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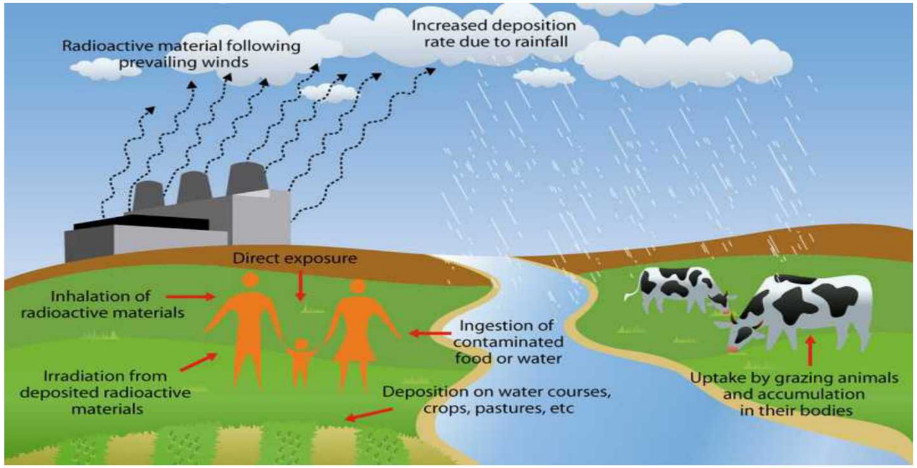

Practical Aspects for Performing Consequence Analyses for a Multi-Unit, Level 3 PSA

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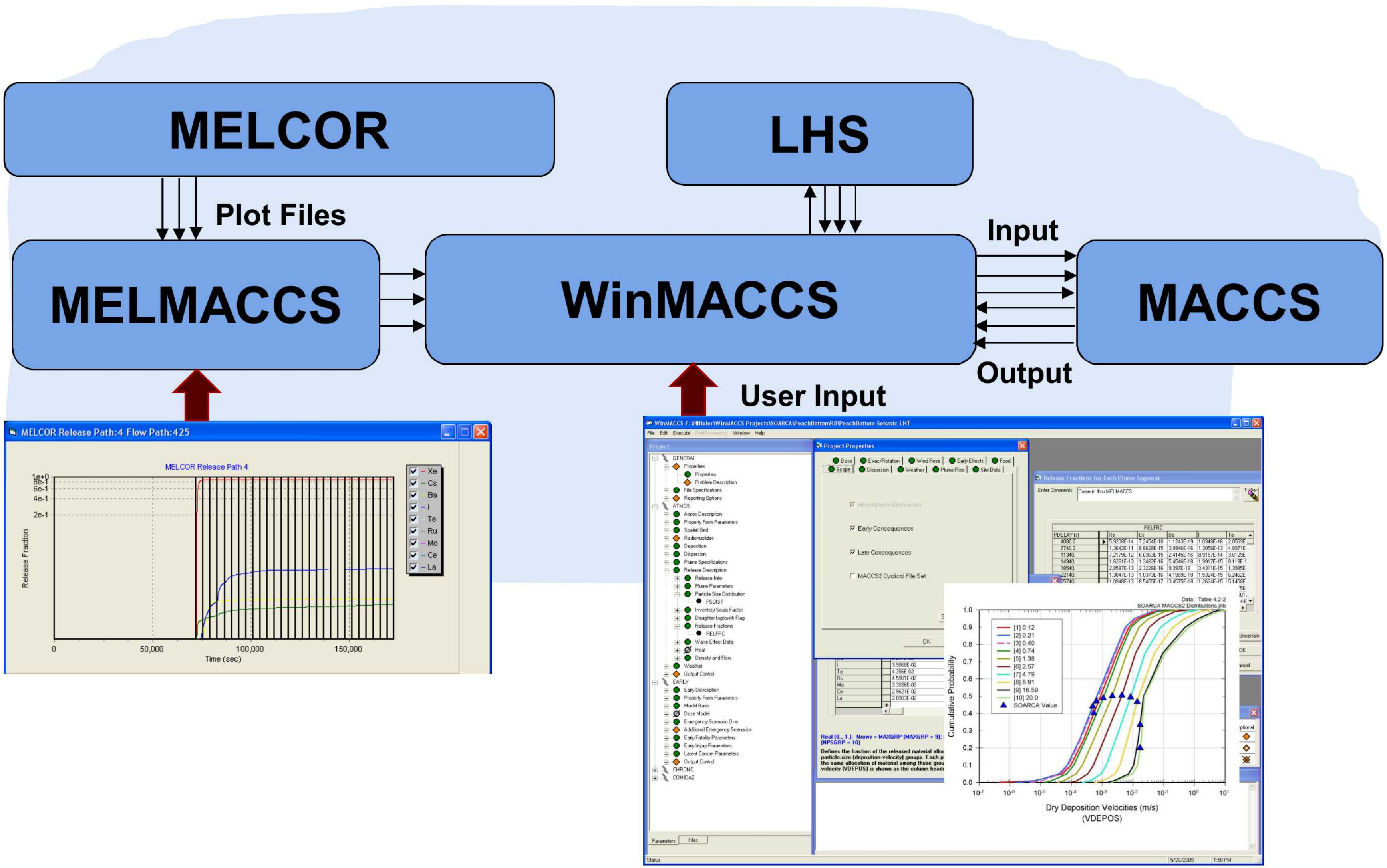
Outline

- MACCS framework for performing a MUPSA
- Source term properties and current Limitations
- Simplified Approaches
- Evaluation of Approaches
- Summary

WinMACCS Calculation Framework for a Level-3 PSA Analysis



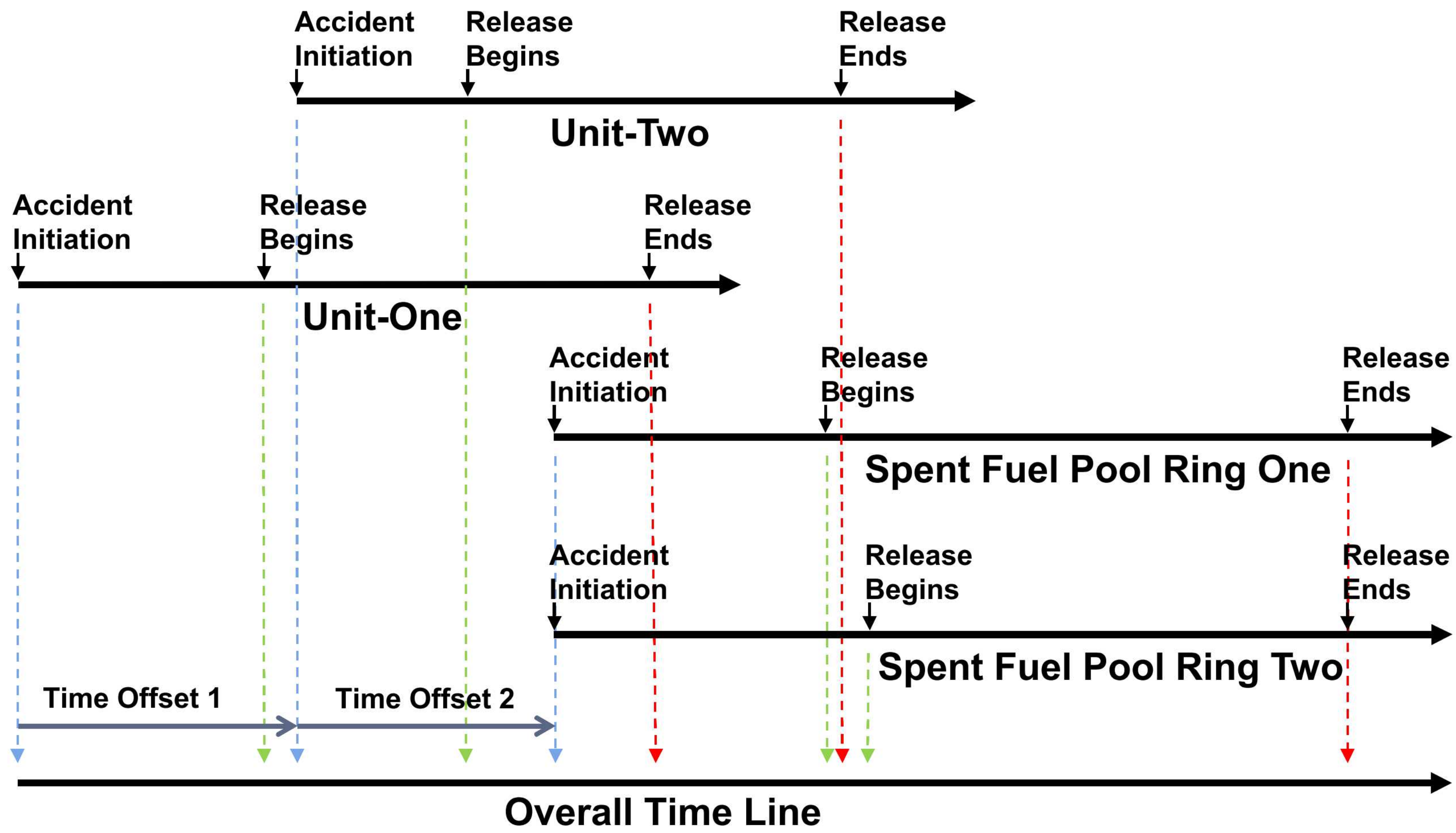
Best Estimate Framework for Multi-Unit Consequence Analyses

- Ability to treat multiple, overlapping source terms
  - Different accident initiation times
  - Different release signatures
  - Different isotopic inventories
- Spent fuel pools present a special case
  - Multiple fuel cooling times (different inventories)
  - Release signature may be a function of cooling time
- Overall release may continue for more than a week

Process for Multi-Unit Consequence Analysis

Integrating Multiple Source Terms

- Time offsets account for delays between initiating events
- Radioactive decay is relative to each initiating event



Source Term Properties

- Source term for each unit can have unique properties
  - Initiation event time
  - Inventory
  - Release timing and signature
  - Initial release height and buoyancy
  - Aerosol size distribution
  - Building dimensions
  - Release elevation
- All source-term properties have an effect on consequence results

Strengths and Weaknesses of Best-Estimate Framework

- Primary strength is that current framework contains a very general treatment for superposing source terms from multiple units
- Primary weakness is that it is difficult to calculate more than a small number of consequence results
  - Works adequately for two unit analyses
  - Not easily automated to assess a large set of source-term combinations
- Current framework is limited to a single release location
  - Adequate for most MUPSA analyses that report results over a 10-km or larger radius
  - May not be valid for near-field effects, e.g., doses near site boundary and early health effects

Requirements for Best Estimate MUPSA with N Unique Units

Number of Consequence Variations for M Unique Units with N Source Term Categories								
Number of Source Term Categories (N)	Number of Units Undergoing Accident (M)							
	1	2	3	4	5	6	7	8
5	5	25	125	625	3,125	15,625	78,125	390,625
10	10	100	1,000	10,000	100,000	1,000,000	10,000,000	100,000,000
15	15	225	3,375	50,625	759,375	11,390,625	170,859,375	2,562,890,625
20	20	400	8,000	160,000	3,200,000	64,000,000	1,280,000,000	25,600,000,000

- Number of required consequence analyses is N^M
- Not practical for more than 3 units with more than about 5 source term categories

Requirements for Best Estimate MUPSA with N Identical Units

Number of Consequence Variations for M Identical Units with N Source Term Categories								
Number of Source Term Categories (N)	Number of Units Undergoing Accident (M)							
	1	2	3	4	5	6	7	8
5	5	15	35	70	126	210	330	495
10	10	55	220	715	2,002	5,005	11,440	24,310
15	15	120	680	3,060	11,628	38,760	116,280	319,770
20	20	210	1,540	8,855	42,504	177,100	657,800	2,220,075

- Number of required consequence analyses is (N+M-1)!/[(N-1)!M!]
- Not practical for more than 4 units with more than about 5 source term categories

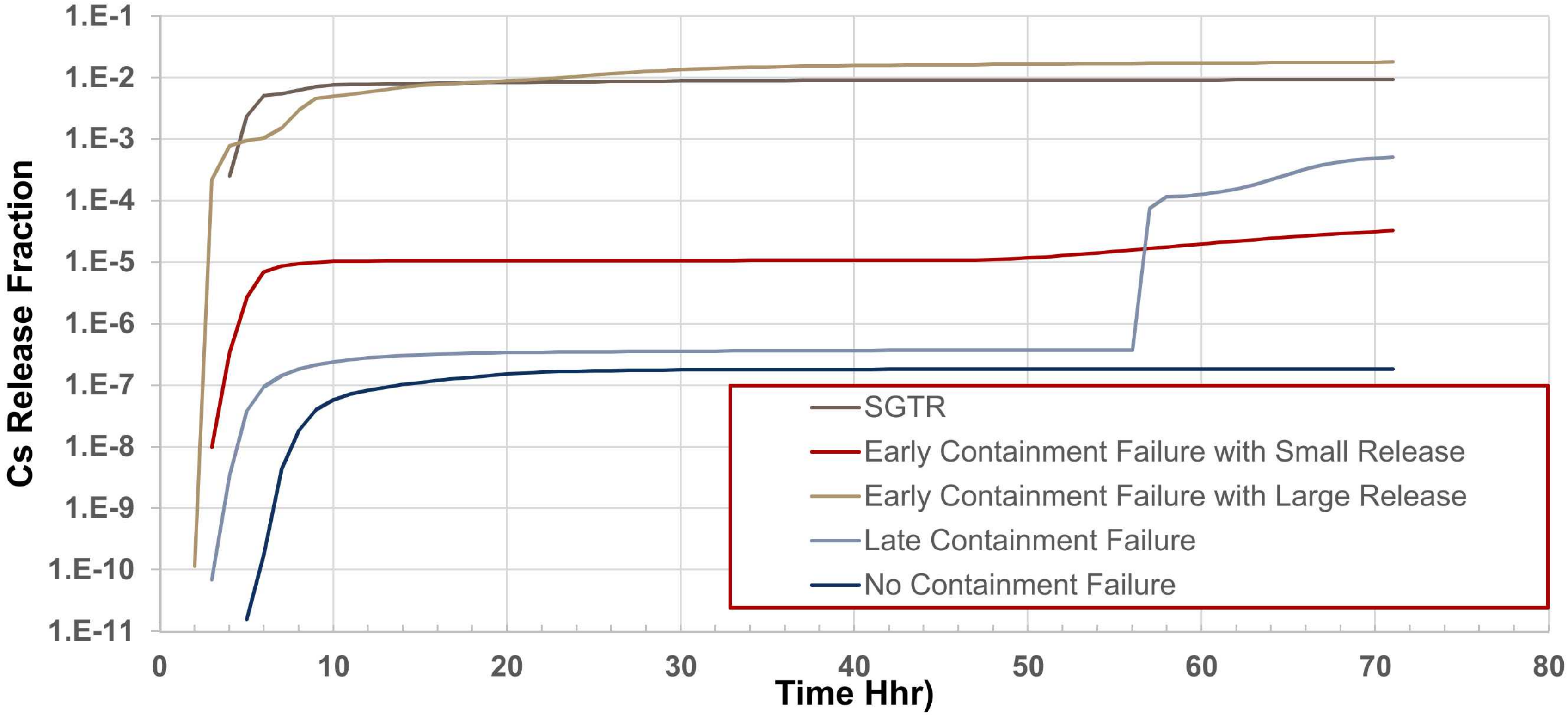
Issues for Performing a Level 3 MUPSA Analysis

- Current best estimate framework works well for sites with a few units but does not scale to sites with a large number of collocated units.
- A simplified framework is needed that scales to a large number of collocated units.
  - An acceptably accurate method is needed for combining source terms from multiple units into a single, approximate, source term.
  - An approach is needed to reduce the number of source-term combinations to be evaluated.
- The simplified framework must be tested to ensure that accuracy is acceptable.

First Test Problem to Evaluate Approximate Source Term

- Assume initiation of severe accident at a single unit due to a seismic event
- Select five source terms from SOARCA uncertainty analysis to represent range of possible source terms (source term categories)
  - Induced SGTR (Conditional Probability = 0.12)
  - Early containment failure with small release (CP = 0.315)
  - Early containment failure with large release (CP = 0.01)
  - Late containment failure (CP = 0.435)
  - No containment failure (CP = 0.12)

Integral Cs Release Fractions for Five Source Term Categories



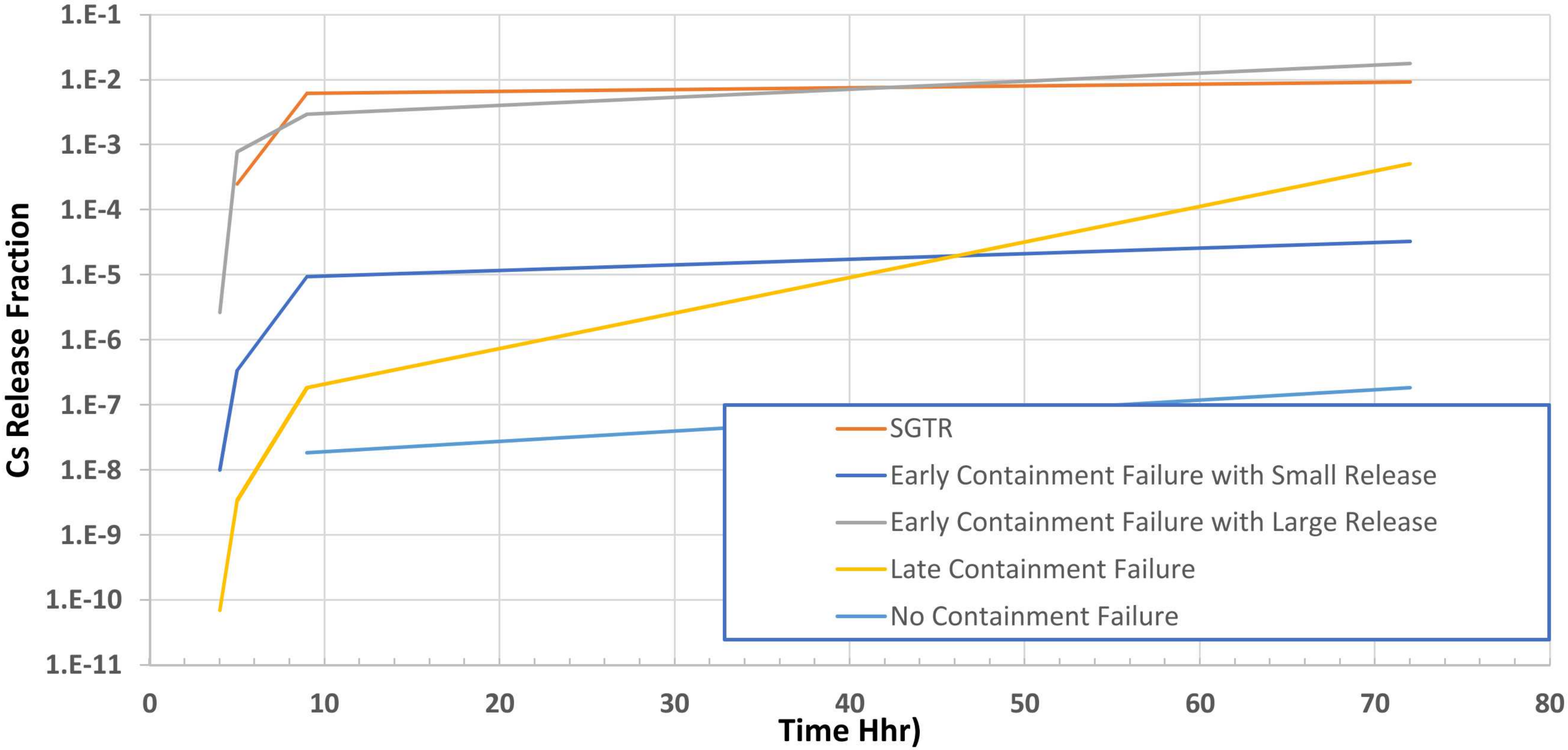
- SGTR and Early Containment Failure with Large Release are same order but have different timing
- Notice that all but two source terms separated by an order of magnitude in total Cs release fraction

Simplified Source Term Description

- Release timing and signature different for five source terms
  - Uniform release rate over 3 time intervals
    - Beginning of release until evacuation begins
    - During evacuation
    - After evacuation is complete
  - Extension of method in paper by S. Y. Kim et al. to be published in Nuclear Engineering and Technology
- Initial release height and buoyancy same for all source terms
- Aerosol size distribution same for all five source terms

- Subsequent comparisons are for
  - Standard best-estimate source term (BEST)
  - Simplified source term (SST) described above
  - Relative errors for a several results are reported as (SST – BEST)/BEST

Simplified Integral Cs Release Fractions for Five Source Term Categories



- Hourly release fractions are uniform over three periods

Relative Error in Simplified Source Term Method

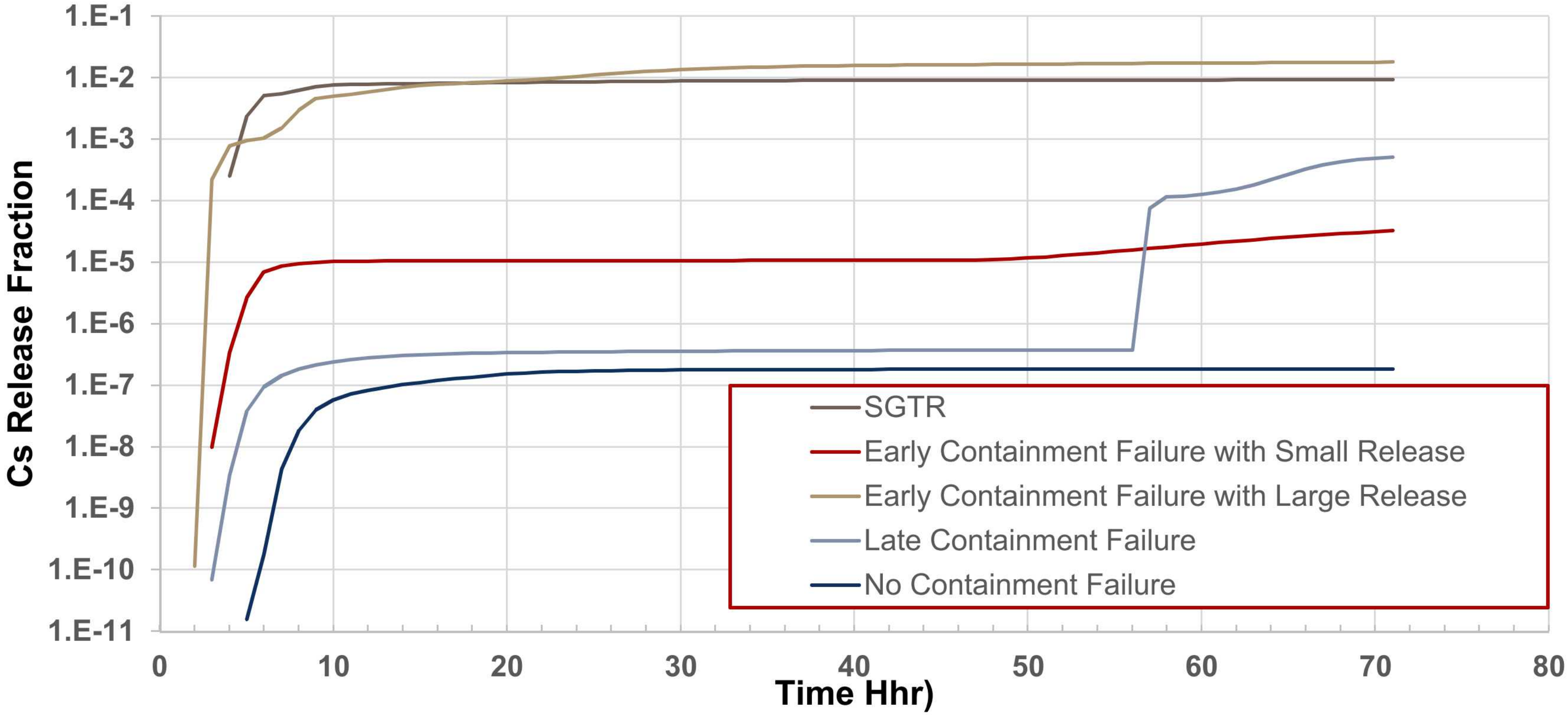
Source Term	Population Dose (0 to 80 km)	LCF Risk (0 to 80 km)	Early Fatality Risk (0 to 1.6 km)	Land Area Exceeding 1 μCi Cs-137/m^2	Land Area Exceeding 5 μCi Cs-137/m^2	Land Area Exceeding 15 μCi Cs-137	Land Area Exceeding 40 μCi Cs-137	Economic Losses	Area Decontaminated	Population Displaced by Decontamination
SGTR	-0.15	-0.17	0.00	-0.24	-0.22	-0.25	-0.27	-0.38	-0.29	-0.41
ECF, Small Release	-0.11	-0.27	0.00	-0.70	-0.68	-0.92	-0.99	0.02	-0.95	0.00
ECF, Large Release	-0.13	-0.14	0.00	-0.39	-0.47	-0.48	-0.57	-0.62	-0.45	-0.44
LCF	2.25	2.24	0.00	0.25	-0.09	0.72	36.22	-0.75	-0.54	-0.70
No CF	-0.35	-0.39	0.00	-1.00	0.00	0.00	0.00	0.03	0.00	0.00

- Yellow highlighting indicates results differ by more than a factor of 2
- Relative error in consequence results can be a factor of 10 or more
- Relative error in non-threshold consequence results can be a factor of 4
- Expectation is that large majority of results should be within factor of 2 for MUPSA applications

Partially Simplified Source Term Description

- Release timing and signature treated for each source term
  - Release fractions evaluated for each hour of release
- Initial release height and buoyancy treated for each source term
- Aerosol size distribution treated for each source term

Integral Cs Release Fractions for Five Source Term Categories



- SGTR and Early Containment Failure with Large Release are same order but have different timing
- Notice that all but two source terms separated by an order of magnitude in total Cs release fraction

Relative Error in Partially Simplified Source Term Method

Source Term	Population Dose (0 to 80 km)	LCF Risk (0 to 80 km)	Early Fatality Risk (0 to 1.6 km)	Land Area Exceeding 1 μCi Cs-137	Land Area Exceeding 5 μCi Cs-137
SGTR	-0.17	-0.19	0.00	-0.12	-0.06
ECF, Small Release	-0.27	-0.38	0.00	-0.63	-0.67
ECF, Large Release	-0.08	-0.01	0.00	-0.21	-0.39
LCF	0.32	0.33	0.00	0.43	0.32
No CF	-0.28	-0.31	0.00	-1.00	0.00

Land Area Exceeding 15 μCi Cs-137	Land Area Exceeding 40 μCi Cs-137	Economic Losses	Area Decon.	Population Displaced by Decon.
-0.27	-0.24	-0.09	-0.35	-0.52
-0.93	-0.97	0.00	-0.91	0.00
-0.50	-0.59	-0.40	-0.45	-0.51
-0.04	-0.28	0.95	0.22	0.77
0.00	0.00	0.01	0.00	0.00

- Only 5 threshold-type results differ by more than factor of 2
- More detailed source term method appears to be acceptable for MUPSA applications

Summary of Source Term Simplification

- Representing source terms as uniform over a few periods may not provide acceptable accuracy
- Accounting for more details in source term description provides acceptable accuracy
  - Hourly release fractions
  - Hourly rate of release of sensible heat
  - Aerosol size distribution
- Rules for creating composite source terms are needed for MUPSA applications

Composite Source Terms

- Hourly values for each unit are added to create composite source terms
  - Release fractions
  - Rate of release of sensible heat
- Aerosol size distribution for unit with largest integral release is used to represent the composite source term

Simplified Framework – Source Term Combinations

- Organize source term categories so that integrated release fractions of important chemical groups are factors of X, e.g., X = 10 and source term categories are
  - STC 1 – Cs release fraction between 10^{0} and 10^{-1}
  - STC 2 – Cs release fraction less than 10^{-1} and 10^{-2}
  - STC3 – Cs release fraction less than 10^{-2} and 10^{-3}
  - …
- Only evaluate results for combinations of source term categories that differ by 0 or 1
- Conservatively apply next larger combination of categories in place of smaller ones
- Create simplified source term descriptions so multiple source terms can be combined into a single source term

Simplified Framework Example

Comparison of Number of Consequence Variations for 2 Identical Units with 5 Source Term Categories - Best Estimate Vs. Simplified Approach															
	Source Term Combinations for 2 Units and 5 Source Terms														
Source Term Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Best Estimate	1 x 1	1 x 2	1 x 3	1 x 4	1 x 5	2 x 2	2 x 3	2 x 4	2 x 5	3 x 3	3 x 4	3 x 5	4 x 4	4 x 5	5 x 5
Simplified Approach	1 x 1	1 x 2	1 x 2	1 x 2	1 x 2	2 x 2	2 x 3	2 x 3	2 x 3	3 x 3	3 x 4	3 x 4	4 x 4	4 x 5	5 x 5

- In this example, the number of required consequence analyses is reduced from 15 to 9

Second Test Problem to Evaluate Simplified Framework

- Assume simultaneous initiation of severe accidents at two collocated units due to seismic event
- Five source terms chosen from SOARCA uncertainty analysis to represent range of accident progression variations (source term categories)
  - Induced SGTR (Conditional Probability = 0.12)
  - Early containment failure with small release (CP = 0.315)
  - Early containment failure with large release (CP = 0.01)
  - Late containment failure (CP = 0.435)
  - No containment failure (CP = 0.12)
- Use composite, partially simplified source term method
- Assess accuracy of simplified framework

Requirements for Simplified Framework for MUPSA

Number of Consequence Variations for M Identical Units with N Source Term Categories Using Simplified Approach								
Number of Source Term Categories (N)	Number of Units Undergoing Accident (M)							
	1	2	3	4	5	6	7	8
5	5	9	13	17	21	25	29	33
10	10	19	28	37	46	55	64	73
15	15	29	43	57	71	85	99	113
20	20	39	58	77	96	115	134	153

- Number of required consequence analyses is M*(N-1)+1.
- Practical for any reasonable number of units and source term categories!
- Accuracy of simplified approach requires evaluation.
- Requirements are same when units are unique, but source term categories must be chosen to represent all units.

Simplified Framework Used for Second Test Problem

Comparison of Number of Consequence Variations for 2 Identical Units with 5 Source Term Categories - Best Estimate Vs. Simplified Approach															
	Source Term Combinations for 2 Units and 5 Source Terms														
Source Term Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Best Estimate	1 x 1	1 x 2	1 x 3	1 x 4	1 x 5	2 x 2	2 x 3	2 x 4	2 x 5	3 x 3	3 x 4	3 x 5	4 x 4	4 x 5	5 x 5
Simplified Framework	1 x 1	1 x 2	1 x 4	1 x 4	1 x 4	2 x 2	3 x 4	2 x 4	2 x 5	3 x 3	3 x 4	3 x 4	4 x 4	4 x 5	5 x 5

- Second Test Problem does not follow the order-of-magnitude spacing rule
- The number of required consequence analyses is only reduced from 15 to 11 instead of 9

Relative Error in Risk Introduced by Simplified Source Term & Simplified Framework

Method Used	Population Dose (Sv) (0 to 80 km)	LCF Risk (0 to 80 km)	Early Fatality Risk (0 to 1.6 km)	Land Area (ha) Exceeding 1 mCi Cs-137	Land Area (ha) Exceeding 5 mCi Cs-137	Land Area (ha) Exceeding 15 µCi Cs-137	Land Area (ha) Exceeding 40 µCi Cs-137	Economic Losses ($M)	Area Decontaminated (ha)	Population Displaced by Decontaminated
Best Estimate	3,983	4.97E-05	0.00E+00	90,600	13,125	3,605	969	303,170	5,211	10,123
Simplified ST	4,402	5.61E-05	0.00E+00	86,386	12,817	3,144	874	454,688	4,794	9,933
Relative Error	11%	13%	0%	-5%	-2%	-13%	-10%	50%	-8%	-2%
Simplified ST & FW	4,831	6.20E-05	0.00E+00	87,667	12,927	3,162	877	510,106	5,116	10,640
Relative Error	21%	25%	0%	-3%	-2%	-12%	-9%	68%	-2%	5%

Summary

- A method for simplifying source terms has been evaluated that produces adequate accuracy for MUPSA applications
- A method for creating composite source terms has been evaluated for identical units
  - Allows automation of large sets of source term combinations
- A simplified framework has been evaluated for reducing the number of consequence analyses needed for MUPSAs with more than 3 or 4 units

- Evaluating risks for a large set of units appears to be feasible!

Additional Thoughts

Simplified framework

- When X is significantly less than 10 it may be necessary to modify the process as follows
  - Only evaluate results for combinations of source term categories that differ by 0 to L
  - Number of required consequence analyses for the general case is ?

Composite source terms

- When unit inventories are not the same, combine source terms based release fraction times core inventory

Multiple release locations

- Need to treat explicitly for large source term combinations and threshold-type consequences in the near field