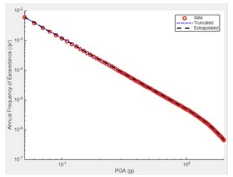
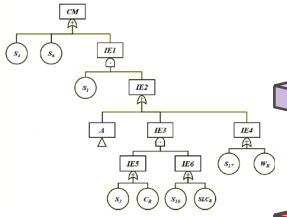
EHRA Structure

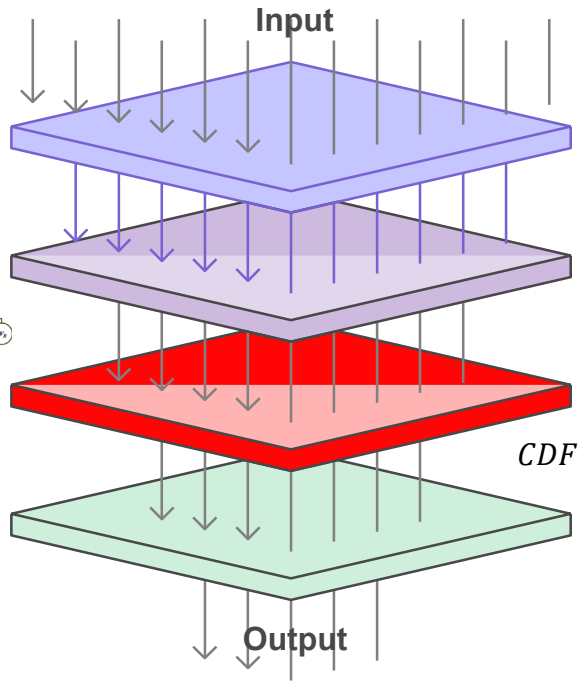
EHRA Program Modules

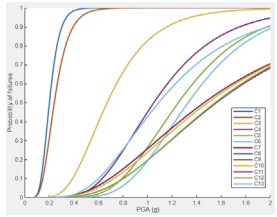


Hazard Input



Systems Analysis
Model Input





Fragility Input

$$CDF = \int_0^{\infty} F_s(a) \left| \frac{dH(a)}{da} \right| da$$

Risk
Quantification

Risk Assessment Results

Matlab GUI Application Configuration

MATLAB App

Input File Settings Results Help

Basic Input - 1

1. External Hazard Information

Intensity	AFE (/yr)
0.0500	0.0055
0.0600	0.0037
0.0700	0.0027
0.0800	0.0020
0.0900	0.0015
0.1000	0.0012
0.1100	0.0010
0.1200	0.0008
0.1300	0.0007
0.1400	0.0005
0.1500	0.0005

Hazard Input (XLS)

(a)

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

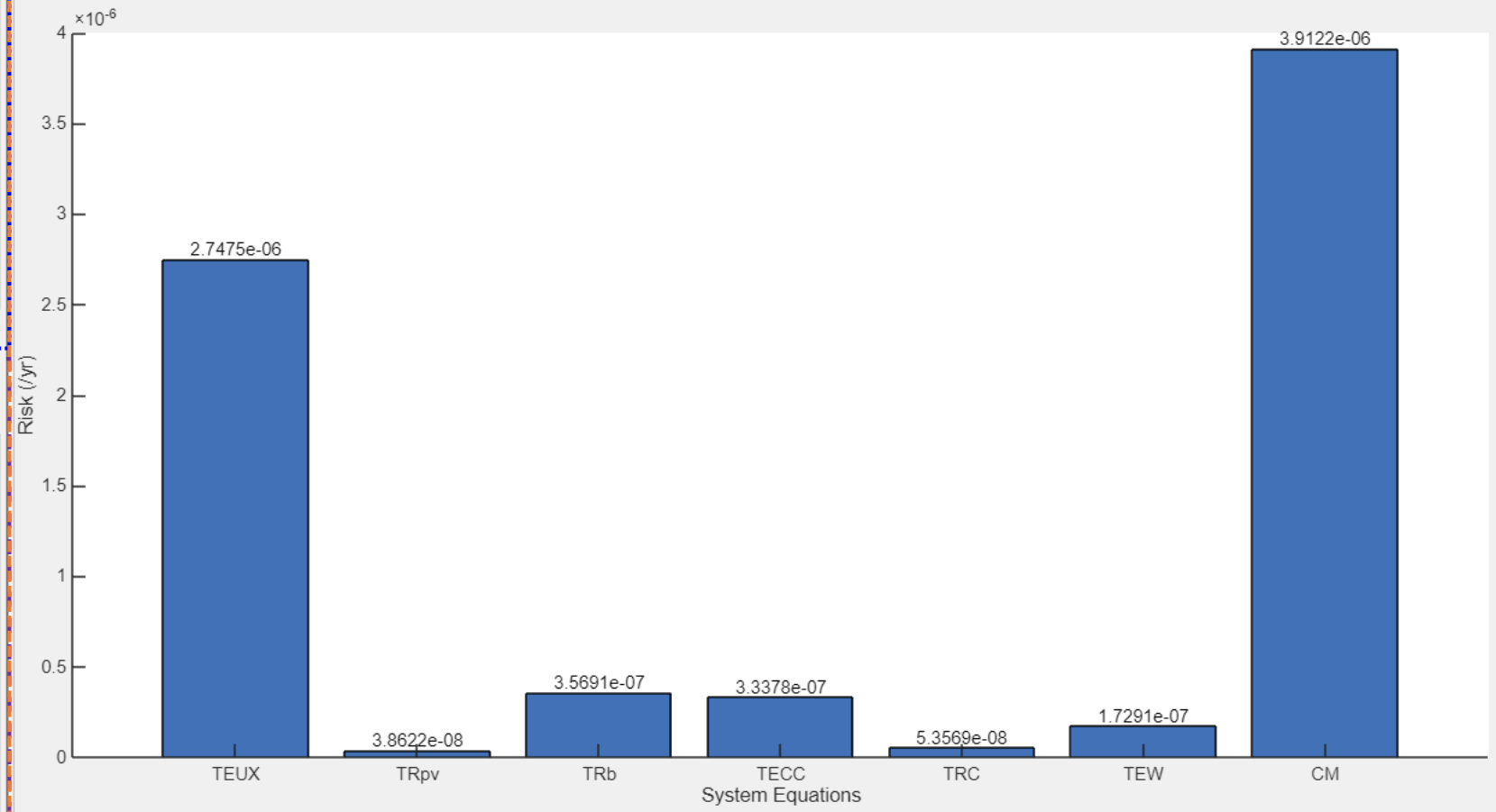
Fragility Input (XLS)

(b)

Output

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

<System Risk Result Bar>



(e)

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)

(c)

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)

(d)

Example: LGS Nuclear Power Plant (Seismic) Hazard Curves

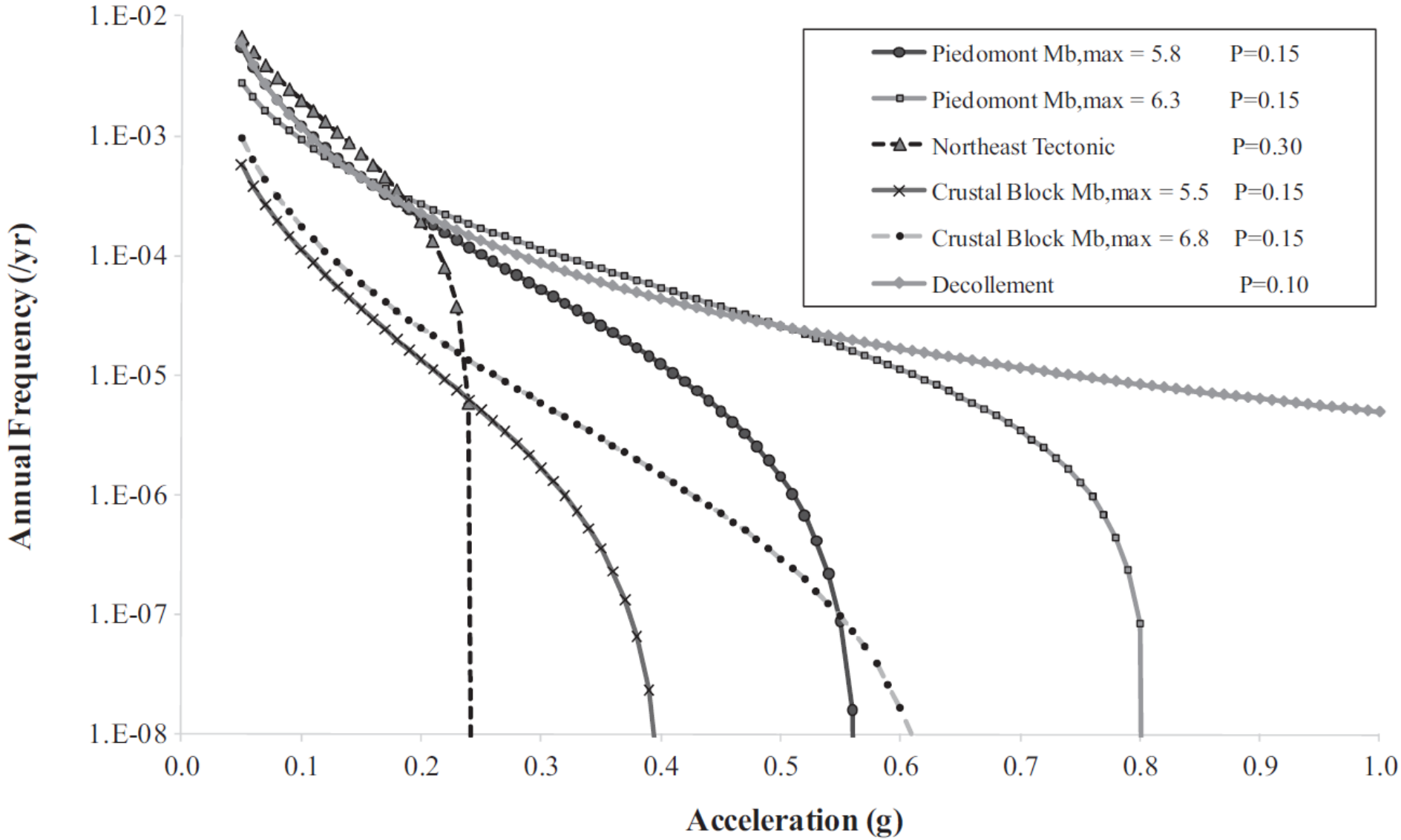


Fig. 12. Seismic hazard curves for all seismogenic zones at LGS site (SARA-LGS).

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.

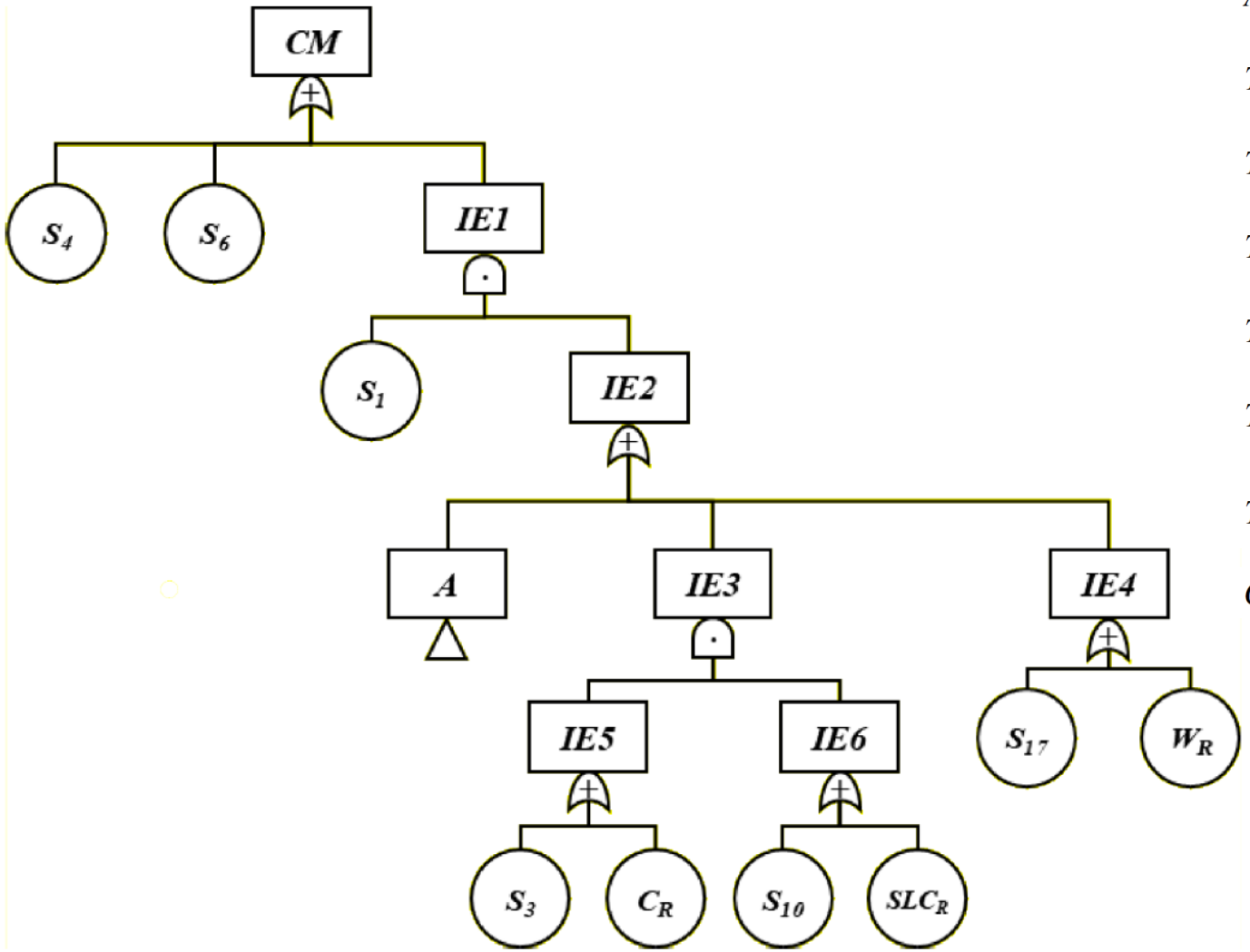


Fig. 5. Fault tree expression of scenario *CM*.

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

$$T_s E_s UX = S_1 \cap A \tag{16}$$

$$T_s R_b = S_4 \tag{17}$$

$$T_s R_{pv} = S_6 \tag{18}$$

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

$$T_s R_b C_m = S_4 \cap (C_R \cup S_3) \tag{20}$$

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

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

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.

Example: LGS Nuclear Power Plant

Seismic Harzard Curve Input & Confirmation

MATLAB App

Input File Settings Results Help

Basic Input - 1

1. External Hazard Information

Intensity	AFE (/yr)
0.0500	0.0055
0.0600	0.0037
0.0700	0.0027
0.0800	0.0020
0.0900	0.0015
0.1000	0.0012
0.1100	0.0010
0.1200	0.0008
0.1300	0.0007
0.1400	0.0005
0.1500	0.0005

Hazard Input (XLS)

2. Hazard Fragility Information

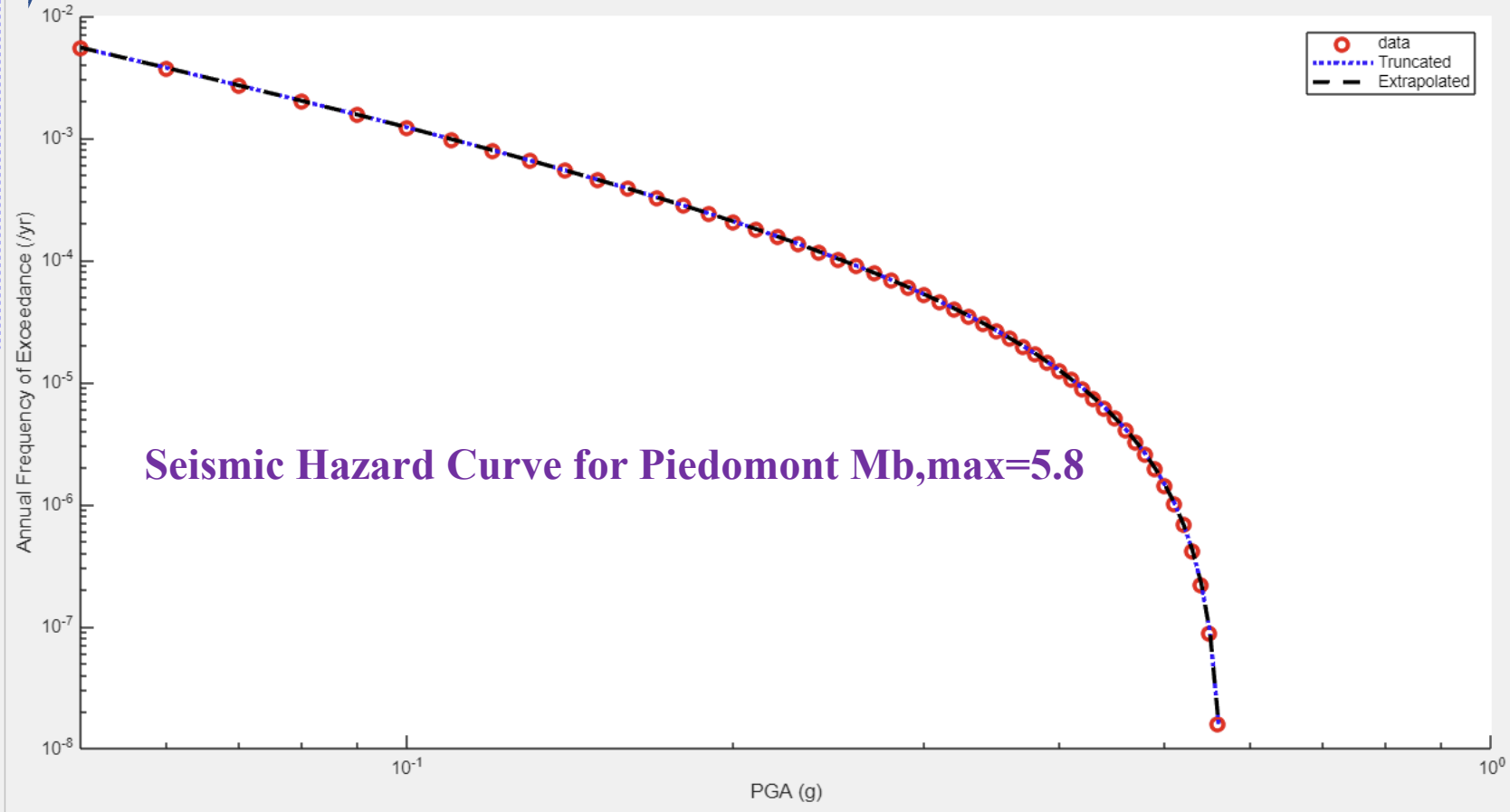
Componenet
C1: S1 Offsite power
C2: S2 CST
C3: S3 Reactor internals
C4: S4 Reactor enclosure structure
C5: S6 Reactor pressure vessel
C6: S10 SLC tank
C7: S11 440-V bus/SG breakers
C8: S12 440-V bus transformer breaker
C9: S13 125/250-V DC bus
C10: S14 4-kV bus/SG
C11: S15 Diesel generator circuit

Fragility Input (XLS)

Output

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

<External Hazard Curves>



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 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)

MATLAB App

Input File Settings Results Help

Basic Input - 1

1. External Hazard Information

Intensity	AFE (/yr)
0.0500	0.0055
0.0600	0.0037
0.0700	0.0027
0.0800	0.0020
0.0900	0.0015
0.1000	0.0012
0.1100	0.0010
0.1200	0.0008
0.1300	0.0007
0.1400	0.0005
0.1500	0.0005

Hazard Input (XLS)

2. Hazard Fragility Information

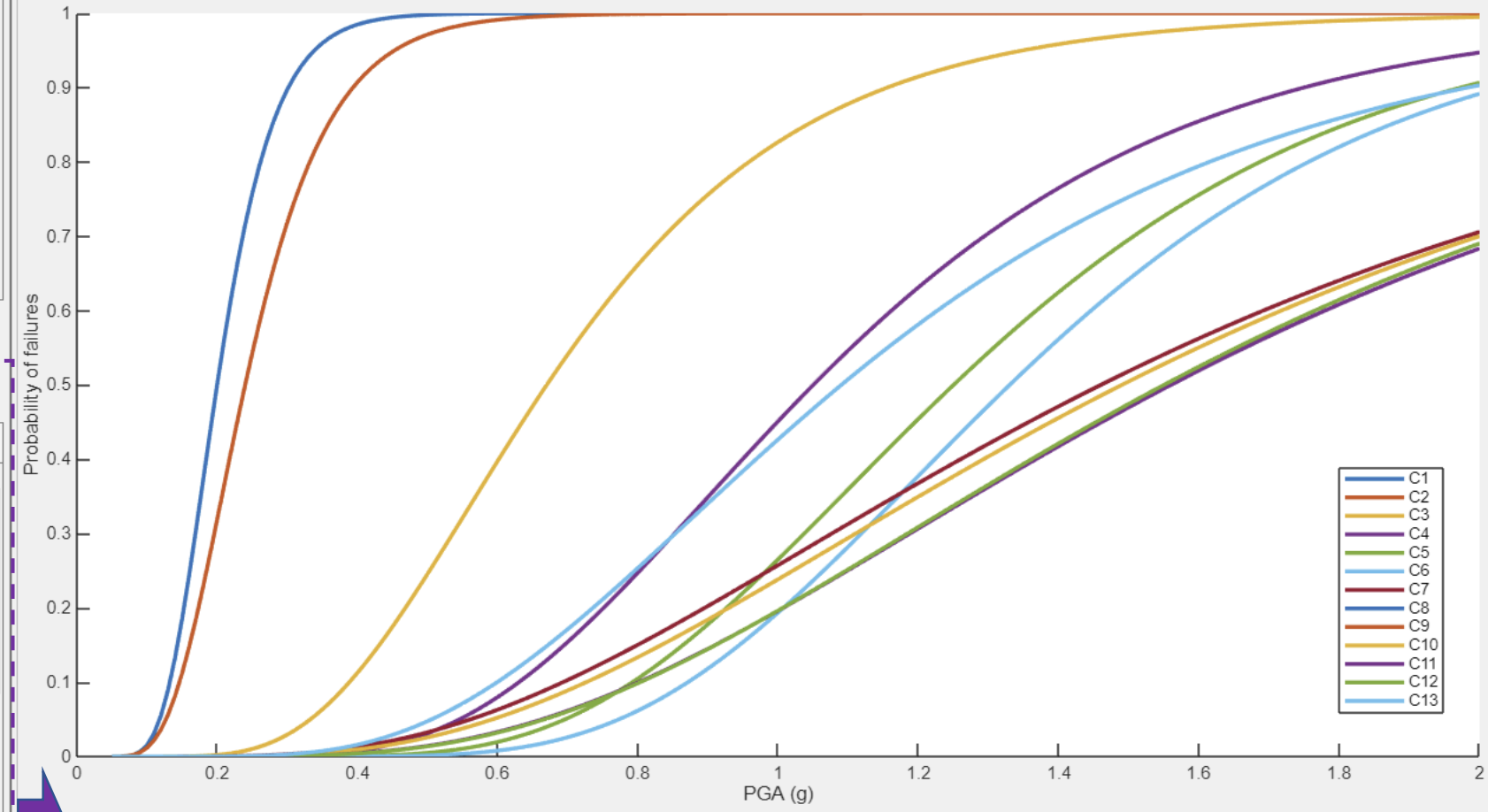
Componenet
C1: S1 Offsite power
C2: S2 CST
C3: S3 Reactor internals
C4: S4 Reactor enclosure structure
C5: S6 Reactor pressure vessel
C6: S10 SLC tank
C7: S11 440-V bus/SG breakers
C8: S12 440-V bus transformer breaker
C9: S13 125/250-V DC bus
C10: S14 4-kV bus/SG
C11: S15 Diesel generator circuit

Fragility Input (XLS)

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(:
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 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)

Example: LGS Nuclear Power Plant

Systems Analysis Model Input & System Fragility Results

MATLAB App

Input File Settings Results Help

Basic Input - 1

1. External Hazard Information

Intensity	AFE (/yr)
0.0500	0.0055
0.0600	0.0037
0.0700	0.0027
0.0800	0.0020
0.0900	0.0015
0.1000	0.0012
0.1100	0.0010
0.1200	0.0008
0.1300	0.0007
0.1400	0.0005
0.1500	0.0005

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

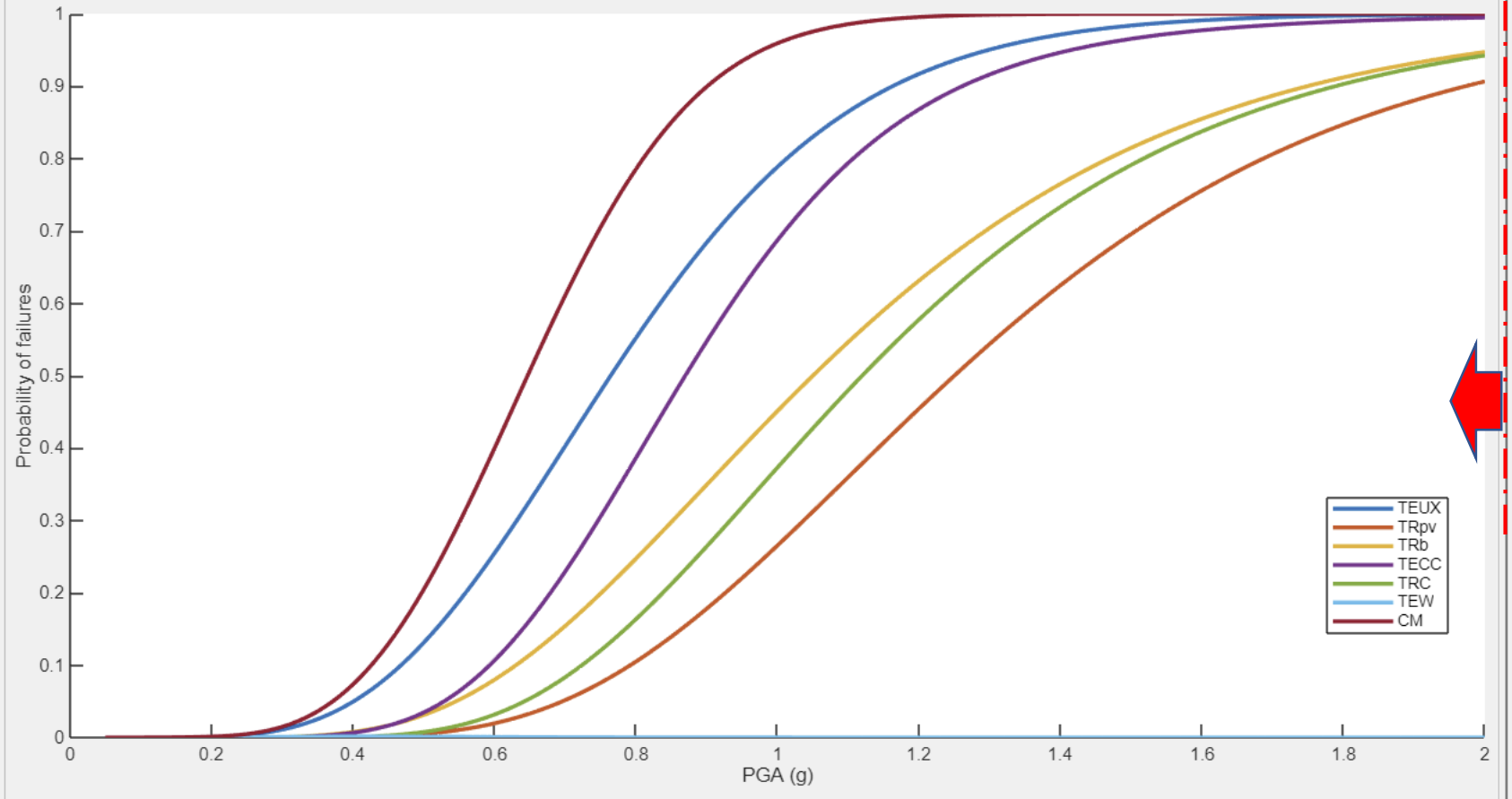
Fragility Input (XLS)

Output

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

Two Types of Systems Analysis Models:
(1) Logic Equation, and (2) UMB-type Equation

<System Fragility Results>



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 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)

MATLAB App

Input File Settings Results Help

Basic Input - 1

1. External Hazard Information

Intensity	AFE (/yr)
0.0500	0.0055
0.0600	0.0037
0.0700	0.0027
0.0800	0.0020
0.0900	0.0015
0.1000	0.0012
0.1100	0.0010
0.1200	0.0008
0.1300	0.0007
0.1400	0.0005
0.1500	0.0005

Hazard Input (XLS)

2. Hazard Fragility Information

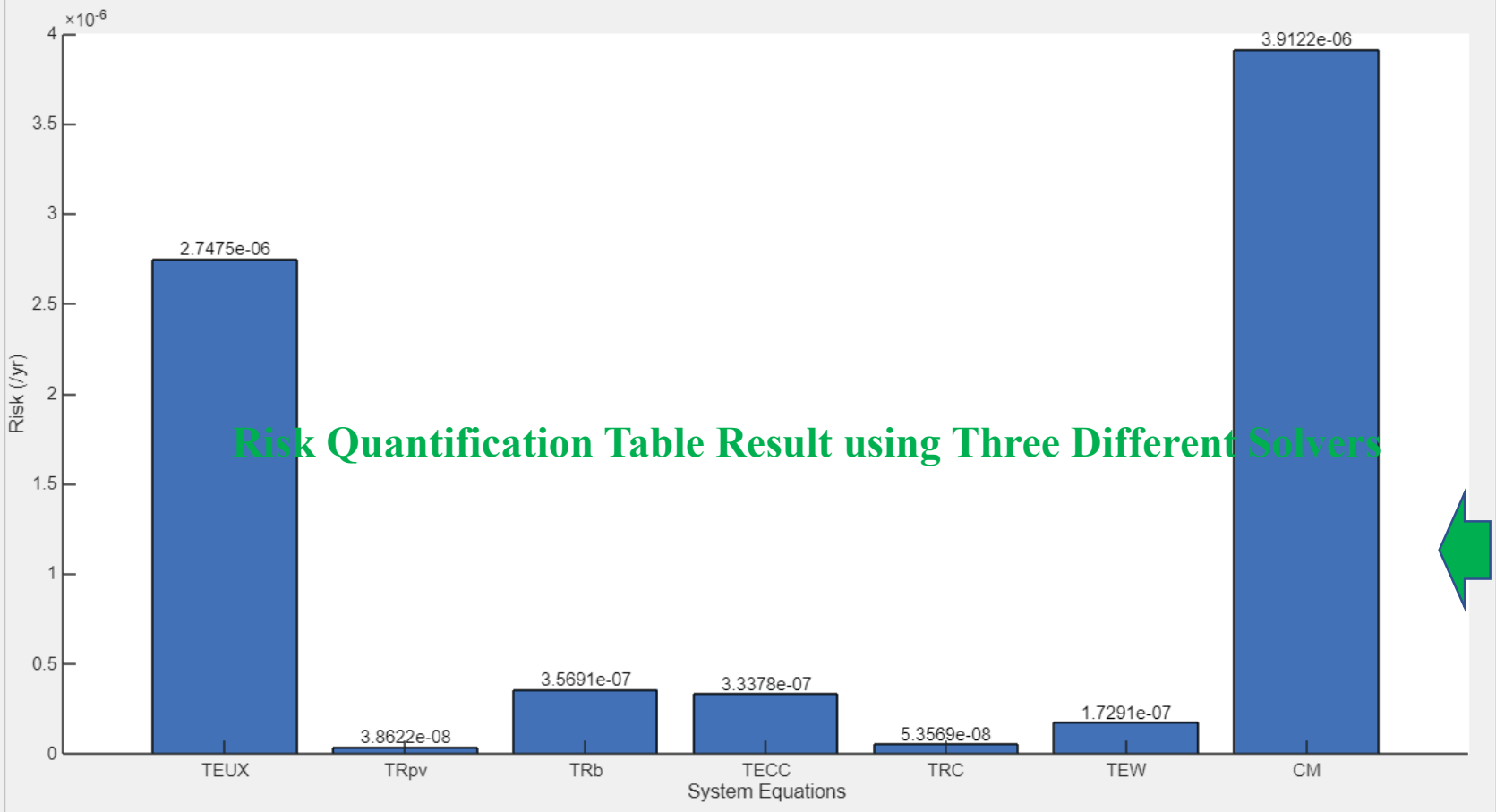
Componenet
C1: S1 Offsite power
C2: S2 CST
C3: S3 Reactor internals
C4: S4 Reactor enclosure structure
C5: S6 Reactor pressure vessel
C6: S10 SLC tank
C7: S11 440-V bus/SG breakers
C8: S12 440-V bus transformer breaker
C9: S13 125/250-V DC bus
C10: S14 4-kV bus/SG
C11: S15 Diesel generator circuit

Fragility Input (XLS)

Output

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

<System Risk Result Bar>



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) & ~(C(:,7) | C(:,8) | C(:,9
CM	C(:,4) | C(:,5) | C(:,1) & ((C(:,7)

System 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)

MATLAB App

Input File Settings Results Help

Basic Input - 1

1. External Hazard Information

Intensity	AFE (/yr)
0.0500	0.0055
0.0600	0.0037
0.0700	0.0027
0.0800	0.0020
0.0900	0.0015
0.1000	0.0012
0.1100	0.0010
0.1200	0.0008
0.1300	0.0007
0.1400	0.0005
0.1500	0.0005

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)

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 Bar 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) & ~(C(:,7) | C(:,8) | C(:,9
CM	C(:,4) | C(:,5) | C(:,1) & ((C(:,7)

System 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)

Appendix. File Type and Import for Example Case

Appendix. File Type and Import

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)

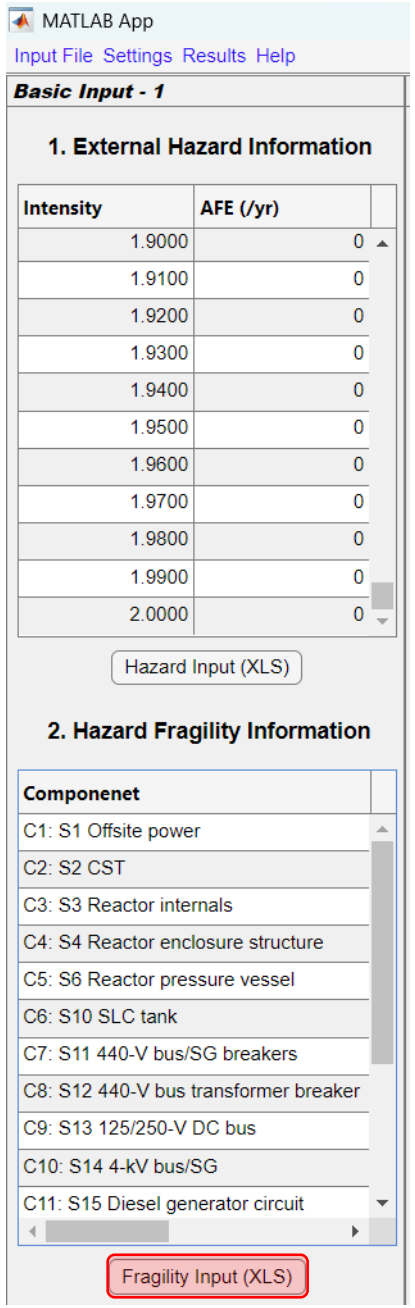
Button Click and Import Sheet1 of the EXCEL file.

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

Appendix. File Type and Import



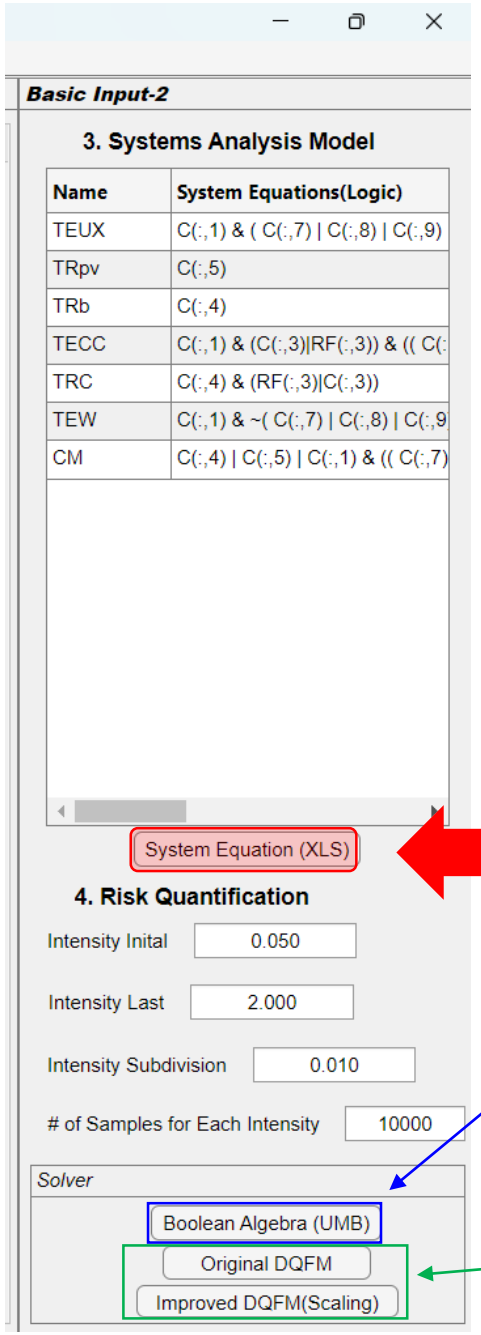
Button Click and Import Sheet2 of the EXCEL file.

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

Appendix. File Type and Import



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) & ~(C(:,7) | C(:,8) | C(:,9) | C(:,10) | C(:,11) | C(:,12) | RF(:,1)) & ((~C(:,13) & RF(:,2)) | (~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"

	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 - (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 -(1 -C(:,6)).*(1 -RF(:,4)))).*(1 -(1 -(1 -C(:,13)).*(1 -RF(:,2)))))	1	

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