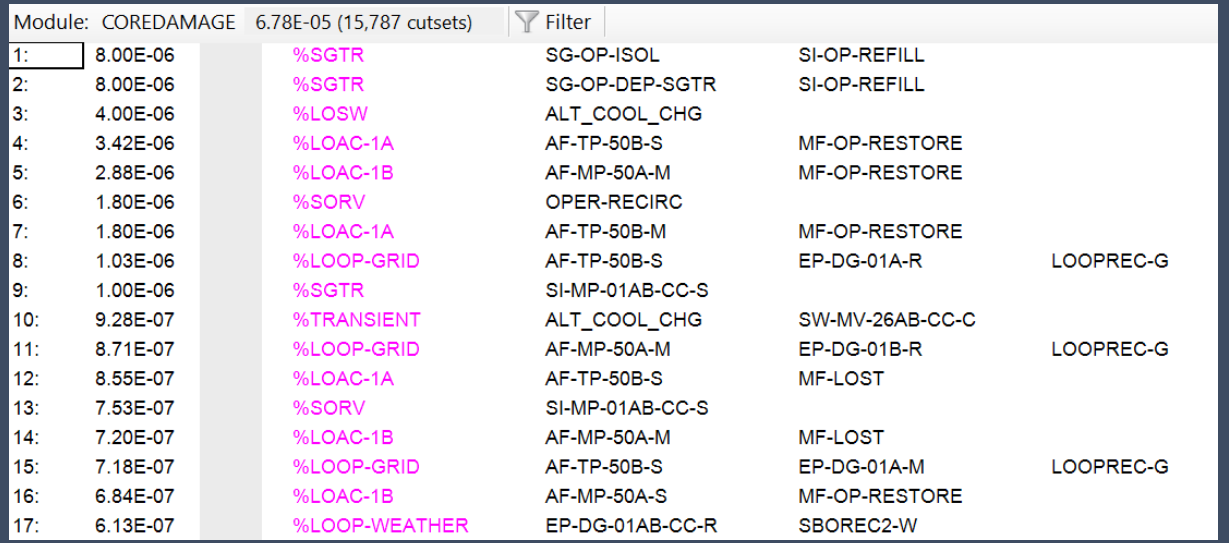
About the Instructor

- Project Manager for CAFTA, Phoenix Risk Monitor, and HRA Calculator
- Been with EPRI for 11 years
- Worked as a PRA engineer for FirstEnergy for 7 years supporting the Perry Nuclear Power Plant
- Worked in aerospace (Lockheed Martin, Ohio Aerospace supporting NASA GRC, and FAA)
- Nuclear submarine officer on the USS Tucson

Learning Objectives

After this presentation, you will be able to:

1. Use cut sets to confirm that a fault tree is built correctly
2. Use cut sets to calculate importance measures for basic events in a fault tree
3. Perform sensitivity studies with cut sets
4. Use cut sets to identify vulnerabilities in a modeled system
5. Post-process cut sets

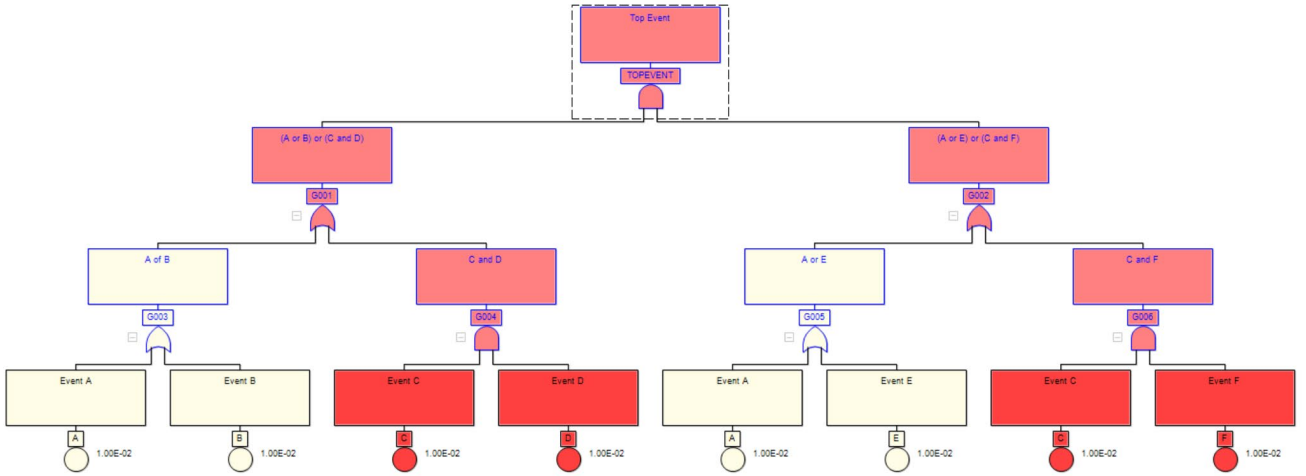


Module: COREDAMAGE 6.78E-05 (15,787 cutsets) Filter

1:	8.00E-06		%SGTR	SG-OP-ISOL	SI-OP-REFILL	
2:	8.00E-06		%SGTR	SG-OP-DEP-SGTR	SI-OP-REFILL	
3:	4.00E-06		%LOSW	ALT_COOL_CHG		
4:	3.42E-06		%LOAC-1A	AF-TP-50B-S	MF-OP-RESTORE	
5:	2.88E-06		%LOAC-1B	AF-MP-50A-M	MF-OP-RESTORE	
6:	1.80E-06		%SORV	OPER-RECIRC		
7:	1.80E-06		%LOAC-1A	AF-TP-50B-M	MF-OP-RESTORE	
8:	1.03E-06		%LOOP-GRID	AF-TP-50B-S	EP-DG-01A-R	LOOPREC-G
9:	1.00E-06		%SGTR	SI-MP-01AB-CC-S		
10:	9.28E-07		%TRANSIENT	ALT_COOL_CHG	SW-MV-26AB-CC-C	
11:	8.71E-07		%LOOP-GRID	AF-MP-50A-M	EP-DG-01B-R	LOOPREC-G
12:	8.55E-07		%LOAC-1A	AF-TP-50B-S	MF-LOST	
13:	7.53E-07		%SORV	SI-MP-01AB-CC-S		
14:	7.20E-07		%LOAC-1B	AF-MP-50A-M	MF-LOST	
15:	7.18E-07		%LOOP-GRID	AF-TP-50B-S	EP-DG-01A-M	LOOPREC-G
16:	6.84E-07		%LOAC-1B	AF-MP-50A-S	MF-OP-RESTORE	
17:	6.13E-07		%LOOP-WEATHER	EP-DG-01AB-CC-R	SBOREC2-W	

What Are Cut Sets?

- Approximate solution to a fault tree
- Combinations of basic events that, if TRUE, make the top event TRUE
- Ignore non-minimal cut sets
- Calculated using Minimum Cut Set Upper Bound



ISSS Tutorial.cut

Module: TOPEVENT 1.010197E-02 (5 cutsets) Filter

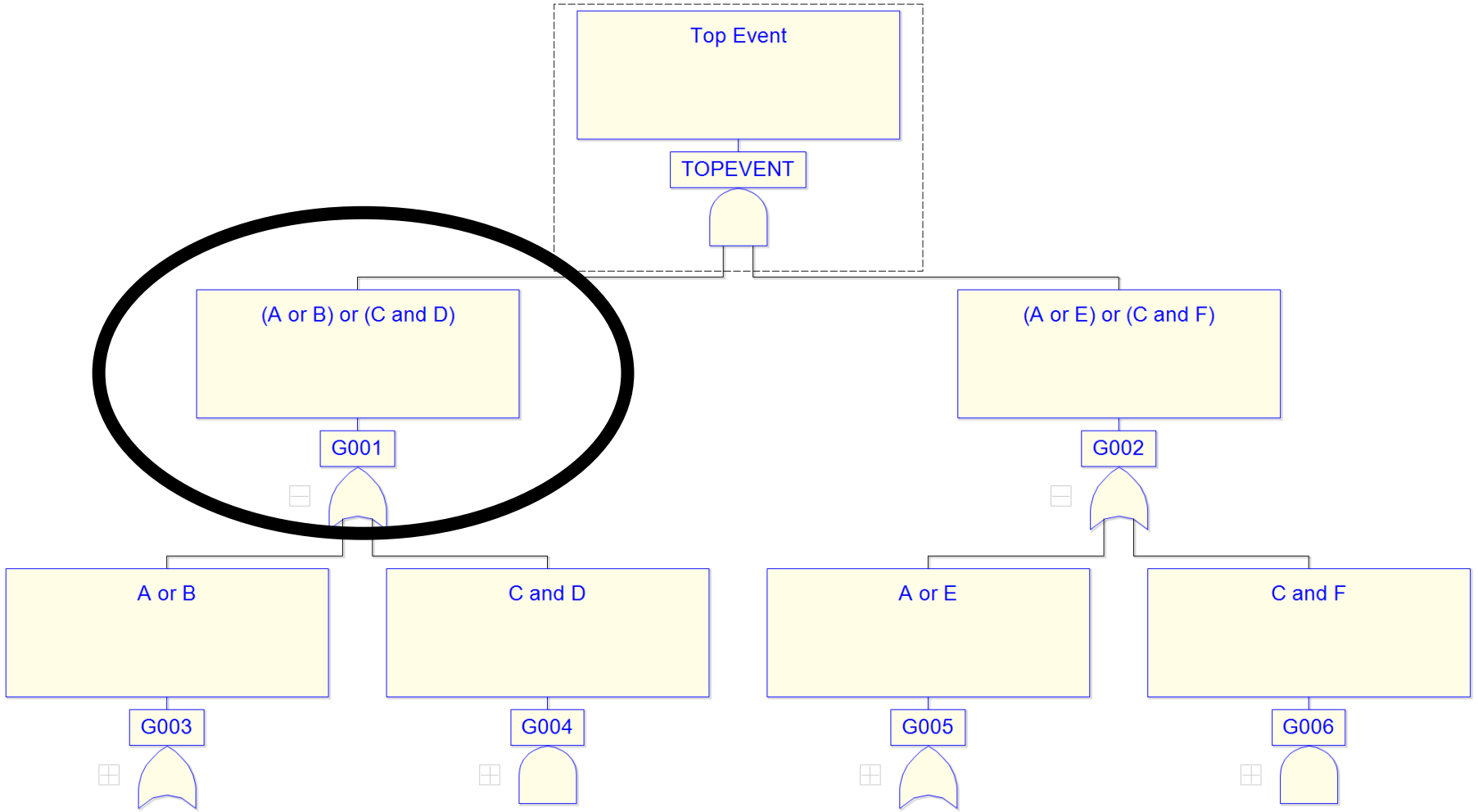
1:	1.000000E-02	A		
2:	1.000000E-04	B	E	
3:	9.999999E-07	C	D	F
4:	9.999999E-07	C	D	E
5:	9.999999E-07	B	C	F

$$P(Top) = \left(1 - \prod_{i=1}^{n} (1 - P(C_i))\right)$$

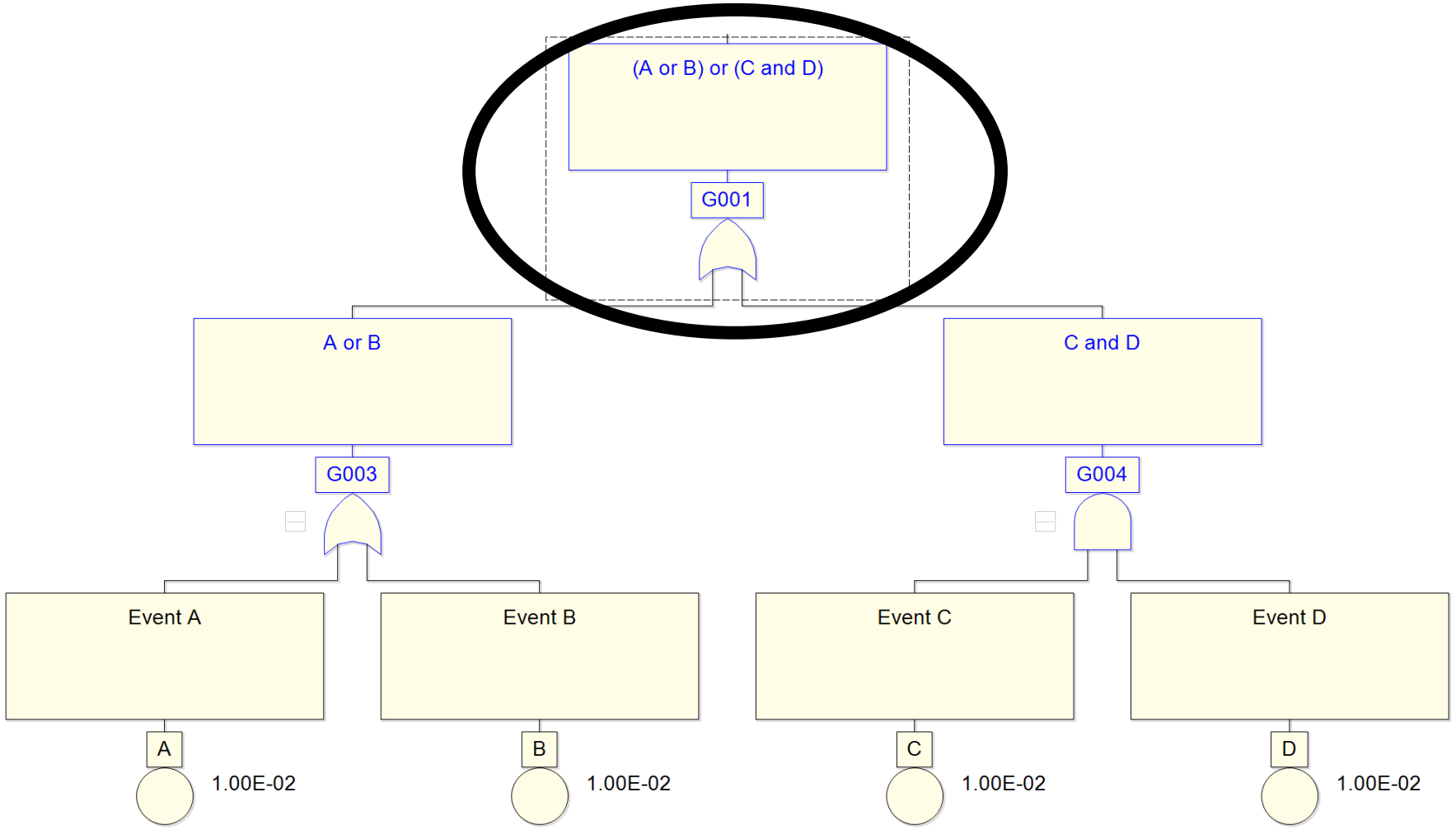
Cut Sets Are an Approximation

- Cut sets are used to estimate the top event probability when the fault tree's top event cannot be calculated exactly
- The min-cut upper bound can introduce double counting
  - For small probabilities of failure (<1E-3), this is very small
  - When high probability events (>0.1) appear in many cut sets, this can be a significant effect
- For complicated fault trees, not all minimal cut sets can be generated, so the results are truncated
  - At some point, the cut set probability will exceed the "TRUE" probability, but there is no way to determine when this point is crossed

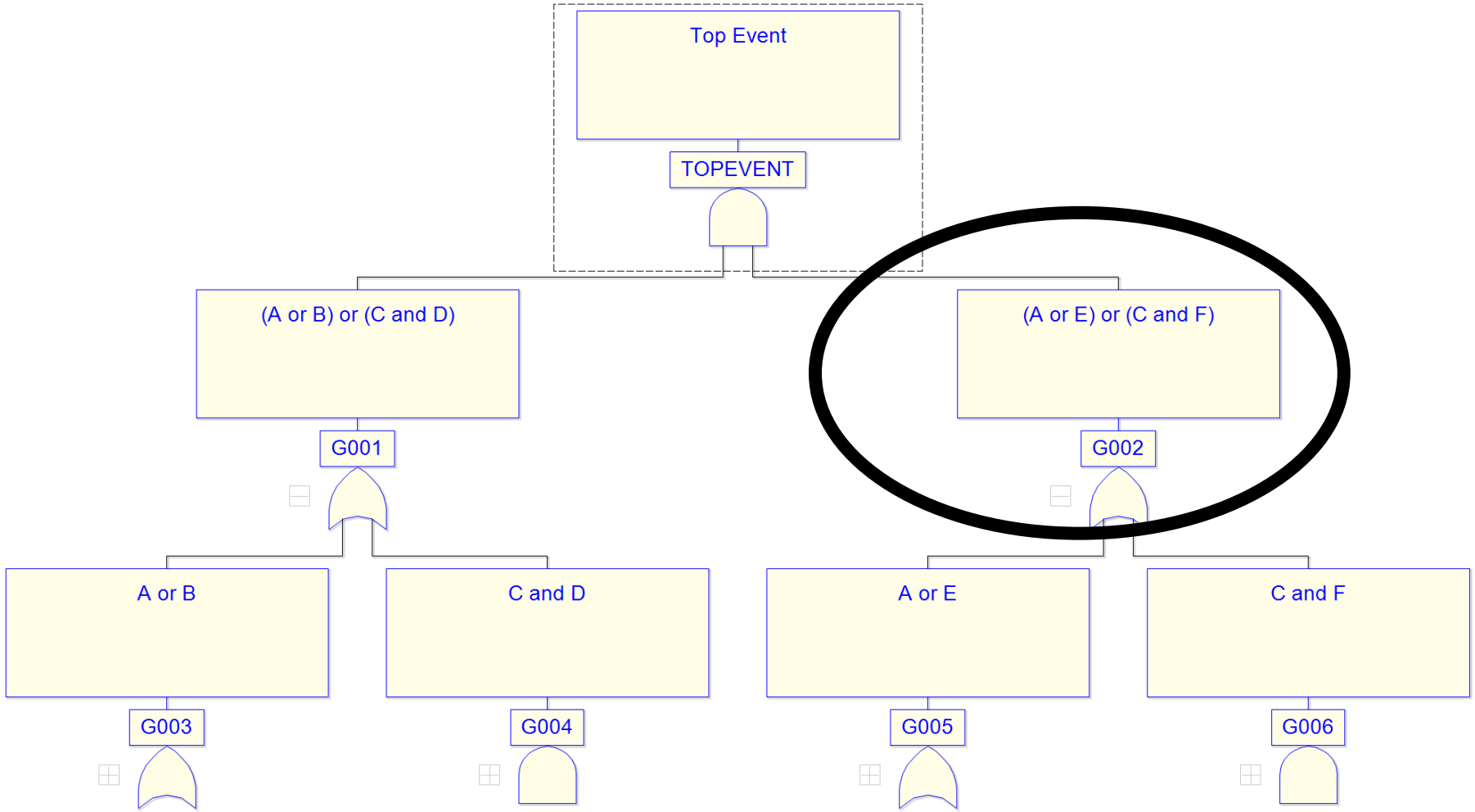
Example Fault Tree



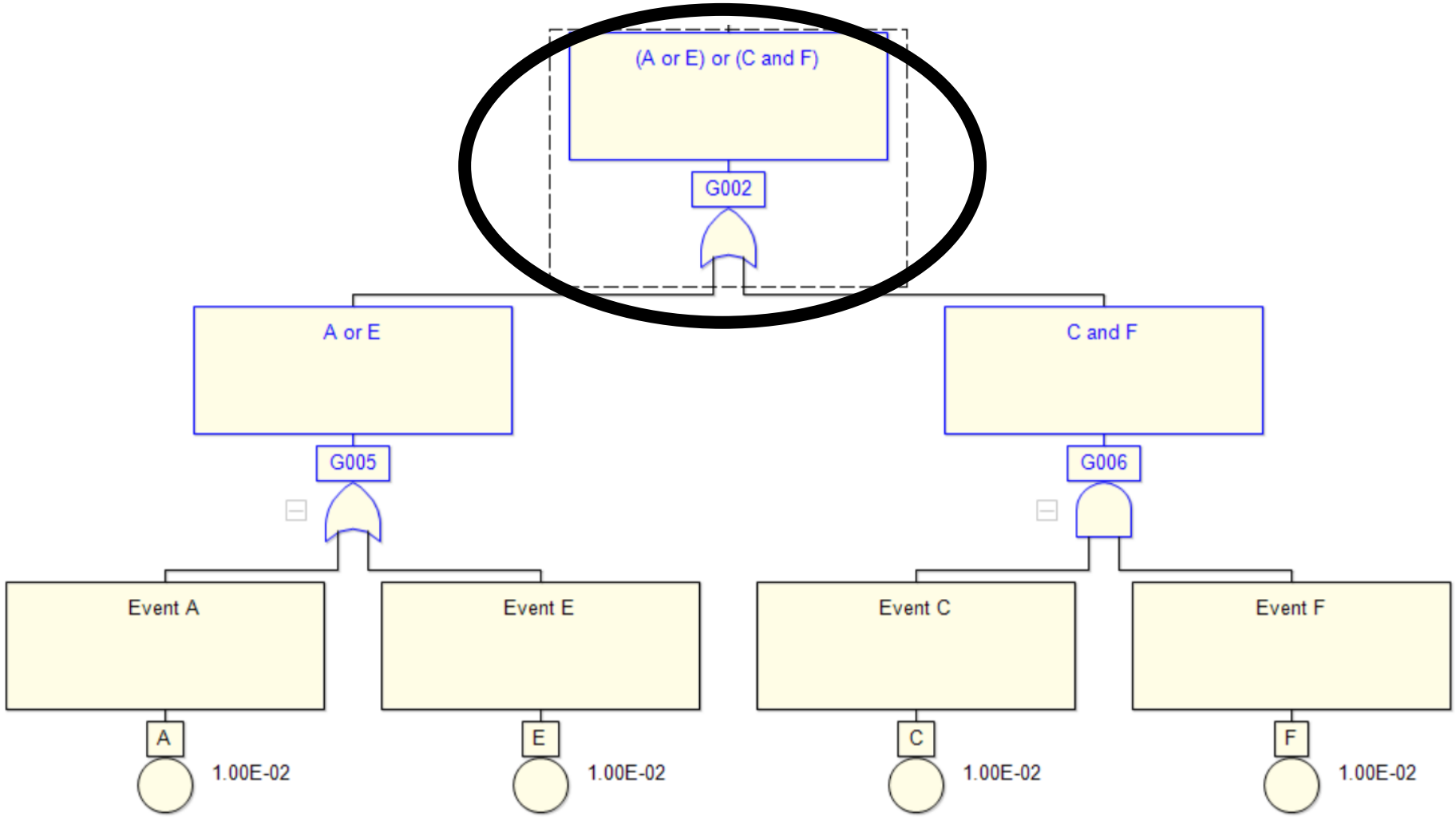
Example Fault Tree



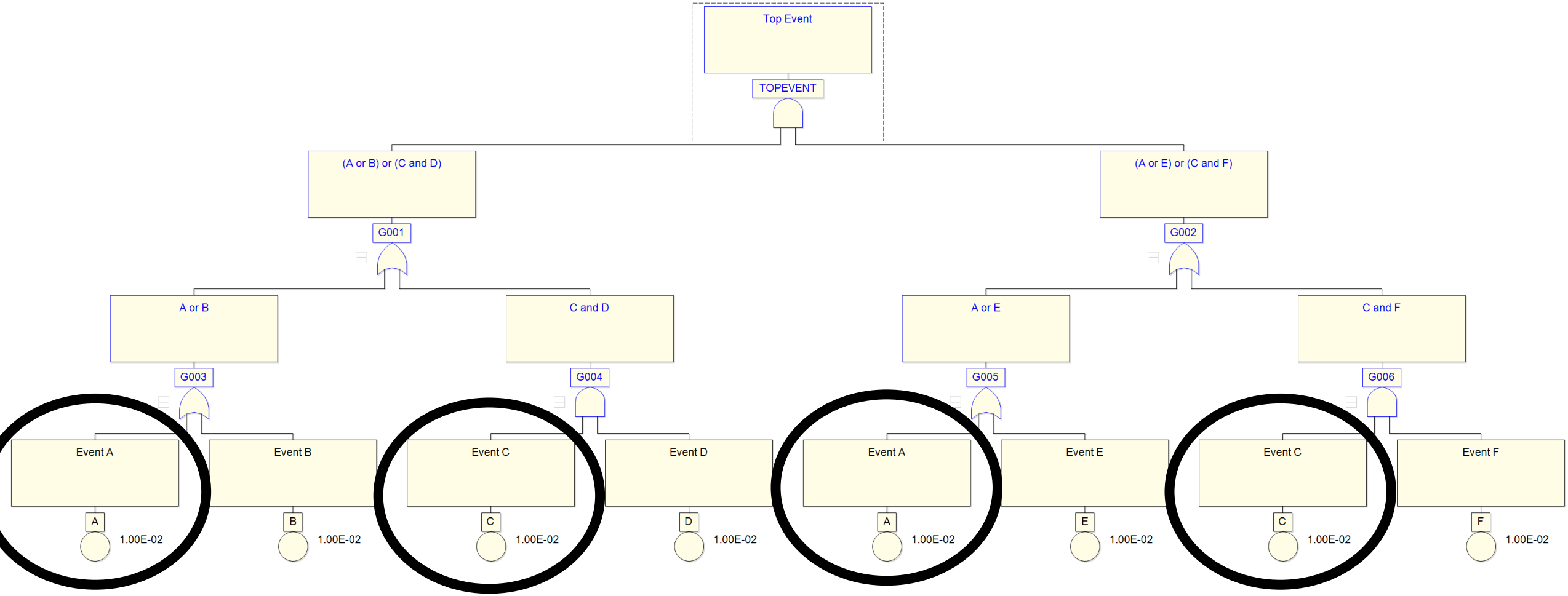
Example Fault Tree



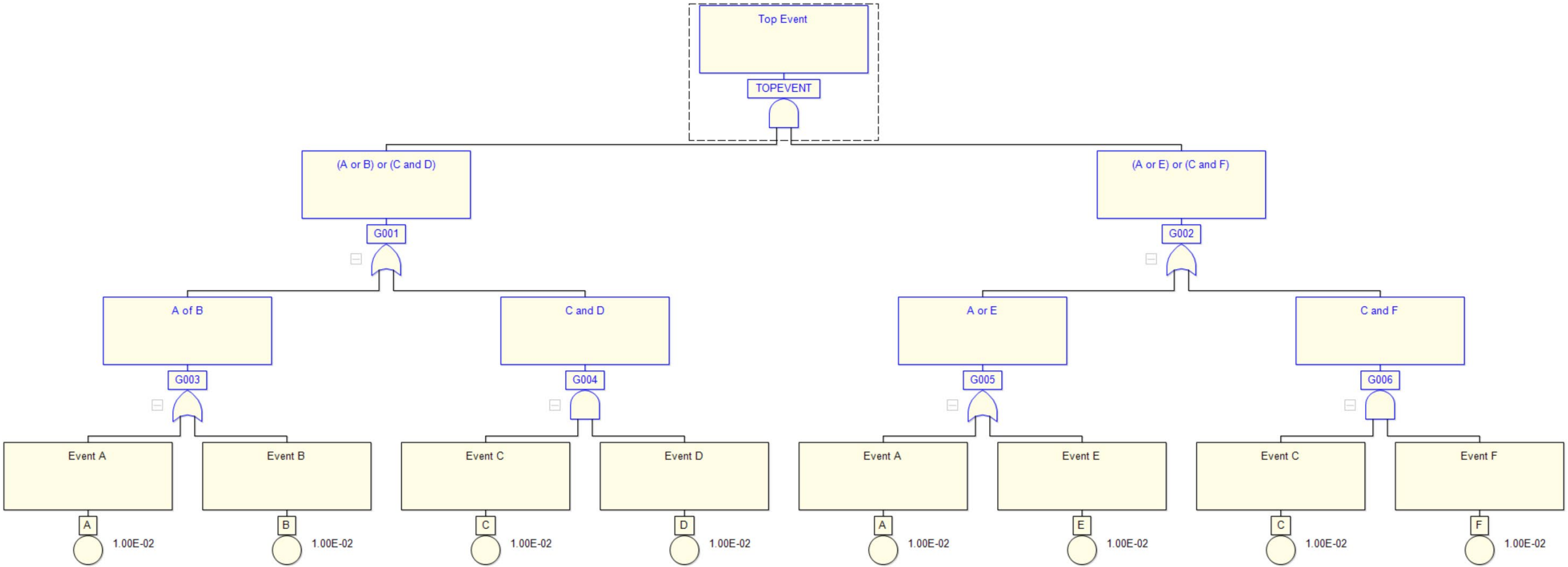
Example Fault Tree



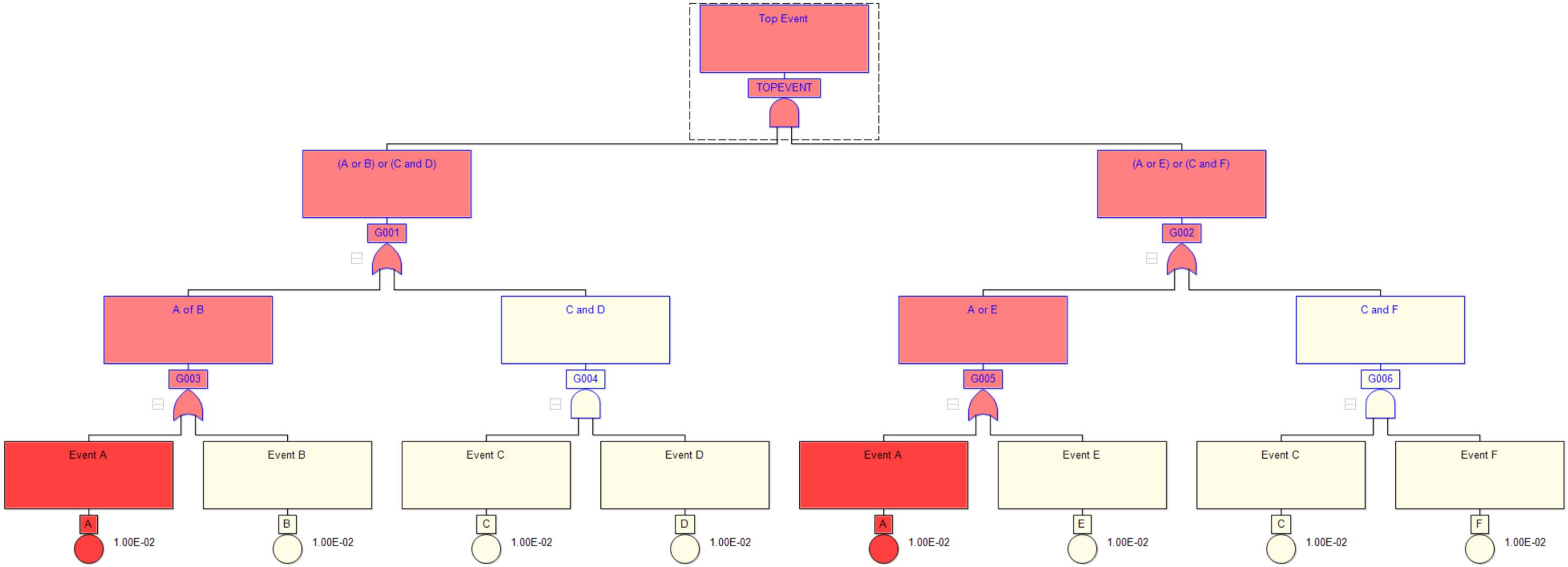
Example Fault Tree



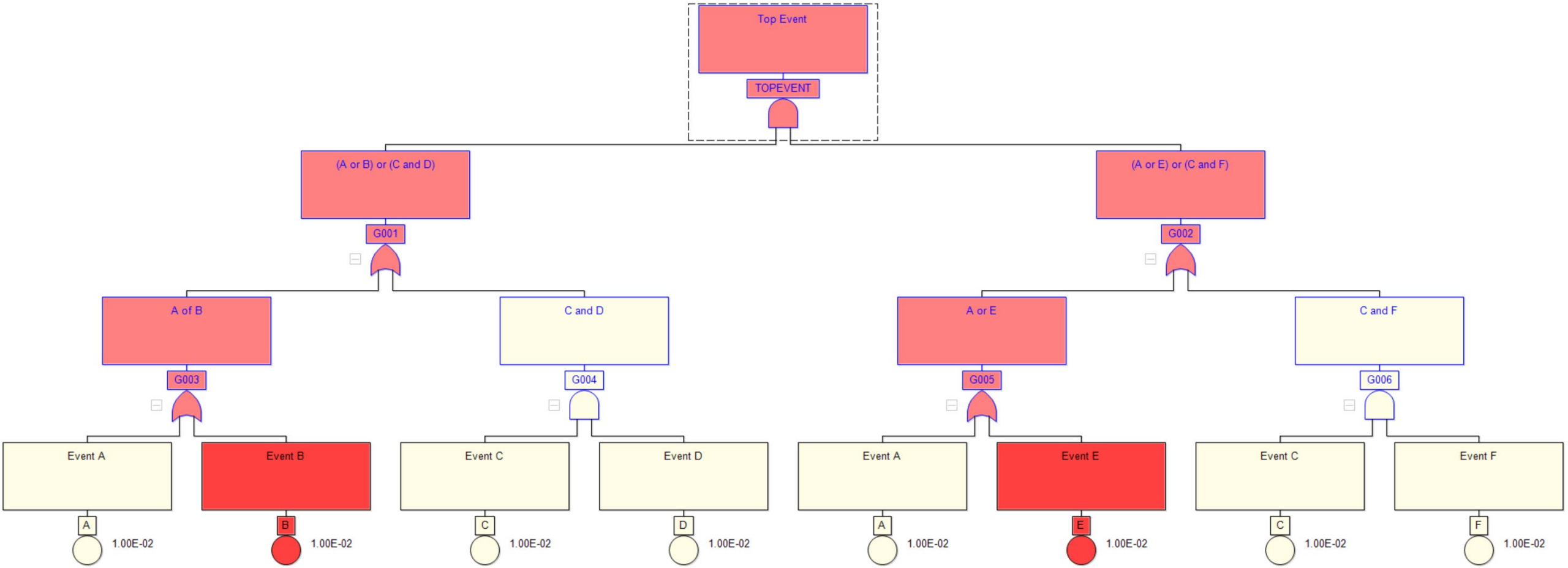
Identify the Cut Sets



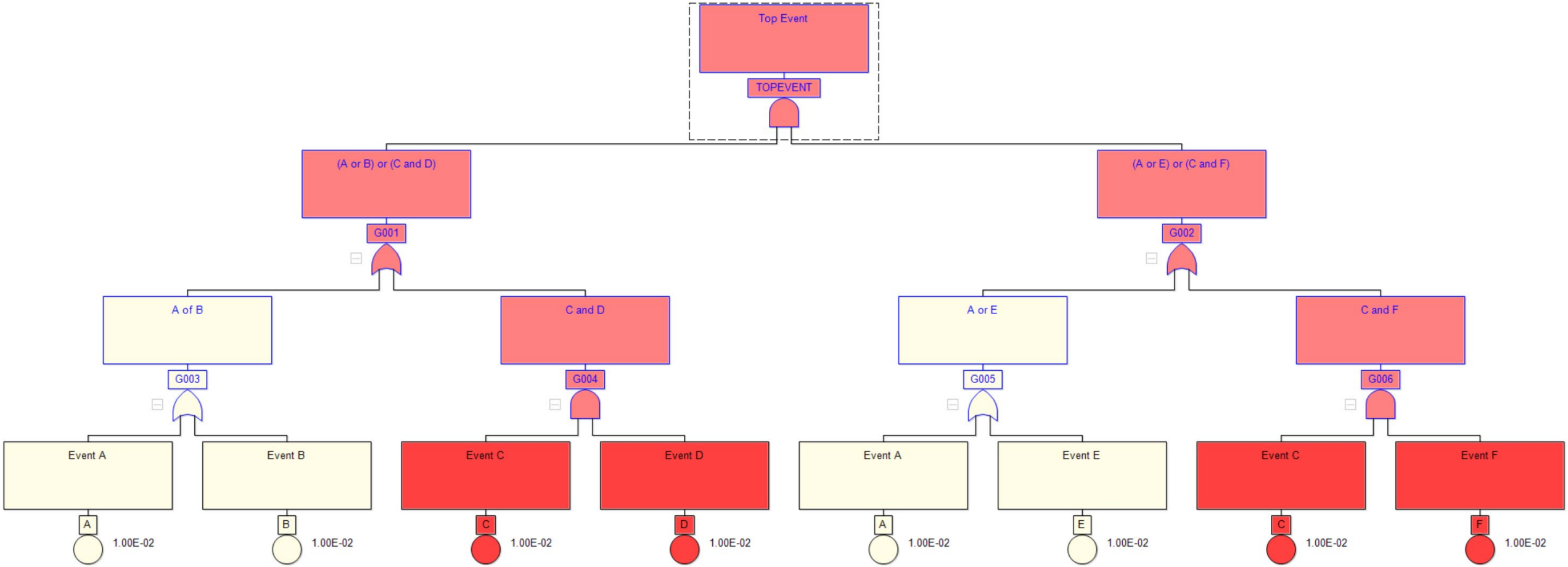
Cut Set: A



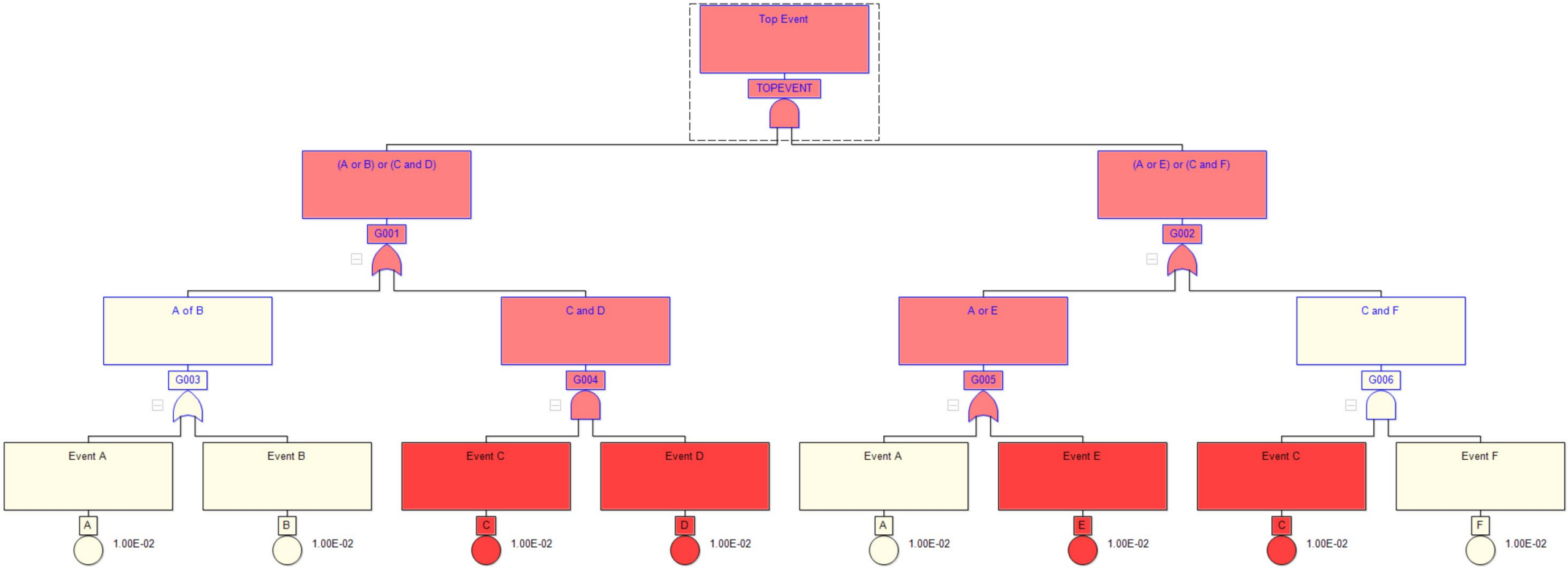
Cut Set: B * E



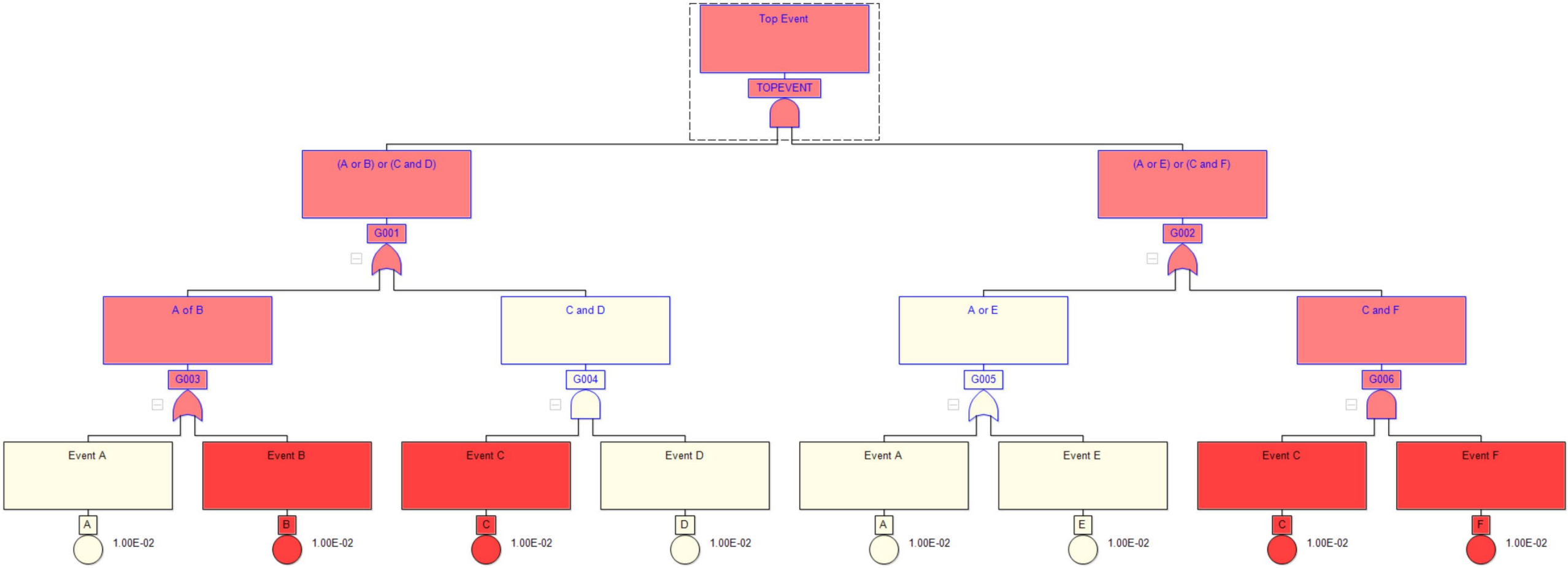
Cut Set: C * D * F



Cut Set: C * D * E



Cut Set: B * C * F



Use Cut Sets to Confirm the Underlying Fault Tree Is Correct

- Remember: Cut sets are the combinations of failures that cause the top event to be true
- **If the cut sets are correct, then the fault tree is correct**
- Verify the existing cut sets SHOULD make the top event TRUE
- Look for anything missing:
  - Single points of failure
  - Expected symmetry
  - Expected asymmetry
  - Manual actions as backup to automation

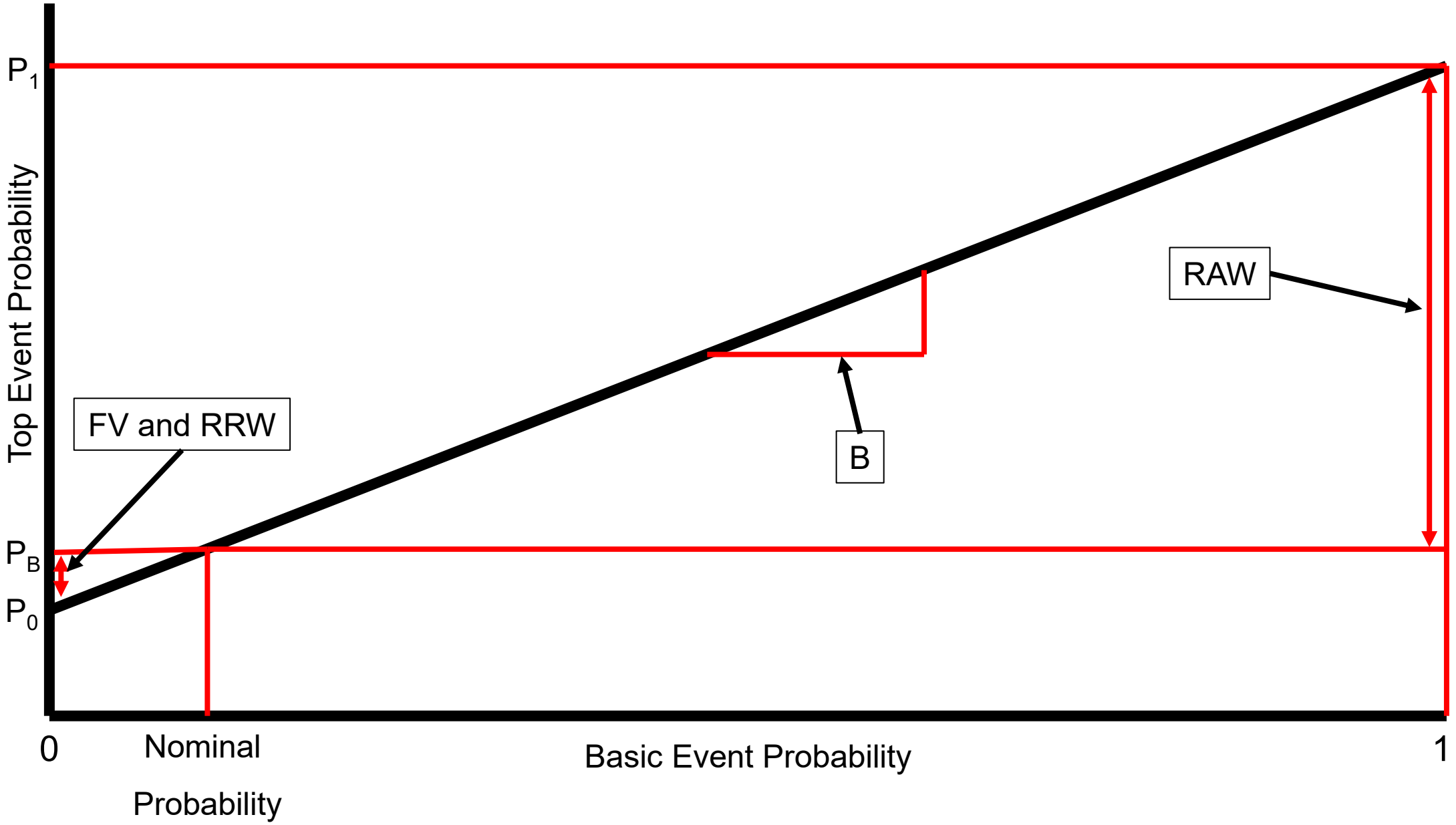
Importance Measures

- How important are each of the basic events?
- Importance measures can assess impact of reliability and availability
- Common importance measures:
  - Fussell-Vesely (FV)
  - Risk Achievement Worth (RAW)
  - Risk Reduction Worth (RRW)
  - Birnbaum (B)
- Importance measures are easily calculated from cut sets

Importance Measures

- FV = $(P_B - P_0)/P_B$
- RAW = P_1/P_B
- RRW = P_B/P_0 (Note: Some define this as P_0/P_B)
- B = P_1/P_0

- P is your top event probability
- P_B is the probability with nominal values (baseline)
- P_0 is the probability when an event's probability set to 0 (FALSE)
- P_1 is the probability when an event's probability set to 1 (TRUE)



Fussell-Vesely (FV) Importance

- $FV = (P_B - P_0)/P_B$
- FV is the fraction of risk that includes a particular failure
- FV is a measure of how much risk can be reduced if you improve the reliability of a component
  - If the probability of failure goes down for a component with a high FV, risk will go down
  - If a component has a low FV, improving the reliability will not impact risk

Risk Reduction Worth (RRW) Importance

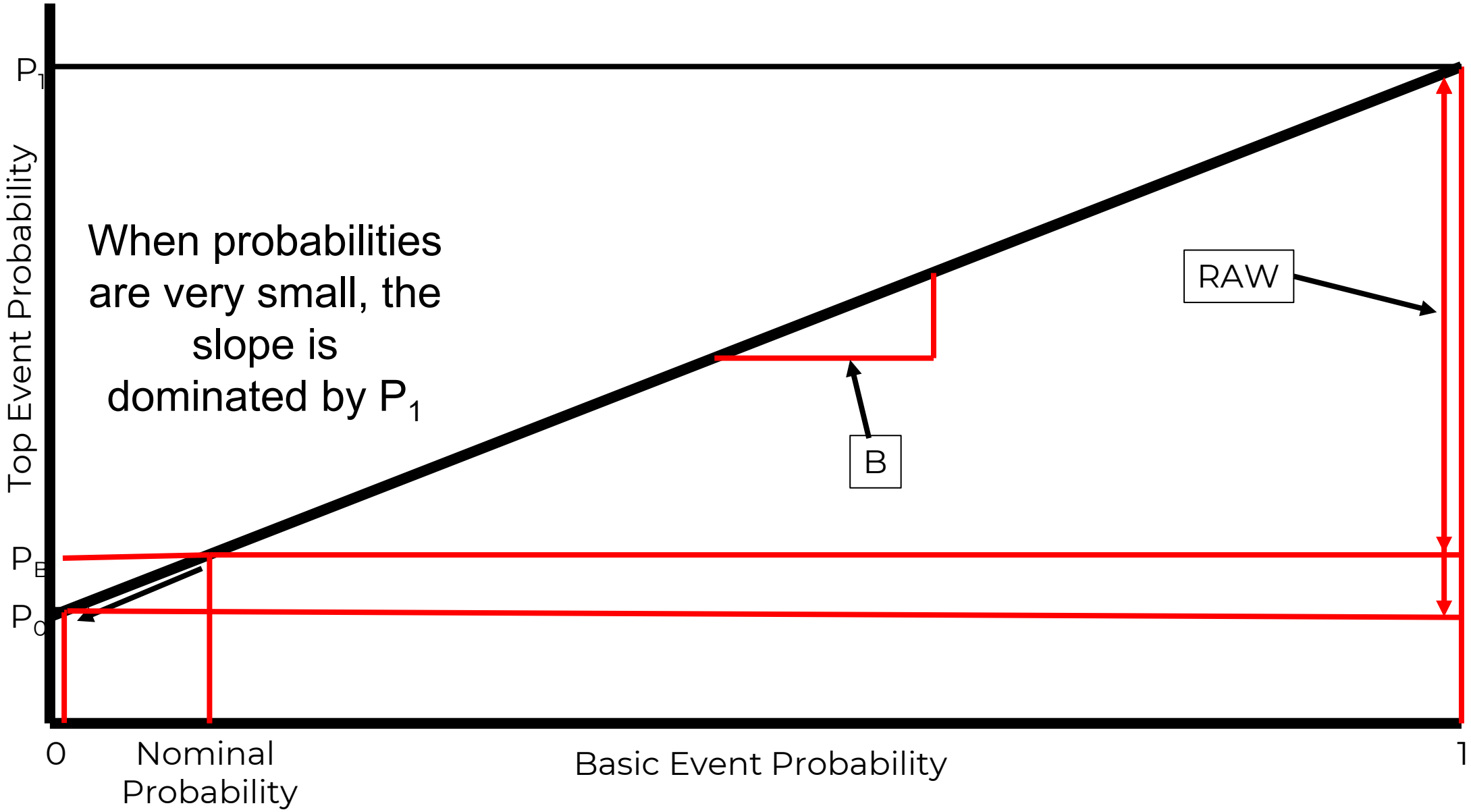
- RRW = P_B/P_0
- The RRW gives similar insights as FV
- The measure is a ratio of how good risk can get by improving an item compared to the baseline risk

Risk Achievement Worth (RAW) Importance

- RAW = P_1/P_B
- RAW is a measure of how high risk will go if a component fails regardless of how reliable it is
- Improving the reliability of a component will not reduce the RAW
- To reduce the RAW, you must make the component less important in the model
  - Add redundancy or diversity to the function modeled to make it less important
  - Add credit for human actions to compensate for a component failure

Birnbaum (B) Importance

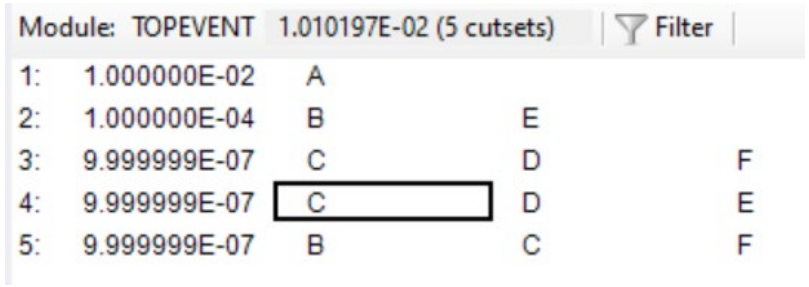
- $B = P_1/P_0$
- B attempts to combine reliability and availability impacts into a single measure
- B is the slope of the line of top event probability vs. the item's probability of failure
  - How much reduction in risk do you get from an incremental improvement in reliability?
- In practice, if failure rates are small (<1E-3), the risk insights from B are similar to RAW, because the slope is dominated by P_1



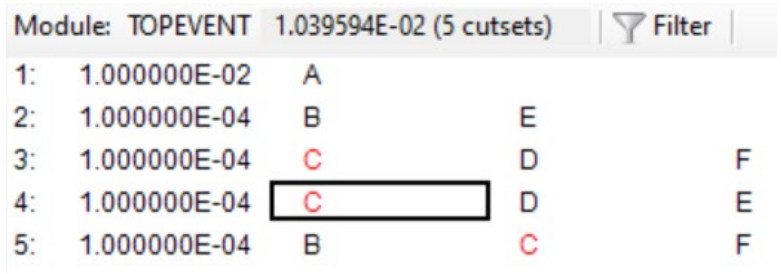
Sensitivity Studies

- Sensitivity studies assess the impact of a change to the model
  - What if a component fails?
  - How important is this assumption?
  - What if my failure rate changes?
- Adjustments can be made to an existing cut set file to perform sensitivity studies
  - Set an event to TRUE/FALSE
  - Change a probability of an event

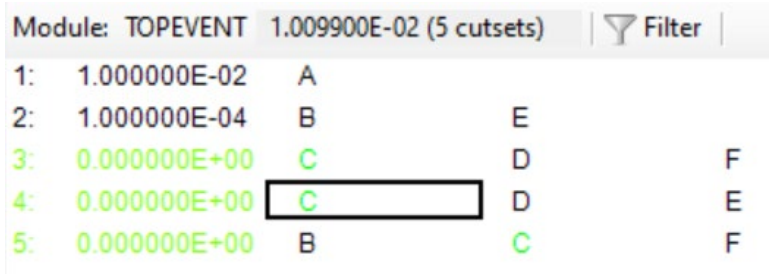
Sensitivity Study – Set C to TRUE/FALSE



Baseline: Top Event Prob = 1.01E-2



C=TRUE: Top Event Prob = 1.04E-2



C=FALSE: Top Event Prob = 1.01E-2

Conclusion: Top event is not sensitive to the probability of C
(because risk is dominated by single point of failure A)

Sensitivity Study – Set A to TRUE/FALSE

Module: TOPEVENT 1.010197E-02 (5 cutsets) Filter

1:	1.000000E-02	A		
2:	1.000000E-04	B	E	
3:	9.999999E-07	C	D	F
4:	9.999999E-07	C	D	E
5:	9.999999E-07	B	C	F

Baseline: Top Event Prob = 1.01E-2

Module: TOPEVENT 1.000000E+00 (5 cutsets) Filter

1:	1.000000E+00	A		
2:	1.000000E-04	B	E	
3:	9.999999E-07	C	D	F
4:	9.999999E-07	C	D	E
5:	9.999999E-07	B	C	F

A=TRUE: Top Event Prob = 1.0

Module: TOPEVENT 1.029997E-04 (5 cutsets) Filter

1:	0.000000E+00	A		
2:	1.000000E-04	B	E	
3:	9.999999E-07	C	D	F
4:	9.999999E-07	C	D	E
5:	9.999999E-07	B	C	F

A=FALSE: Top Event Prob = 1.03E-4

Conclusion: Top event is very sensitive to the probability of A

Importance Measures/Sensitivity Studies – Notes

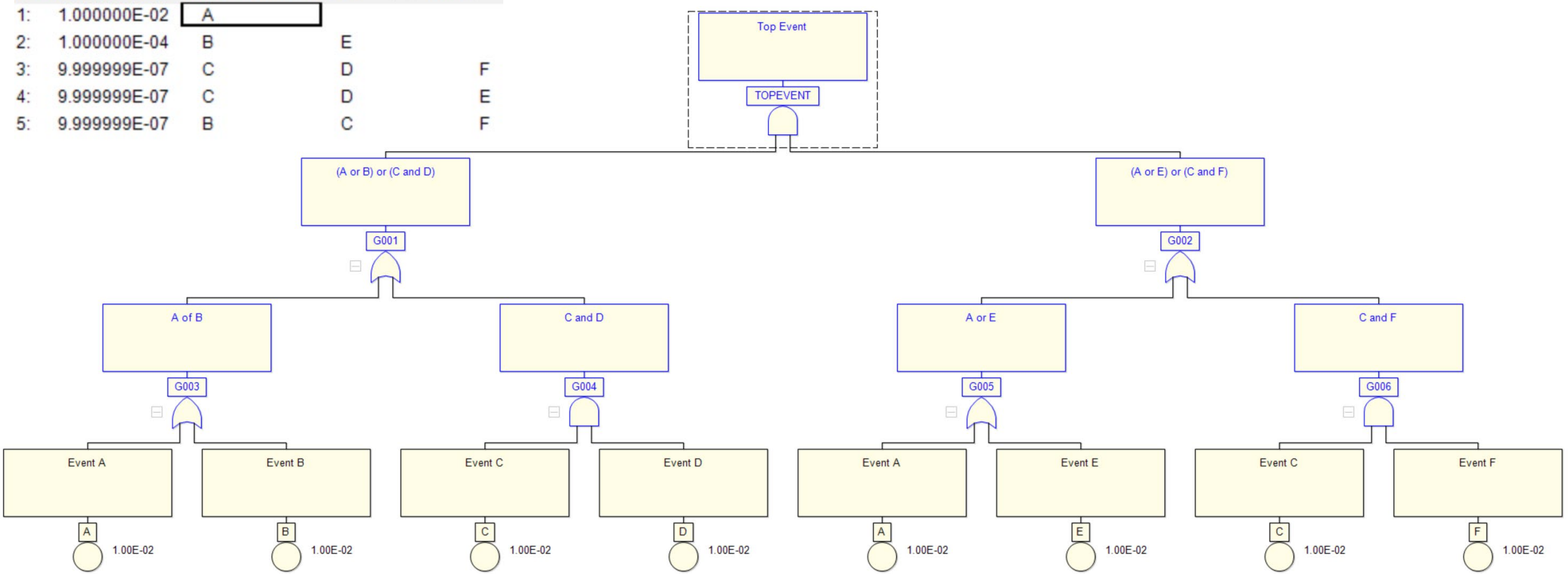
- When setting basic events to TRUE, you should remove non-minimal cut sets for more accurate answer
- When cut sets are truncated, you may need to requantify the model with events set to 1.0 to get more accurate results for RAW and Birnbaum (especially for low probability events)
- RRW, FV, and RAW are relative importance measures – they are normalized by the baseline top event probability

Identify Vulnerabilities

- Calculating the top event probability is just the beginning of risk assessment
- More important is “What can we do about it?”
- Cut sets point to the failures that contribute most to risk
- This can identify potential improvements to reduce risk
  - Add human action to compensate for failure
  - Add redundant or diverse means to accomplish a function
  - Improve the reliability of risk-important components

What Could We Do to Reduce Risk?

Module: TOPEVENT	1.010197E-02 (5 cutsets)	Filter		
1:	1.000000E-02	A		
2:	1.000000E-04	B	E	
3:	9.999999E-07	C	D	F
4:	9.999999E-07	C	D	E
5:	9.999999E-07	B	C	F



Post-Processing of Cut Sets (Recovery Rules)

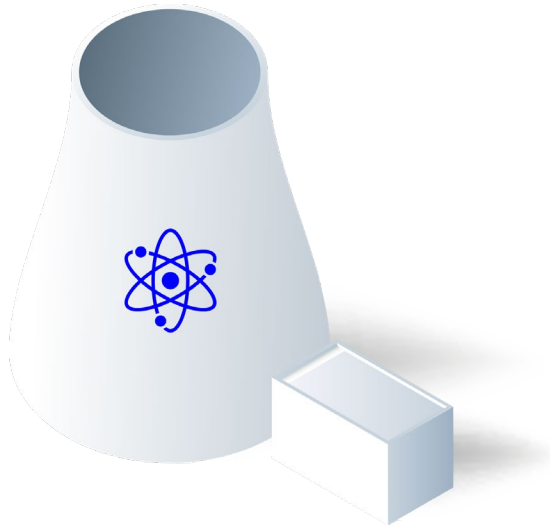
- Sometimes it is easier to post-process cut sets than to model a feature in a fault tree
- Once the cut sets are generated, you can establish rules to modify a cut set based on the basic events in it
- Example recovery rules:
  - Add a basic event to the cut set
  - Delete a cut set
  - Replace one basic event with another basic event in a cut set

Example Recovery Rule

- A credited human action has a high probability of failure due to a very short time margin for success
- If the cut set indicates a pump failed to run for the mission time, some more time was available for the human action to be successful
- A recovery rule could look for a cut set with the human action and pump failure-to-run event and replace the human action basic event with a different one with a lower probability of failure

Risk Assessment in Commercial Nuclear Power

- The U.S. commercial nuclear power industry has been using probabilistic risk assessment since the 1980s
- PRA models, through importance measures and cut set reviews, identified vulnerabilities and pointed to potential solutions to address those vulnerabilities



- In that time, the overall risk of existing plants has gone down, while the capacity factor (percent of time at power) has gone up
- Plants are now safer and operating more reliably

Any Questions?

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