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Automating the Level 2-Level 3 Interface:

Lessons Learned from SOARCA and the NRC Site Level 3 PRA Project

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MACCS Overview

	Early (Emergency) Phase	Intermediate Phase	Long-Term Phase
Primary Offsite Accident Response Objective(s)	• Protect public from exposures to passing plume and deposited materials	• Protect public from exposures to deposited materials • Plan for long-term cleanup and recovery activities	• Protect public from exposures to deposited materials • Conduct long-term cleanup and recovery activities
Typical Duration and Time Frame	~1 week, starting at the time of the accident initiation	Weeks to months, starting at the end of the early phase	Months to years, starting at the end of the intermediate phase
Exposure Pathways	• Inhalation • Skin Deposition • Cloudshine • Groundshine	• Groundshine • Inhalation of resuspended materials	• Groundshine • Inhalation of resuspended materials • Food and water ingestion
Protective Actions	• Sheltering • KI ingestion • Evacuation • Relocation	• Relocation	• Decontamination • Interdiction • Condemnation

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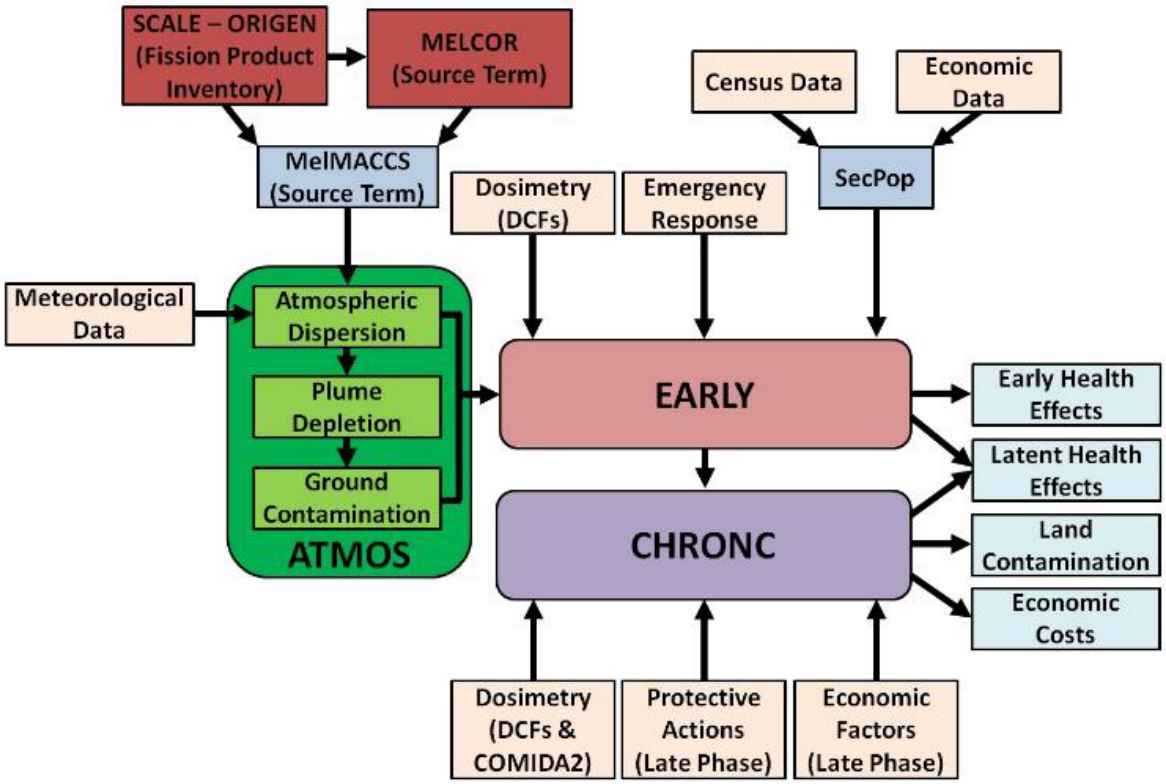
MACCS Overview

MACCS is a fully integrated, engineering-level severe accident consequence computer code developed to analyze the offsite consequences of a hypothetical release of radioactive material to the environment



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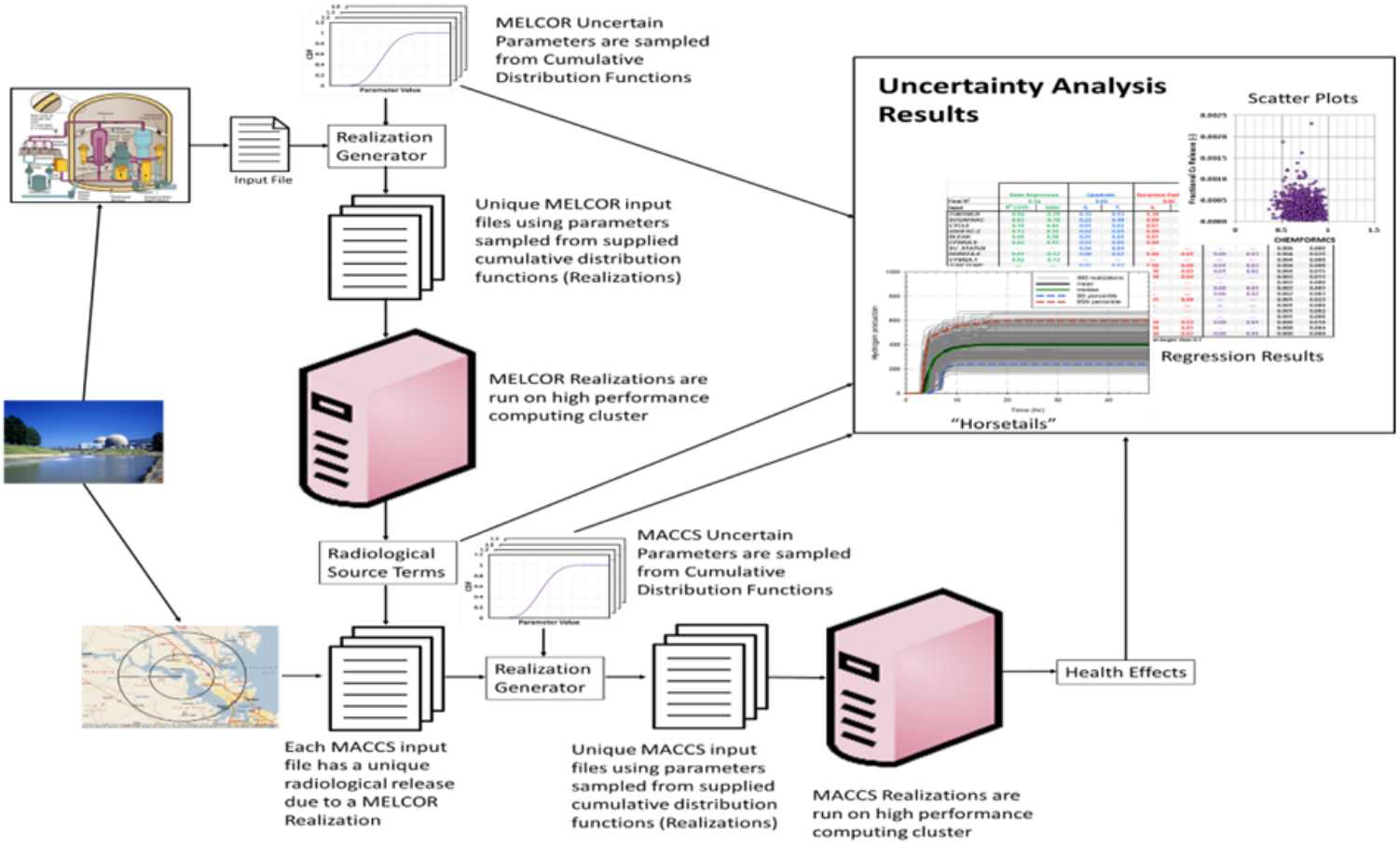
SOARCA - UA Process



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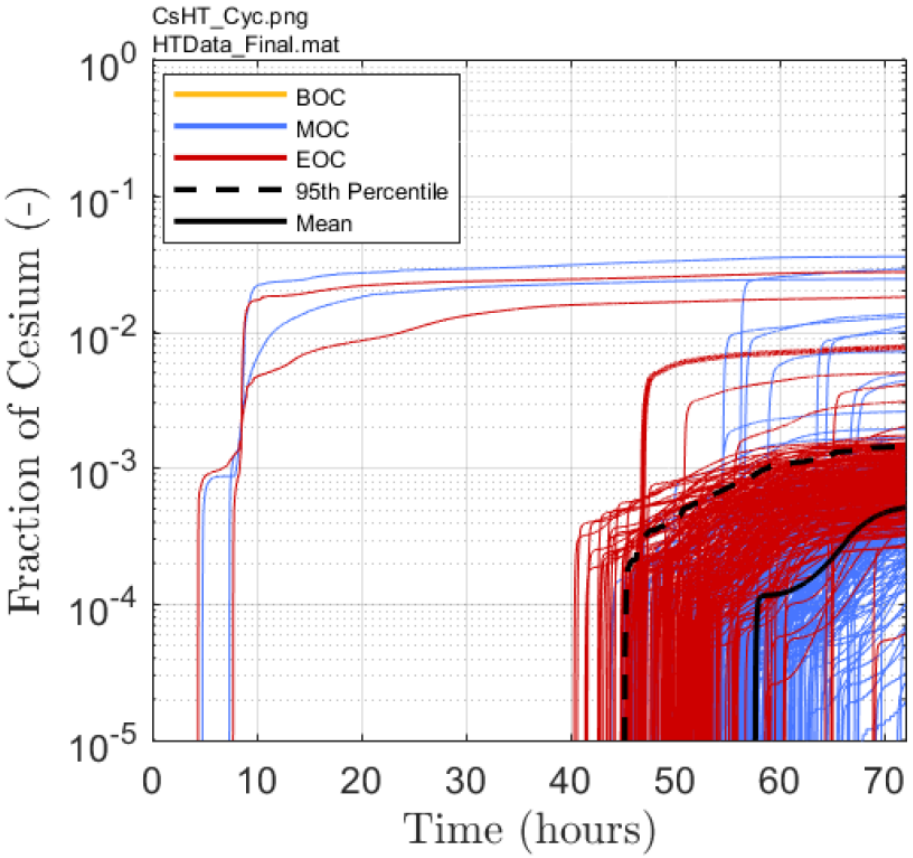
Level 3 PRA

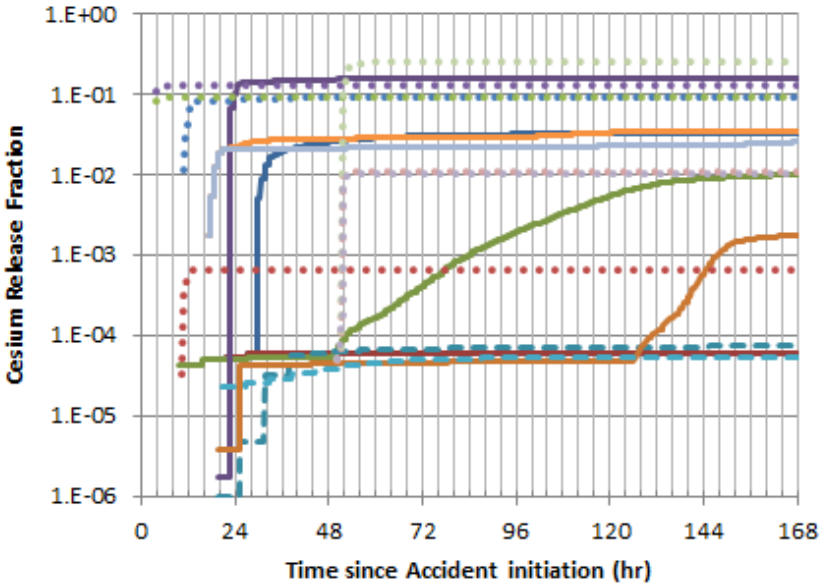
- Numerous Release Categories (16) with representative source terms and release category frequencies
- Representative accident sequences have specific Emergency Action Level (EAL) timings
- Five possible Emergency Plans depending on source term characteristics
  - 0-16.1 km [0-10 mile] EPZ evacuation (e.g. ~7 cohorts)
  - 0-16.1 km [0-10 mile] EPZ evacuation with 16.1-24.1 km [10-15 mile] expanded evacuation with/without a schools cohort (e.g. ~12/13 cohorts)
  - 0-16.1 km [0-10 mile] EPZ evacuation with 16.1-32.2 km [10-20 mile] expanded evacuation with/without a schools cohort (e.g. ~17/18 cohorts)

SOARCA vs Level 3 PRA Source Terms

SOARCA Sequoyah



Level 3 PRA - IEIF



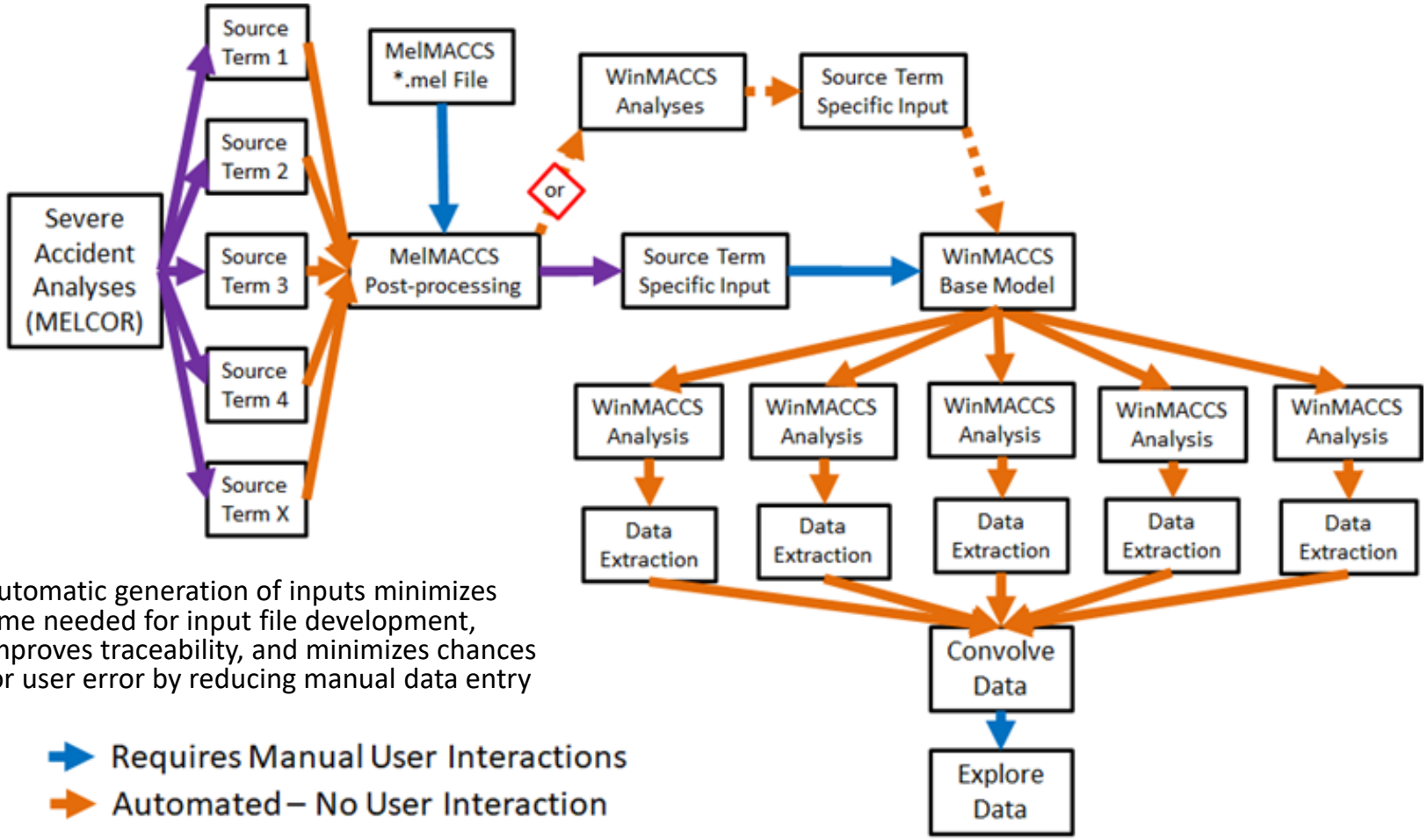
Level 3 PRA

- Want to rely on WinMACCS to create and execute MACCS calculations
  - Challenge
    - 16 source terms
    - Perform a base set of calculations along with potential sensitivities
    - MACCS models have a lot of release category dependent input which could be error prone if building multiple models
- Goal: Minimize potential input error by creating a base model which defines global input and change only emergency plan and source term input
  - Ideally a user could define an emergency plan and add it to a MelMACCS source term and execute the calculation as a cyclic file set
    - Challenge: Users must define the number of cohorts at the beginning of the problem, which must be acknowledged by the user
  - Want to create a text file which defines source term and emergency plan
    - Import model changes and execute the calculation with WinMACCS

WinMACCS Methodology

- Create a calculation pipeline to minimize user interaction during calculations
  - Excel macro created to execute pipeline
- Three phases to calculation methodology employed:
  - MelMACCS processing of MELCOR Source Terms
  - MACCS Non-Evacuating Calculations
    - Used to select Emergency Plan
  - MACCS Consequence Calculations
    - Including additional sensitivities

WinMACCS Methodology



- Automatic generation of inputs minimizes time needed for input file development, improves traceability, and minimizes chances for user error by reducing manual data entry

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MelMACCS

- Rely on batch processing of MELCOR source terms
- Create a **.mel* file which defines flowpath and plume segment information
  - Defined for all flowpaths in a MELCOR problem
- Execute MelMACCS from Windows Command Prompt
  - Create batch files to perform calculations

demo.mel

```
* If other inventories are loaded (place inventory file in \MelMACCS_Docs\Inventories
*   inventory folder found in user system folder, c:\users\loginName\etc...) the
*   keyword in the /CORE-LABEL section can be referenced below
* this is required (no default available)
*
/Reactor_Type HIGH_BWR

* Keyword: ATime
* Parameter following keyword: Decimal
* Meaning: accident initiation time (sec)
/ATime 0.0

* Keyword: Ground_Height
* Parameter following keyword: Decimal
* Meaning: ground height relative to height recorded on Melcor plot file (m)
/Ground_Height 0.0

* Keyword: Path
* Parameter: Array
*   each line associated with a Melcor release path.  Values on a line are as follows:
*   Integer: path
*   Decimal: Building Height (m)
*   Decimal: Initial SigmaY (m)
*   Decimal: Initial SigmaZ (m)
* this is required (no default available)
/Path
51  40.0    10.0    20.0
99  40.0    10.0    20.0
/End

* Keyword: Adjusted_Release_Height
*  Parameter: Array
*   each line associated with a Melcor release path.  Values on a line are as follows:
*   Integer: path
*   Decimal: Adjusted Release Height (m)
* if values for a path are not specified, then the default values will be used
* These values override the MelMACCS calculation based on the value specified in
* /Ground_Height and the MELCOR Release Path Height
/Adjusted_Release_Height
51  0.0
99  0.0
/End
```

Demo.mel from MelMACCS distribution

```
>melmaccs.exe ProjectFile.mel -i SourceTerm.ptf -o MACCSSourceTerm.inp -r
```

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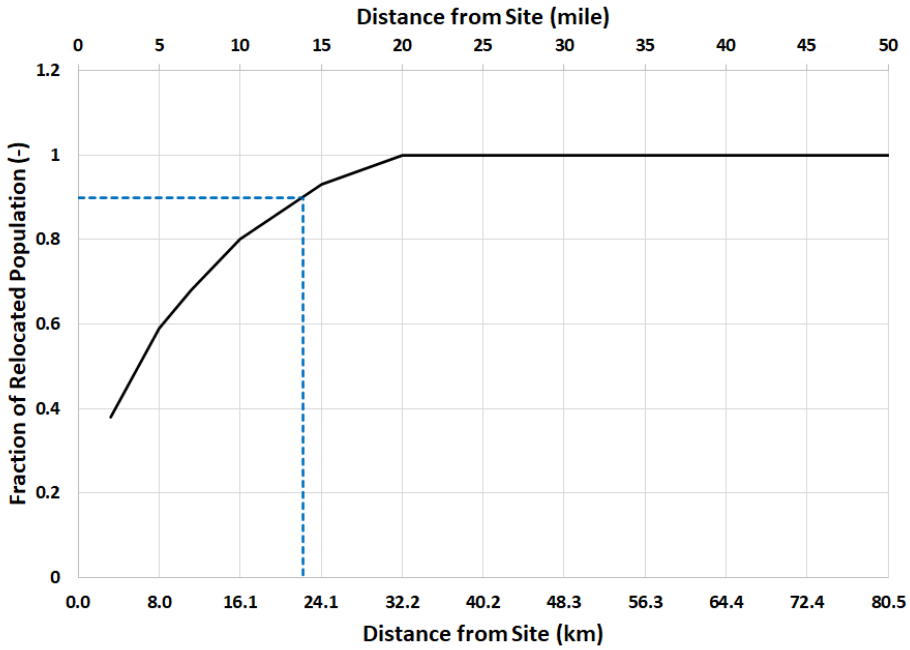
Non-Evacuating Calculations

- Used to select base-case emergency response models
- Simplified analysis with single non-evacuating cohort
  - Used subset of weather trials based on SOARCA methodology
  - Estimates the size of population subject to normal and hotspot early-phase relocation (i.e. exceeding the early phase PAG levels of 10-50 mSv [1-5 rem] in 4 days) as a function of distance from the site
  - Estimate distance range encompassing 90% of affected population to select emergency plan
  - Estimate the size of the affected population to determine the intermediate- and long-term phase durations
    - Data from Fukushima suggests most recovery actions would be focused on the area adjacent to residences, farmland, and public spaces



- Example: Fraction of population affected by emergency phase protective actions curve
  - EP Model 2 selected

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WinMACCS Level 3 PRA Base Consequence Model

- Create a Base Consequence Model containing all possible cohorts (18 cohorts)
- 8760 weather trials
- Tabulated results include:

Measure	MACCS Output Type	Spatial Interval	Units
Collective total effective dose	5	0–50 and 0-100 mi	person-rem
Total latent fatality cases	1	0–50 and 0-100 mi	persons
Population-weighted individual latent fatality risk	8	0–10 mi	individual risk (unitless)
Total early fatality cases	1	0–50 mi	persons
Population-weighted individual early fatality risk	8	0–1.8 mi	individual risk (unitless)
Area exceeding 555 kBq/m^2 Cs-137	D	0–50 and 0-100 mi	mi^2
Population relocated during intermediate phase	14	0–50 and 0-100 mi	persons
Total economic costs	10	0–50 and 0-100 mi	2015$

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WinMACCS Emergency Plan Consequence Models

- SUMPOP file
  - Provides spatially dependent population distributions for individual cohorts
  - Create a SUMPOP file for each Emergency Plan (EP)
    - 5 files
  - If a cohort is not present in an emergency plan, its population distribution is set to 0 for all grid sectors
    - Population of neglected cohorts is shifted into remaining non-evacuating cohort
- Base model was copied and a EP specific SUMPOP files provided to define EP specific consequence model

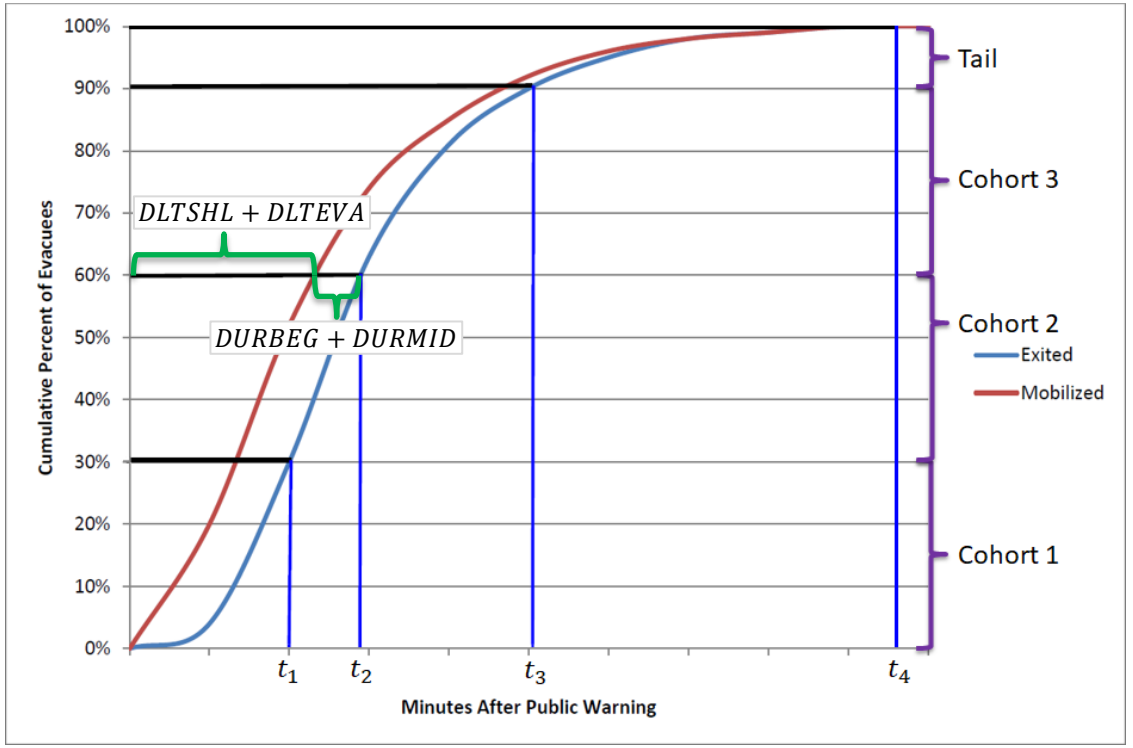
Emergency Plan Definition

- OALARM – reference point from which protected actions are initiated
  - Set to 0 seconds for this analysis
- Delay-to-Shelter (DLTSHL) – time from OALARM to until cohort begins to shelter
  - Time from accident initiation until cohort begins to shelter since OALARM is set to 0 seconds
  - Covers time for a protective action recommendation to the offsite response organization, notification of the public to evacuate by the offsite response organization, and the time needed to begin sheltering
- Delay-to-Evacuation (DLTEVA) – length of the sheltering period from the time a cohort enters the shelter until the cohort begins to evacuate
- Cohorts are assumed to travel a fixed average distance during evacuation phase
  - DURBEG – Beginning phase of the evacuation
    - Typically a few minutes as evacuees begin to enter the evacuation network
    - Has accompanying travel speed: ESPEED1
  - DURMID – remaining time required to safely exit the evacuation zone
    - Travel speed assumed to decrease due to congestion on evacuation network
    - Has accompanying travel speed: ESPEED2
- ESPEED3
  - Cohort speed from the end of the evacuation zone to the end of evacuation network
- DLTEVA, DURBEG, DURMID, ESPEED1, ESPEED2, and ESPEED3 assumed to be independent of release category

Emergency Plan Definition

- Mobilized
  - Time until cohort is ready to begin evacuation
- Exited
  - Time cohort has fully exited the evacuation zone
- Cohort 1
  - 30% of the EPZ population (0-30%)
- Cohort 2
  - 30% of the EPZ population (30-60%)
- Cohort 3
  - 30% of the EPZ population (60%-90%)
- Tail
  - 10% of the EPZ population (90%-100%)

Evacuation Time Estimate (ETE)



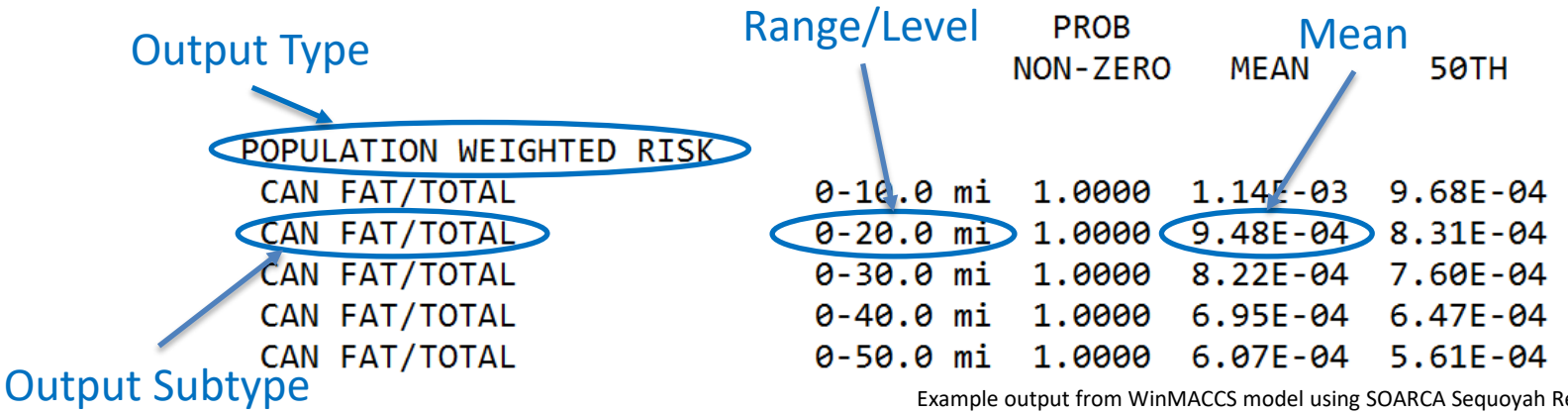
Emergency Plan Definition

- Relocation time (Hotspot and Normal)
  - Non-evacuating individuals relocated based on dose projections
  - Amount of time affected non-evacuating individuals are exposed prior to relocating
- Based on the longest evacuating cohort
- Assumes 4 hours to identify areas subject to evacuation following plume arrival
- Hotspot relocation
  - 4 hours plus 90% ETE
- Normal relocation
  - 4 hours plus 100% ETE

Consequence Calculations

- Excel macro:
  - Creates a directory for the release category consequence model
  - Copies emergency plan specific base consequence model into the release category directory
    - Selection based on simplified non-evacuating calculation
      - Determines if school cohort is necessary based on timing of the accident progression
  - Creates text file defining source term and release category emergency plan
- User individually imports source term and emergency plan file then executes MACCS models

Output Post-Processing



Example output from WinMACCS model using SOARCA Sequoyah Realization 554 source term

- A script may be used to post-process the model1.out files and convert them into a database format
- Post-processed files for each source term are concatenated into one file
  - Enables quick parsing of the data
- Scripts were written to automatically create plots based on user input
  - User supplies the Cohort, Output Type, Output Subtype, and Range/Level to define a specific figure
  - A graphical user interface was constructed to enable the exploration of data

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Output Post-Processing

- WinMACCS 3.11 can output results to tab delimited text file
  - Change `DEBUG_BIN_RESULTS` flag in WinMACCS.ini file to `TRUE`
    - Binary file contents saved as text file in RESULTS_DB folder
    - `tbl_outStat.txt` and `tbl_outCCDF.txt`

Model1.out

Example output from WinMACCS model using SOARCA Sequoyah Realization 554 source term

		PROB	QUANTILES					PEAK	PEAK	PEAK
		NON-ZERO	MEAN	50TH	90TH	95TH	99TH	99.5TH	CONSEQ	PROB	TRIAL
POPULATION WEIGHTED RISK											
CAN FAT/TOTAL	0-10.0 mi	1.0000	1.14E-03	9.68E-04	1.78E-03	2.26E-03	4.66E-03	6.83E-03	8.79E-03	1.14E-04	219
CAN FAT/TOTAL	0-20.0 mi	1.0000	9.48E-04	8.31E-04	1.52E-03	1.90E-03	2.44E-03	2.69E-03	3.42E-03	1.12E-03	831
CAN FAT/TOTAL	0-30.0 mi	1.0000	8.22E-04	7.60E-04	1.23E-03	1.43E-03	2.00E-03	2.19E-03	2.68E-03	1.12E-03	831
CAN FAT/TOTAL	0-40.0 mi	1.0000	6.95E-04	6.47E-04	1.08E-03	1.21E-03	1.57E-03	1.76E-03	2.13E-03	1.12E-03	831
CAN FAT/TOTAL	0-50.0 mi	1.0000	6.07E-04	5.61E-04	9.52E-04	1.07E-03	1.32E-03	1.45E-03	1.77E-03	1.12E-03	831

tbl_outStat.txt

5375	1	16	"Population Dose (rem)"	"Evacuation Overall L-ICRP60ED [0.,50.](mi) "	0.9999973	1150656	444230.9	564413.5	1045674	1416761	1614740	2068594	2172811	2416197	1.1
5376	1	16	"Population Dose (rem)"	"Evacuation Overall L-ICRP60ED [0.,100.](mi) "	0.9999973	1864055	914504.7	1032774	1677426	2530614	2844171	3362973	3575330	4080919	1.11872
5377	1	19	"Population-Weighted Risk (none)"	"Evacuation Overall CAN FAT/TOTAL [0.,9.99998](mi) "	0.9999973	1.144736E-03	4.153618E-04	5.363977E-04	9.67805E-04	1.7					
5378	1	19	"Population-Weighted Risk (none)"	"Evacuation Overall CAN FAT/TOTAL [0.,20.](mi) "	0.9999973	9.477495E-04	2.839216E-04	3.683566E-04	8.308995E-04	1.5					
5379	1	19	"Population-Weighted Risk (none)"	"Evacuation Overall CAN FAT/TOTAL [0.,30.](mi) "	0.9999973	8.22051E-04	2.448993E-04	3.312382E-04	7.597576E-04	1.23346					
5380	1	19	"Population-Weighted Risk (none)"	"Evacuation Overall CAN FAT/TOTAL [0.,40.](mi) "	0.9999973	6.948038E-04	2.216549E-04	3.042303E-04	6.472536E-04	1.0					
5381	1	19	"Population-Weighted Risk (none)"	"Evacuation Overall CAN FAT/TOTAL [0.,50.](mi) "	0.9999973	6.073551E-04	2.172924E-04	2.747898E-04	5.608217E-04	9.5					
5382	1	19	"Population-Weighted Risk (none)"	"Evacuation Overall CAN FAT/TOTAL [9.99998,20.](mi) "	0.9999973	8.977829E-04	2.131445E-04	3.193215E-04	7.789225E-04						
5383	1	19	"Population-Weighted Risk (none)"	"Evacuation Overall CAN FAT/TOTAL [20.,30.](mi) "	0.9999973	5.33972E-04	1.52762E-04	2.112722E-04	5.230033E-04	8.08658E-04					

*One data block-must break into subcomponents

Conclusion

- Creating a calculation pipeline for consequence calculations requires upfront effort but assists in future analysis efforts
  - Increases efficiency for future analyses
    - e.g. sensitivities, alternative initiating events, potential reruns due to calculation errors
  - Increases quality assurance of results by minimizing user interaction

References

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