Hot gas/steam release in Gas circulator Hall

Laurent Rouault

5 April 2018
Objectives

Table of contents

- EDF Energy UK Centre
- Purpose of the project
- Geometry and mesh
- Model
- Results
- Conclusion
EDF Energy in the UK

- Generation: 72.5 TWh
  - Nuclear: 77%
  - Coal: 22.5%
  - Combined cycle gas and cogeneration: 0.2%
  - Other renewables: 0.3%
- Installed capacity: 13 GWe
  - Nuclear: 67.6%
  - Gas: 0.7%
  - Coal: 31%
  - Other renewables: 0.7%

- Sales & marketing: 52.8 TWh electricity sold, 25.7 TWh gas sold, 5.8 million customers
- Nuclear power stations: 8 (14 AGRs, 1 PWR)
- Wind farms: 31 (including 1 off-shore)
- Coal gas powered stations: 2 + 1
- EPRs in project at Hinkley Point
EDF Energy R&D in the UK

People, Processes & Buildings

Local delivery of Global Value

100 people (FTE)
40 PhD
£40m of investment in R&D

Part of EDF Group International R&D Centres
(500m€ investment per annum, 2100 people)
Today: Nuclear has provided safe and secure electricity in the UK for over half a century. Today it contributes 20% of supply. The nuclear industry is well established across the lifecycle (operations, new build and decommissioning), and is firmly supported by world-class science and technology, a robust regulatory regime and strong international collaborations.
State of the project

Advance Gas-cooled Reactor (AGR)

- Designed and Operated in the UK
- 14 AGRs owned and operated by EDF Energy
- Coolant: Carbon dioxide

Objective of the project

- Better understanding of Loss Of Coolant Accident scenario (LOCA)
- Establish a bank of CFD results
- Guidance for operators concerning the CO₂ level of exposure

<table>
<thead>
<tr>
<th>CO₂ level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04%</td>
<td>In air</td>
</tr>
<tr>
<td>3%</td>
<td>Legal limit (15min)</td>
</tr>
<tr>
<td>10%</td>
<td>Visual trouble</td>
</tr>
<tr>
<td>15%</td>
<td>Fainting</td>
</tr>
<tr>
<td>25%</td>
<td>Respiratory arrest</td>
</tr>
</tbody>
</table>
Hot gas release in gas circulator hall

- Adiabatic walls
- Vents (~60 m²)
- Hot gas release (CO₂)

\[ \dot{m} = \dot{m}_0 \exp(-\alpha t) \]

- Base mesh
  (1 million cells)
Base Model

Modelling of the pipes
- Not explicitly taken into account
- Volumetric heat source term
- Heat release 3.6MW
- Positioned between the drip tray and the top vents

Release description
- Mass flow decaying in time
- Breach diameter: 7.6cm → 37.2cm
- Sonic speed to avoid pressure waves
- Incompressible model
- Temperature 300°C

Gas properties
- Variable gas properties (X)
- 1 additional transport equation for CO₂ mass fraction (Y_{CO₂})
\[
\frac{1}{X_{mix}} = \frac{Y_{CO₂}}{X_{CO₂}} + \frac{1 - Y_{CO₂}}{X_{Air}}
\]

General properties
- Unsteady flow (1 hour real time)
- \(κ-ω\) SST turbulence model
- 1 phase flow

R&D UK Centre - Low Carbon Generation
Results

Reference model - global

- CO2 concentration

Figure 16: $CO_2$ concentration at different times.

- Temperature

Figure 17: Bulk temperature at different times.
Results  Base model - general

- Previous work done on sensitivity studies:
  - Mesh
  - Turbulence model
  - Time step
  - Pressure-Velocity coupling
  - Energy source term

Temperature in the room

![Temperature graph]

CO₂ concentration in the room

![CO₂ concentration graph]
Results  Base model - details

- Same temperature profile
- Local temperature difference up to 10°C
- At the beginning all the vents expel some gas
- After 10 minutes a ventilation loop from bottom to top occurs
Results  TC1: Jet temperature – 600°C instead of 300°C

- Significant effect of the drip tray
- Ventilation loop is stronger
- Increase in Temperature
- Reduction of the CO₂ concentration
Results  TC2.1: Initial stratification – Temperature stratification

- Test without jet
- Current system codes don’t take into account the initial state
- Results shown after 2 hours (45 minutes to get steady state)
Results  TC2.2: Jet + Initial stratification – Comparison with basic initialisation

- Same temperature profile after 15 minutes
- Same mass flow profile after 15 minutes
- Initial ventilation loop allows to reduce the CO$_2$ concentration
Results  TC3: Jet position – opposite side of the room

- Maximum temperature in the room

- Volumetric averages are similar
- Local maximum differs
Results  TC4: Wall heat transfer

Wall properties

\[ \rho = 2300 \]
\[ c_p = 900 \]
\[ \lambda = 2 \]

Flux

\[ q = h (T_{fluid} - T_{surface}) \]

Non-dimensionless number

\[ Bi = \frac{hLc}{\lambda} = 0.39 \]
\[ Fo(1h) = \frac{\lambda t}{\rho c_p L^2} = 0.054 \]

Previous work

1D code:
Maximum temperature
73 °C

Transient temperature in semi infinite concrete

Choice in the model

- Constant wall temperature
- Heat exchange coefficient

Results  TC4: Wall condition

- Maximum temperature decrease by 30°C
- Ventilation loop weaker
- Increased CO$_2$ concentration
Conclusion

Project achievement

- CFD is showing more details regarding the gas and temperature distribution inside the room compared to current practices.
- We are able to analyse different scenarios/assumptions:
  - TC1 - 600°C: Large difference in the first 30 minutes
  - TC2 - Stratification: Effects negligible after 60 minutes
  - TC3 - Jet at the opposite direction: Variation from the mean up to 5°C
  - TC4 - Wall heat transfer: Large difference in temperature and CO₂ concentration

 Perspective

- TC5: Wind condition at the exterior
- TC6: Forced ventilation
- TC7: Steam release
- TC?: Increase of release rate
- TC?: Better modelling of the release (compressible model)