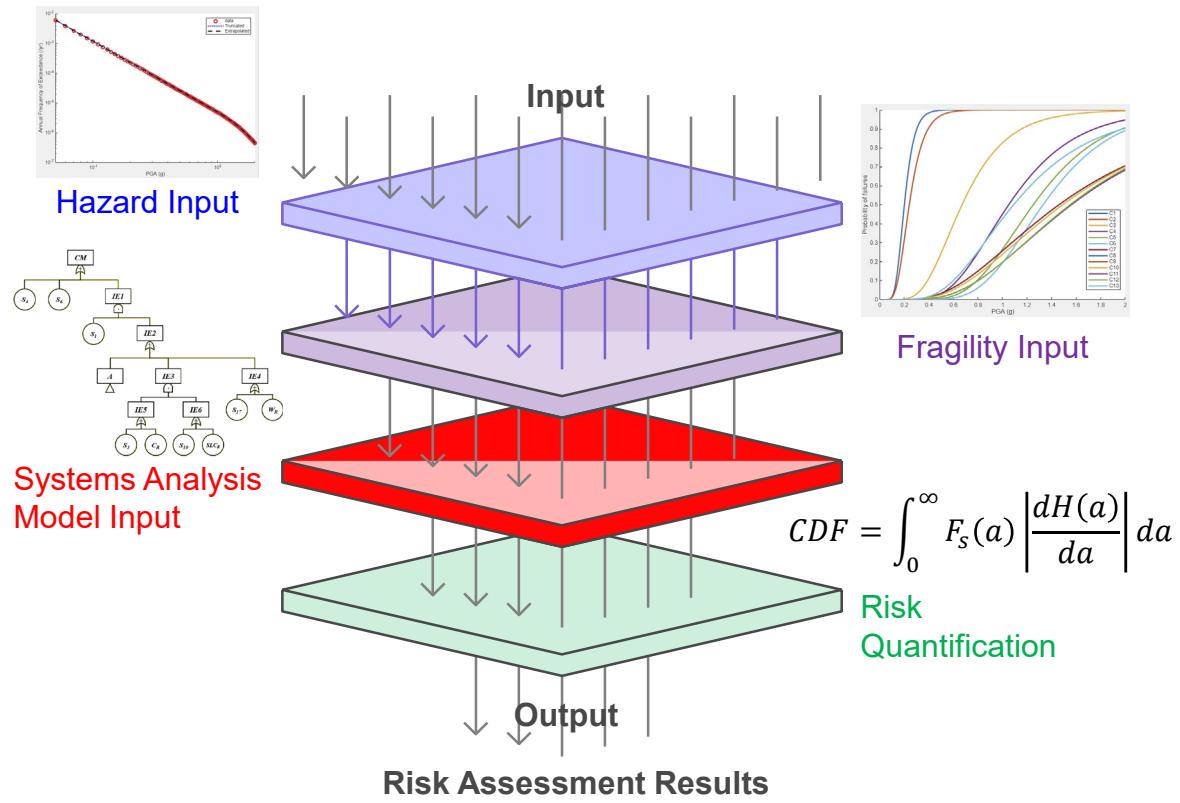
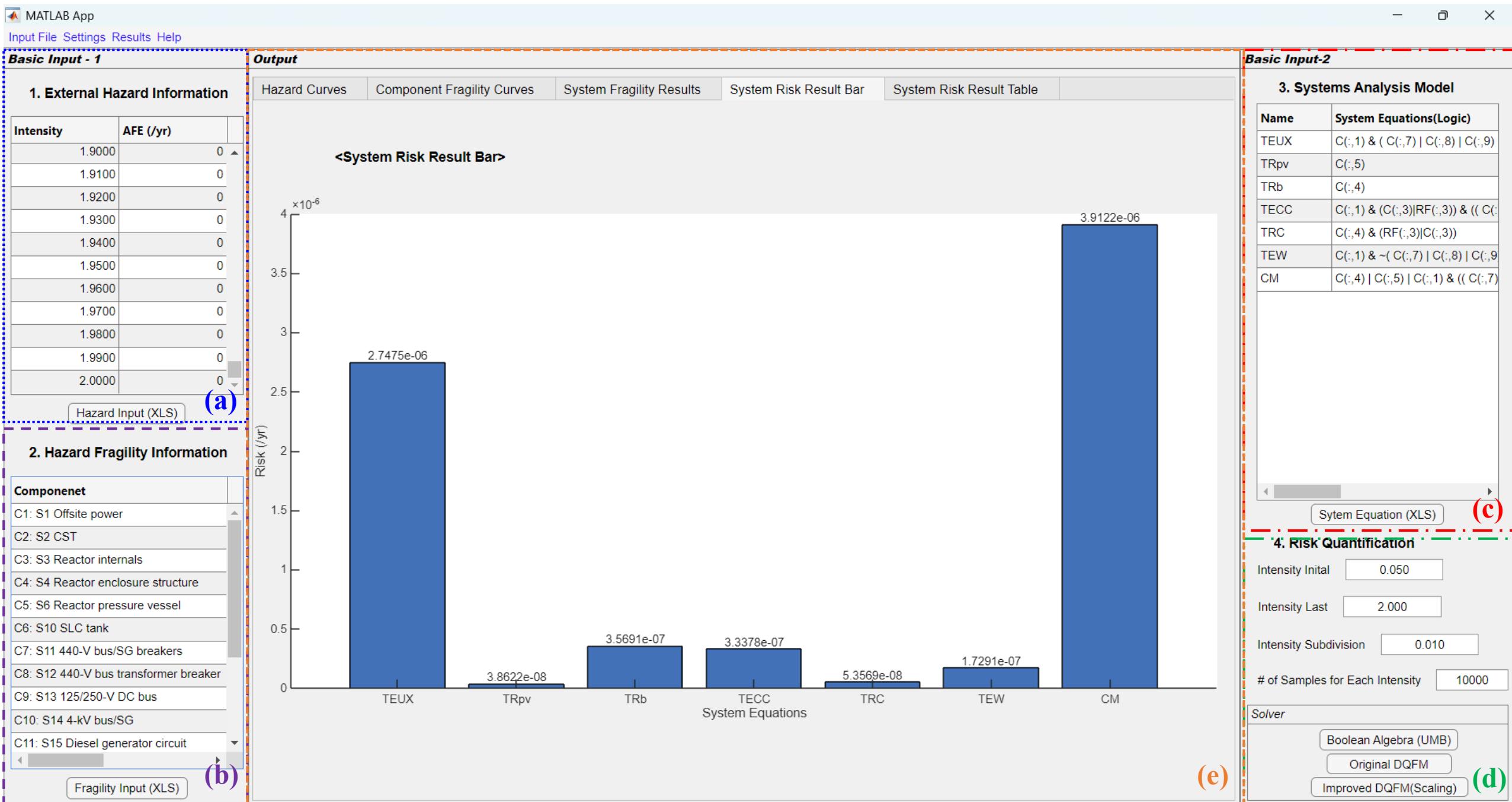


EHRA Program Modules



Matlab GUI Application Configuration



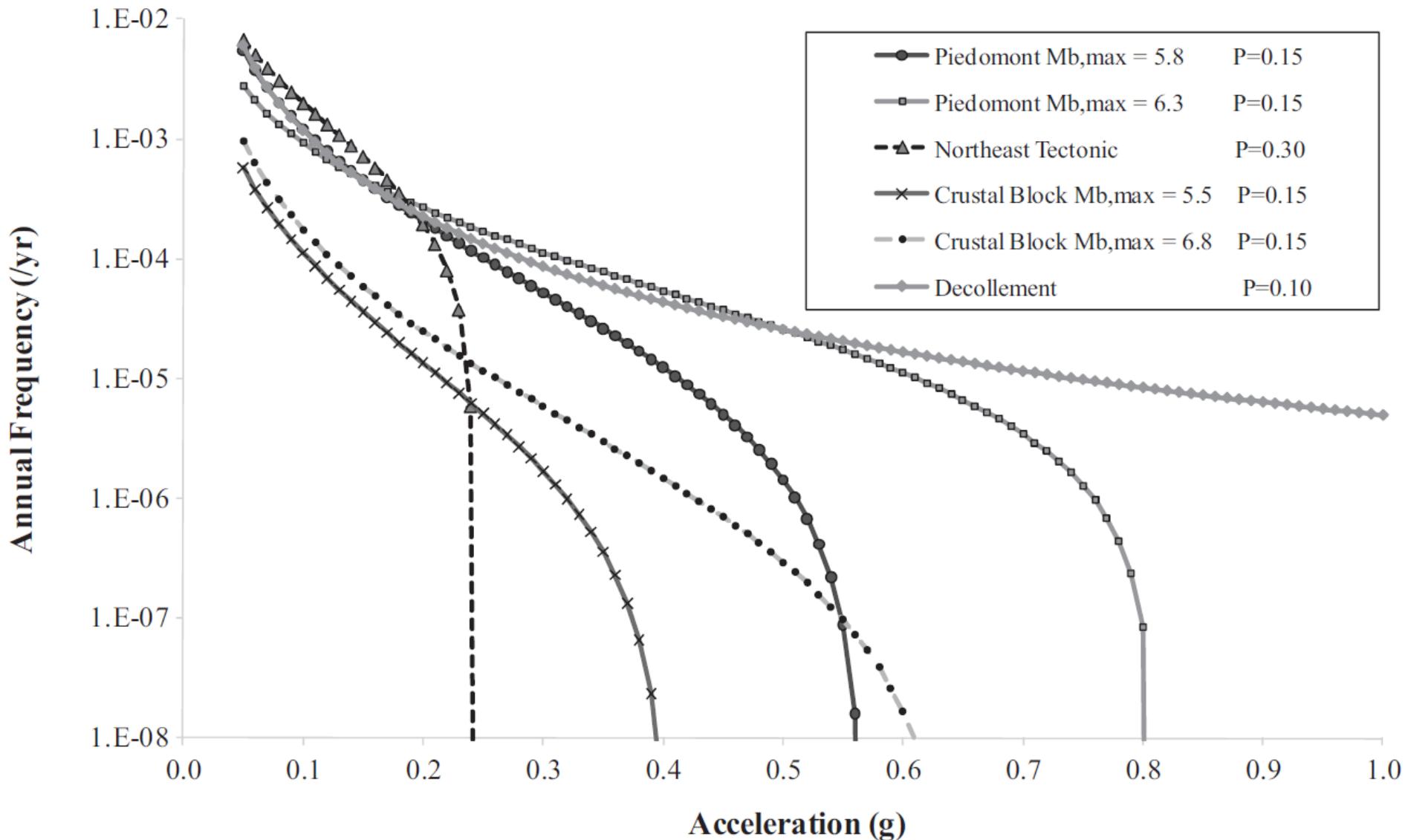
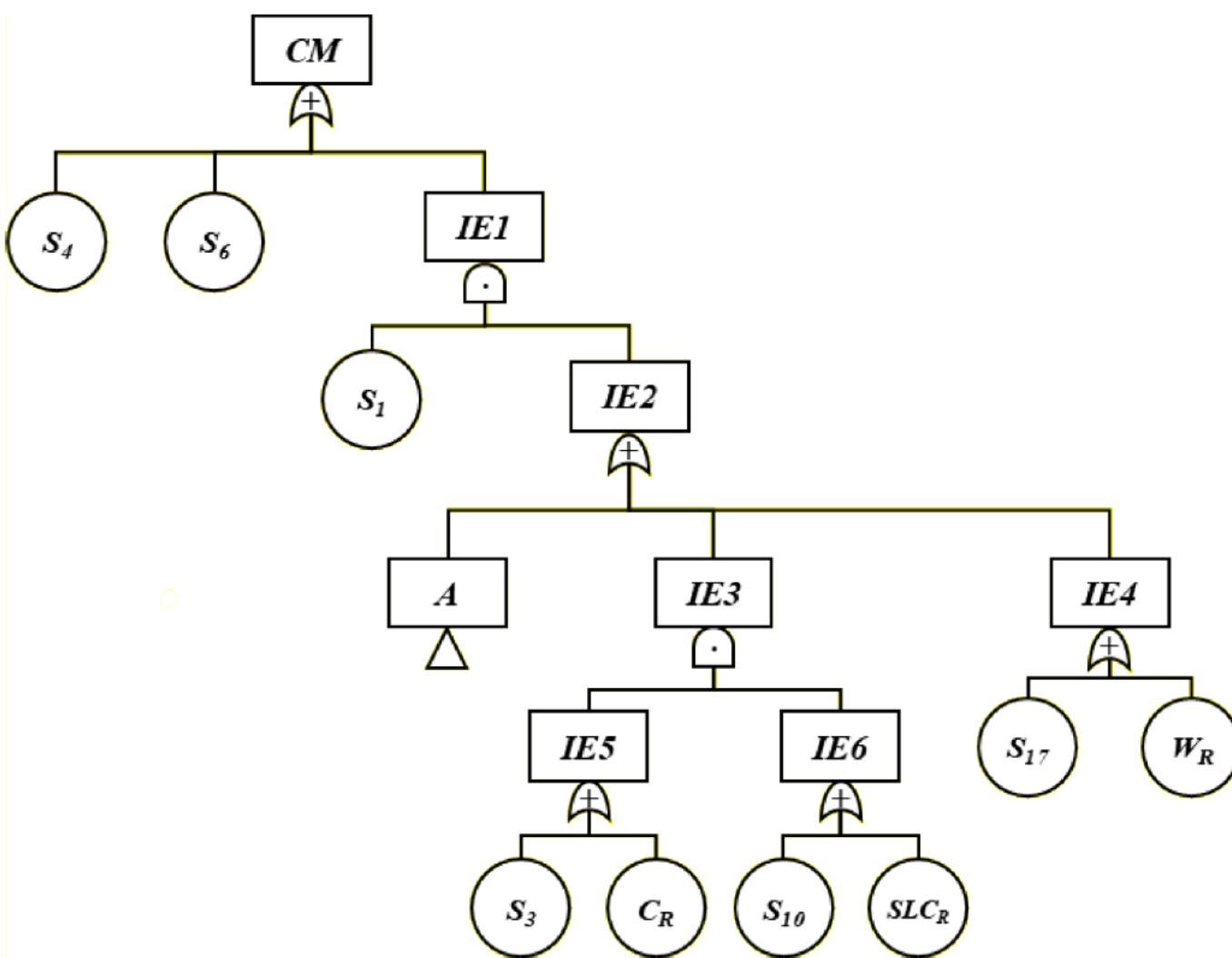


Fig. 12. Seismic hazard curves for all seismogenic zones at LGS site (SARA-LGS).

Table 1Seismic 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 |



$$A = S_{11} \cup S_{12} \cup S_{13} \cup S_{14} \cup S_{15} \cup S_{16} \cup DG_R \quad (15)$$

$$T_s E_s UX = S_1 \cap A \quad (16)$$

$$T_s R_b = S_4 \quad (17)$$

$$T_s R_{pv} = S_6 \quad (18)$$

$$T_s E_s C_m C_2 = S_1 \cap (S_3 \cup C_R) \cap (A \cup S_{10} \cup SLC_R) \quad (19)$$

$$T_s R_b C_m = S_4 \cap (C_R \cup S_3) \quad (20)$$

$$T_s E_s W = S_1 \cap \bar{A} \cap (\overline{S_{17}} \cap W_R \cup \overline{S_2} \cap S_{17}) \quad (21)$$

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

Fig. 5. Fault tree expression of scenario CM.

MATLAB App

Input File Settings Results Help

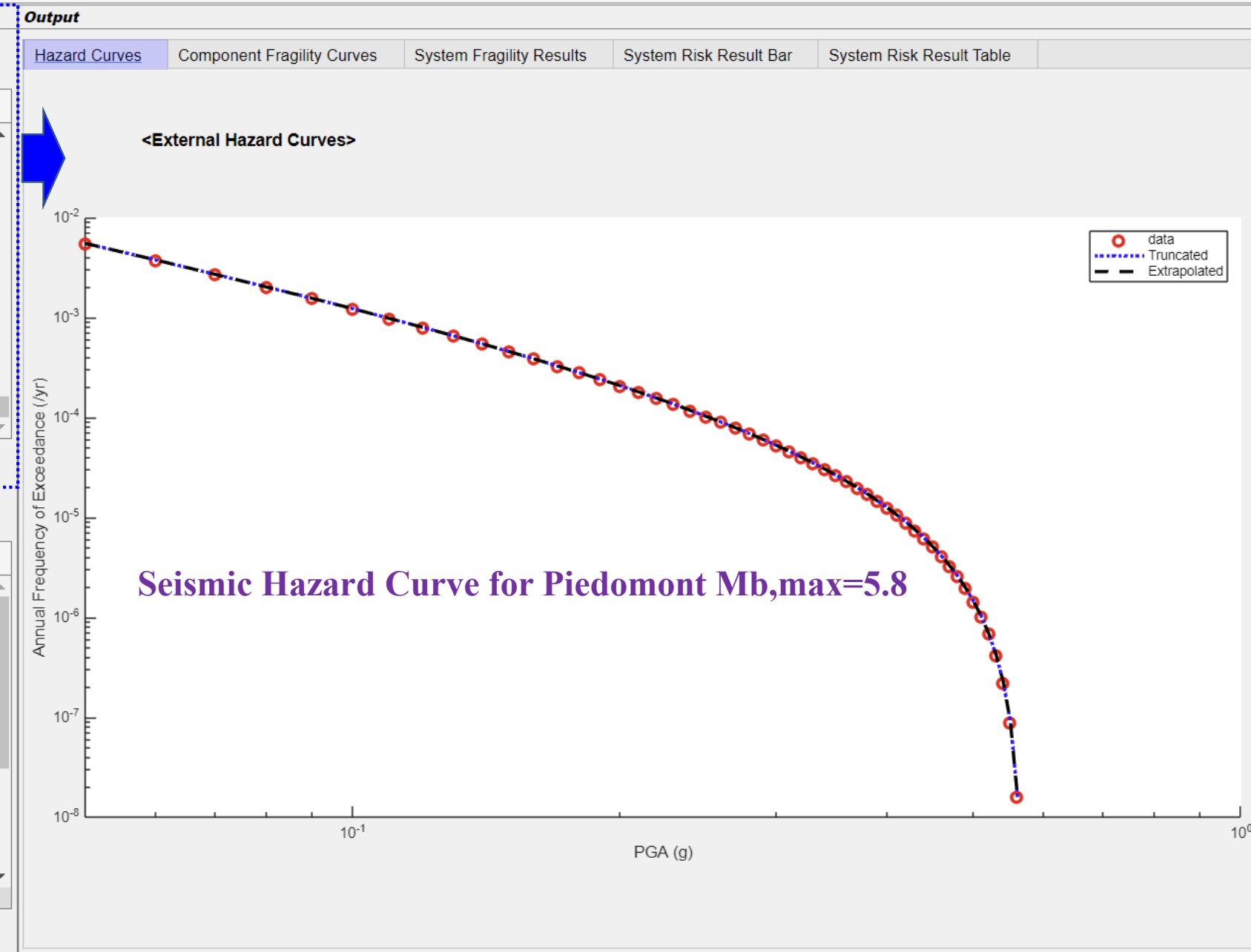
| Basic Input - 1 | |
|--------------------------------|-----------|
| 1. External Hazard Information | |
| Intensity | AFE (/yr) |
| 1.9000 | 0 |
| 1.9100 | 0 |
| 1.9200 | 0 |
| 1.9300 | 0 |
| 1.9400 | 0 |
| 1.9500 | 0 |
| 1.9600 | 0 |
| 1.9700 | 0 |
| 1.9800 | 0 |
| 1.9900 | 0 |
| 2.0000 | 0 |

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)



| 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 | $C(:,4) C(:,5) C(:,1) \& ((C(:,7)$ |

System 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)

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

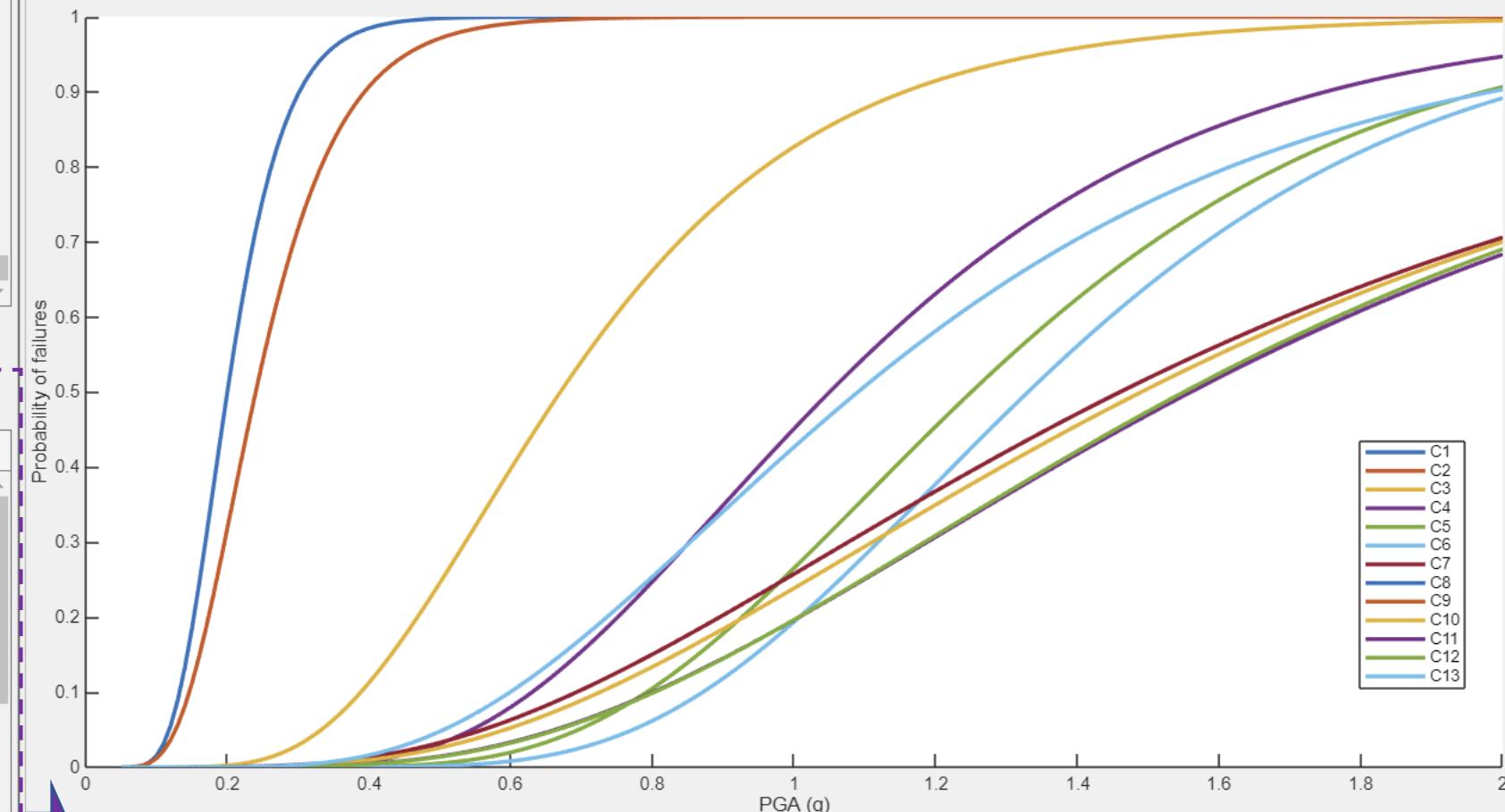
| Component |
|---------------------------------------|
| C1: S1 Offsite power |
| C2: S2 CST |
| C3: S3 Reactor internals |
| C4: S4 Reactor enclosure structure |
| C5: S6 Reactor pressure vessel |
| C6: S10 SLC tank |
| C7: S11 440-V bus/SG breakers |
| C8: S12 440-V bus transformer breaker |
| C9: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

Fragility Input (XLS)

Output

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

<Component External Fragility Curves for SSCs>



Component Seismic Fragility Curves for LGS NPP SSCs

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 | $C(:,1) \& (C(:,3) RF(:,3)) \& ((C(:,2) C(:,4)) \& (C(:,5) C(:,6)))$ |
| TRC | $C(:,4) \& (RF(:,3) C(:,3))$ |
| TEW | $C(:,1) \& \sim(C(:,7) C(:,8) C(:,9))$ |
| CM | $C(:,4) C(:,5) C(:,1) \& ((C(:,7) C(:,8)) \& (C(:,9) C(:,10)))$ |

System 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)

MATLAB App

Input File Settings Results Help

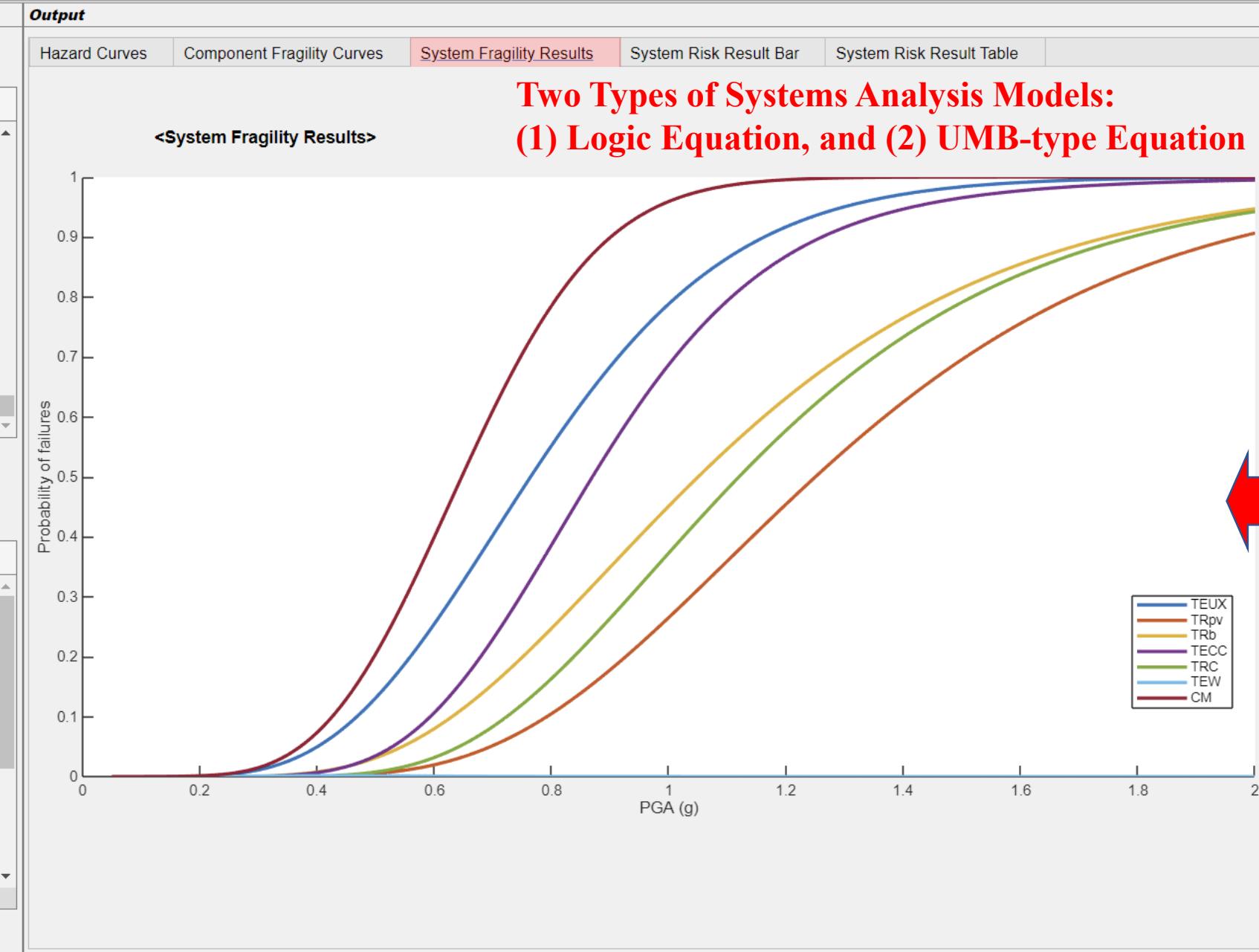
| Basic Input - 1 | |
|--------------------------------|-----------|
| 1. External Hazard Information | |
| Intensity | AFE (/yr) |
| 1.9000 | 0 |
| 1.9100 | 0 |
| 1.9200 | 0 |
| 1.9300 | 0 |
| 1.9400 | 0 |
| 1.9500 | 0 |
| 1.9600 | 0 |
| 1.9700 | 0 |
| 1.9800 | 0 |
| 1.9900 | 0 |
| 2.0000 | 0 |

Hazard Input (XLS)

2. Hazard Fragility Information

| Componenet |
|---------------------------------------|
| 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)



| 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 | $C(:,1) \& (C(:,3) RF(:,3)) \& ((C(:,2) C(:,4)) \& (C(:,5) C(:,6)))$ |
| TRC | $C(:,4) \& (RF(:,3) C(:,3))$ |
| TEW | $C(:,1) \& \sim(C(:,7) C(:,8) C(:,9))$ |
| CM | $C(:,4) C(:,5) C(:,1) \& ((C(:,7) C(:,8)) \& (C(:,9) C(:,10)))$ |

System Equation (XLS)

4. Risk Quantification

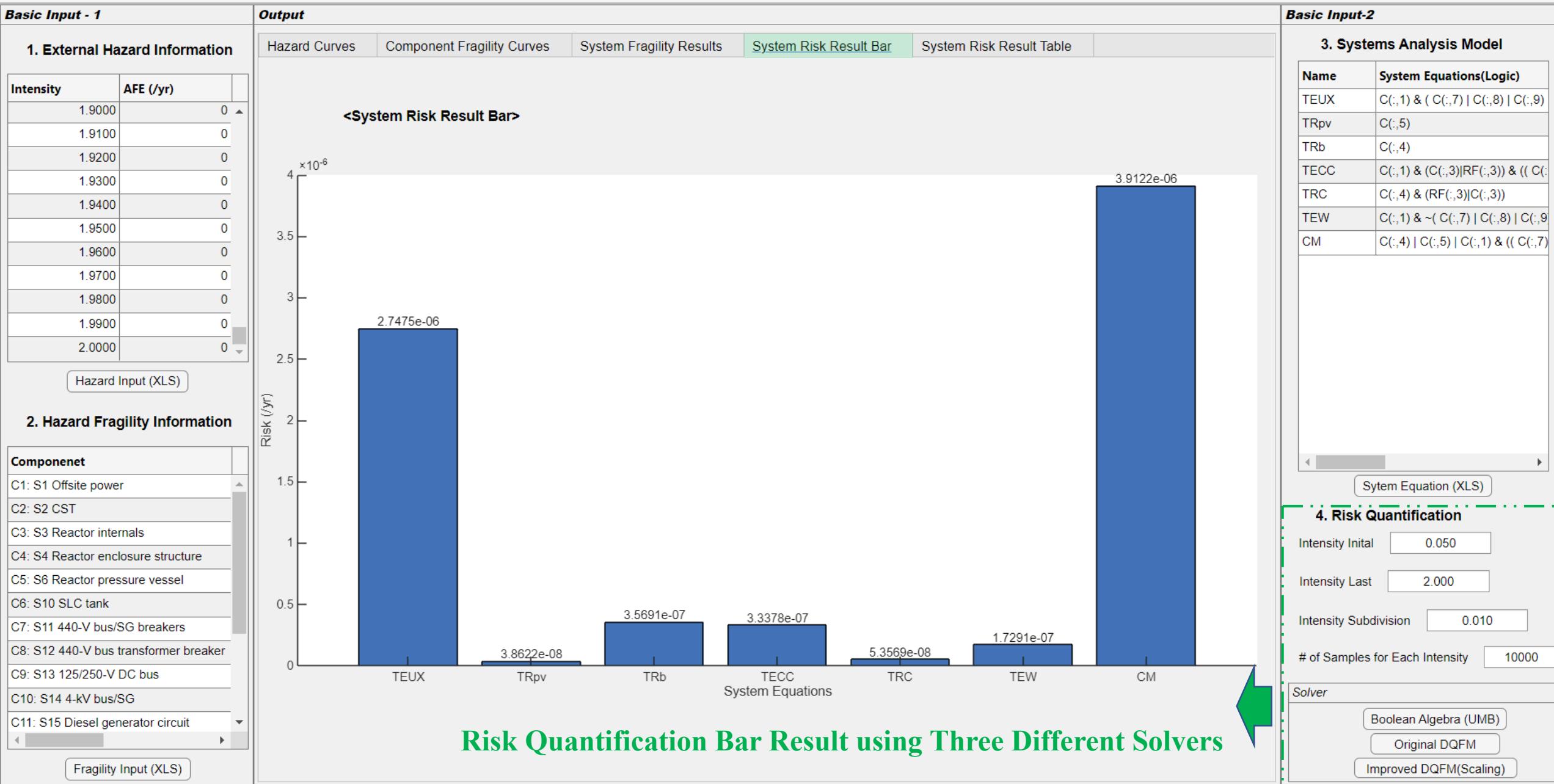
| | |
|---------------------------------|-------|
| Intensity Initial | 0.050 |
| Intensity Last | 2.000 |
| Intensity Subdivision | 0.010 |
| # of Samples for Each Intensity | 10000 |

Solver

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

MATLAB App

Input File Settings Results Help



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)

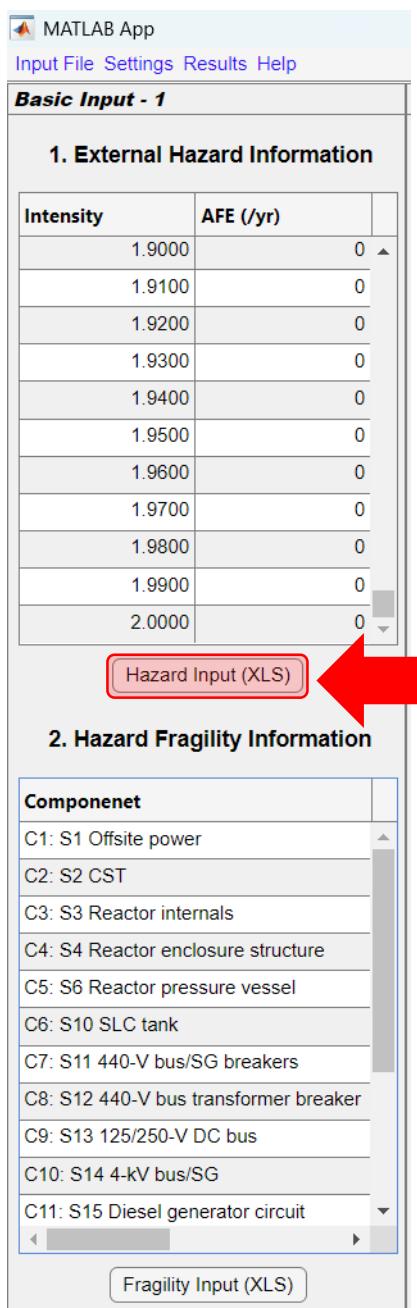
| Output | | |
|---|----------------------------|-----------------------|
| Hazard Curves | Component Fragility Curves | |
| System Fragility Results | | |
| System Risk Result Bar | System Risk Result Table | |
| <System Risk Result Table> | | |
| Name | Risk(/yr) | CDF contribution(/yr) |
| TEUX | 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

| 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 | $C(:,1) \& \sim(C(:,7) C(:,8) C(:,9))$ |
| CM | $C(:,4) C(:,5) C(:,1) \& ((C(:,7)$ |
| 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) | |

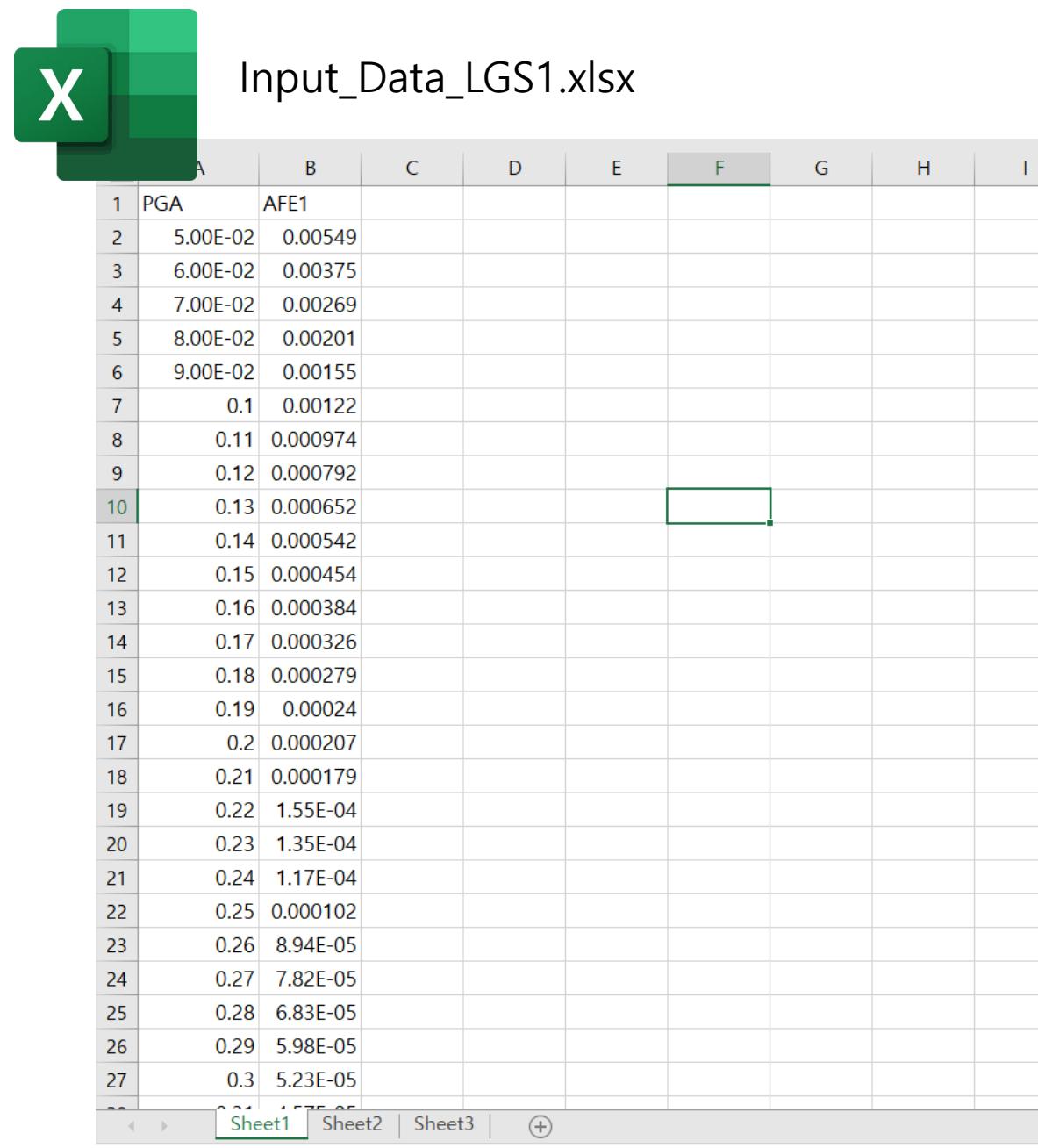
System Equation (XLS)

Appendix. File Type and Import for Example Case

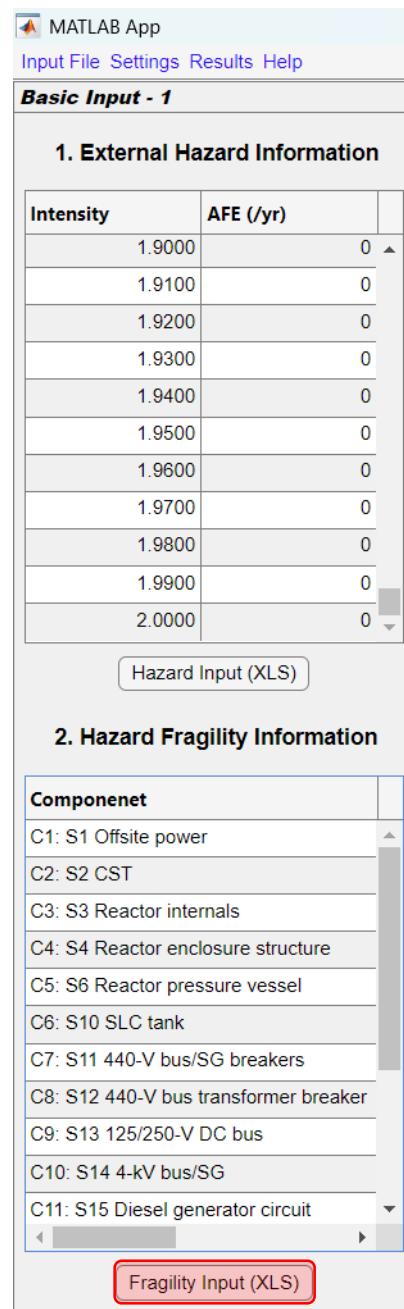


Hazard Input (XLS)

Button Click and Import Sheet1 of the EXCEL file.



| | 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 | | | | | | | |



Button Click and Import Sheet2 of the EXCEL file.

| 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 | | | | |

| 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 | $C(:,1) \& \sim(C(:,7) C(:,8) C(:,9))$ |
| CM | $C(:,4) C(:,5) C(:,1) \& ((C(:,7)$ |

| 4. Risk Quantification | |
|---------------------------------|-------|
| Intensity Initial | 0.050 |
| Intensity Last | 2.000 |
| Intensity Subdivision | 0.010 |
| # of Samples for Each Intensity | 10000 |

| Solver | |
|--|--|
| <input checked="" type="radio"/> Boolean Algebra (UMB) | |
| <input type="radio"/> Original DQFM | |
| <input type="radio"/> Improved DQFM(Scaling) | |



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 | |
| | ⋮ |

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

Button Click and Import Sheet3 of the EXCEL file.

| 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 $1 - C(:,4) * (1 - C(:,5)) * (1 - C(:,1)) * (1 - (1 - (1 - C(:,7)) * (1 - C(:,8)) * (1 - C(:,9)) * (1 - C(:,10)) * (1 - C(:,11)) * (1 - C(:,12)) * (1 - RF(:,1))) * (1 - (1 - C(:,3)) * (1 - RF(:,3))) * (1 - (1 - C(:,6)) * (1 - RF(:,4))) * (1 - (1 - C(:,13)) * (1 - RF(:,2)))$ | | 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"