U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

MACCS2 Analyses Supporting Filtered Containment Venting Systems Commission Paper

Nathan Bixler (Sandia National Laboratories)
and Tina Ghosh (NRC)

Advisory Committee on Reactor Safeguards Meeting

October 3, 2012

Outline

- Overview of MACCS2
  - MACCS2 Modules
    - ATMOS: Atmospheric Modeling
    - EARLY: Emergency Phase Modeling
    - CHRONC: Long Term Phase Modeling
  - MACCS2 Uses
  - References
- MACCS2 analysis for filtered containment venting systems
  - Scope of analysis
  - Inputs
  - Results of calculations, venting with and without filter

U.S.NRC

2

Overview of MACCS2

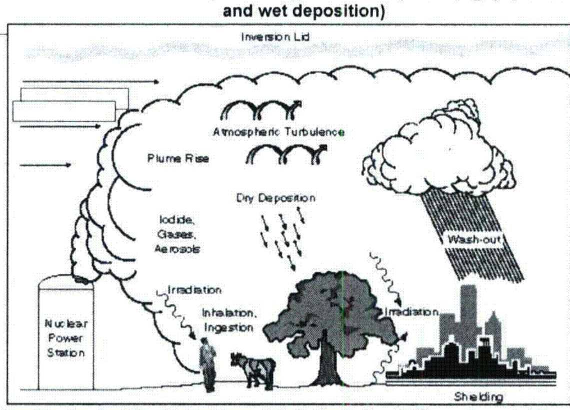
- MACCS2: MELCOR Accident Consequence Code System 2
  - Level-3 PRA tool to assess the risk and consequence associated with a hypothetical release of radioactive material into the atmosphere
  - Released in 1997
  - Evolved from series of codes: CRAC, CRAC2, MACCS, MACCS2
  - Estimates consequences
    - Health effects – numbers and risks
    - Economic impacts – land areas and costs
- WinMACCS Graphical User Interface
  - Assist the user in creating MACCS2 inputs
  - Preprocessor for MACCS2 input
  - Postprocessor for MACCS2 output
  - Allow uncertainty mode sampling

U.S.NRC

3 3

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)

U.S.NRC

4 4

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; 50 years typical)
  - Latent health effects
  - Effects of decontamination, interdiction, and condemnation

U.S.NRC

5 5

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 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)

U.S.NRC

6 6

ATMOS Module (continued)

- 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

U.S.NRC

7 7

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

U.S.NRC

8 8

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

U.S.NRC

9 9

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

U.S.NRC

10 10

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

U.S.NRC

11 11

MACCS2 Uses

- PRAs and other severe accident studies (NUREG-1150, 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 about 10 other countries)

U.S.NRC

12 12

References

- Jow, H-N, J. L. Sprung, J. A. Rollstin, L. T. Ritchie, D. I. Chanin (1990), MELCOR Accident Consequence Code System (MACCS): Model Description, NUREG/CR-4691, Volume 2.
- Chanin, D., M. L. Young, J. Randall, K. Jamali (1998), Code Manual for MACCS2: Volume 1, User's Guide, NUREG/CR-6613.
- Chanin, D., M. L. Young, J. Randall, K. Jamali (1998), Code Manual for MACCS2: Volume 2, Preprocessor Codes COMIDA2, FGRDCF, IDCF2, NUREG/CR-6613.
- Young, M. L., D. Chanin (1997 draft), DOSFAC2 User's Guide, NUREG/CR-6547.
- Bixler, N. E., S. A. Shannon, C. W. Morrow, B. E. Meloche, and J. N. Ridgely (2003), SECPOP2000: Sector Population, Land Fraction, and Economic Estimation Program, NUREG/CR-6525 Rev. 1.
- C.R. Molenkamp, N.E. Bixler, C.W. Morrow, J.V. Ramsdell, Jr., J.A. Mitchell(2004), "Comparison of Average Transport and Dispersion Among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model," NUREG/CR-6853.
- *Consolidated NUREG/CR Manual Under Development*

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

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)
- Habitability (return) criterion used is 500 mrem/year
- 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

U.S.NRC

15

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%)

U.S.NRC

16

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

U.S.NRC

17

Example MACCS Results Per Event

Event	Base case Case 2	Base case with wetwell venting Case 3 Unfiltered filtered	Base case with core spray Case 6	Base case with wetwell venting and core spray Case 7 Unfiltered Filtered	Base case with containmen t spray Case 14	Base case with wetwell venting and containment spray Case 15 Unfiltered Filtered
Population dose 50 mile radius *per event* (rem)	510,000	400,000 180,000	300,000	240,000 37,000	86,000	280,000 43,000
Population weighted latent cancer fatality (LCF) risk 50 mile radius *per event*	4.8E-05	3.3E-05 1.3E-05	2.45E-05	1.6E-05 2.2E-06	6.4E-06	2.1E-05 2.7E-06
Contaminated area with level exceeding 15 Ci/km2 *per event*(km2)	350	54 8	91	34 0.4	12	28 0.3
Total economic cost 50 mile radius *per event*($M)	1,900	1,700 270	847	480 18	116	590 20

U.S.NRC

18

Mapping Release Sequence End States to MELCOR/MACCS2 Cases

			Release Sequence End State			
		Identifier	vented	LMT	OP	OP + LMT
		Vented	yes	yes	no	no
		Drywell Status	wet	dry	wet	dry
		Sequences	1,4,5,10,13	2,6,11,14	7	3,8,9,12,15,16
Vent Location	**Filter**	**Mod(s)**	**MELCOR/MACCS2 Case**			
Wetwell	No	0 - none 1 - manual 2 – passive	Case 7 or 15 (no filter)	Case 3 (no filter)	Case 6	Case 2
Drywell	No	3 - manual 4 – passive	Case 13 (no filter)	Case 12 (no filter)	Case 14	Case 2
Wetwell	Yes	5 - manual 6 – passive	Case 7 or 15 (filter)	Case 3 (filter)	Case 6	Case 2
Drywell	Yes	7 - manual 8 - passive	Case 13 (filtered)	Case 12 (filter)	Case 14	Case 2

U.S.NRC

19 19

List of Acronyms

CRAC: Calculation of Reactor Accident Consequences
DBA: Design Basis Accident
DCF: Dose Conversion Factor (used to calculate doses from exposures)
DOE: Department of Energy
DF: Decontamination factor
EIS: Environmental Impact Statement
GUI: Graphical user interface
LCF: Latent cancer fatality
LHS: Latin Hypercube Sampling
MACCS: MELCOR Accident Consequence Code System
MACCS2: MELCOR Accident Consequence Code System (version 2)
NEPA: National Environmental Policy Act
NRC: Nuclear Regulatory Commission
PRA: Probabilistic Risk Assessment
SAMA: Severe Accident Mitigation Alternatives
SAMDA: Severe Accident Mitigation Design Alternatives
SOARCA: State-of-the-Art Reactor Consequence Analysis

U.S.NRC

20 20

ENCLOSURE 5

BWR MARK I AND MARK II FILTERED CONTAINMENT VENTING TECHNICAL ANALYSIS

Contents

BWR Mark I and Mark II Filtered Containment Venting Technical Analysis

1.0 Executive Summary

To support the staff's assessment of the quantitative costs and benefits of severe accident capable vents (Option 2) and filtered containment venting (Option 3), members of the Office of Nuclear Regulatory Research (RES) staff performed an analysis of selected accident scenarios for a boiling water reactor (BWR) plant with a Mark I containment using the NRC's severe accident analysis code MELCOR, and its companion code, the MELCOR Accident Consequence Code System, Version 2 (MACCS2). The RES staff was also assisted by the Sandia National Laboratory (SNL). The MELCOR code calculated fission product release estimates for each of the selected accident scenarios, and this information was then used to calculate health consequence and offsite property damage assessments using MACCS2. The results were used to inform the staff's cost-benefit analyses for various accident prevention and/or mitigation options within NRC's current regulatory framework. The NRC's regulatory analysis guidelines in NUREG/BR-0058 and NUREG/BR-0184 ~~specifically~~ recommend the use of MACCS2 to estimate the averted "offsite property damage" cost (benefit) and the offsite averted dose cost elements.

Comment [s1]: John M made this change in the MACCS section

The selected severe accident cases used in the MELCOR and MACCS2 analysis should be considered as reasonable and adequate representations of relevant accident sequences that are only intended to provide insights into the decision-making process. The scenarios are illustrative of potential accident sequences and serve as a means to provide comparisons of the quantifiable benefits for each of the proposed options. Selected cases are not meant to provide any insights into what the staff may believe is "the next accident" or even what it considers as bounding. Additionally, the staff notes that uncertainty always accompanies specific plant responses and timing during potential accident scenarios. Therefore, the most useful information stemming from this analysis are not individual results or consequences; rather, the "deltas" or comparisons between the selected cases.

The staff also performed a risk evaluation to estimate the reduction in risk resulting from the installation of a severe accident (SA) capable venting system in a BWR with either a Mark I or Mark II containment design. This information provides a major input to the regulatory and backfit analyses of the SA and filtered containment venting systems.

Finally, on September 25, 2012, the Electric Power Research Institute (EPRI) published a study relating to BWR Mark I and Mark II containment venting. The report titled, "Investigation of Strategies for Mitigating Radiological Releases in Severe Accidents - *BWR Mark I and Mark II Studies*," (EPRI Final Report 1026539), was made available to the NRC staff through EPRI's public web site (http://my.epri.com/portal/server.pt?Product_id=000000000001026539).

The purpose of the report was to document research on investigations into potential strategies for reducing the environmental and public health effect consequences of severe reactor accidents. The results of the report were also the subject of two public meetings. On August 8, 2012, the staff held a public meeting where representatives from EPRI provided an overview and preliminary results of the research efforts documented in the September 25 report. In addition, EPRI briefed the Advisory Committee on Reactor Safeguards (ACRS) Fukushima Subcommittee on September 5, 2012, providing information relating to its preliminary evaluation of strategies for mitigating radiological releases during severe accidents at BWRs with Mark I and II containments.

The NRC's MECOR/MACCS2 analysis and EPRI's investigations using the MAAP code sparked considerable discussions between the industry representatives and staff. The discussions often focused on how each of the codes calculated the quantity the initial core inventory that remained in the vessel, the core fraction that was plated-out in various plant systems, including the suppression pool, or the fraction of the core that was released to the environment. While no attempt was made to perform a detailed comparison or evaluation of the differences in results using the MELCOR and MAAP codes, the differences highlighted the difficulty and challenges researchers face regarding the realities of severe accident simulation. The analyses also underscored the importance of input assumptions and modeling uncertainties associated with calculating various plant features' (e.g., containment spray and suppression pool) decontamination efficacy.

For example, the staff noted the following differences in input assumptions:

Input Assumption	NRC	EPRI
Analysis duration	48 hours	72 hours
RCIC run duration	16 hours	4 hours
Portable pump flow rates	300 GPM	500 GPM
Vent Valve Cycling	at 60 PSIG	controlled between 40 - 60 PSIG

RES analyses showed only "slight improvement" in effective decontamination with cycled venting, while industry's analysis showed substantial improvement in decontamination factors (from approximately 500 to as much as 3,000). Again, the results highlight the importance of input assumptions and the uncertainties in severe accident analysis.

In summary, the staff's technical analysis provided relevant insights into the merits of severe accident capable venting and filtered containment venting. The results were used to help quantify the benefits of various options under the NRC's current regulatory framework. As such, the reader is cautioned in what conclusions may be drawn from the results of the staff's analysis. The following sections describe the NRC staff's technical analysis:

- Enclosure 5a - MELCOR Accident Analysis
- Enclosure 5b - MACCS2 Analysis
- Enclosure 5c - Filtered Containment Venting Risk Analysis

ENCLOSURE 5

BWR MARK I AND MARK II FILTERED CONTAINMENT VENTING TECHNICAL ANALYSIS

Contents

BWR Mark I and Mark II Filtered Containment Venting Technical Analysis

1.0 Executive Summary

To support the staff's assessment of the quantitative costs and benefits of severe accident capable vents (Option 2) and filtered containment venting (Option 3), members of the Office of Nuclear Regulatory Research (RES) staff performed an analysis of selected accident scenarios for a boiling water reactor (BWR) plant with a Mark I containment using the NRC's severe accident analysis code MELCOR, and its companion code, the MELCOR Accident Consequence Code System, Version 2 (MACCS2). The RES staff was also assisted by the Sandia National Laboratory (SNL). The MELCOR code calculated fission product release estimates for each of the selected accident scenarios, and this information was then used to calculate health consequence and offsite property damage assessments using MACCS2. The results were used to inform the staff's cost-benefit analyses for various accident prevention and/or mitigation options within NRC's current regulatory framework. The NRC's regulatory analysis guidelines in NUREG/BR-0058 and NUREG/BR-0184 ~~specifically~~ recommend the use of MACCS2 to estimate the averted "offsite property damage" cost (benefit) and the offsite averted dose cost elements.

Comment [s1]: John M made this change in the MACCS section

The selected severe accident cases used in the MELCOR and MACCS2 analysis should be considered as reasonable and adequate representations of relevant accident sequences that are only intended to provide insights into the decision-making process. The scenarios are illustrative of potential accident sequences and serve as a means to provide comparisons of the quantifiable benefits for each of the proposed options. Selected cases are not meant to provide any insights into what the staff may believe is "the next accident" or even what it considers as bounding. Additionally, the staff notes that uncertainty always accompanies specific plant responses and timing during potential accident scenarios. Therefore, the most useful information stemming from this analysis are not individual results or consequences; rather, the "deltas" or comparisons between the selected cases.

The staff also performed a risk evaluation to estimate the reduction in risk resulting from the installation of a severe accident (SA) capable venting system in a BWR with either a Mark I or Mark II containment design. This information provides a major input to the regulatory and backfit analyses of the SA and filtered containment venting systems.

Finally, on September 25, 2012, the Electric Power Research Institute (EPRI) published a study relating to BWR Mark I and Mark II containment venting. The report titled, "Investigation of Strategies for Mitigating Radiological Releases in Severe Accidents - *BWR Mark I and Mark II Studies*," (EPRI Final Report 1026539), was made available to the NRC staff through EPRI's public web site (http://my.epri.com/portal/server.pt?Product_id=000000000001026539).

The purpose of the report was to document research on investigations into potential strategies for reducing the environmental and public health effect consequences of severe reactor accidents. The results of the report were also the subject of two public meetings. On August 8, 2012, the staff held a public meeting where representatives from EPRI provided an overview and preliminary results of the research efforts documented in the September 25 report. In addition, EPRI briefed the Advisory Committee on Reactor Safeguards (ACRS) Fukushima Subcommittee on September 5, 2012, providing information relating to its preliminary evaluation of strategies for mitigating radiological releases during severe accidents at BWRs with Mark I and II containments.

The NRC's MECOR/MACCS2 analysis and EPRI's investigations using the MAAP code sparked considerable discussions between the industry representatives and staff. The discussions often focused on how each of the codes calculated the quantity the initial core inventory that remained in the vessel, the core fraction that was plated-out in various plant systems, including the suppression pool, or the fraction of the core that was released to the environment. While no attempt was made to perform a detailed comparison or evaluation of the differences in results using the MELCOR and MAAP codes, the differences highlighted the difficulty and challenges researchers face regarding the realities of severe accident simulation. The analyses also underscored the importance of input assumptions and modeling uncertainties associated with calculating various plant features' (e.g., containment spray and suppression pool) decontamination efficacy.

For example, the staff noted the following differences in input assumptions:

Input Assumption	NRC	EPRI
Analysis duration	48 hours	72 hours
RCIC run duration	16 hours	4 hours
Portable pump flow rates	300 GPM	500 GPM
Vent Valve Cycling	at 60 PSIG	controlled between 40 - 60 PSIG

RES analyses showed only "slight improvement" in effective decontamination with cycled venting, while industry's analysis showed substantial improvement in decontamination factors (from approximately 500 to as much as 3,000). Again, the results highlight the importance of input assumptions and the uncertainties in severe accident analysis.

In summary, the staff's technical analysis provided relevant insights into the merits of severe accident capable venting and filtered containment venting. The results were used to help quantify the benefits of various options under the NRC's current regulatory framework. As such, the reader is cautioned in what conclusions may be drawn from the results of the staff's analysis. The following sections describe the NRC staff's technical analysis:

- Enclosure 5a - MELCOR Accident Analysis
- Enclosure 5b - MACCS2 Analysis
- Enclosure 5c - Filtered Containment Venting Risk Analysis