UK’s MELCOR and Severe Accident Activities and User Experiences Under Low Flow, Low Decay Heat Conditions

Presentation to
European MELCOR Users Meeting

Presented by
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Severe accidents – TAS, Serco
The UK’s activity in Severe Accidents analyses
User MELCOR Experiences
Future involvement in MELCOR use and research by Serco
Conclusions.
SARNET, UK and Serco

- UK is a member of SARNET.
- National Nuclear lab and Newcastle University are actively involved in the programme.
- Possibility of Serco investing in the programme.
- Winfrith site involved in CORA tests in late 1990s.
- Winfrith used MELCOR for VVER severe accident analysis in Armenia up to 2001.
- Risley involved in PHEBUS FTP1 MELCOR assessments.
- Majority of MELCOR use is presently for Naval MOD research work at Risley, Warrington.
- Newcastle University highly active in SARNET with ARTIST.
UK Submarines

- Pioneering early submarines developed and deployed in the River Thames near London in 1620s.
- First British military submarine, Holland Class launched in 1901.
- UK naval fleet have been nuclear powered since HMS Dreadnought in 1960.
- Naval PWR reactors are typically smaller and are different to typical commercially available reactors.
Severe Accident Research in the UK for Naval Fleet

- UK’s nuclear safety record onboard submarine’s is world class. No major nuclear related accident or contaminations.

- The UK has developed its own severe accident code, UKSA, specifically for the naval MOD severe accidents research.

- MELCOR has been shown to be a valid and important code for independent verification of UKSA.

- Much insight has been gained from using MELCOR as a secondary code.
Comparison of Key Quantities and Timings.

<table>
<thead>
<tr>
<th>Event in LOCA Study</th>
<th>UKSA</th>
<th>MELCOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for the hottest fuel element to reach T°C</td>
<td>101.2%</td>
<td>100%</td>
</tr>
<tr>
<td>No. of fuel nodes covered at T°C</td>
<td>113.6%</td>
<td>100%</td>
</tr>
<tr>
<td>Time to the start of core melt</td>
<td>101.3%</td>
<td>100%</td>
</tr>
<tr>
<td>No. of fuel nodes covered at the start of fuel melt.</td>
<td>200%</td>
<td>100%</td>
</tr>
<tr>
<td>Time to the start of quenching</td>
<td>102.0%</td>
<td>100%</td>
</tr>
<tr>
<td>RPV water mass at the start of debris quenching</td>
<td>81.2%</td>
<td>100%</td>
</tr>
<tr>
<td>Total hydrogen generated</td>
<td>309.2%</td>
<td>100%</td>
</tr>
<tr>
<td>Peak RC Pressure</td>
<td>107.3%</td>
<td>100%</td>
</tr>
</tbody>
</table>
## Comparison of Key Quantities and Timings

<table>
<thead>
<tr>
<th>Event in ICF Study</th>
<th>UKSA</th>
<th>MELCOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to First Relief Valve Lift</td>
<td>93.7%</td>
<td>100%</td>
</tr>
<tr>
<td>Time when RPV Coolant Begins to Boil</td>
<td>98.3%</td>
<td>100%</td>
</tr>
<tr>
<td>Time to core uncoverage</td>
<td>95.3%</td>
<td>100%</td>
</tr>
<tr>
<td>Time to the start of core melt</td>
<td>98.7%</td>
<td>100%</td>
</tr>
<tr>
<td>Time to which molten debris first enters the lower plena</td>
<td>96.4%</td>
<td>100%</td>
</tr>
<tr>
<td>Total hydrogen generated</td>
<td>197.2%</td>
<td>100%</td>
</tr>
<tr>
<td>Hydrogen mass relieved to RC</td>
<td>162.6%</td>
<td>100%</td>
</tr>
</tbody>
</table>
• Probabilistic Safety Assessments include the possibility of a post-trip (SCRAM) loss of heat sink accident at low decay heats.

• Suppose there is a failure of onboard safety systems, consider the accident occurring out in the middle of an ocean.

• In such circumstances, assistance may take many hours-days to arrive. Accurate prediction of time to core melt, clad rupture and containment atmosphere are needed to guide procedure.
BWR Geometry, although very different to Naval Core design, is most appropriate for UK Naval purposes.
Accident Transient

- Complete loss of heat sink during post-shutdown.
- This is a high pressure accident.
- The Pressure Relief System was modelled as simple flow paths which discharge water in the Containment once the pressure reaches particular set points.
- Bulk boiling occurs.
- Core heat up due to uncovery -> oxidation reaction -> core melt, relocation and blockage.
Clad Temperature

Clad Temperature

Temperature vs. Time for different COR-TCL labels (204 to 211)
Pressure Offset in Time

Partial Pressure of Steam

Pressure [Pa]

time [sec]

CVH-PPART.3.109
Heat Transfer Coefficients – problems at low flow

\[ Nu = 4.36 \left[ 1 + \frac{0.00826}{0.0011 + \frac{\Delta z}{D_h \cdot Re \cdot Pr}} \right] \]

- Developed flow scale factor in parenthesis is set such that $\Delta z = 1000m$.
- Laminar Forced convection dominates in MELCOR in low flow regimes.
- However $Ra < Ra_c$ - for superheated steam.
- 4.36 Scale factor is user defined.
- Default of $C(1212) = 4.36$ also affects calculation of Sherwood Number used for calculating oxidation rate when limited by hydrogen diffusion.
Comparison of Nusselt’s Number correlations
Clad Temperature when C1212=0

Clad Temp (C1212=0)

Temperature

Time

COR-TCL.104
COR-TCL.105
COR-TCL.106
COR-TCL.107
COR-TCL.108
COR-TCL.109
COR-TCL.110
COR-TCL.111
For low decay heats, MELCOR’s limit of \( n=2 \) may be important.

Only two fields are available in MELCOR to describe oxidation effects.

Nagase correlations for \( K(T) \) based on \( x10 \) of critical oxidant supply.

MELCOR assumes well-mixed hydraulic volumes, in reality not well mixed – becomes important at significant \( H_2 \) concentrations.

Validity Chapman-Enskog equations at high pressure?
Clad ballooning is a phenomena of interest in naval and civil fields.

Flow blockage due to ballooning can cause:

- flow acceleration,
- droplet break-up in reflood studies,
- improved mixing,
- Establishment of new boundary layers, which effects the heat transfer.
- Heat transfer surface area can change substantially.
**Ballooning**

- Effect is modelled crudely by user in MELCOR, using valves and restarts.

- Limited by inability to change geometry on restart.

- Imperial College London are working on a solution to the problem in TRACE by coupling MABEL to TRACE.

- Have already coupled MABEL and RELAP5 (MATARE), interfaced by TALINK.

- Work done by Badreddine Belhouachi, lead by Dr. Simon Walker.

- Solution still desired in MELCOR. Tables?
Most sensitivity studies effected only the time at which key events occurred.

Relaxation coefficients:

\[ m_{dT/dz} = m_{cvh} + \min\left(e^{-\frac{dt}{\tau}}, f\right)(m_{dT/dz} - m_{cvh}) \]

\[ h_{relax} = gh^o + (1 - g)h^n \]

Quantity of H₂ relative to steam is key to naval containment performance.

<table>
<thead>
<tr>
<th>( \tau )</th>
<th>( f )</th>
<th>( g )</th>
<th>Hydrogen Generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.8</td>
<td>0.5</td>
<td>125.6%</td>
</tr>
<tr>
<td>0.1</td>
<td>0.6</td>
<td>0.5</td>
<td>95.5%</td>
</tr>
<tr>
<td>0.1</td>
<td>0.35</td>
<td>0.5</td>
<td>100%</td>
</tr>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>97.9%</td>
</tr>
<tr>
<td>0.1</td>
<td>0.05</td>
<td>0.5</td>
<td>113.9%</td>
</tr>
<tr>
<td>0.01</td>
<td>0.6</td>
<td>0.5</td>
<td>115.3%</td>
</tr>
<tr>
<td>0.1</td>
<td>0.6</td>
<td>0.3</td>
<td>108.6%</td>
</tr>
<tr>
<td>0.1</td>
<td>0.6</td>
<td>0.15</td>
<td>83.2%</td>
</tr>
</tbody>
</table>
Manual states (Section 2.3.3) that Maximum of natural-laminar and natural-turbulent regimes are taken.

However file corcnv.f shows:

```
CALCULATE FREE CONVECTION NUSSELT NUMBERS

C       CALCULATE CRITICAL RAYLEIGH NUMBER TO YIELD NO DISCONTINUITIES
RACRIT = (C1221(1)/C1222(1)*(ZLEN/DHY)**(C1221(3)-C1222(3)))
       ** (ONE/(C1222(2)-C1221(2)))
IF (RAF .LT. RACRIT) THEN
C
C ----- LAMINAR FREE CONVECTION
XNUHT = C1221(1) * RAF**C1221(2) * (ZLEN/DHY)**C1221(3)
ELSE
C
C ----- TURBULENT FREE CONVECTION
XNUHT = C1222(1) * RAF**C1222(2) * (ZLEN/DHY)**C1222(3)
```

Error, also printed in MELCOR 2.1 Draft manual.

corcnv.f hard-codes pool heat transfer coefficient to 1000 W/(m²K):

```
C *** SHOULD EQUIVALENCE HTCONV WITH SENSITIVITY COEFFICIENT
DATA HTCONV /1000.D0/
```
Future of Severe Accidents Research in the UK

- More active and continued roll in SARNET.
- Newcastle University heavily involved in ARTIST.
- Expertise at Newcastle in aerosol behaviour and multi-layer re-suspension.
- Newcastle University are committed to supporting the SARNET community with ARTIST2.
- Imperial College look to using thermohydraulics-reactor physics code FLUIDICS for SARNET assessments.
- Imperial College will further develop couple ballooning models.
Future of Severe Accidents Research in the UK

- Naval research application of MELCOR, very likely to continue, with a view in the longer term to MELCOR’s containment capabilities.

- UK is committed to a large scale civil nuclear programme. Serco at Winfrith, the civil side of our business may look to a more active roll in MELCOR in the future for new build assessments and research.

- Possibility of using FARO tests for MELCOR assessments.

- New Naval severe accident research experiments planned.

- Development of CFD based Severe Accident codes.
Conclusions - General

- Broad agreement between totally independent codes, MELCOR and UKSA except in hydrogen production and rate of melt.
- COR heat transfer correlation under review for low decay heat, loss of heat sink accident.
- Questions raised in MELCOR capabilities in high hydrogen concentrations and low flow conditions.
- Need for ballooning model is identified, but solutions are in development. May require to simulate the physics in MELCOR using tables.
- Serco are serious about contributing to the severe accident international community and is committed to MELCOR as an essential independent and extremely powerful accident analysis tool.
- Serco supports the European MELCOR Group.
Thank you