

Solution to Perform a Large Number of MACCS Calculations using MAAP Results

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Introduction

Introduction

- Increasing Necessity of a Large Number of Consequence Calculations
 - A new trend of single-unit consequence analysis
 - Full spectrum of Level 3 PSA considering all source terms rather than categorized representative source terms
 - Multi-unit consequence analysis
 - Rapidly increasing number of multi-unit accident scenarios by the number of units and the number of STCs

Number of combinations assuming same STCs for all units: $(n + 1)^k - 1$

Number of STCs (N)	Number of Units Undergoing Accident (M)							
	1	2	3	4	5	6	7	8
5	5	35	215	1,295	7,775	46,655	279,935	1,679,615
10	10	120	1,330	14,640	161,050	1,771,560	19,487,170	214,358,880
15	15	255	4,095	65,535	1,048,575	16,777,215	268,435,455	4,294,967,295
20	20	440	9,260	194,480	4,084,100	85,766,120	1,801,088,540	37,822,859,360

Number of combinations assuming same STCs for all units that are collocated: $n+1 H_k - 1$

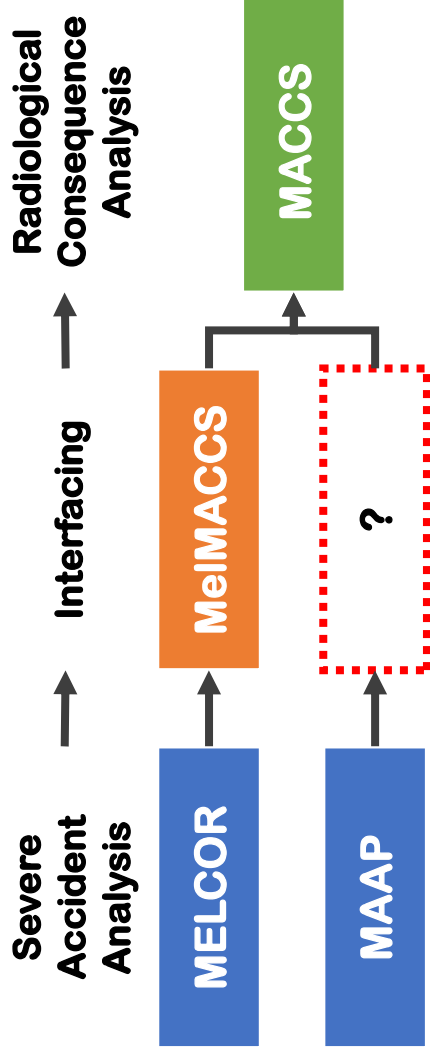
Number of STCs (N)	Number of Units Undergoing Accident (M)							
	1	2	3	4	5	6	7	8
5	5	20	55	125	251	461	791	1,286
10	10	65	285	1,000	3,002	8,007	19,447	43,757
15	15	135	815	3,875	15,503	54,263	170,543	490,313
20	20	230	1,770	10,625	53,129	230,229	888,029	3,108,104

S.Y. Kim et al., Multi-unit Level 3 probabilistic safety assessment: Approaches and their application to a six-unit nuclear power plant site, *Nuclear Engineering and Technology*, 50 (2018) 1246–1254

N. E. Bixler & S.Y. Kim, Performing a multi-unit Level-3 PSA with MACCS, *Nuclear Engineering and Technology*, 53 (2021) 386–392

Introduction

- Absence of Clear Method to Interface MAAP and MACCS



- Motives and Objectives
 - Provide a **method and tool** to perform MACCS analysis using MAAP results
 - Provide a **capability** to handle **enormous** number of MACCS calculations
 - Finally, provide a solution to support
 - Full spectrum single-unit Level 3 PSA
 - Multi-unit Level 3 PSA

MUST (Multi-Unit Source Term) Converter

MUST Converter

- MUST Converter Calculates Source Term Information

- Amount of release

- Cumulative release amount by time
- Cumulative release fraction by time (**RELFRC**)
 - › Converted to release amount by multiplying core inventory (CORINV)

- Manner of release

- Delay and duration of release (**PDELAY** & **PLUDUR**)
- Release height (**PLHITE**)
- Energy accompanied with release
 - › Heat (**PLHEAT**)
 - › Density and flow (**PLMDEN** & **PLMFLA**)
- Particle size distribution (**PSDIST**)

- Based on

- S.Y. Kim et al., *Interfacing between MAAP and MACCS to perform radiological consequence analysis, Nuclear Engineering and Technology, Under Review*
- 9 chemical groups categorized in the SOARCA study



*Image from HotSpot code homepage: <https://hrrac.llnl.gov/hotspot>

MUST Converter

■ MUST Converter Calculates Source Term Information

• Using MAAP Data

Time Independent

- Initial mass of element (MFPIN)
- Initial mass of FP group (MFP0)
- Element mole fraction in FP group (FAFP0)
- Initial number of FP atoms in group (MTFP0)
- Floor elevation of compartment relative to ground level (ZFRB)
- Bottom of junction height with respect to donor compartment floor (ZJUNC)
- Height of junction (XHJUNC)

Time Dependent

- Release mass of element (MRELEL)
- Fraction of aerosols in each particle size array (FMXRB)
- Fission product flow through junction (WFPJ)
- Enthalpy in compartment (HGRB)
- Mass flow rate through junction (WRB)
- Specific volume in compartment (VGRB)
- Pressure in the compartment (PEX0)

MUST Converter

■ Graphic User Interface

Project

Help

MACCS-STC13.D95.CSV

MACCS-STC14.D95.CSV

MACCS-STC15.D95.CSV

MACCS-STC16.D95.CSV

MACCS-STC17.D95.CSV

MACCS-STC18.D95.CSV

MACCS-STC19.D95.CSV

MACCS-STC20.D95.CSV

MACCS-STC21.D95.CSV

MACCS-STC13.D95.CSV

MACCS-STC14.D95.CSV

MACCS-STC15.D95.CSV

MACCS-STC16.D95.CSV

MACCS-STC17.D95.CSV

MACCS-STC18.D95.CSV

MACCS-STC19.D95.CSV

MACCS-STC20.D95.CSV

MACCS-STC21.D95.CSV

MACCS-STC13.D95.CSV

MACCS-STC14.D95.CSV

MACCS-STC15.D95.CSV

MACCS-STC16.D95.CSV

MACCS-STC17.D95.CSV

MACCS-STC18.D95.CSV

MACCS-STC19.D95.CSV

MACCS-STC20.D95.CSV

MACCS-STC21.D95.CSV

Source Term Category (STC) list

Add...

Edit...

Delete

Select	Saved	Unit	STC	Name
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC01.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC02.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC03.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC04.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC05.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC06.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC08.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC09.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC10.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC12.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC13.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC14.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC15.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC16.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC17.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC18.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC19.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC20.D95.C...
<input type="checkbox"/>	<input checked="" type="checkbox"/>			MACCS-STC21.D95.C...

Core Inventory

Radionuclide	Core Inventory [kg]
RDCORINV001	Kr-85
RDCORINV002	Kr-85m
RDCORINV003	Kr-87
RDCORINV004	Kr-88
RDCORINV005	Xe-133
RDCORINV006	Xe-135
RDCORINV007	Xe-135m
RDCORINV008	Cs-134
RDCORINV009	Cs-136
RDCORINV010	Cs-137
RDCORINV011	Rb-86
RDCORINV012	Rb-88
RDCORINV013	Ba-139
RDCORINV014	Ba-140
RDCORINV015	Sr-89
RDCORINV016	Sr-90
RDCORINV017	Sr-91
RDCORINV018	Sr-92
RDCORINV019	Ba-137m
RDCORINV020	I-131
RDCORINV021	I-132
RDCORINV022	I-133
RDCORINV023	I-134
RDCORINV024	I-135
RDCORINV025	Te-127
RDCORINV026	Te-127m
RDCORINV027	Te-129
RDCORINV028	Te-129m
RDCORINV029	Te-131m
RDCORINV030	Te-132
RDCORINV031	Te-131
RDCORINV032	Rh-105
RDCORINV033	Ru-103
RDCORINV034	Ru-105

Source Term Category (STC) Detail

Apply to All STC...

Time Intervals of Plume Segments

Uniform Interval [sec]: 99935.302
List of time intervals [sec]: 259200.325
Manual Input [sec]:
Add
Delete

Max Risk Plume

Important: Radionuclide:

Core Exit Temperature (K):
Alarm Time
Cutoff Value:
Cutoff Release Fraction
Additional Delay Time to Alarm (s):

Particle Size Distribution

12

Table with 12 columns: BIN1, BIN2, BIN3, BIN4, BIN5, BIN6, BIN7, BIN8, BIN9, BIN10, BIN11, BIN12. Rows include RDPSPDIST001 to RDPSPDIST009.

Legend: XE, CS, BA, I, TE, RU, MO, CE, LA. Graph showing concentration vs. distance.

Buttons: Select All, Combine Checked Source, Automatic Subset Combination of Checked Source, Save & Build This STC, Save & Build All.

Ready



Korea Atomic Energy
Research Institute

MUST Converter

- Additional Features

- **Cutoff release fraction**

- Avoid to produce plume segments for negligible amount of releases
- Reduce the running time of MACCS calculation

- **Maximum risk plume (MAXRIS)**

- Assign maximum risk plume which has maximum release fraction of selected radionuclide

- **Alarm time (OALARM)**



The screenshot shows a section titled "Alarm Time" with two input fields. The first field is labeled "Core Exit Temperature (K):" and the second field is labeled "Additional Delay Time to Alarm (s):". Both fields are empty text boxes.

- $OALARM = ① + ②$

- ① **Time to reach emergency condition**

- › MUST Converter extracts the time when maximum core exit temperature (CET of MAAP) reaches to the temperature criterion of emergency condition (user input)

- ② **Delay time to alarm (user input)**

Ex) Recognition of emergency condition + Delay to announce emergency + Delay to recommend public protection action

- Since OALARM is not defined in CombineSource.out but defined in EARLY input, MUST Converter produces separate OALARM.inp file which can be called and used by Mr Manager to change the OALARM information in EARLY input

MUST Converter

- Additional Features
 - **Number of particle size bins**
 - MAAP employs 30 particle size bins
 - Most of MAAP models use only 15 particle size bins
 - Current version of MUST Converter employs 2 choices
 - › 6 bins for 15-bin-models
 - › 12 bins for 30-bin-models

Particle Size Distribution 6												
	BIN1	BIN2	BIN3	BIN4	BIN5	BIN6	BIN7	BIN8	BIN9	BIN10	BIN11	BIN12
RDPDSDIST001	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667						
RDPDSDIST002	0	0.0009	0.0219	0.1347	0.246	0.5966						
RDPDSDIST003	0	0.0009	0.0216	0.133	0.2427	0.6018						
RDPDSDIST004	0	0.0009	0.0214	0.1337	0.2459	0.5981						
RDPDSDIST005	0	0.0009	0.0216	0.1332	0.2433	0.601						
RDPDSDIST006	0	0.0008	0.0209	0.1307	0.2407	0.6069						
RDPDSDIST007	0	0.0008	0.0206	0.1296	0.2396	0.6093						
RDPDSDIST008	0	0.001	0.0231	0.1379	0.2477	0.5903						
RDPDSDIST009	0	0.001	0.0241	0.1412	0.2507	0.583						

Particle Size Distribution 12												
	BIN1	BIN2	BIN3	BIN4	BIN5	BIN6	BIN7	BIN8	BIN9	BIN10	BIN11	BIN12
RDPDSDIST001	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833
RDPDSDIST002	0	0.0009	0.0219	0.1347	0.246	0.5966		0	0	0	0	0
RDPDSDIST003	0	0.0009	0.0216	0.133	0.2427	0.6018		0	0	0	0	0
RDPDSDIST004	0	0.0009	0.0214	0.1337	0.2459	0.5981		0	0	0	0	0
RDPDSDIST005	0	0.0009	0.0216	0.1332	0.2433	0.601		0	0	0	0	0
RDPDSDIST006	0	0.0008	0.0209	0.1307	0.2407	0.6069		0	0	0	0	0
RDPDSDIST007	0	0.0008	0.0206	0.1296	0.2396	0.6093		0	0	0	0	0
RDPDSDIST008	0	0.001	0.0231	0.1379	0.2477	0.5903		0	0	0	0	0
RDPDSDIST009	0	0.001	0.0241	0.1412	0.2507	0.583		0	0	0	0	0

MUST Converter

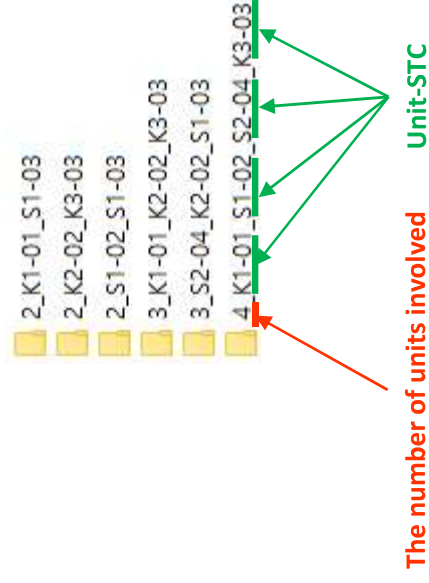
■ Multi-Unit Source Term Combination

• User input

- Name of unit
- Number of STC
- Time offset

• Source term combination

- Combine checked source
- Subset combination of checked source



Source Term Category (STC) List

Add... Edit... Delete

Select	Saved	Unit	STC	Time Offset	Name
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	K1	01	0	MACCS-STC01.D...
<input type="checkbox"/>	<input checked="" type="checkbox"/>	K2	02	3600	MACCS-STC02.D...
<input type="checkbox"/>	<input checked="" type="checkbox"/>	K3	03	7200	MACCS-STC03.D...
<input type="checkbox"/>	<input checked="" type="checkbox"/>	S1	02	10000	MACCS-STC04.D...
<input type="checkbox"/>	<input checked="" type="checkbox"/>	S1	03	3600	MACCS-STC05.D...
<input type="checkbox"/>	<input checked="" type="checkbox"/>	S2	04	5000	MACCS-STC06.D...
<input type="checkbox"/>	<input checked="" type="checkbox"/>				Case_00001-SBO...
<input type="checkbox"/>	<input checked="" type="checkbox"/>				Case_00002-SLO...
<input type="checkbox"/>	<input checked="" type="checkbox"/>				Case_00003-MLO...
<input type="checkbox"/>	<input checked="" type="checkbox"/>				Case_00004-SBO...

Select All

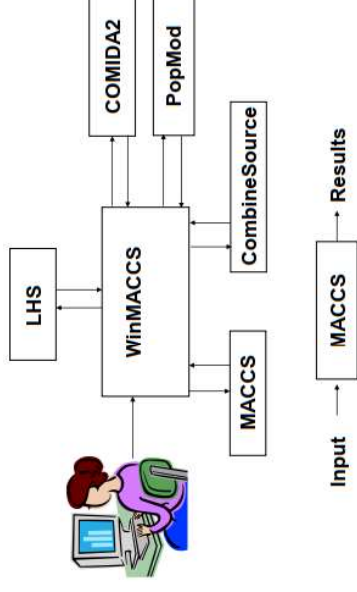
Combine Checked Source

Automatic Subset Combination of Checked Source

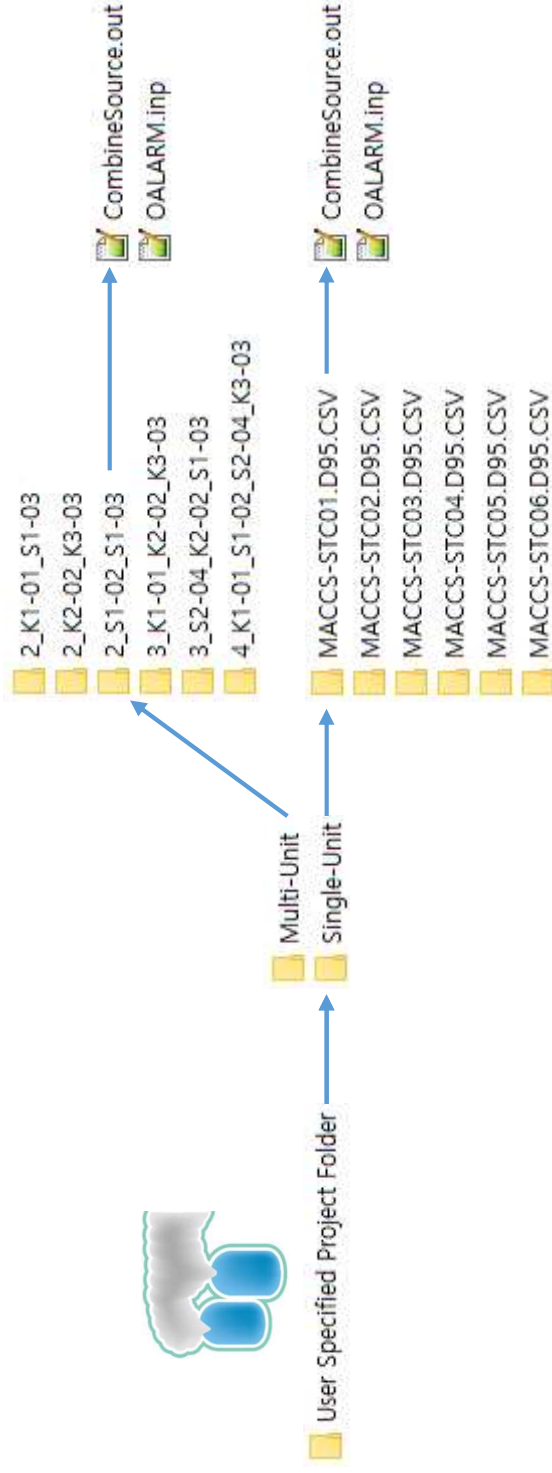
MUST Converter

■ Output

- CombineSour.out
 - Source term information
- OALARM.inp (Optional)
 - Alarm time information



*Image from MACCS User Guide – Version 4.0



MUST Converter

■ Verification & Validation

- Testing
 - Manual calculation tool made by Microsoft Excel
- Third-party testing
 - Another testing spreadsheet created by a third-party tester who was not involved in the software development after being informed about the design of MUST Converter

The screenshot displays a complex spreadsheet interface. The top section contains a header with various labels and a large table of numerical data. The data is organized into columns and rows, with some cells containing formulas like '=SUM(A1:A10)' and others containing specific values. The bottom section shows a summary of the data, including a total count and a list of items. The spreadsheet is titled 'MUST Converter' and includes a footer with the text 'MUST Converter' and 'MUST Converter'.

Excel Spreadsheet for Testing

A	B	C	D	E	F	G	H	I	J
	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉
1	ROELRC001	3.944E-03	2.075E-07	2.631E-11	1.954E-07	1.981E-07	1.171E-10	3.114E-08	3.02E-12
2	ROELRC002	1.234E-07	6.948E-06	2.335E-09	5.878E-06	5.888E-06	3.592E-09	9.520E-07	5.193E-11
3	ROELRC003	1.681E-07	2.148E-06	8.066E-10	2.132E-06	2.041E-06	1.246E-09	3.304E-07	2.147E-11
4	ROELRC004	9.104E-07	1.408E-06	5.295E-10	1.4839E-06	1.3394E-06	8.146E-10	2.167E-07	1.404E-11
5	ROELRC005	7.8705E-02	1.2047E-06	4.3273E-10	1.3407E-06	1.0915E-06	6.6571E-10	1.7660E-07	1.1475E-11
6	ROELRC006	6.7447E-02	1.0286E-06	3.5275E-10	1.2514E-06	8.7939E-07	5.467E-10	1.4386E-07	9.543E-11
7	ROELRC007	5.6488E-02	8.6902E-07	2.7702E-10	1.1939E-06	6.968E-07	4.2644E-10	1.132E-07	7.5508E-12
8	ROELRC008	4.4624E-02	7.1077E-07	2.0292E-10	1.1407E-06	5.0851E-07	3.1218E-10	8.283E-08	5.3813E-12
9	ROELRC009	3.005E-02	4.921E-07	1.1956E-10	9.410E-07	3.000E-07	1.8391E-10	4.8792E-08	3.170E-12
10	ROELRC010	5.1883E-03	9.2307E-08	1.9284E-11	2.0084E-07	4.8743E-08	2.9607E-11	7.2697E-09	5.1139E-13
11	ROELRC011	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
12	ROELRC012	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13	ROELRC013	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
14	ROELRC014	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15	ROELRC015	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
16	ROELRC016	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
17	ROELRC017	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
18	ROELRC018	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
19	ROELRC019	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
20	ROELRC020	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
21	ROELRC021	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
22	ROELRC022	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
23	ROELRC023	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
24	ROELRC024	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
25	ROELRC025	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
26	ROELRC026	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
27	ROELRC027	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
28	ROELRC028	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
29	ROELRC029	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Mean Output the lower 29

Model

Train

Test

Accuracy

Score

Loss

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Third-party Testing Spreadsheet

Mr (Multi-run) Manager

Mr Manager

■ Features

• File load

- Multiple source term files
 - › CombineSource.out
- MACCS execution files
 - › MACCS.exe
 - › Batch file
- MACCS input files to be shared for runs
 - › ATMOS / EARLY / CHRONC files
 - › Site data file
 - › Meteorological data file
 - › Radionuclide data file
 - › Dose coefficient file
 - › Food chain model file
 - › Product key file (from WinMACCS Ver. 4)

• Multi-run of MACCS

- Recognize the number of processors
- Maintain the number of MACCS runs as the number of user specified

Mr Manager

■ Features



MUST Converter



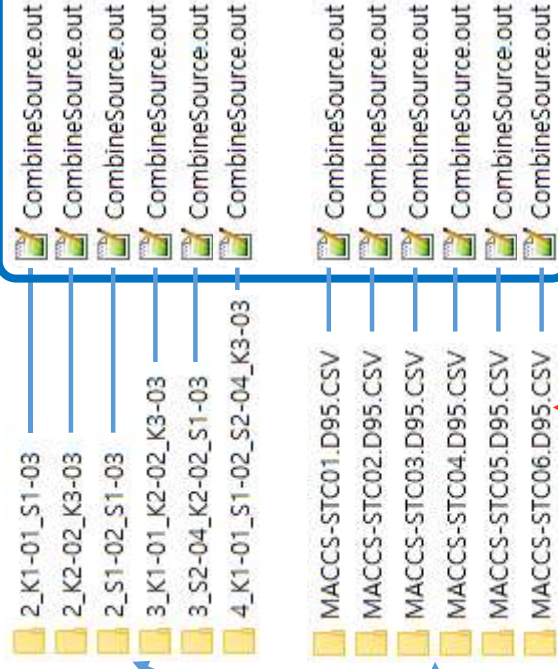
User Specified Project Folder



Multi-Unit

Single-Unit

Source Term Input



① Copy to each folder



Site & Other Input



Mr Manager

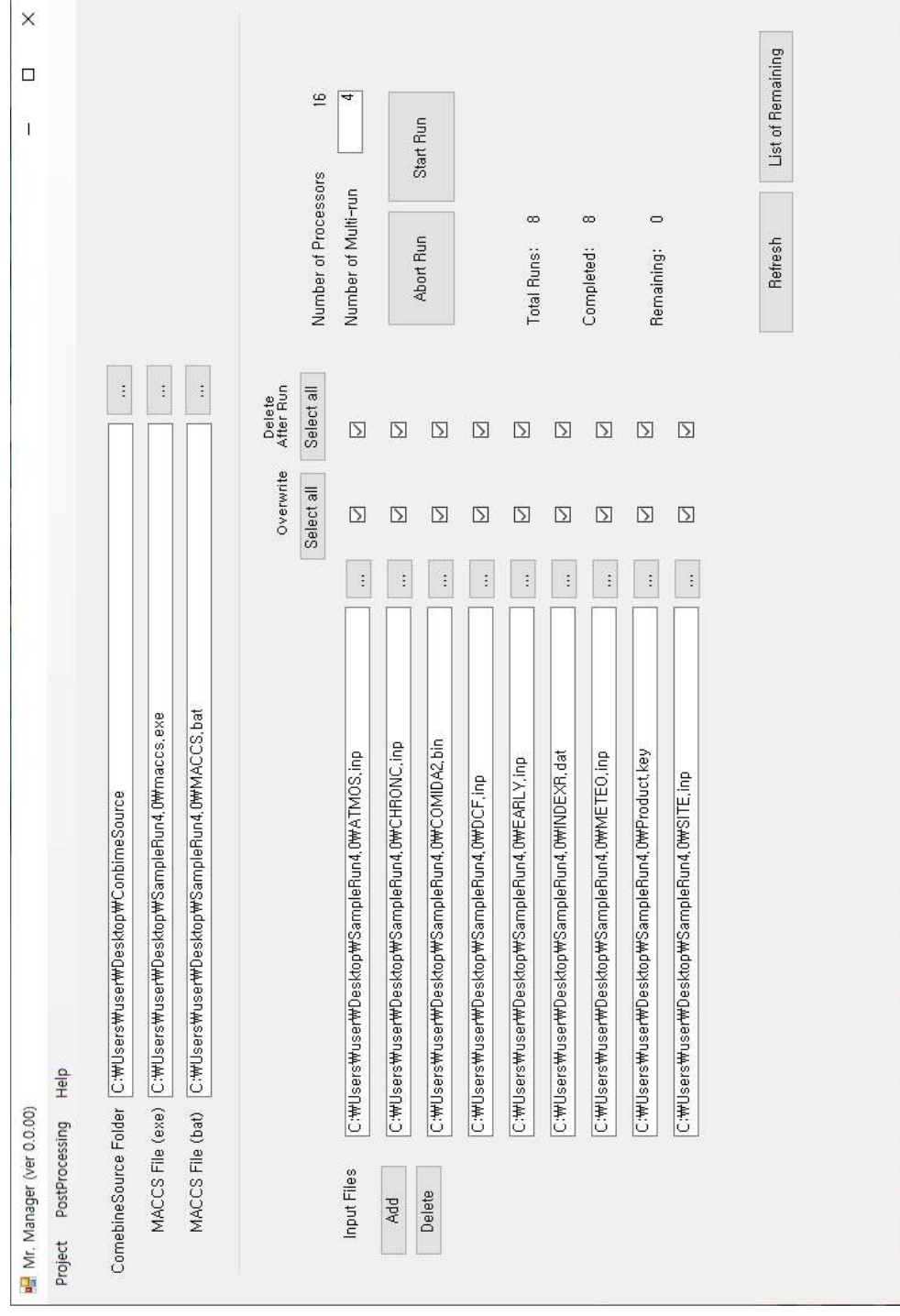


② Multi-run of MACCS

A Number of MACCS Output

Mr Manager

■ Graphic User Interface



Mr Manager

■ Additional Features

• OALARM

- If there exists OALARM.inp in source term folder, Mr Manager change OALARM in EARLY input file after copying EARLY input to each source term folder



```
*  
* OALARM, time after accident initiation that off-site alarm is initiated (s)  
EZOALARM001 17280.  
*
```

Source Term Folder

OALARM Information

Ex) Change EZOALARM001 in EARLY.inp (17280.) into the value of OALARM.inp (30905.745)

• Time offset (Multi-unit)

- MUST Converter prints time offset information in CombineSource.out as annotation at the end of each source term description
- Mr Manager copies and pastes time offset information to ATMOS input file after copying ATMOS input to each source term folder



Source Term Folder

```
*ISOFFSET001 0.  
* End of Source Term  
*  
*  
*ISOFFSET002 10000.  
* End of Source Term  
*  
*  
*ISOFFSET003 5000.  
* End of Source Term  
*  
*  
* TIMEOFF, time offset associated with each source term  
ISOFFSET001 0.  
ISOFFSET002 10000.  
ISOFFSET003 5000.  
*  
* MSMDL, multi source term model (TRUE, FALSE)  
ISMSMDL001 .TRUE.  
*  
* MSFILE_LNK, file created by program CombineSource  
SRC_FILE001 'CombineSource.out'  
*  
* NUM_SOURCES, number of MELMACS created source term files  
ISNUMSRC001 3  
*  
* TIMEOFF, time offset associated with each source term  
ISOFFSET001 0.  
ISOFFSET002 10000.  
ISOFFSET003 5000.  
*  
* Write ISOFFSET in ATMOS.inp
```

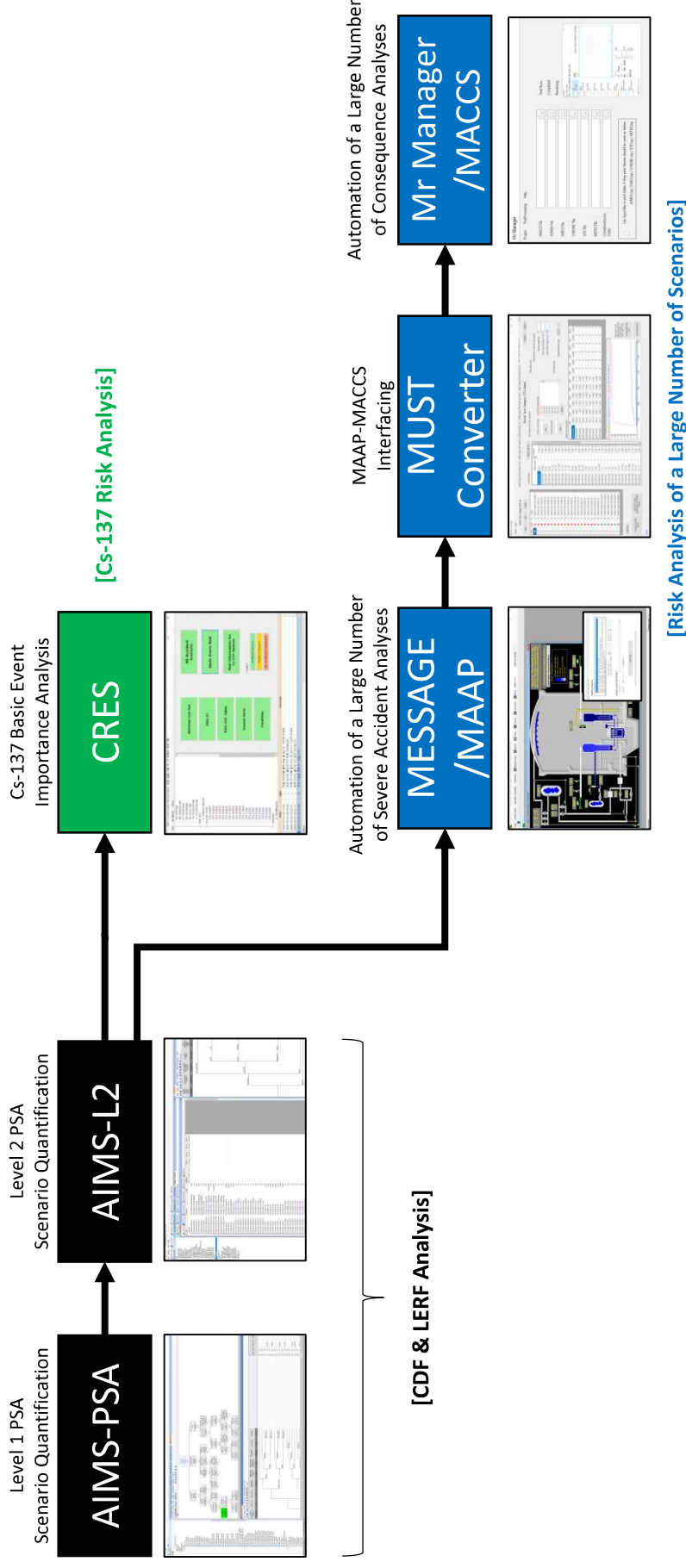
Software Demo

Software Tool to Perform PSA in KAERI

Software Tool to Perform PSA in KAERI

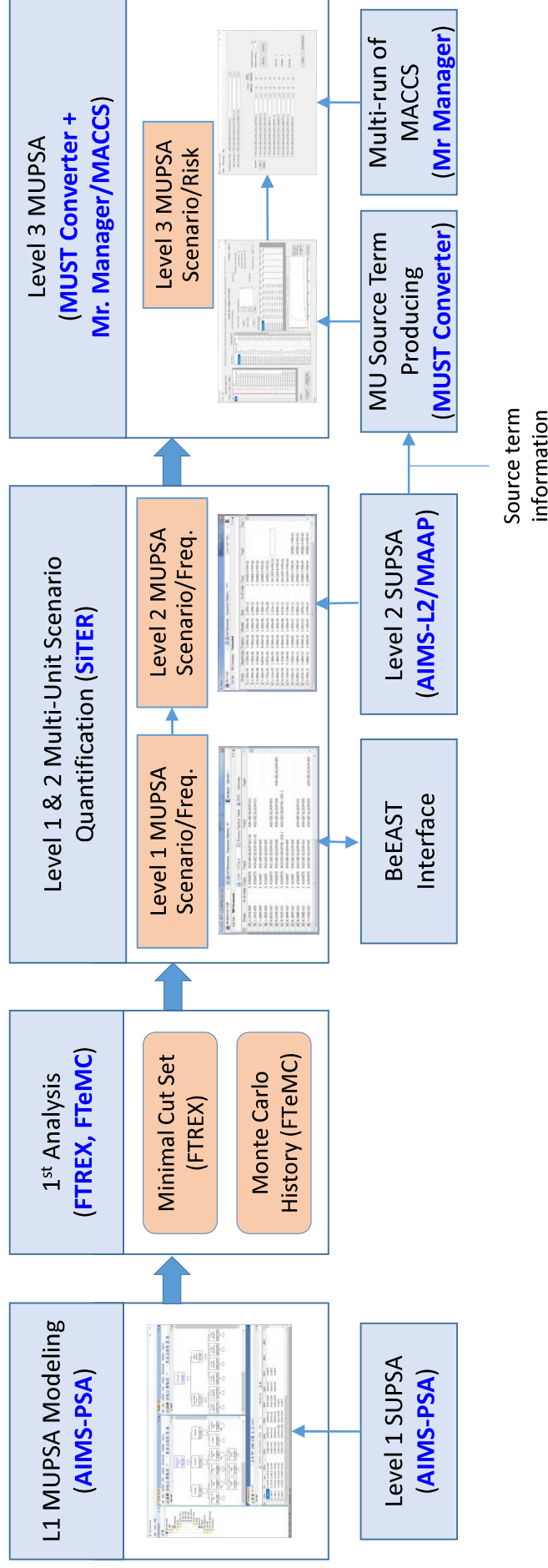
■ Optimal Analysis of Safety Goal

- Safety goal
 - Total frequency of accident scenarios with Cs-137 releases over 100TBq < $10^{-6}/\text{yr}$
 - 0.1% rule: Risk of early fatality and cancer fatality (or CDF, LERF)



Software Tool to Perform PSA in KAERI

■ Multi-Unit Risk Assessment



Summary & Conclusions

Summary & Conclusions

- **MUST (Multi-Unit Source Term) Converter** has been developed to extract and calculate source term information from MAAP results
- **Mr (Multi-run) Manager** has been developed to manage multiple MACCS runs
- It is expected that established solution can be a **base capability to run and manage a large number of consequence analyses**
- It is expected that **additional approaches to reduce the number of consequence analyses** can be developed to perform multi-unit Level 3 PSA
 - Categorization of multi-unit source terms
 - Consequence Substitution Approaches (CSAs)
 - N. E. Bixler and S. Y. Kim, *Performing a Multi-unit Level-3 PSA with MACCS, Nuclear Engineering and Technology*, Vol 53 (2021), pp. 386-392, 2021.
 - Etc.

References

- Detailed information of each software
 - S.Y. Kim and D.S. Kim, **Development of MUST (Multi-Unit Source Term) Converter Version 1.0**, *Transactions of the Korean Nuclear Society Autumn Meeting*, October 21-22, 2021, Changwon, Korea.
 - S.Y. Kim, **Development of Mr (Multi-run) Manager Version 1.0**, *Transactions of the Korean Nuclear Society Autumn Meeting*, October 21-22, 2021, Changwon, Korea.

Thank you.

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