MACCS2 Analyses Supporting Filtered Containment Venting Systems Commission Paper

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Outline

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Overview of MACCS2

- MACCS2: MELCOR Accident Consequence Code System 2
  - Level-3 PRA tool to assess the risk and consequence associated with a hypothetical release of radioactive material into the atmosphere
  - Released in 1997
  - Evolved from series of codes: CRAC, CRAC2, MACCS, MACCS2
  - Estimates consequences
    - Health effects – numbers and risks
    - Economic impacts – land areas and costs
  - No equivalent industry code
- WinMACCS Graphical User Interface
  - Assist the user in creating MACCS2 inputs
  - Preprocessor for MACCS2 input
  - Postprocessor for MACCS2 output
  - Allow uncertainty mode sampling
- Use of MACCS2 in State-of-the-Art Reactor Consequences Analyses study peer-reviewed by independent panel of experts

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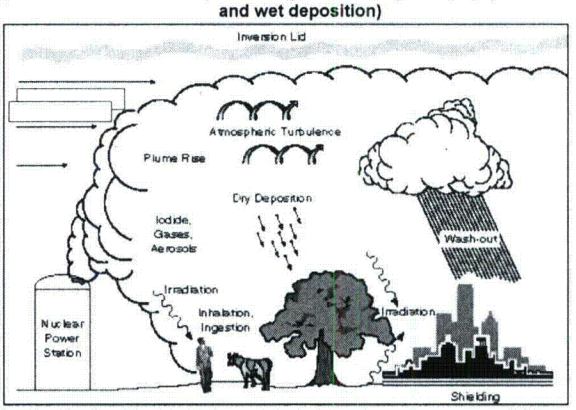
Pathways to Receptors from Atmospheric Release

MACCS2 models the radioactive transport through the atmosphere (e.g. plume rise, dispersion, dry and wet deposition)



MACCS2 estimates the health effects from: inhalation, cloudshine, groundshine, skin deposition, and ingestion (e.g. water, milk, meat, crops)

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MACCS2 Modules

- ATMOS
  - Not associated with a phase
  - Atmospheric transport and deposition
- EARLY (1 day to 1 week)
  - Emergency-phase
  - Prompt and latent health effects
  - Effects of sheltering, evacuation, and relocation
- CHRONC
  - Intermediate phase (0 to 1 year)
  - Long-term phase (0 to 317 years; 30-50 years typical)
  - Latent health effects
  - Effects of decontamination, interdiction, and condemnation

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ATMOS Module

Atmospheric Transport and Dispersion (ATD) Estimates

- Dispersion based on Gaussian plume segment model
  - Provisions for meander and surface roughness effects
  - Phenomena not treated in detail in this model: irregular terrain, spatial variations in wind field, temporal variations in wind direction
  - A study (NUREG/CR-6853) comparing the MACCS2 ATD model with two Gaussian puff codes and a Lagrangian particle tracking code showed that the MACCS2 mean results (over weather) were within a factor of 2 for arc-averages and a factor of 3 at a specific grid location out to 100 miles from the point of release.
- Multiple Plume Segments (up to 200)
- Plume rise from initial release height
- Effects of building wake on initial plume size
- Dry and wet deposition
- Radioactive decay and ingrowth (150 radionuclides, 6 generations)

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ATMOS Module (continued)

- MELCOR source term is input via MELMACCS
- Meteorological data required
  - Wind speed and direction
  - Pasquill stability category
  - Precipitation rate
  - Seasonal AM and PM mixing-layer height
- User selectable meteorology sampling options
  - Single weather sequence
  - Multiple weather sequences
    - Statistical sampling to represent uncertain conditions at the time of a hypothetical accident
- Outputs
  - Dispersion parameters, χ/Q, fraction remaining in plume
  - Air and ground concentrations; land contamination

EARLY Module

- Emergency-phase consequences
  - Acute and lifetime doses for following dose pathways
    - Inhalation (direct and resuspension),
    - Cloudshine
    - Groundshine
    - Skin deposition
  - Associated health effects
    - Early injuries/fatalities from acute doses
    - Latent health effects from lifetime committed doses
- Doses are subject to effects of
  - Sheltering
  - Evacuation
    - Speed can vary by phase, location, precipitation
  - Relocation criteria for individuals
    - Based on projected dose
- Outputs
  - Doses, health effects, land contamination areas

CHRONC Module

- Intermediate Phase (optional, 0 to 1 year)
  - Dose pathways
    - Groundshine
    - Resuspension inhalation
  - Continued relocation is only protective action
- Long-Term Phase (up to 317 years, 30 to 50 typical)
  - Dose pathways
    - Groundshine
    - Resuspension inhalation
    - Ingestion
  - Protective actions
    - Based on habitability and farmability
    - Actions include
      - Decontamination
      - Interdiction
      - Condemnation

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CHRONC Module (continued)

Decision logic for long-term protective actions

- Habitability criterion initially met?
  - No actions required
  - Population home at beginning of long-term phase
- Decontamination sufficient to restore habitability?
  - First-level decontamination performed if sufficient
  - Sequentially higher levels of decontamination performed if required
  - Population returns home following decontamination
- Decontamination plus interdiction sufficient to restore habitability?
  - Highest-level decontamination performed
  - Property is interdicted up to 30 years
  - Population returns home following decontamination plus interdiction
- Property is condemned when
  - Habitability cannot be restored within 30 years
  - Cost to restore habitability > value of property

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CHRONC Module (continued)

- Economic costs
  - Per diem and lost income for evacuation/relocation
  - Moving expense lost income for interdicted property
  - Decontamination labor and materials
  - Loss of use of property
  - Condemned property
  - Contaminated crops and dairy
- Output
  - Doses by pathway and organ
  - Latent health effects
  - Economic costs

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MACCS2 Uses

- PRAs and other severe accident studies (e.g., SOARCA)
  - Risks from operating a facility
  - Relative importance of the risk contributors
  - Insights on potential safety improvements
- NRC Regulatory Analyses
- NEPA Studies (National Environmental Policy Act) such as: License extension and new reactor applications
  - Environmental Impact Statements (EISs)
    - the results of the calculations are typically used to compare the accident risks posed by various alternatives
  - Severe Accident Mitigation Alternatives (SAMAs) and Design Alternative (SAMDAs) analyses required for license renewal and for new licenses
- DOE Applications: Authorization basis analyses performed for DBAs
  - the analyst is interested in conservatively calculated, bounding dose estimates for well-defined DBA and beyond-DBA accident scenarios. The results of this analysis are used to determine if the safety basis of the facility is adequate for operation (DOE 1989, 1992b)
- MACCS2 has an international usership (US plus over 10 other countries)

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- *Consolidated NUREG/CR Manual Under Development*

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Scope of Analysis for Filtered Vents

MACCS2 used to calculate:

- Offsite population doses
  - Includes doses to public as well as off-site decontamination workers
- Land contamination
  - For different thresholds of Cs-137 concentration in soil (Ci/km^2)
- Economic cost
- For 50-mile radius around plant

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Inputs

- Work is based on the SOARCA project, which is documented in NUREG-1935 and NUREG/CR-7110 Volume 1
- Started with SOARCA inputs for Peach Bottom Atomic Power Station pilot plant (with exception of source term, and ingestion pathway modeled)
- Habitability (return) criterion used is 500 mrem/year, per Pennsylvania State guideline
- Statistical sampling of weather sequences used to represent uncertain conditions at the time of a hypothetical accident (~1,000 weather trials)
- Linear-no-threshold dose response model

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Inputs – Six Emergency Phase Cohorts

- Cohort 1: 0 to 10 Public
- Cohort 2: 10 to 20 Shadow
- Cohort 3: 0 to 10 Schools and 0 to 10 Shadow
- Cohort 4: 0 to 10 Special Facilities
- Cohort 5: 0 to 10 Tail
- Cohort 6: Non-Evacuating Public (assumed to be 0.5%)

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Inputs – Decontamination Factor of Filters

- Neither MELCOR nor MACCS2 models mechanistically the decontamination effect of an external filter
- A prescribed decontamination factor (DF) value is assigned for an external filter
- This DF is applied to only a portion of the total fractional release - the portion which is released through a flow path connected to venting
- For the MACCS2 input, the MELCOR source term from the relevant flow path was reduced by the DF

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MACCS Results Per Event

Event	Base case Case 2	Base case with WW venting Case 3 Unfiltered Filtered DF = 10	Base case with core spray Case 6	Base case with WW venting and core spray Case 7 Unfiltered Filtered DF = 10
Population dose 50 mile radius *per event* (rem)	510,000	400,000 180,000	300,000	240,000 37,000
Population weighted latent cancer fatality (LCF) risk 50 mile radius *per event*	4.8E-05	3.3E-05 1.3E-05	2.5E-05	1.6E-05 2.2E-06
Contaminated area with level exceeding 15 Ci/km2 *per event*(km2)	350	54 8	91	34 0.4
Total economic cost 50 mile radius *per event* ($M)	1,900	1,700 270	85	480 18

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MACCS Results Per Event (continued)

Event	Base case with CS Case 14	Base case with WW venting & CS Case 15 Unfiltered Filtered DF = 10	Base case with Drywell venting Case 12 Unfiltered Filtered 1 DF=5,000 Filtered 2 DF=1,000	Base case with DW venting and DW spray Case 13 Unfiltered Filtered DF=1,000
Population dose 50 mile radius *per event* (rem)	86,000	280,000 43,000	3,200,000 210,000 230,000	3,900,000 60,000
Population weighted latent cancer fatality (LCF) risk 50 mile radius *per event*	6.4E-06	2.1E-05 2.7E-06	3.2E-04 1.4E-05 1.6E-05	3.3E-04 3.7E-06
Contaminated area with level exceeding 15 Ci/km2 *per event*(km2)	12	28 0.3	9,200 25 28	8,800 2
Total economic cost 50 mile radius *per event* ($M)	116	590 20	33,000 370 390	33,000 38

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Insights from MACCS2 Calculations

- The health effect of interest is latent cancer fatality risk, which is largely controlled by the habitability (return) criterion
  - Essentially no prompt fatality risk
- In terms of long-term radiation, the most important isotope is Cs-137, and most of the doses are from groundshine
- There is a non-linear relationship between decontamination factor and both land contamination area and health effects

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