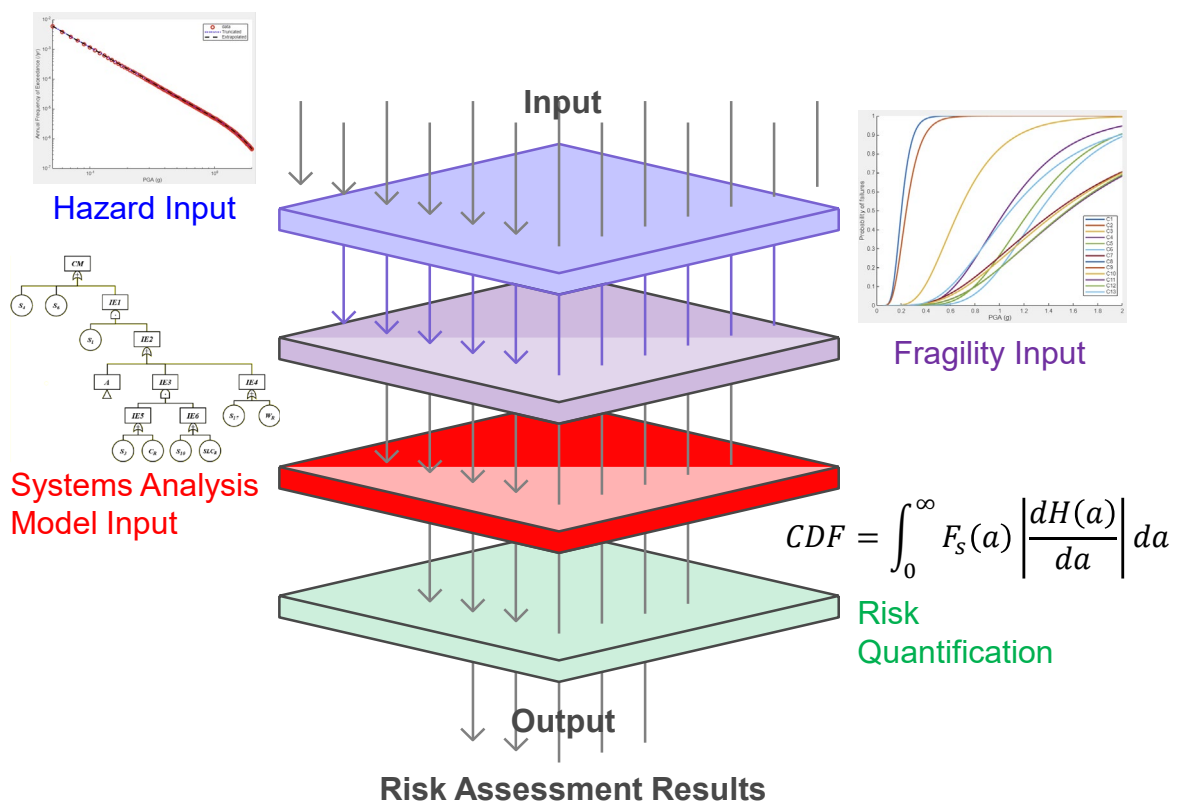
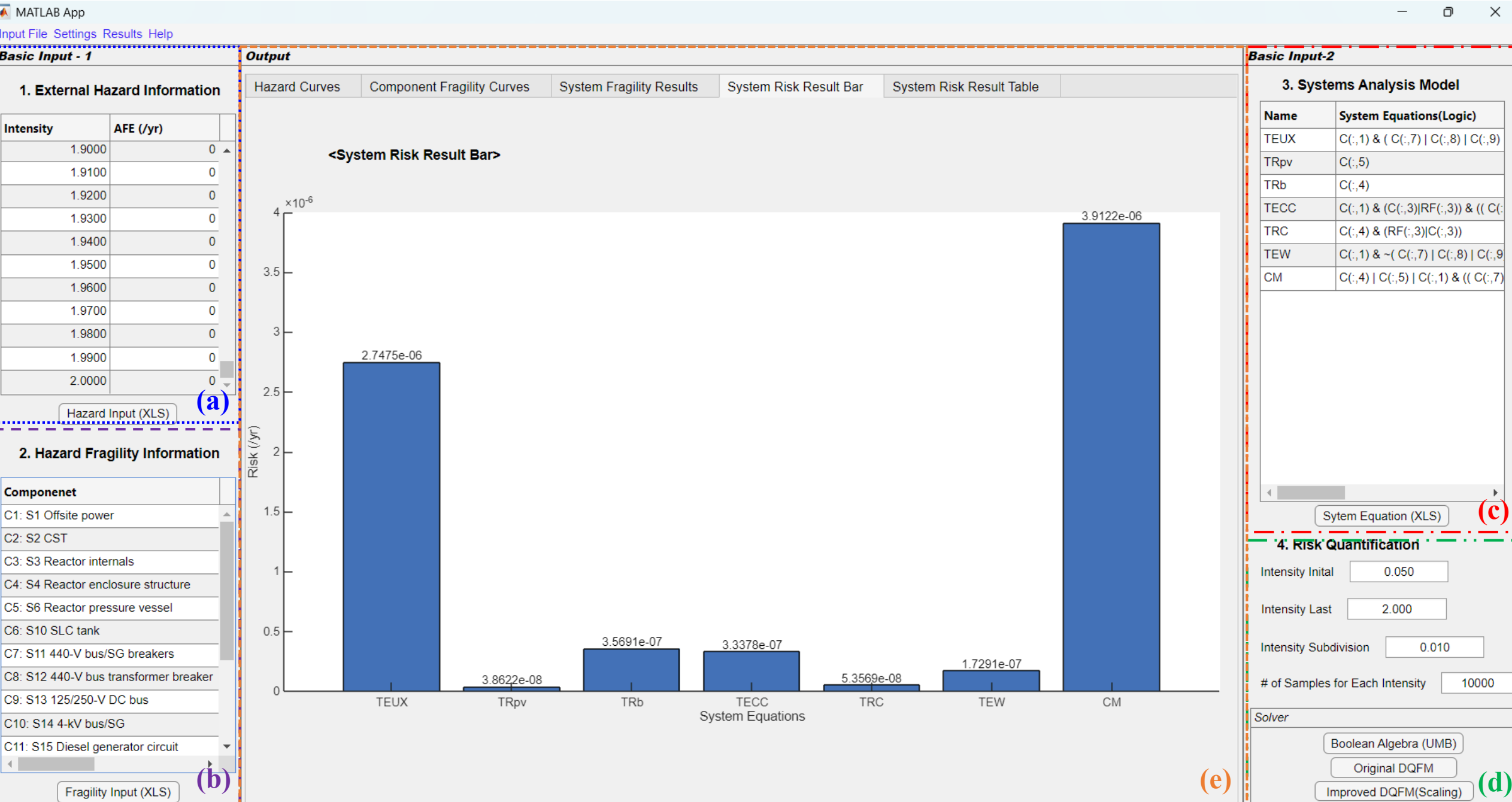


EHRA Program Modules



Matlab GUI Application Configuration



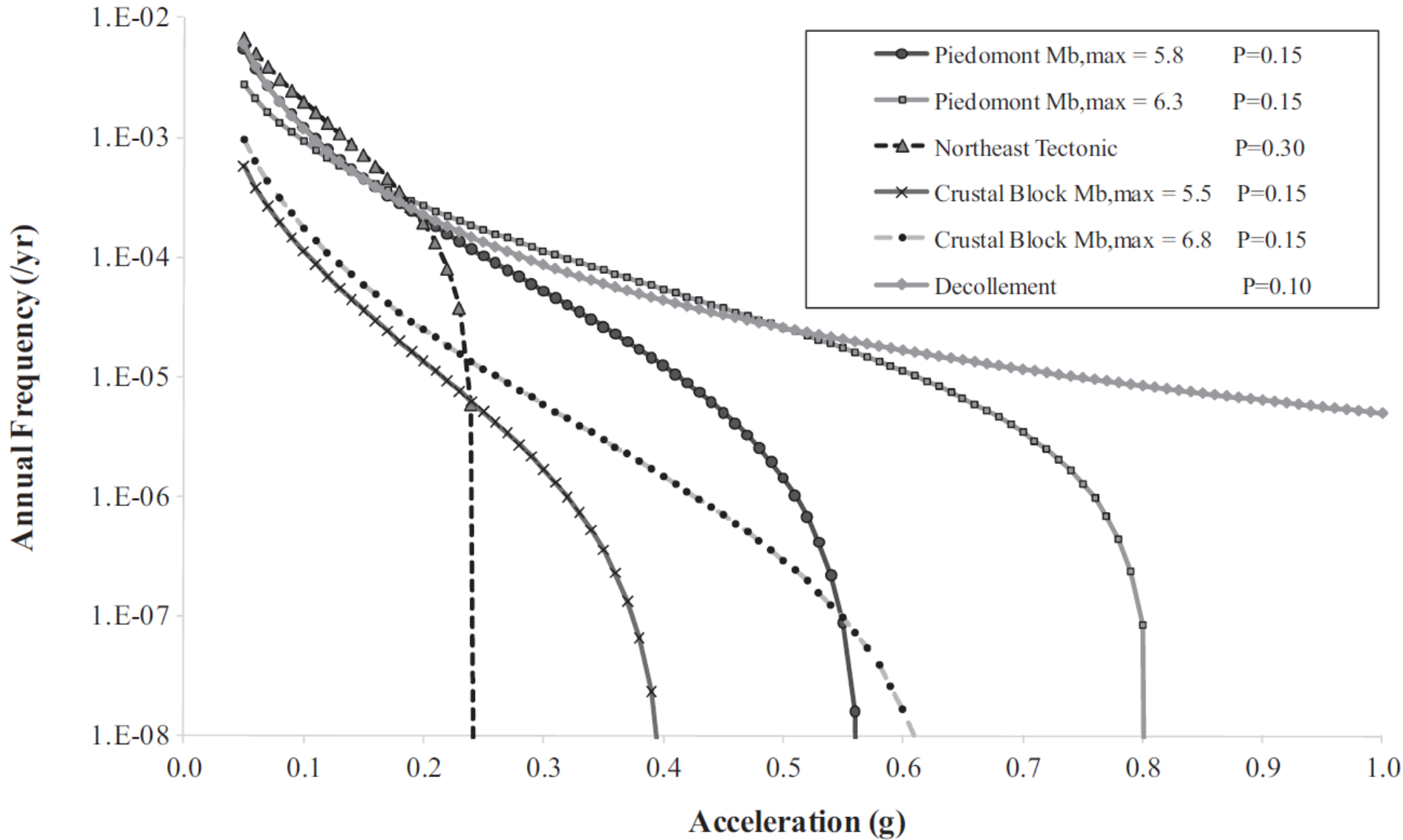


Fig. 12. Seismic hazard curves for all seismogenic zones at LGS site (SARA-LGS).

Ellingwood, B. (1990). Validation studies of seismic PRAs. *Nuclear Engineering and Design*, 123(2-3), 189-196.
Kim, J. H., Choi, I. K., & Park, J. H. (2011). Uncertainty analysis of system fragility for seismic safety evaluation of NPP. *Nuclear Engineering and Design*, 241(7), 2570-2579.
Kwag, S., Choi, E., Eem, S., Ha, J. G., & Hahm, D. (2021). Toward improvement of sampling-based seismic probabilistic safety assessment method for nuclear facilities using composite distribution and adaptive discretization. *Reliability Engineering & System Safety*, 215, 107809.

Table 1
Seismic fragility and random failure probability information of components of LGS NPP (A_m is a seismic intensity when the probability of failure is 50%) [30].

| Components | | $R_m (A_m)$ | S_m | β_R | β_S | β_C | Mean failure rate (per yr) |
|------------|--------------------------------------|-------------|-------|-----------|-----------|-----------|----------------------------|
| S_1 | Offsite power | 0.20g | 0.20g | 0.226 | 0.226 | 0.320 | - |
| S_2 | Condensate storage tank | 0.24g | 0.24g | 0.273 | 0.273 | 0.386 | - |
| S_3 | Reactor internals | 0.67g | 0.67g | 0.300 | 0.300 | 0.425 | - |
| S_4 | Reactor enclosure structure | 1.05g | 1.05g | 0.282 | 0.282 | 0.398 | - |
| S_6 | Reactor pressure vessel | 1.25g | 1.25g | 0.252 | 0.252 | 0.356 | - |
| S_{10} | SLC tank | 1.33g | 1.33g | 0.233 | 0.233 | 0.330 | - |
| S_{11} | 440-V bus/SG breakers | 1.46g | 1.46g | 0.411 | 0.411 | 0.582 | - |
| S_{12} | 440-V bus transformer breaker | 1.49g | 1.49g | 0.397 | 0.397 | 0.561 | - |
| S_{13} | 125/250-V DC bus | 1.49g | 1.49g | 0.397 | 0.397 | 0.561 | - |
| S_{14} | 4-kV bus/SG | 1.49g | 1.49g | 0.397 | 0.397 | 0.561 | - |
| S_{15} | Diesel generator circuit | 1.56g | 1.56g | 0.368 | 0.368 | 0.520 | - |
| S_{16} | Diesel generator heat and vent | 1.55g | 1.55g | 0.363 | 0.363 | 0.513 | - |
| S_{17} | RHR heat exchangers | 1.09g | 1.09g | 0.330 | 0.330 | 0.466 | - |
| DG_R | DGR – diesel generator common mode | | - | - | - | | 0.00125 |
| W_R | WR – containment heat removal | | - | - | - | | 0.00026 |
| C_R | CR – scram system mechanical failure | | - | - | - | | 1.00E-05 |
| SLC_R | SLCR – standby liquid control | | - | - | - | | 0.01 |

Ellingwood, B. (1990). Validation studies of seismic PRAs. Nuclear Engineering and Design, 123(2-3), 189-196.
Kim, J. H., Choi, I. K., & Park, J. H. (2011). Uncertainty analysis of system fragility for seismic safety evaluation of NPP. Nuclear Engineering and Design, 241(7), 2570-2579.
Kwag, S., Choi, E., Eem, S., Ha, J. G., & Hahm, D. (2021). Toward improvement of sampling-based seismic probabilistic safety assessment method for nuclear facilities using composite distribution and adaptive discretization. Reliability Engineering & System Safety, 215, 107809.

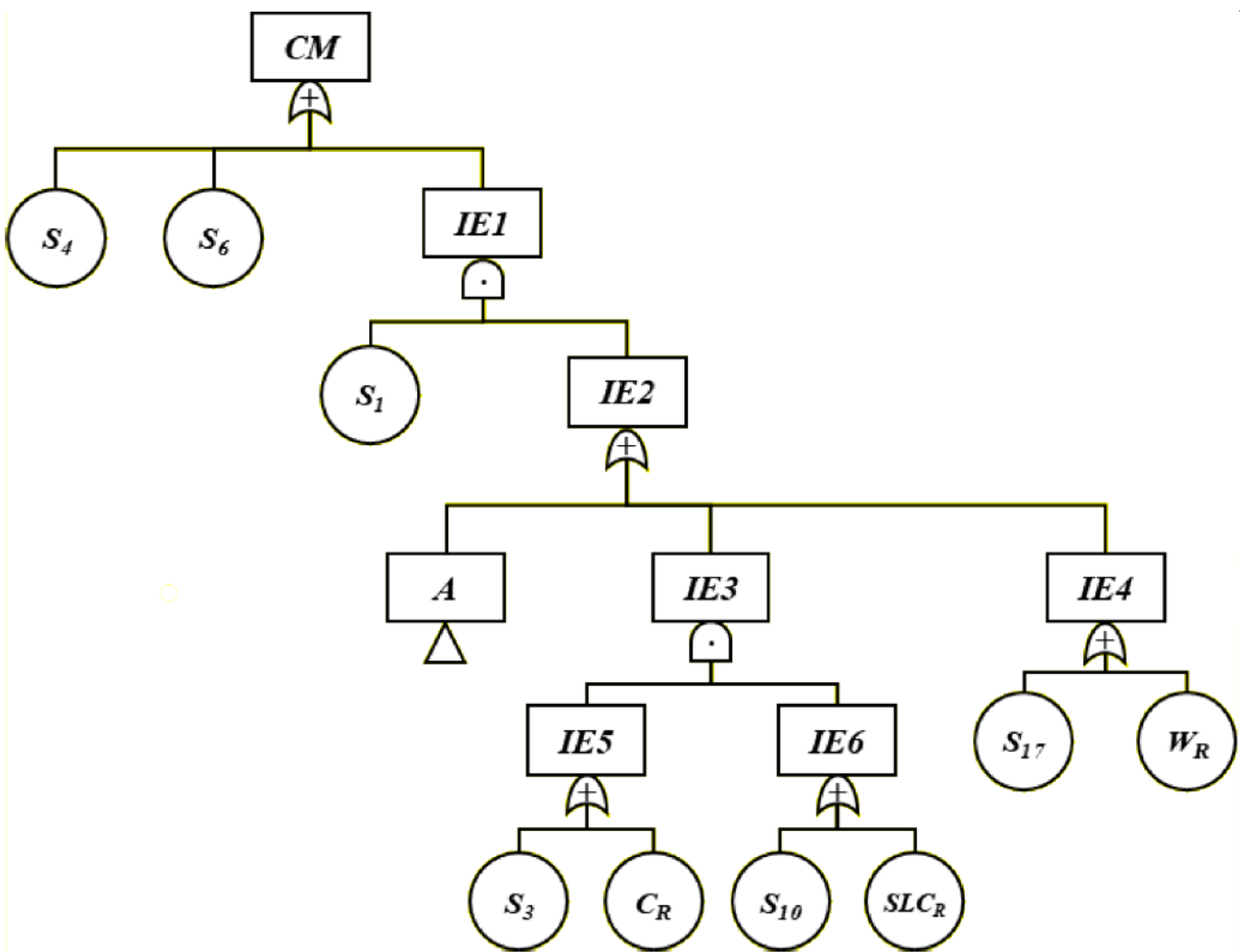


Fig. 5. Fault tree expression of scenario *CM*.

$$A = S_{11} \cup S_{12} \cup S_{13} \cup S_{14} \cup S_{15} \cup S_{16} \cup DG_R \tag{15}$$

$$T_sE_sUX = S_1 \cap A \tag{16}$$

$$T_sR_b = S_4 \tag{17}$$

$$T_sR_{pv} = S_6 \tag{18}$$

$$T_sE_sC_mC_2 = S_1 \cap (S_3 \cup C_R) \cap (A \cup S_{10} \cup SLC_R) \tag{19}$$

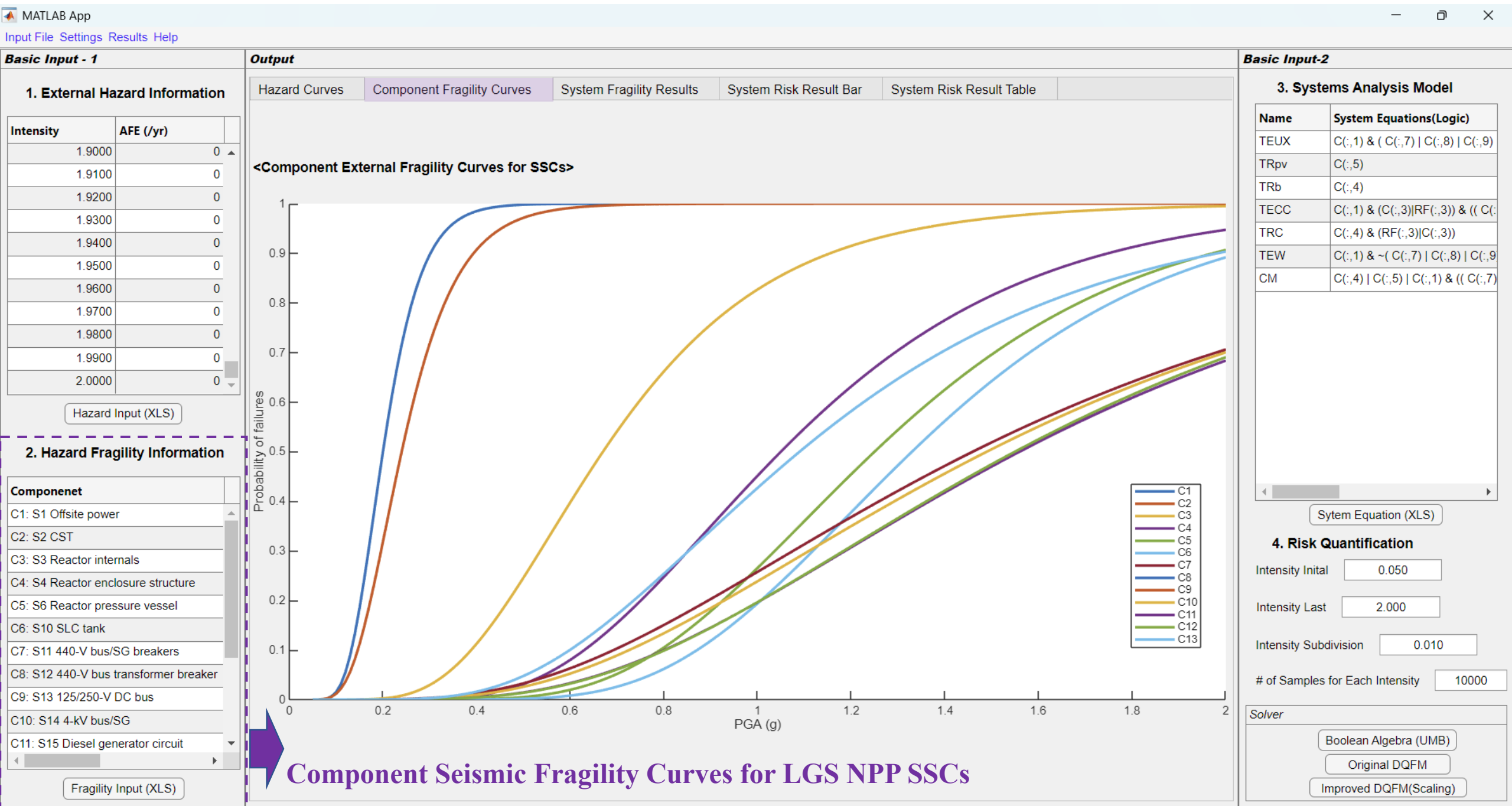
$$T_sR_bC_m = S_4 \cap (C_R \cup S_3) \tag{20}$$

$$T_sE_sW = S_1 \cap \overline{A} \cap \left(\overline{S_{17}} \cap W_R \cup \overline{S_2} \cap S_{17} \right) \tag{21}$$

$$CM = S_4 \cup S_6 \cup S_1 \cap [A \cup (S_3 \cup C_R) \cap (S_{10} \cup SLC_R) \cup (S_{17} \cup W_R)] \tag{22}$$

Seismic Harzard Curve Input & Confirmation

Improved DQFM(Scaling)



Basic Input - 1

1. External Hazard Information

| Intensity | AFE (/yr) | |
|-----------|-----------|---|
| 1.9000 | | 0 |
| 1.9100 | | 0 |
| 1.9200 | | 0 |
| 1.9300 | | 0 |
| 1.9400 | | 0 |
| 1.9500 | | 0 |
| 1.9600 | | 0 |
| 1.9700 | | 0 |
| 1.9800 | | 0 |
| 1.9900 | | 0 |
| 2.0000 | | 0 |

Hazard Input (XLS)

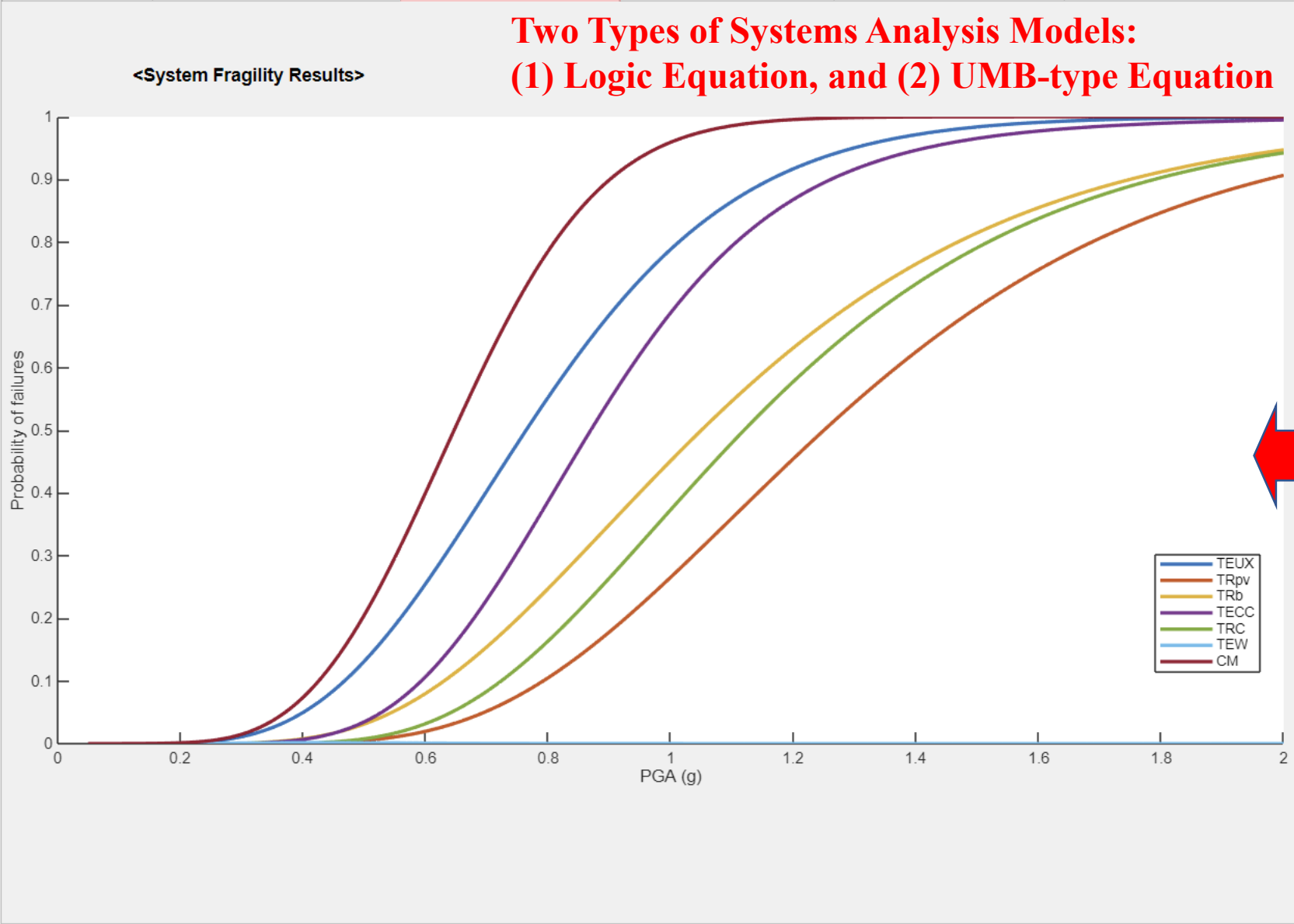
2. Hazard Fragility Information

| Component |
|---------------------------------------|
| C1: S1 Offsite power |
| C2: S2 CST |
| C3: S3 Reactor internals |
| C4: S4 Reactor enclosure structure |
| C5: S6 Reactor pressure vessel |
| C6: S10 SLC tank |
| C7: S11 440-V bus/SG breakers |
| C8: S12 440-V bus transformer breaker |
| C9: S13 125/250-V DC bus |
| C10: S14 4-kV bus/SG |
| C11: S15 Diesel generator circuit |

Fragility Input (XLS)

Output

- Hazard Curves
- Component Fragility Curves
- System Fragility Results
- System Risk Result Bar
- System Risk Result Table



Basic Input-2

3. Systems Analysis Model

| Name | System Equations(Logic) |
|------|--|
| TEUX | $C(:,1) \& (C(:,7) C(:,8) C(:,9))$ |
| TRpv | $C(:,5)$ |
| TRb | $C(:,4)$ |
| TECC | $C(:,1) \& (C(:,3) RF(:,3)) \& ((C(:,1) C(:,2)) C(:,3))$ |
| TRC | $C(:,4) \& (RF(:,3) C(:,3))$ |
| TEW | $C(:,1) \& \sim(C(:,7) C(:,8) C(:,9))$ |
| CM | $C(:,4) C(:,5) C(:,1) \& ((C(:,7) C(:,8) C(:,9))$ |

Sytem Equation (XLS)

4. Risk Quantification

Intensity Initial: 0.050

Intensity Last: 2.000

Intensity Subdivision: 0.010

of Samples for Each Intensity: 10000

Solver:

- Boolean Algebra (UMB)
- Original DQFM
- Improved DQFM(Scaling)

1. External Hazard Information

| Intensity | AFE (/yr) |
|-----------|-----------|
| 1.9000 | 0 |
| 1.9100 | 0 |
| 1.9200 | 0 |
| 1.9300 | 0 |
| 1.9400 | 0 |
| 1.9500 | 0 |
| 1.9600 | 0 |
| 1.9700 | 0 |
| 1.9800 | 0 |
| 1.9900 | 0 |
| 2.0000 | 0 |

Hazard Input (XLS)

2. Hazard Fragility Information

| Component |
|---------------------------------------|
| C1: S1 Offsite power |
| C2: S2 CST |
| C3: S3 Reactor internals |
| C4: S4 Reactor enclosure structure |
| C5: S6 Reactor pressure vessel |
| C6: S10 SLC tank |
| C7: S11 440-V bus/SG breakers |
| C8: S12 440-V bus transformer breaker |
| C9: S13 125/250-V DC bus |
| C10: S14 4-kV bus/SG |
| C11: S15 Diesel generator circuit |

Fragility Input (XLS)

Output

Hazard Curves

Component Fragility Curves

System Fragility Results

System Risk Result Bar

System Risk Result Table

<System Risk Result Bar>

| System Equations | Risk (/yr) |
|------------------|------------|
| TEUX | 2.7475e-06 |
| TRpv | 3.8622e-08 |
| TRb | 3.5691e-07 |
| TECC | 3.3378e-07 |
| TRC | 5.3569e-08 |
| TEW | 1.7291e-07 |
| CM | 3.9122e-06 |

Basic Input-2

3. Systems Analysis Model

| Name | System Equations(Logic) |
|------|--------------------------------------|
| TEUX | C(:,1) & (C(:,7) C(:,8) C(:,9) |
| TRpv | C(:,5) |
| TRb | C(:,4) |
| TECC | C(:,1) & (C(:,3) RF(:,3)) & ((C(:, |
| TRC | C(:,4) & (RF(:,3) C(:,3)) |
| TEW | C(:,1) & ~(C(:,7) C(:,8) C(:,9 |
| CM | C(:,4) C(:,5) C(:,1) & ((C(:,7) |

Sytem Equation (XLS)

4. Risk Quantification

Intensity Inital

0.050

Intensity Last

2.000

Intensity Subdivision

0.010

of Samples for Each Intensity

10000

Solver

Boolean Algebra (UMB)

Original DQFM

Improved DQFM(Scaling)

Risk Quantification Bar Result using Three Different Solvers

Risk Quantification Input & System Risk Results

| |
|----------------------|
| Basic Input-2 |
|----------------------|

System Risk Result Table

| | | | | |
|---------------|----------------------------|--------------------------|------------------------|---------------------------------|
| Hazard Curves | Component Fragility Curves | System Fragility Results | System Risk Result Bar | <u>System Risk Result Table</u> |
|---------------|----------------------------|--------------------------|------------------------|---------------------------------|

| <System Risk Result Table> | | |
|----------------------------|------------|-----------------------|
| Name | Risk(/yr) | CDF contribution(/yr) |
| TEUX | 2.7475e-06 | 2.7475e-06 |
| TRpv | 3.8622e-08 | 3.8622e-08 |
| TRb | 3.5691e-07 | 3.5691e-07 |
| TECC | 3.3378e-07 | 3.3378e-07 |
| TRC | 5.3569e-08 | 5.3569e-08 |
| TEW | 1.7291e-07 | 1.7291e-07 |
| CM | 3.9122e-06 | 3.9122e-06 |

Risk Quantification Table Result using Three Different Solvers

Risk Quantification Table Result using Three Different Solvers

3. Systems Analysis Model



System Equation (XLS)

4. Risk Quantification

Downloaded from <http://ajph.org/> at University of California, San Diego on September 11, 2014

| | |
|----------------|-------|
| Intensity Last | 2.000 |
|----------------|-------|

| | |
|-----------------------|-------|
| Intensity Subdivision | 0.010 |
|-----------------------|-------|

of Samples for Each Intensity 10000

Solver

Boolean Algebra (UMB)

Original DQFM

Improved DQFM(Scaling)

Appendix. File Type and Import for Example Case

Seismic Harzard Curve Input

Button Click and Import Sheet1 of the EXCEL file.

Input_Data_LGS1.xlsx

| | A | B | C | D | E | F | G | H | I |
|----|----------|----------|---|---|---|---|---|---|---|
| 1 | PGA | AFE1 | | | | | | | |
| 2 | 5.00E-02 | 0.00549 | | | | | | | |
| 3 | 6.00E-02 | 0.00375 | | | | | | | |
| 4 | 7.00E-02 | 0.00269 | | | | | | | |
| 5 | 8.00E-02 | 0.00201 | | | | | | | |
| 6 | 9.00E-02 | 0.00155 | | | | | | | |
| 7 | 0.1 | 0.00122 | | | | | | | |
| 8 | 0.11 | 0.000974 | | | | | | | |
| 9 | 0.12 | 0.000792 | | | | | | | |
| 10 | 0.13 | 0.000652 | | | | | | | |
| 11 | 0.14 | 0.000542 | | | | | | | |
| 12 | 0.15 | 0.000454 | | | | | | | |
| 13 | 0.16 | 0.000384 | | | | | | | |
| 14 | 0.17 | 0.000326 | | | | | | | |
| 15 | 0.18 | 0.000279 | | | | | | | |
| 16 | 0.19 | 0.00024 | | | | | | | |
| 17 | 0.2 | 0.000207 | | | | | | | |
| 18 | 0.21 | 0.000179 | | | | | | | |
| 19 | 0.22 | 1.55E-04 | | | | | | | |
| 20 | 0.23 | 1.35E-04 | | | | | | | |
| 21 | 0.24 | 1.17E-04 | | | | | | | |
| 22 | 0.25 | 0.000102 | | | | | | | |
| 23 | 0.26 | 8.94E-05 | | | | | | | |
| 24 | 0.27 | 7.82E-05 | | | | | | | |
| 25 | 0.28 | 6.83E-05 | | | | | | | |
| 26 | 0.29 | 5.98E-05 | | | | | | | |
| 27 | 0.3 | 5.23E-05 | | | | | | | |

Sheet1 Sheet2 Sheet3

MATLAB App

Input File Settings Results Help

Basic Input - 1

1. External Hazard Information

| Intensity | AFE (/yr) |
|-----------|-----------|
| 1.9000 | 0 |
| 1.9100 | 0 |
| 1.9200 | 0 |
| 1.9300 | 0 |
| 1.9400 | 0 |
| 1.9500 | 0 |
| 1.9600 | 0 |
| 1.9700 | 0 |
| 1.9800 | 0 |
| 1.9900 | 0 |
| 2.0000 | 0 |

Hazard Input (XLS)

2. Hazard Fragility Information

| Component |
|---------------------------------------|
| C1: S1 Offsite power |
| C2: S2 CST |
| C3: S3 Reactor internals |
| C4: S4 Reactor enclosure structure |
| C5: S6 Reactor pressure vessel |
| C6: S10 SLC tank |
| C7: S11 440-V bus/SG breakers |
| C8: S12 440-V bus transformer breaker |
| C9: S13 125/250-V DC bus |
| C10: S14 4-kV bus/SG |
| C11: S15 Diesel generator circuit |

Fragility Input (XLS)

Button Click and Import Sheet2 of the EXCEL file.



Input_Data_LGS1.xlsx

| | A | B | C | D | E |
|----|---|------|------|------|----------------|
| 1 | | Am | br | bu | random_failure |
| 2 | C1: S1 Offsite power | 0.2 | 0.2 | 0.25 | 0 |
| 3 | C2: S2 CST | 0.24 | 0.23 | 0.31 | 0 |
| 4 | C3: S3 Reactor internals | 0.67 | 0.28 | 0.32 | 0 |
| 5 | C4: S4 Reactor enclosure structure | 1.05 | 0.31 | 0.25 | 0 |
| 6 | C5: S6 Reactor pressure vessel | 1.25 | 0.28 | 0.22 | 0 |
| 7 | C6: S10 SLC tank | 1.33 | 0.27 | 0.19 | 0 |
| 8 | C7: S11 440-V bus/SG breakers | 1.46 | 0.38 | 0.44 | 0 |
| 9 | C8: S12 440-V bus transformer breaker | 1.49 | 0.36 | 0.43 | 0 |
| 10 | C9: S13 125/250-V DC bus | 1.49 | 0.36 | 0.43 | 0 |
| 11 | C10: S14 4-kV bus/SG | 1.49 | 0.36 | 0.43 | 0 |
| 12 | C11: S15 Diesel generator circuit | 1.56 | 0.32 | 0.41 | 0 |
| 13 | C12: S16 Diesel generator heat and vent | 1.55 | 0.28 | 0.43 | 0 |
| 14 | C13: S17 RHR heat exchangers | 1.09 | 0.32 | 0.34 | 0 |
| 15 | RF1: DGR Diesel generator common mode | 0 | 0 | 0 | 0.00125 |
| 16 | RF2: WR Containment heat removal | 0 | 0 | 0 | 0.00026 |
| 17 | RF3: CR Scram system mechanical failure | 0 | 0 | 0 | 1.00E-05 |
| 18 | RF4: SLCR Standby liquid control | 0 | 0 | 0 | 0.01 |
| 19 | | | | | |
| 20 | | | | | |
| 21 | | | | | |

Sheet1 Sheet2 Sheet3

Basic Input-2

3. Systems Analysis Model

| Name | System Equations(Logic) |
|------|--|
| TEUX | $C(:,1) \& (C(:,7) C(:,8) C(:,9))$ |
| TRpv | $C(:,5)$ |
| TRb | $C(:,4)$ |
| TECC | $C(:,1) \& (C(:,3) RF(:,3)) \& ((C(:,7) C(:,8) C(:,9) C(:,10) C(:,11) C(:,12) RF(:,1)) C(:,6) RF(:,4))$ |
| TRC | $C(:,4) \& (RF(:,3) C(:,3))$ |
| TEW | $C(:,1) \& \sim(C(:,7) C(:,8) C(:,9) C(:,10) C(:,11) C(:,12) RF(:,1)) \& ((\sim C(:,13) \& RF(:,2)) (\sim C(:,2) \& C(:,13)))$ |
| CM | $C(:,4) C(:,5) C(:,1) \& ((C(:,7) C(:,8) C(:,9) C(:,10) C(:,11) C(:,12) RF(:,1)) (C(:,3) RF(:,3))\&(C(:,6) RF(:,4)) (C(:,13) RF(:,2)))$ |

4. Risk Quantification

Intensity Initial0.050

Intensity Last2.000

Intensity Subdivision0.010

of Samples for Each Intensity10000

Solver

Boolean Algebra (UMB)

Original DQFM

Improved DQFM(Scaling)

Button Click and Import Sheet3 of the EXCEL file.



Input_Data_LGS1.xlsx

| | A | B |
|----|------|--|
| 1 | Name | System Equations (Logic Tree) |
| 2 | TEUX | $C(:,1) \& (C(:,7) C(:,8) C(:,9) C(:,10) C(:,11) C(:,12) RF(:,1))$ |
| 3 | TRpv | $C(:,5)$ |
| 4 | TRb | $C(:,4)$ |
| 5 | TECC | $C(:,1) \& (C(:,3) RF(:,3)) \& ((C(:,7) C(:,8) C(:,9) C(:,10) C(:,11) C(:,12) RF(:,1)) C(:,6) RF(:,4))$ |
| 6 | TRC | $C(:,4) \& (RF(:,3) C(:,3))$ |
| 7 | TEW | $C(:,1) \& \sim(C(:,7) C(:,8) C(:,9) C(:,10) C(:,11) C(:,12) RF(:,1)) \& ((\sim C(:,13) \& RF(:,2)) (\sim C(:,2) \& C(:,13)))$ |
| 8 | CM | $C(:,4) C(:,5) C(:,1) \& ((C(:,7) C(:,8) C(:,9) C(:,10) C(:,11) C(:,12) RF(:,1)) (C(:,3) RF(:,3))\&(C(:,6) RF(:,4)) (C(:,13) RF(:,2)))$ |
| 9 | | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | |

"Event Tree and Fault Tree-type" Model -> "Logical Expression"

| | C | D | E |
|----|--|---|--------------|
| 1 | System Equations (UMB) | | Secondary ET |
| 2 | $C(:,1)* (1 - (1 - C(:,7))* (1 - C(:,8))* (1 - C(:,9))* (1 - C(:,10))* (1 - C(:,11))* (1 - C(:,12))* (1 - RF(:,1)))$ | | 1 |
| 3 | $C(:,5)$ | | 1 |
| 4 | $C(:,4)$ | | 1 |
| 5 | $C(:,1)* (1 - (1 - C(:,3))* (1 - RF(:,3))) * (1 - (1 - (1 - C(:,7))* (1 - C(:,8))* (1 - C(:,9))* (1 - C(:,10))* (1 - C(:,11))* (1 - C(:,12))* (1 - RF(:,1)))) * (1 - C(:,6))* (1 - RF(:,4))$ | | 1 |
| 6 | $C(:,4)* (1 - (1 - RF(:,3))* (1 - C(:,3)))$ | | 1 |
| 7 | $C(:,1)* (1 - (1 - (1 - C(:,7))* (1 - C(:,8))* (1 - C(:,9))* (1 - C(:,10))* (1 - C(:,11))* (1 - C(:,12))* (1 - RF(:,1)))) * (1 - (1 - (1 - C(:,13))* RF(:,2))) * (1 - (1 - C(:,2))* C(:,13))$ | | 1 |
| 8 | $1 - (1 - C(:,4))* (1 - C(:,5))* (1 - C(:,1))* (1 - (1 - (1 - (1 - C(:,7))* (1 - C(:,8))* (1 - C(:,9))* (1 - C(:,10))* (1 - C(:,11))* (1 - C(:,12))* (1 - RF(:,1)))) * (1 - (1 - (1 - C(:,3))* (1 - RF(:,3))) * (1 - C(:,6))* (1 - RF(:,4)))) * (1 - (1 - (1 - C(:,13))* (1 - RF(:,2))))$ | | 1 |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | |
| 18 | | | |
| 19 | | | |
| 20 | | | |

"Event Tree and Fault Tree-type" Model -> "Uni-Modal Bound(UMB) Approach-type Mathematical Expression"