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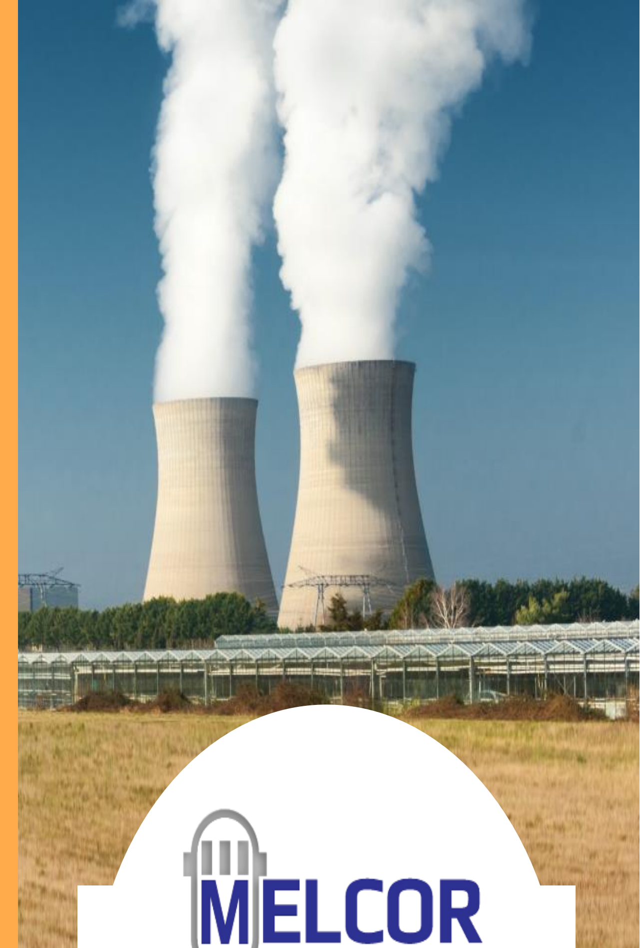

MELCOR

CAV/LHC & CORQUENCH Development

2025 European MELCOR Users' Group Meeting

April 7th-11th, 2025

U.S.NRC

SAND2025-04007PE

U.S. DEPARTMENT OF ENERGY NNSA

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Overview

Review CAV package modernization

- CAV package modernization
- CAV/CORQUENCH (CAV/CQ) and CAV/CORCON-MOD3 (CAV/CCM3)
- Implementation approach

Update

- Solution framework
- Data and physics models for debris and cavity
- CCM3 models in CAV/CQ framework
  - Debris spreading
  - Cavity ablation and recession
  - Chemistry and fission product release

MELCOR CAV/CQ to stand-alone CORQUENCH benchmarks

- Dry cavity
- Wet cavity

Future work and summary

Review – CAV Modernization

CAV package modernization

- Debuted the effort at EMUG ’24
- Chose to first pursue CAV/CQ development
- Major points of emphasis:
  - Preserve CAV/CCM3
  - Implement an alternative CORQUENCH-style debris solution methodology (CAV/CQ)
  - Expand CAV/CQ to include desirable features of CAV/CCM3
    - Debris layering and mixing/separation
    - Debris spreading
    - Cavity geometry/recession model
    - Chemistry
    - VANESA
    - Multi-cavity and rupture/overflow
  - Reconcile LHC debris modeling to CAV/CCM3 or CAV/CQ
  - Preserve LHC structure modeling in some form

Use modern MELCOR development methods

- Field manager and physics manager
- Preferred database structures (flattened arrays)
- Modernized input parser
- Object-oriented FORTAN and procedural polymorphism

Review - CORQUENCH

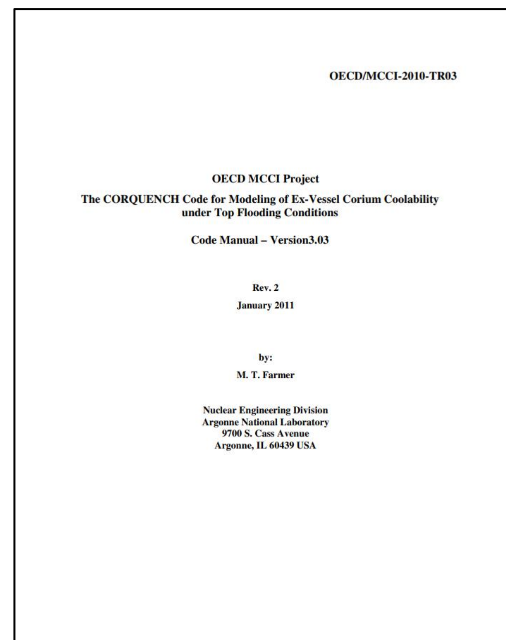
CORium QUENCHing (CORQUENCH)

- In support of Melt Attack and Coolability Experiment (MACE) and OECD/MCCI program
- Developed at Argonne National Laboratory since early 1990's (largely by Farmer)
- Targets integral analysis of heat/mass transfer processes of corium ex-vessel
- First-order analysis of plant accident scenarios
- Latest advancements include modeling related to debris spreading

Overlaps with CCM3 for ex-vessel modeling with some similar methods/models

Differs in important ways from CCM3:

- Debris pool conceptualization (e.g. single layer)
- Solution methodology (simultaneous time integration)
- Concrete treatment (more detailed alternatives)
- Methods of predicting/computing the "trouble spots"
  - Incipient growth of crusts and crust dynamics
  - Transitions in heat/mass transfer processes
  - Treatment of certain phenomena (e.g. melt eruption)
- Excludes certain phenomena (RN release and VANESA)



OECD/MCCI-2010-TR03

OECD MCCI Project
The CORQUENCH Code for Modeling of Ex-Vessel Corium Coolability under Top Flooding Conditions

Code Manual – Version3.03

Rev. 2
January 2011

by:
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Review – CQ & CCM3

MELCOR

CCM3 is the current calculational framework for ex-vessel

- Has served well in the past,
- Is difficult to debug and maintain, and very difficult to modify or improve
  - Physics and numerical methods of solution algorithm are intimately entangled
  - Several development efforts from recent years speak to the difficulty
    - Water ingression and melt eruption model development
    - Physics-based debris spreading
    - LHC "simplified CAV" debris modeling approach
- Is limited in its concrete/structural modeling capabilities (quasi-steady ablation only)

CCM3 will remain an alternative in CAV moving forward

Incorporate CAV/CQ as a CAV/LHC alternative…why?

- Repository of knowledge gleaned from recent experimental program (Farmer, ANL)
- Different and theoretically more robust debris solution approach
  - Notionally easier debugging/maintenance and development
  - Better performance in severe accident calculations, particularly with wet cavities
- Improved (more detailed) concrete cavity modeling
- Well-documented models & methods consistent with experimental observations
- Translate F77-style CORQUENCH source & incorporate into actively developed code

Review – Implementation Approach

MELCOR

Physics manager facilitates CAV/CCM3 “switch off” and CAV/CQ “switch on”

CAV/CQ replaces CAV/CCM3:

- Enter during MELCOR time-step, check for cavity “awakening”
- If a cavity “wakes up”, do a sequence of initialization calculations:
  - Concrete cavity initializations
  - Miscellaneous variable initializations
  - Debris/melt initializations
- If an awake cavity is continuing on, do normal CQ solve (time-step integration):
  - Time integration loop - Integration of solution variables & computation of time derivatives
  - Given new “state” of debris, perform a series of checks and updates:
    - Conservation of mass, top crust and heat transfer, bottom and side crusts and heat transfer,
    - Debris/melt thermophysical properties, concrete properties, check bottom/side debris heat transfer
    - Ablation, debris/melt superficial gas velocity, check top debris heat transfer
    - Gas bubble diameter and terminal rise velocity, top crust growth
    - Debris source-in (COR), concrete off-gas and condensed material generation
    - Update overall energy balance and fluxes

Iterative approach for development

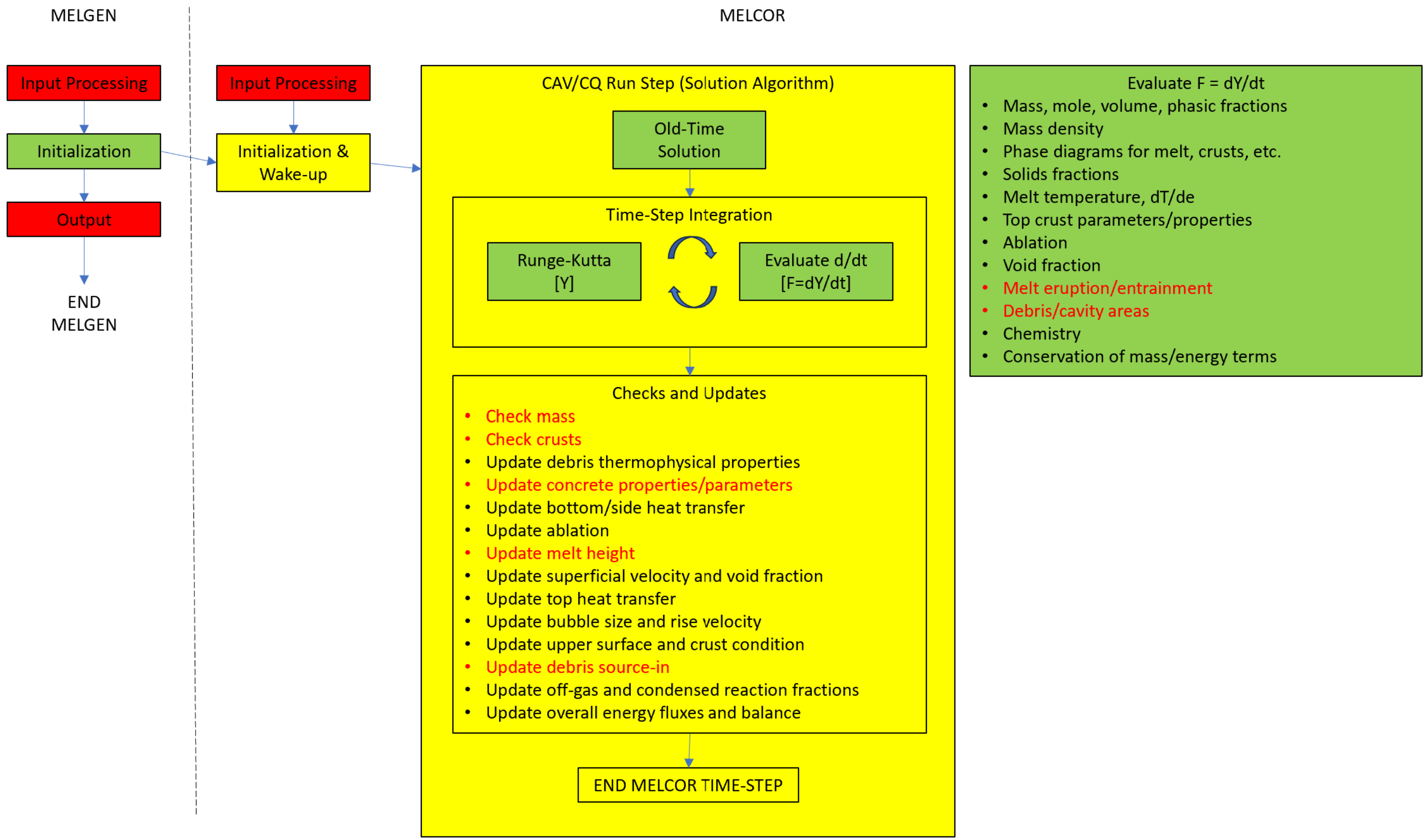
- Add a model or two
- Benchmark stand-alone CQ vs. MELCOR CAV/CQ

Update

CAV/CQ includes at present

- Solution framework
  - Core of the IVP time integration algorithm
  - Mass and energy conservation plus various change rate equations
  - Developed to be flexible and readily extensible
- Data
  - Debris
    - Oxidic and metallic phase diagram information
    - All oxide and metal data for thermodynamic, transport, mechanical, and chemical properties
    - All noncondensibles and oxidation products
  - Concrete – built-in defaults and methods for user-defined layers
  - Placeholders for data expected but not yet needed
  - Ability to disconnect, reconnect, and easily change parts of or the entire materials database
- Physics models
  - Phasic and averaged property models
  - Dry cavity (top debris surface) models (crust-free, incipient, stable)
  - Wet cavity (top surface) models (crust-free, incipient, stable, WI/ME, boiling transitions)
  - Bottom and side debris surface models
    - Ablation – quasi-steady, fully-developed, or transient
    - Interface heat/mass transfer (Bradley-Malenkov, gas film, gas film slag transition, Sevon)
  - Auxiliary models (void fraction, bubble diameter and velocity, etc.)
  - Desirable additions from MELCOR CAV/CCM3

Solution Methodology



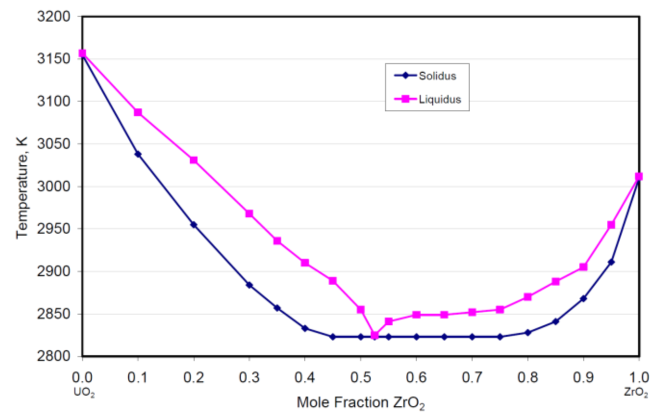
Database

Debris – All requisite oxide/metal materials data to facilitate phasic and mixture:

- Enthalpy/temperature and density
- Phase diagrams (solidus/liquidus temperatures)
- Thermal conductivity, viscosity, emissivity, and surface tension
- Various mechanical properties (useful for mechanical stability and water ingress)
- Also gases (H_2O, H_2, CO_2, CO factoring into heat/mass transfer and oxidation)

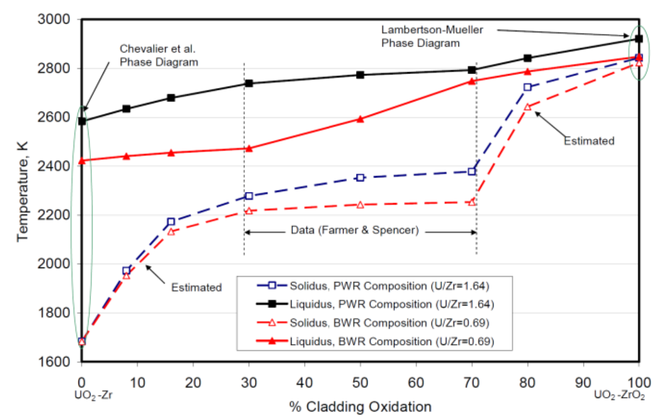
$$e_i(T) = a_{sol,i}T^2 + b_{sol,i}T + c_{sol}$$

$$e_i(T) = b_{liq,i}T + c_{liq}$$



Cavity – All requisite materials data to facilitate:

- Enthalpy/temperature
- Density
- Phase diagram (adjust for concrete oxide uptake)
- Thermal conductivity and emissivity
- Decomposition/ablation and dry-out



More will be needed (CCM3 chemistry, VANESA)

Benchmarks

Build stand-alone CQ problems to benchmark MELCOR CAV/CQ

Dry cavity

- UO_2-only
  - Quasi-steady ablation
    - Bradley-Malenkov/Kutateladze
    - Gas film
  - Fully-developed ablation
  - Transient ablation
- ZrO_2-only (with similar variation to UO_2-only)
- Mixed metal/oxide (UO_2 and SS with similar variation to UO_2-only)
- SS-only (with similar variation to UO_2-only)

Wet cavity

- UO_2-only
- Impervious crust
- Water ingression (and variations on modeling options)

All of the above with 1-D ablation, LCS concrete, and CQ hierarchical chemistry

Benchmarks

SS-only debris pool, dry cavity, quasi-steady ablation, 3300 K initial temperature

CQ

CURRENT MELT, CRUST, & PARTICLE BED BREAKDOWNS

CONSTITUENT	MELT MASS (KG)	WT FR	ML FR (KG)	VL FR	CRUST MASS (KG)	WT FR	PART. BED MASS	WT FR
UO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ZRO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CR2O3	38.571	0.11668	0.46722E-01	0.12125	0.0000	0.11668	0.0000	0.11668
NIO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B2O3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	170.00	0.51425	0.56043	0.37671	0.0000	0.51425	0.0000	0.51425
CR	8.6093	0.26043E-01	0.30484E-01	0.21296E-01	0.0000	0.26043E-01	0.0000	0.26043E-01
NI	50.000	0.15125	0.15679	0.99960E-01	0.0000	0.15125	0.0000	0.15125
ZR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
U	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B4C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NA2O	0.97674	0.29546E-02	0.29014E-02	0.66840E-02	0.0000	0.29546E-02	0.0000	0.29546E-02
TIO2	0.88795E-01	0.26860E-03	0.20461E-03	0.34304E-03	0.0000	0.26860E-03	0.0000	0.26860E-03
SIO2	25.573	0.77358E-01	0.78358E-01	0.18654	0.0000	0.77358E-01	0.0000	0.77358E-01
CAO	23.442	0.70911E-01	0.76959E-01	0.12649	0.0000	0.70911E-01	0.0000	0.70911E-01
MGO	8.7019	0.26323E-01	0.39743E-01	0.42998E-01	0.0000	0.26323E-01	0.0000	0.26323E-01
AL2O3	3.1966	0.96697E-02	0.57720E-02	0.13272E-01	0.0000	0.96697E-02	0.0000	0.96697E-02
FEO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE2O3	1.4207	0.42977E-02	0.16379E-02	0.44588E-02	0.0000	0.42977E-02	0.0000	0.42977E-02
FE3O4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	330.58		0.0000		0.0000			

CURRENT THERMOPHYSICAL PROPERTIES

MATERIAL	K (W/M*K)	P (KG/M**3)	CP (J/KG*K)	U (KG/M*S)	SIGMA (N/M)	EMIS (-)	LATENT HEAT (KJ/KG)
MELT	10.160	5135.2	931.77	0.40661E-01	1.1225	0.56608	1577.2
CRUST	10.160	5639.5				0.56608	296.02
DECOMP GAS	0.14023	0.22462	1611.6	0.72143E-04			

```
KEY MELT THERMALHYDRAULIC CONDITIONS

  TMELT=     1786.0     K      EMELT=     1.5772     MJ/KG
  TOX,SOL=   1393.0     K      TOX,LIQ=   1568.0     K
  TM,SOL=    1709.3     K      TM,LIQ=    1746.6     K
  VOXSOL=    0.0000            VTOTSOL=   0.0000
  VCRIT=     0.0000     CM/S   JGAS=      13.451     CM/S
  VOIDF=    0.14539            QCHEM=     15.435     KW
  RBUBBLE=  0.74112     CM     UBRISE=    25.399     CM/S
  QDECM=     0.0000     KW     QDECCR=    0.0000     KW

MELT UPPER SURFACE HEAT TRANSFER DATA

  TINT=  1735.6    K  HWAT=  122.89    W/M**2*K  QWAT=  30.281    KW
  TTOP=  1735.6    K  HTOP=  2406.9    W/M**2*K  QTOP=  30.281    KW
  TFRT=  1656.9    K  DCRT=  0.0000    MM

MELT LOWER SURFACE HEAT TRANSFER DATA

  ADEP=  14.599    CM          BLDEP=  0.0000    CM  ARATE=  2.6056    MM/MIN
  HBOT=  677.99    W/M**2*K    QBOT=   48.469    KW

TERM-BY-TERM COMPONENTS OF ENERGY EQUATION

  QNTBN= -35.459    KW  QDCML=  0.0000    KW  QBOTE= -48.469    KW
  QSIDE=  0.0000    KW  QTOPE= -30.281    KW  QBMBN=  36.749    KW
  QCRBN=  0.0000    KW  QOXTO=  15.435    KW  QERUP=  0.0000    KW
  QMASB=  1.2896    KW  QDRPV=  0.0000    KW  DENDT= -62.025    KW

INTEGRATED ENERGY SOURCE/SINK DATA

  E->ATMOSPHERE=  36.112    MJ   E->CHEM. RXS.=  58.281    MJ
  E->DOWN ABL.=   162.94    MJ   E->SIDE ABL.=   0.0000    MJ
  E->DECAY HEAT=  0.0000    MJ

METAL GAS AND CONDENSED PHASE REACTION FRACS.

  ZR/GAS=  0.0000     ZR/SIO2=  0.0000     ZR/SI=  1.0000
  CR/GAS=  1.0000     FE/GAS=   0.0000

CUMULATIVE NONCONDENSABLE GAS RELEASE (MOLES)

  MOLES H2=   312.11     MOLES H2O=  0.0000     MOLES CO=   449.21
  MOLES CO2=  0.0000     MOLES SIO=  0.0000     TOT MOLES=  761.33
```

MEL

MELT, TOP CRUST, AND PARTICLE BED MASS BREAKDOWNS

CONSTITUENT	MELT MASS (KG)	WT FR	ML FR (KG)	VL FR	CRUST MASS (KG)	WT FR	PBED MASS	WT FR
UO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ZRO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CR2O3	38.616	0.11678	0.46767E-01	0.12133	0.0000	0.11678	0.0000	0.11678
NIO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B2O3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	170.00	0.51411	0.56032	0.37652	0.0000	0.51411	0.0000	0.51411
CR	8.5787	0.25943E-01	0.30370E-01	0.21209E-01	0.0000	0.25943E-01	0.0000	0.25943E-01
NI	50.000	0.15121	0.15676	0.99910E-01	0.0000	0.15121	0.0000	0.15121
ZR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
U	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B4C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NA2O	0.97788	0.29573E-02	0.29042E-02	0.66883E-02	0.0000	0.29573E-02	0.0000	0.29573E-02
TIO2	0.88898E-01	0.26884E-03	0.20481E-03	0.34327E-03	0.0000	0.26884E-03	0.0000	0.26884E-03
SIO2	25.603	0.77427E-01	0.78435E-01	0.18666	0.0000	0.77427E-01	0.0000	0.77427E-01
CAO	23.469	0.70975E-01	0.77034E-01	0.12657	0.0000	0.70975E-01	0.0000	0.70975E-01
MGO	8.7120	0.26347E-01	0.39781E-01	0.43026E-01	0.0000	0.26347E-01	0.0000	0.26347E-01
AL2O3	3.2003	0.96784E-02	0.57776E-02	0.13280E-01	0.0000	0.96784E-02	0.0000	0.96784E-02
FEO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE2O3	1.4224	0.43015E-02	0.16395E-02	0.44618E-02	0.0000	0.43015E-02	0.0000	0.43015E-02
FE3O4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	330.67	1.0000	1.0000	1.0000	0.0000	1.0000	0.0000	1.0000

CURRENT THERMOPHYSICAL PROPERTIES

MATERIAL	K (W/M*K)	P (KG/M**3)	CP (J/KG*K)	U (KG/M*S)	SIGMA (N/M)	EMIS (-)	ENTHALPY (KJ/KG)
MELT	10.155	5133.9	931.87	0.40624E-01	1.1221	0.56625	1578.3
TOP CRUST	10.155	5638.0				0.56625	296.78
DECOMP GAS	0.14027	0.22455	1611.6	0.72164E-04			

```
KEY MELT THERMALHYDRAULIC CONDITIONS

  TMELT=     1786.5       K      EMELT=     1.5783     MJ/KG
  TOX,SOL=   1393.0       K      TOX,LIQ=   1568.0     K
  TM,SOL=    1709.4       K      TM,LIQ=    1746.6     K
  VOXSOL=    0.0000              VTOTSOL=   0.0000
  VCRIT=   -0.62774E+69   CM/S   JGAS=      13.489     CM/S
  VOIDF=     0.14563             QCHEM=     15473.     KW
  RBUBBLE=   0.74108      CM     UBRISE=    25.399     CM/S
  QDECM=     0.0000       KW     QDECCR=    0.0000     KW

MELT UPPER SURFACE HEAT TRANSFER DATA

  TINT=  1736.1    K  HWAT=  122.99    W/M**2*K  QWAT=  30320.    W
  TTOP=  1736.1    K  HTOP=  2408.5    W/M**2*K  QTOP=  30320.    W
  TFRT=  1656.9    K  DCRT=  0.0000    MM

MELT LOWER SURFACE HEAT TRANSFER DATA

  ADEP=  14.616    CM          BLDEP=  0.0000    CM  ARATE=  2.6120    MM/MIN
  HBOT=  678.42    W/M**2*K    QBOT=   48.588    KW

TERM-BY-TERM COMPONENTS OF ENERGY EQUATION

  QNTBN= -35571.    W  QDCML=  0.0000    W  QBOTE= -48588.    W
  QSIDE=  0.0000    W  QTOPE= -30320.    W  QBMBN=  36839.    W
  QCRBN=  0.0000    W  QOXTO=  15473.    W  QERUP=  0.0000    W
  QMASB=  1267.8    W  QDRPV=  0.0000    W  DENDT= -62167.    W

INTEGRATED ENERGY SOURCE/SINK DATA

  E->ATMOSPHERE= 0.36154E+08 J   E->CHEM. RXS.= 0.58425E+08 J
  E->DOWN ABL.=  0.16313E+09 J   E->SIDE ABL.=   0.0000     J
  E->DECAY HEAT=  0.0000     J

METAL GAS AND CONDENSED PHASE REACTION FRACS.

  ZR/GAS=  0.0000     ZR/SIO2=  0.0000     ZR/SI=  1.0000
  CR/GAS=  1.0000     FE/GAS=   0.0000

CUMULATIVE NONCONDENSABLE GAS RELEASE (MOLES)

  MOLES H2=   312.48     MOLES H2O=  0.0000     MOLES CO=   449.74
  MOLES CO2=  0.0000     MOLES SIO=  0.0000     TOT MOLES=  762.21
```

Benchmarks

MELCOR

UO_2 and SS debris pool, dry cavity, quasi-steady ablation, 2850 K initial temp

CQ

CURRENT MELT, CRUST, & PARTICLE BED BREAKDOWNS

CONSTITUENT	MELT MASS (KG)	WT FR	ML FR (KG)	VL FR	CRUST MASS (KG)	WT FR	PART. BED MASS	WT FR
UO2	279.54	0.50754	0.18238	0.40862	20.463	0.51216	0.0000	0.50754
ZRO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CR2O3	17.160	0.31157E-01	0.19891E-01	0.44360E-01	1.0707	0.26798E-01	0.0000	0.31157E-01
NIO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B2O3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	158.40	0.28761	0.49970	0.28866	11.596	0.29022	0.0000	0.28761
CR	20.872	0.37895E-01	0.70717E-01	0.42455E-01	1.6548	0.41416E-01	0.0000	0.37895E-01
NI	46.589	0.84590E-01	0.13980	0.76596E-01	3.4105	0.85359E-01	0.0000	0.84590E-01
ZR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
U	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B4C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NA2O	0.43455	0.78899E-03	0.12352E-02	0.24454E-02	0.27113E-01	0.67860E-03	0.0000	0.78899E-03
TIO2	0.39505E-01	0.71726E-04	0.87105E-04	0.12551E-03	0.24649E-02	0.61691E-04	0.0000	0.71726E-04
SIO2	11.377	0.20657E-01	0.33359E-01	0.68248E-01	0.70988	0.17767E-01	0.0000	0.20657E-01
CAO	10.429	0.18936E-01	0.32763E-01	0.46277E-01	0.65072	0.16286E-01	0.0000	0.18936E-01
MGO	3.8714	0.70292E-02	0.16919E-01	0.15731E-01	0.24156	0.60457E-02	0.0000	0.70292E-02
AL2O3	1.4222	0.25821E-02	0.24573E-02	0.48556E-02	0.88735E-01	0.22209E-02	0.0000	0.25821E-02
FEO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE2O3	0.63207	0.11476E-02	0.69730E-03	0.16313E-02	0.39438E-01	0.98706E-03	0.0000	0.11476E-02
FE3O4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	550.77		39.955		0.0000			

CURRENT THERMOPHYSICAL PROPERTIES

MATERIAL	K (W/M*K)	P (KG/M**3)	CP (J/KG*K)	U (KG/M*S)	SIGMA (N/M)	EMIS (-)	LATENT HEAT (KJ/KG)
MELT	8.0515	7035.7	669.72	0.75599E-02	1.0133	0.61391	1389.6
CRUST	8.4233	8340.1				0.59911	103.76
DECOMP GAS	0.15794	0.16317	1611.6	0.80677E-04			

```
KEY MELT THERMALHYDRAULIC CONDITIONS

    TMELT=    2458.4     K       EMELT=     1.3896     MJ/KG
    TOX,SOL=  2086.1     K       TOX,LIQ=   3146.9     K
    TM,SOL=   1697.9     K       TM,LIQ=    1742.7     K
    VOXSOL=  0.64901             VTOTSOL= 0.38440
    VCRIT=    3.9077     CM/S    JGAS=      183.31     CM/S
    VOIDF=   0.40000             QCHEM=     183.63     KW
    RBUBBLE= 0.60157     CM      UBRISE=    22.883     CM/S
    QDECM=    0.0000     KW      QDECCR=    0.0000     KW

MELT UPPER SURFACE HEAT TRANSFER DATA

    TINT=  2014.6     K  HWAT=  180.98     W/M**2*K  QWAT=  57.219     KW
    TTOP=  2535.3     K  HTOP=  7498.1     W/M**2*K  QTOP= -144.07     KW
    TFRT=  2535.3     K  DCRT=  19.163     MM

MELT LOWER SURFACE HEAT TRANSFER DATA

    ADEP=  6.9002     CM          BLDEP=  0.0000     CM  ARATE=  25.795     MM/MIN
    HBOT=  2002.6     W/M**2*K  QBOT=   479.83     KW

TERM-BY-TERM COMPONENTS OF ENERGY EQUATION

    QNTBN=  1163.9     KW  QDCML=  0.0000     KW  QBOTE= -479.83     KW
    QSIDE=  0.0000     KW  QTOPE=  144.07     KW  QBMBN=  363.81     KW
    QCRBN= -1526.7     KW  QOXTO=  183.63     KW  QERUP=  0.0000     KW
    QMASB=  1.0575     KW  QDRPV=  0.0000     KW  DENDT= -151.08     KW

INTEGRATED ENERGY SOURCE/SINK DATA

    E->ATMOSPHERE=  16.739     MJ   E->CHEM. RXS.=  29.216     MJ
    E->DOWN ABL.=   77.014     MJ   E->SIDE ABL.=   0.0000     MJ
    E->DECAY HEAT=  0.0000     MJ

METAL GAS AND CONDENSED PHASE REACTION FRACS.

    ZR/GAS=  0.0000      ZR/SIO2=  0.0000      ZR/SI=  1.0000
    CR/GAS=  1.0000      FE/GAS=   0.0000

CUMULATIVE NONCONDENSABLE GAS RELEASE (MOLES)

    MOLES H2=   147.52      MOLES H2O=  0.0000      MOLES CO=   212.32
    MOLES CO2=  0.0000      MOLES SIO=  0.0000      TOT MOLES=  359.84
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MEL

MELT, TOP CRUST, AND PARTICLE BED MASS BREAKDOWNS

CONSTITUENT	MELT MASS (KG)	WT FR	ML FR (KG)	VL FR	CRUST MASS (KG)	WT FR	PBED MASS	WT FR
UO2	279.56	0.50753	0.18237	0.40859	20.445	0.51208	0.0000	0.50753
ZRO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CR2O3	17.167	0.31166E-01	0.19896E-01	0.44371E-01	1.0728	0.26870E-01	0.0000	0.31166E-01
NIO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B2O3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE	158.41	0.28760	0.49969	0.28865	11.585	0.29018	0.0000	0.28760
CR	20.869	0.37888E-01	0.70703E-01	0.42446E-01	1.6512	0.41358E-01	0.0000	0.37888E-01
NI	46.593	0.84588E-01	0.13980	0.76592E-01	3.4074	0.85347E-01	0.0000	0.84588E-01
ZR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
U	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
B4C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SI	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NA2O	0.43471	0.78922E-03	0.12355E-02	0.24460E-02	0.27166E-01	0.68044E-03	0.0000	0.78922E-03
TIO2	0.39519E-01	0.71747E-04	0.87131E-04	0.12554E-03	0.24697E-02	0.61858E-04	0.0000	0.71747E-04
SIO2	11.382	0.20663E-01	0.33369E-01	0.68266E-01	0.71126	0.17815E-01	0.0000	0.20663E-01
CAO	10.433	0.18941E-01	0.32773E-01	0.46289E-01	0.65199	0.16331E-01	0.0000	0.18941E-01
MGO	3.8729	0.70312E-02	0.16924E-01	0.15735E-01	0.24203	0.60621E-02	0.0000	0.70312E-02
AL2O3	1.4227	0.25829E-02	0.24580E-02	0.48569E-02	0.88907E-01	0.22269E-02	0.0000	0.25829E-02
FEO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
FE2O3	0.63231	0.11480E-02	0.69751E-03	0.16317E-02	0.39514E-01	0.98973E-03	0.0000	0.11480E-02
FE3O4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
TOTAL	550.82	1.0000	1.0000	1.0000	39.924	1.0000	0.0000	1.0000

CURRENT THERMOPHYSICAL PROPERTIES

MATERIAL	K (W/M*K)	P (KG/M**3)	CP (J/KG*K)	U (KG/M*S)	SIGMA (N/M)	EMIS (-)	ENTHALPY (KJ/KG)
MELT	8.0512	7035.5	669.79	0.75450E-02	1.0133	0.61393	1391.1
TOP CRUST	8.4203	8337.7				0.59925	102.80
DECOMP GAS	0.15794	0.16310	1611.6	0.80677E-04			

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KEY MELT THERMALHYDRAULIC CONDITIONS

    TMELT=    2459.5     K       EMELT=     1.3911     MJ/KG
    TOX,SOL=  2085.9     K       TOX,LIQ=   3146.9     K
    TM,SOL=   1697.9     K       TM,LIQ=    1742.7     K
    VOXSOL=  0.64785             VTOTSOL= 0.64785
    VCRIT=    3.9855     CM/S    JGAS=      183.87     CM/S
    VOIDF=   0.40000             QCHEM=   0.18410E+06 KW
    RBUBBLE= 0.60157     CM      UBRISE=    22.883     CM/S
    QDECM=    0.0000     KW      QDECCR=    0.0000     KW

MELT UPPER SURFACE HEAT TRANSFER DATA

    TINT=  2014.4     K  HWAT=  182.77     W/M**2*K  QWAT=  57773.      W
    TTOP=  2535.6     K  HTOP=  7509.5     W/M**2*K  QTOP=-0.14288E+06  W
    TFRT=  2535.6     K  DCRT=  18.993     MM

MELT LOWER SURFACE HEAT TRANSFER DATA

    ADEP=  6.9035     CM          BLDEP=  0.0000     CM  ARATE=  25.862     MM/MIN
    HBOT=  2005.5     W/M**2*K  QBOT=   481.08     KW

TERM-BY-TERM COMPONENTS OF ENERGY EQUATION

    QNTBN= 0.11821E+07  W  QDCML=  0.0000       W  QBOTE=-0.48108E+06 W
    QSIDE=  0.0000      W  QTOPE= 0.14288E+06  W  QBMBN= 0.36476E+06 W
    QCRBN=-0.15204E+07  W  QOXTO= 0.18410E+06  W  QERUP=  0.0000      W
    QMASB=  26521.      W  QDRPV=  0.0000       W  DENDT=-0.12758E+06 W

INTEGRATED ENERGY SOURCE/SINK DATA

    E->ATMOSPHERE= 0.16783E+08 J   E->CHEM. RXS.= 0.29230E+08 J
    E->DOWN ABL.=  0.77050E+08 J   E->SIDE ABL.=   0.0000     J
    E->DECAY HEAT=  0.0000     J

METAL GAS AND CONDENSED PHASE REACTION FRACS.

    ZR/GAS=  0.0000      ZR/SIO2=  0.0000      ZR/SI=  1.0000
    CR/GAS=  1.0000      FE/GAS=   0.0000

CUMULATIVE NONCONDENSABLE GAS RELEASE (MOLES)

    MOLES H2=   147.59      MOLES H2O=  0.0000      MOLES CO=   212.42
    MOLES CO2=  0.0000      MOLES SIO=  0.0000      TOT MOLES=  360.02
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Future Work

Continue to integrate remaining CQ models/methods into CAV/CQ

Move on to experimental validations with benchmarks (e.g. CCI, ACE, SNL-SURC)

Develop a methodology for adding remainder of CAV/CCM3 models to CAV/CQ

- Existing (or improved) debris spreading
- Debris/cavity radiation to HS (as opposed to just general “surroundings”)
- GEM (or similar) chemistry
- VANESA for fission product release
- Multi-cavity and cavity rupture/overflow
- Multi-layer (more conservation equations with entrainment/settling source/sink terms)
- Communications with CVH/RN1, and other package interfaces via TP

Allow for instantiation of an LHC structure in place of a cavity structure

- Recently improved finite-volume formulation, or
- More like a COR lower head approach

CAV/CCM3 more “modernized”

Summary

Reviewed CORQUENCH

Discussed plan and progress on CAV/CQ implementation

Showed only a couple of the early stand-alone CQ to CAV/CQ benchmarks

Discussed development agenda in near-future