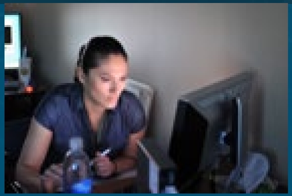
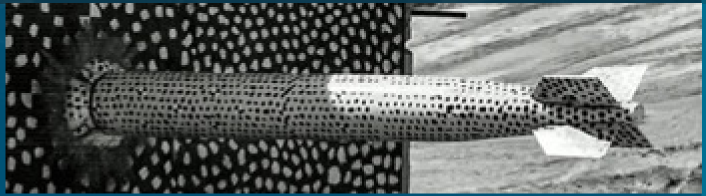
Demonstration of MACCS Capabilities for Advanced Reactors





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Demonstration of Capabilities

As advanced reactor designs mature and progress on the roadmap to licensing, there is great interest in characterizing severe accident scenarios and their associated consequences.

The work was sponsored by DOE NE-NEAMS and DOE NE-ART in order to "leverage ongoing NRC efforts identifying reference accident progression scenarios to perform reference plant analysis demonstrating mod/sim readiness for application to risk-informed, performance-based reactor licensing initiatives"

Research & Development → Conceptual Design → Preliminary Design → Final Design → Regulatory Approval

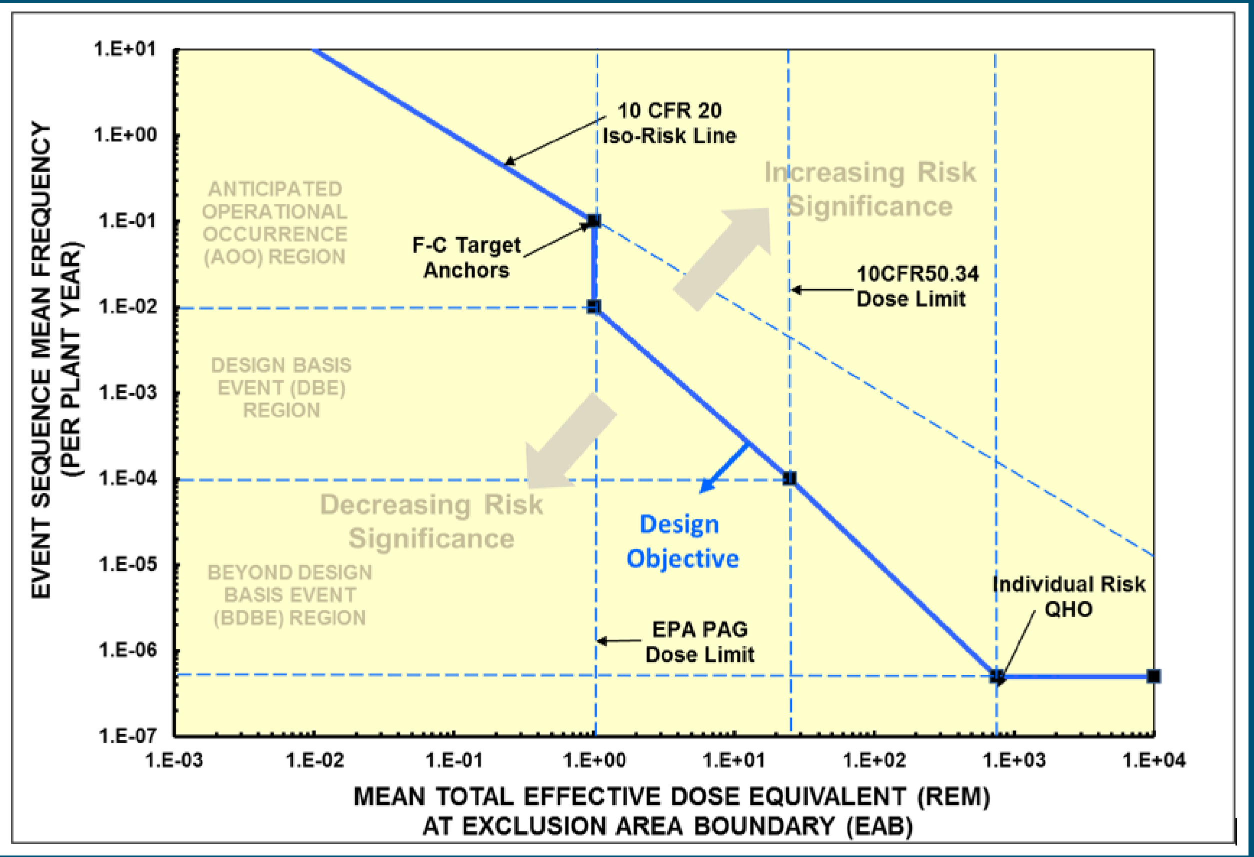
Applicability of Consequence Analysis

NEI 18-04, also referred to as the Licensing Modernization Project (LMP):

- Technology-inclusive
- Risk-informed
- Performance-based

Licensing basis events (LBEs):

- Anticipated Operational Occurrences (AOOs)
- Design Basis Events (DBEs)
- Beyond Design Basis Events (BDBEs)
- Design Basis Accidents (DBASs)

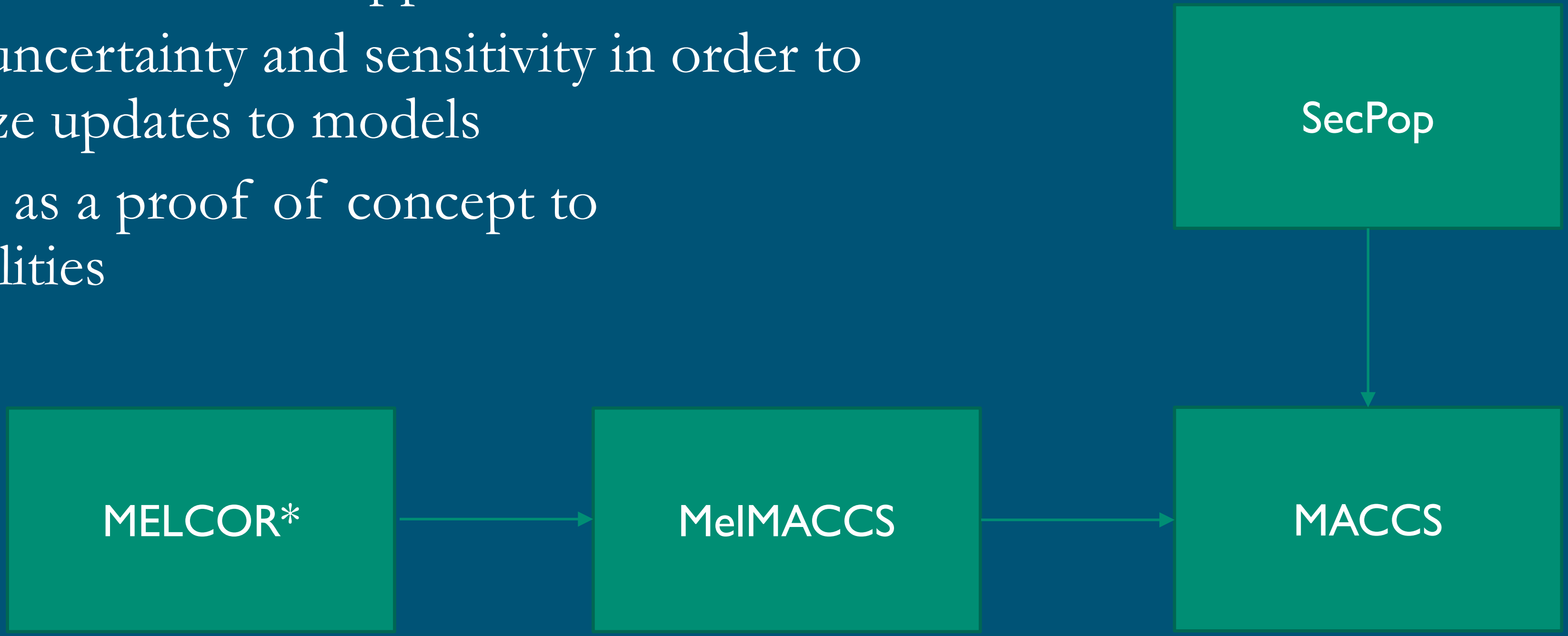


LMP frequency-consequence curve [1]

Consequence analysis for non-LWRs is key to realization of the Licensing Modernization Project!

Approach

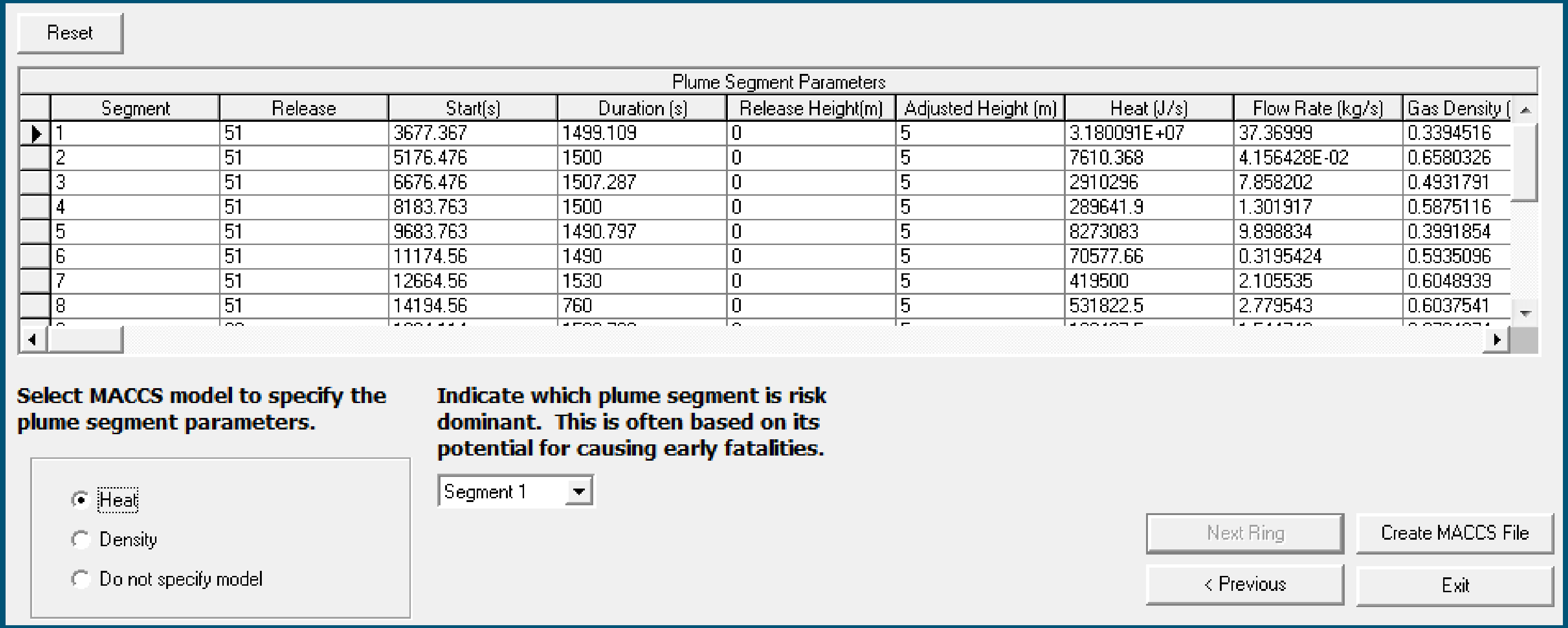
- Study examines an approach to performing an initial consequence analysis for non-LWR accidents
- Four computer codes used in this approach
- Identifies areas of uncertainty and sensitivity in order to inform and prioritize updates to models
- This study is meant as a proof of concept to demonstrate capabilities



* This study utilizes an illustrative source term for demonstration purposes only

MelMACCS

- Part of the MACCS code suite
- Developed in 2002
- Generates MACCS source term files from MELCOR plot files



Segment	Release	Start(s)	Duration (s)	Release Height(m)	Adjusted Height (m)	Heat (J/s)	Flow Rate (kg/s)	Gas Density (
1	51	3677.367	1499.109	0	5	3.180091E+07	37.36999	0.3394516
2	51	5176.476	1500	0	5	7610.368	4.156428E-02	0.6580326
3	51	6676.476	1507.287	0	5	2910296	7.858202	0.4931791
4	51	8183.763	1500	0	5	289641.9	1.301917	0.5875116
5	51	9683.763	1490.797	0	5	8273083	9.898834	0.3991854
6	51	11174.56	1490	0	5	70577.66	0.3195424	0.5935096
7	51	12664.56	1530	0	5	419500	2.105535	0.6048939
8	51	14194.56	760	0	5	531822.5	2.779543	0.6037541

SecPop

- Part of the MACCS code suite
- Calculates estimated population and economic data around any point specified by latitude and longitude
- Utilizes census data and economic data in continental US

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 26 SPATIAL INTERVALS
 16 WIND DIRECTIONS
  7 CROP CATEGORIES
  4 WATER PATHWAY ISOTOPES
  1 WATERSHEDS
 18 ECONOMIC REGIONS
SPATIAL DISTANCES     KILOMETERS
    0.1600    0.5200    1.2100    1.6100    2.1300    3.2200    4.0200
    5.6300    8.0500   11.2700   16.0900   20.9200   25.7500   32.1900
   48.2800   64.3700   80.4700  112.6500  160.9300  241.1400  321.8700
  804.6700 1609.3400
POPULATION
        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.
        0.    43058.   272058.  1793543.   667503.   142685.    52378.
        0.        0.
        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.     4657.   127376.    62233.        0.
        0.        0.
        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.
        0.        0.
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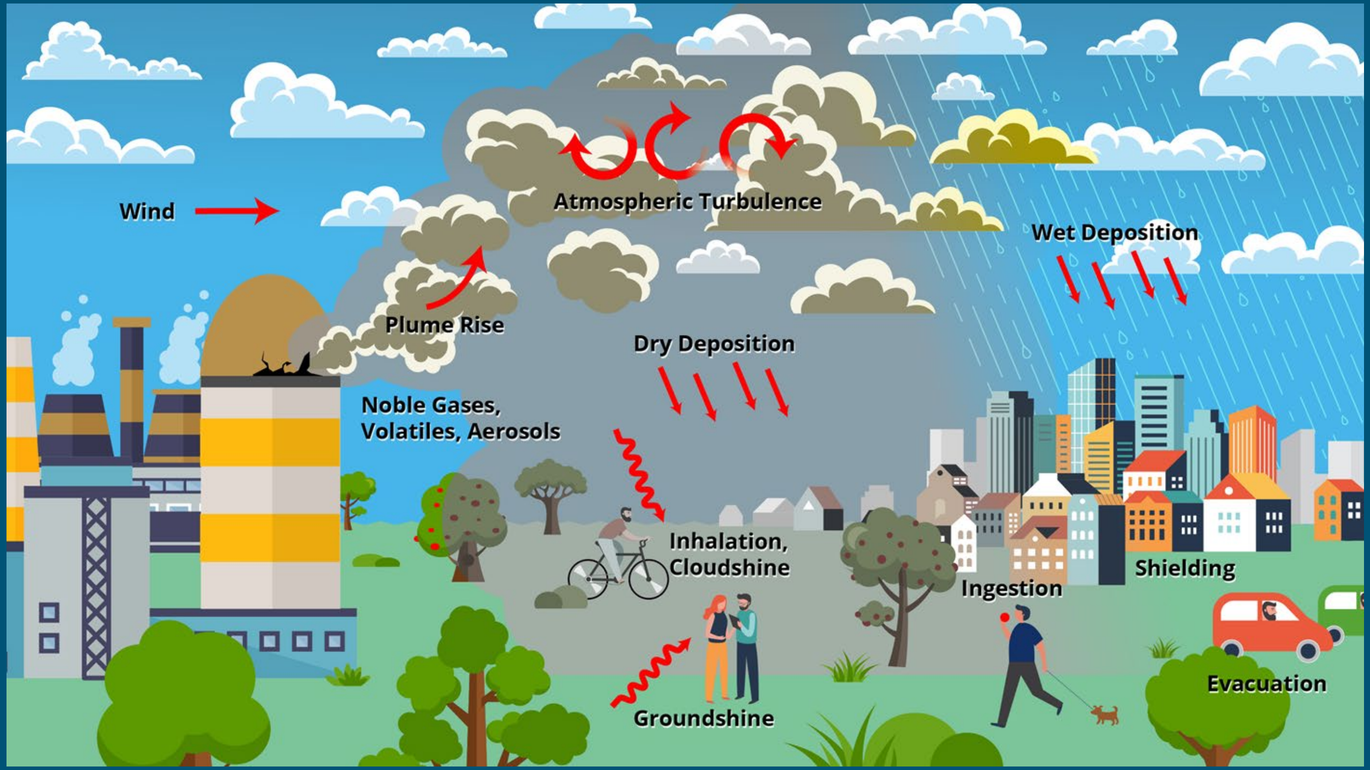
MACCS – MELCOR Accident Consequence Code System

- Origins of MACCS goes back to the 1970s, routinely updated since
- Models:
  - Atmospheric transport and dispersion
  - Wet and dry deposition
  - Probabilistic treatment of meteorology
  - Exposure pathways
  - Emergency phase, intermediate phase, and long-term phase protective actions
  - Dosimetry
  - Health effects
  - Economic impacts

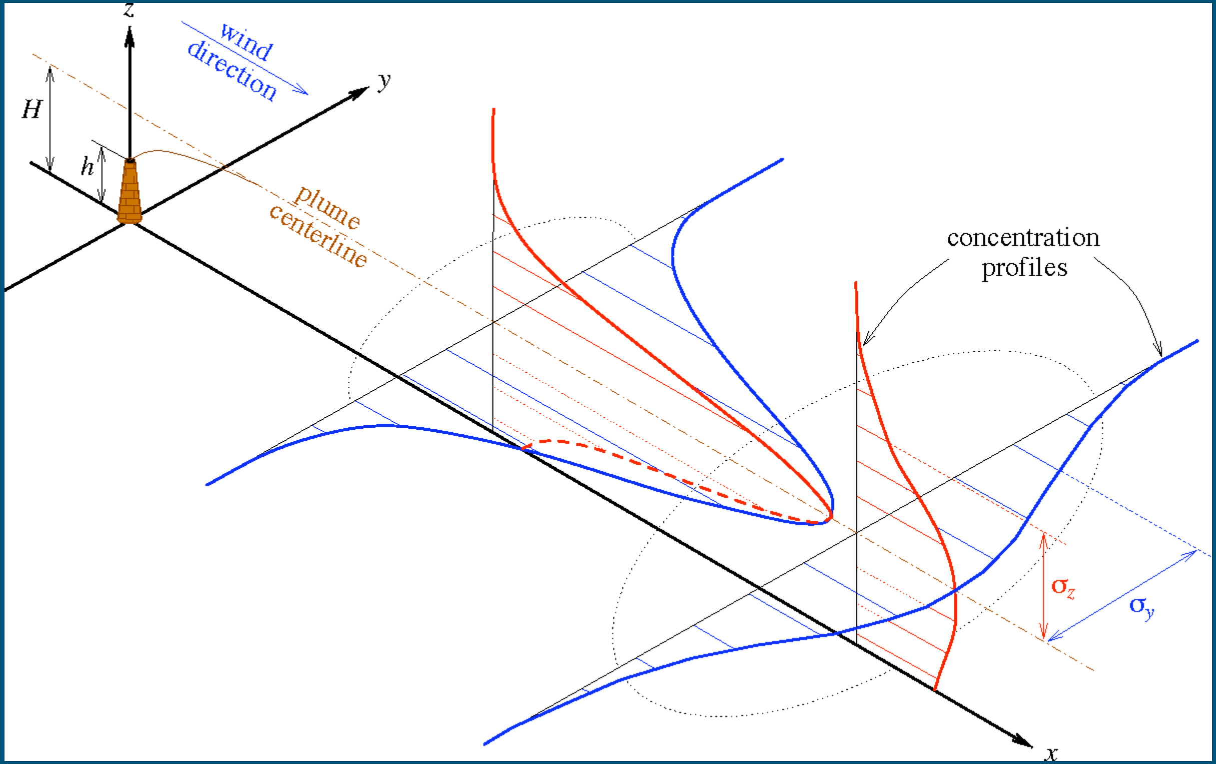


Illustrative Source Term

- Divided into 58 plume segments (3-hours long)
- Important characteristics
  - Energy of the release
  - Mass flow rate
  - Gas density
  - Release fraction of chemical groups
    - Based on measured correlations for Xe, Kr, Sr, Cs, I and Ag with the remainder being inferred from LWR methodology
    - Alkaline Earth group is inferred from Sr data

Chemical Group	Description	Radionuclides
Group 1	Noble Gases	Xe, Kr
Group 2	Alkali Metals	Cs, Rb
Group 3	Alkaline Earths	Ba, Sr
Group 4	Halogens	I
Group 5	Chalcogens	Te
Group 6	Platinoids	Rh, Ru
Group 7	Early Transition	Nb, Co, Mo, Tc,
Group 8	Tetravalents	Ce, Np, Pu, Zr
Group 9	Trivalents	La, Am, Cm, Nd, Pr, Y

Atmospheric Transport and Dispersion Modeling



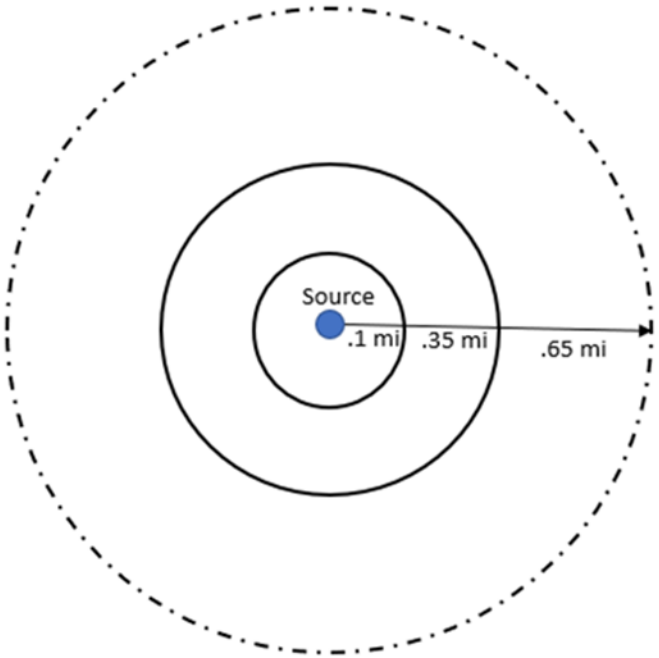
Ionescu, Tudor. (2017). Emergency Response in Action: Expertise, Imaginaries, and Communication in Nuclear Crisis.

- Each segment is modeled as a plume traveling in a straight-line with an assumed Normal distribution
- Crosswind and vertical dimensions are expressed using crosswind (σ_y) and vertical (σ_z) standard deviations of the normal concentration distributions
- Rate of plume expansions in all directions increases when atmospheric turbulence increases
- Vertical expansion increases with increasing surface roughness and is constrained by the ground and temperature structure of atmosphere
- Crosswind spreading is unconstrained

Spatial Grid

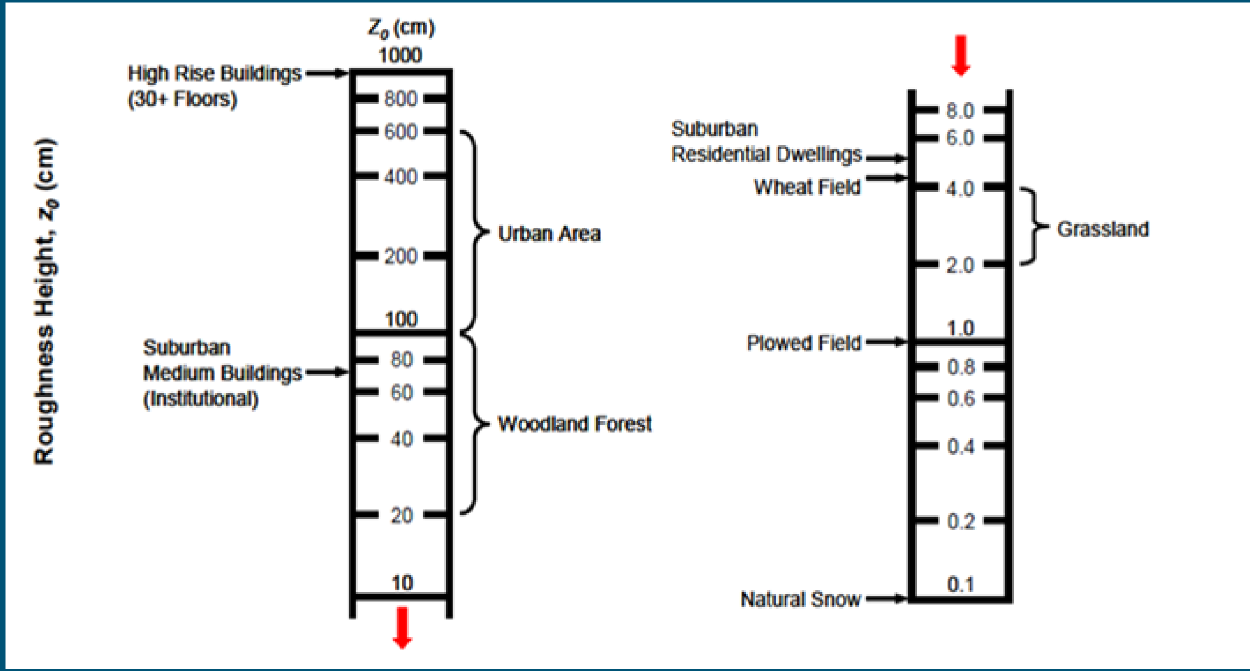
- Two-dimensional polar-coordinate modelling domain
- Used to determine the dose at various distances from the source
- Separates data into spatial intervals
- Spatial grid kept consistent with an emergency planning zone
- Average representation of weather within the U.S.

Radial Number (NUMRAD)	Distance (mi) (SPAEND)
1	0.10
2	0.35
3	0.65
4	1.00
5	1.35
6	2.00
7	2.50
8	3.00
9	3.50
10	5.00
11	7.00
12	10.00



Site Characteristics

- Average suburban environment that includes both institutional and residential buildings
- Building dimensions made to be consistent with anticipated small modular reactor dimensions
  - Width (W) = 20 m (394 ft)
  - Height (H) = 20 m (394 ft)
- Initial plume dimensions based on building dimensions
  - $\sigma_{y,inital}$ = 0.25*W = 4.6 m (15 ft)
  - $\sigma_{z,inital}$ = 0.47*H = 9.4 m (31 ft)
- Surface roughness estimated to be 40 cm (16 in)
  - Applies a linear scaling factor of 1.67 to σ_z



Population Cohorts

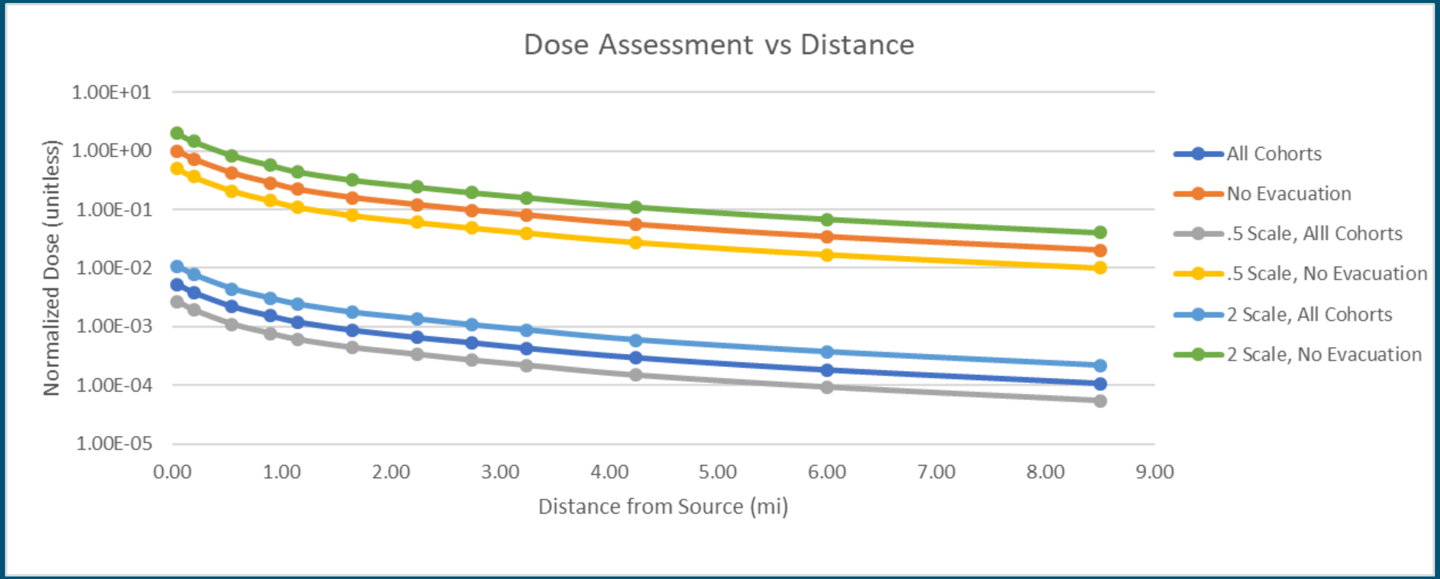
1. Populations with access to private transportation
2. Transit dependent populations
3. Special facility residents
4. School populations
5. Non-evacuating populations

- Population may be divided into cohorts based on the delay time and speed it would take the population to evacuate, if necessary
- Delay time and speed of evacuation dependent on living situation and vehicle access
- Cohort sizes based on U.S. total populations
- Use of demographic survey data from various agencies could be utilized to inform these parameters:
  - Census Bureau
  - Centers for Disease Control and Prevention
  - Department of Justice
  - Department of Education
- Notification delay may also be varied in MACCS

Additional Information

- All other information needed for modeling within MACCS aligns with the MACCS best practices used in the State-of-the-Art Reactor Consequence Analyses (SOARCA) project
  - Analysis was completed for the Peach Bottom Atomic Power Station, Surry Power Station and the Sequoyah Nuclear Generating Station
  - Existing technical basis for MACCS parameters was identified and updates were developed based on current data and information

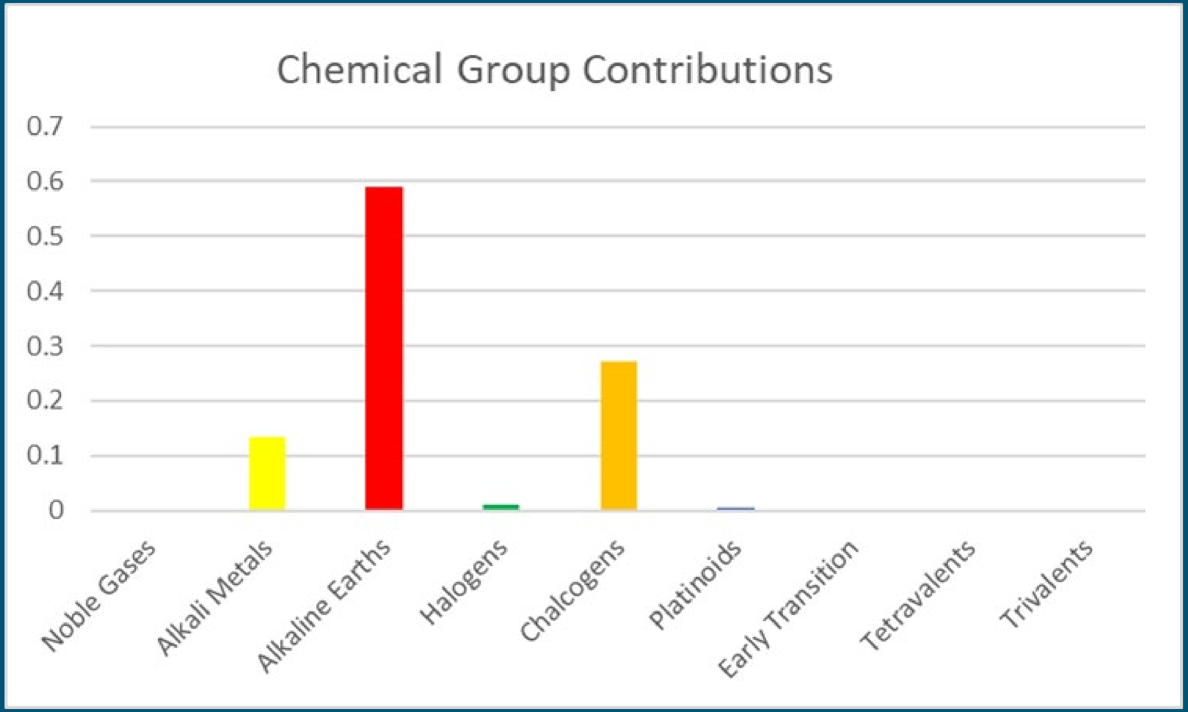
Results Demonstration for Normalized Dose



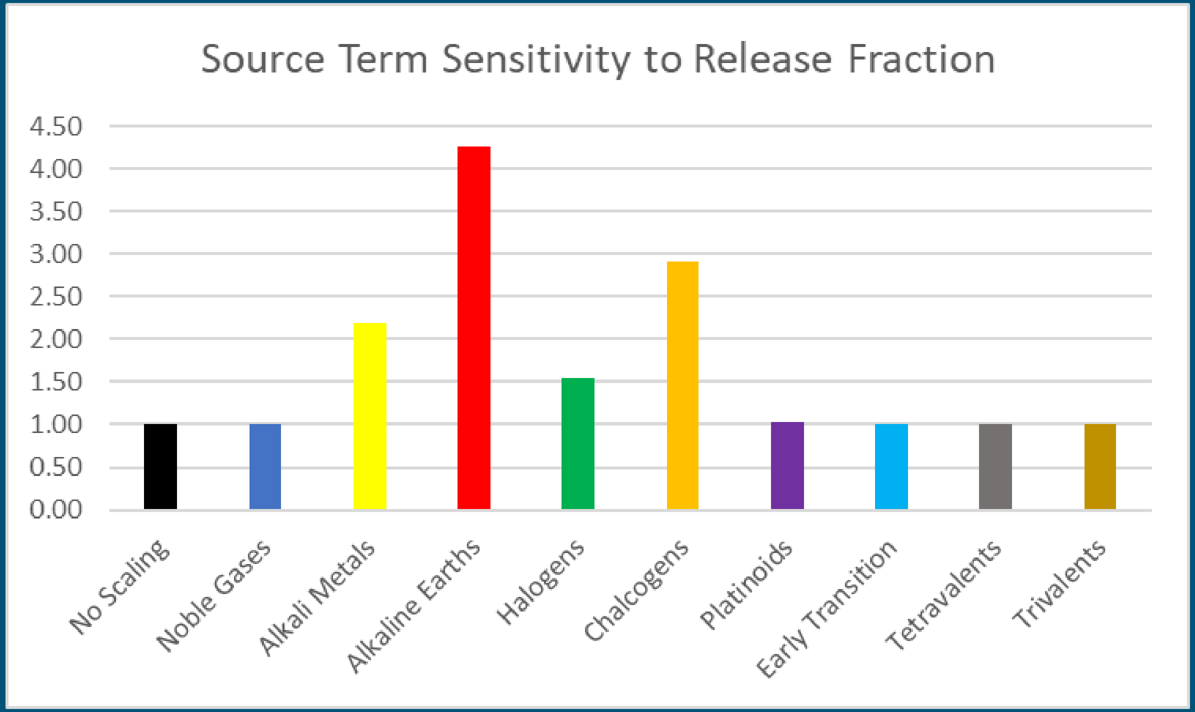
- Inventory scaling factors were applied to the source term
- Dose results examined are over 30 miles
- Data normalized to the 0.05-mile datapoint for the no scaling, non-evacuating cohort
- Normalized dose to non-evacuating cohort for all three inventory sizes is larger than doses to all cohorts

Results Demonstration for Radionuclide Sensitivities

Contribution of each of the chemical groups to estimated dose



Ratio of dose assessment when each chemical group's release fraction is increased by a factor of 10



Summary and Conclusions

- Four computer codes that interact well with one another were used in this approach
- Source term utilized was an illustrative source term
- Gaussian atmospheric transport and dispersion model was used
- Site being analyzed was an average suburban environment
- Population divided based on delay time and speed of evacuation

- Successful demonstration of MACCS capabilities for use on non-LWR source terms
- Examined sensitivities for several parameters to include source term scale, evacuation descriptions, and chemical group contributions
- Non-LWR consequence analysis is possible with MACCS
- Informs areas of greatest uncertainty and sensitivity to inform prioritization of model improvements
- Progression of research will allow the ability to fine tune the needed parameters for analysis

Key Advanced Reactor Atmospheric Transport Issues to be Addressed

- Modeling near-field dispersion
  - May be required to estimate doses and other consequences at or just beyond the Exclusion Area Boundary (EAB), which may be very close to the reactor location
  - Examined MACCS against several near-field dispersion codes (SAND2020-2609)
- Change in the formation of activation products
  - Isotopic inventory, if very different than that of a LWR, may need to be reevaluated to ensure that all important isotopes are included in the analysis
- Change in the chemical form of radionuclides
  - Differences in chemical form are most likely when the oxygen potential within the RCS is substantially different than that of a LWR, where steam is usually the dominant gas-phase component
  - May impact atmospheric transport and require modifications to dose coefficients for internal pathways
- Evolution of deposition behavior
  - May occur either because aerosols are hygroscopic or because some of the radionuclides are chemically reactive and change chemical form
- Cost of decontamination
  - Could be different for advanced reactors if the released isotopes and their unique chemical compositions influence decontamination methods and their effectiveness