PAUL SCHERRER INSTITUT

Wir schaffen Wissen – heute für morgen

# Modeling Experience on Disruption of Hotleg Counter-Current Flow by Thermally-Induced SGTR

Y. Liao and S. Guentay

2nd European MELCOR User Group (EMUG) Workshop

NRI, Czech Republic, March 1-2, 2010

# Outline

- Introduction to SBO hotleg counter-current flow
- Disruption of hotleg counter-current flow by induced SGTR
- MELCOR calculation results
- Impingement heat transfer for a jet issuing from induced rupture
- Summaries

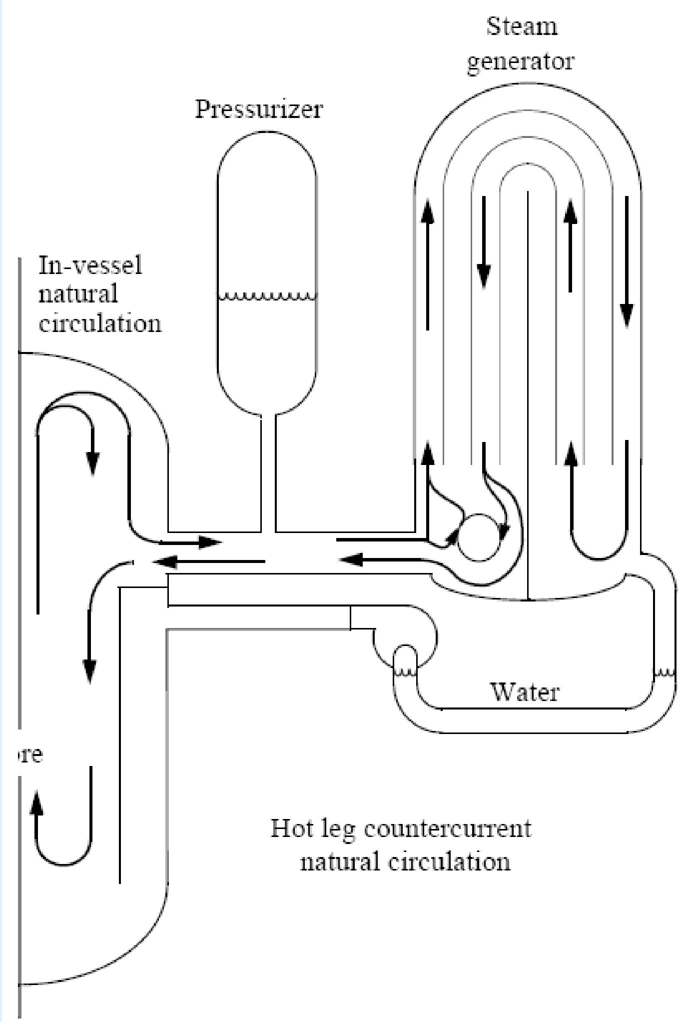
# Introduction to SBO hotleg counter-current flow

## SBO severe accident sequence

- Hotleg voided by venting coolant through pressurizer
- Coldleg loop seal plugged with water
- High pressure primary side, dry SG secondary side

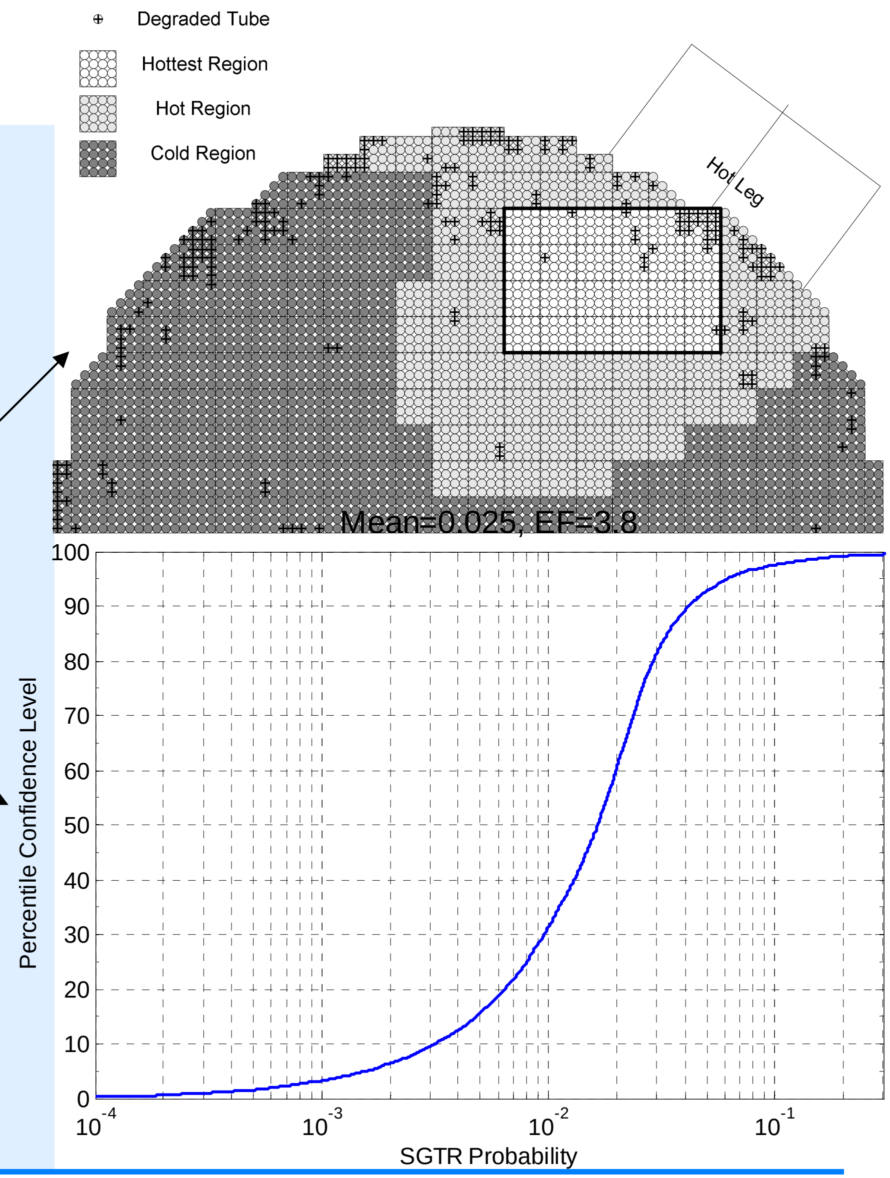
## Hotleg counter-current natural circulation

- Transfer heat to hot leg, surge line and SG tubes
- Hot flow counter-current to cold flow
- Mixing of hot and cold gas in SG inlet plenum
- Flow recirculation through SG U-tubes



# SBO thermally induced SGTR

- SGTR might be induced by thermal challenge in presence of tube degradation
- Distribution of SG tube degradation exhibits statistical features in defect location and size
- SGTR probability has been analyzed by the PRA technique (NED, 2009)
- Around 2% median probability of tube rupture was predicted for new generation SGs



# Objectives and approach

## Suction effects of the rupture flow

- Disrupt hotleg counter-current natural circulation
- Change SG inlet plenum mixing and recirculation flow pattern

## Objectives

- To develop modeling experience for post-tube-rupture scenario
- To examine thermal-dynamic properties of the rupture flow and heat transfer

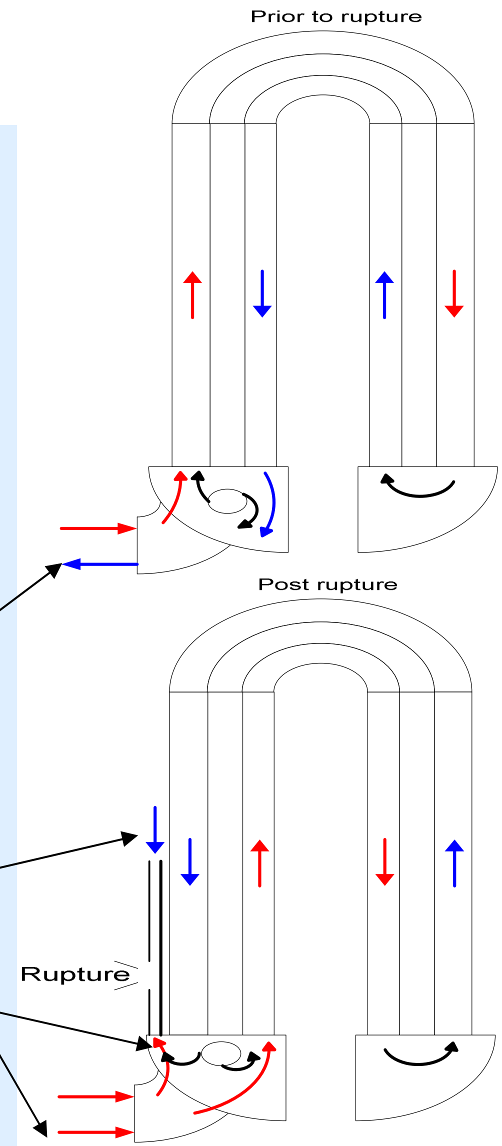
## Approach

- MELOCR 1.8.5 applied to Westinghouse power plant
- This is an exercise to set up the modeling technique
- To predict the actual response requires CFD and experimental data

# Disruption of hotleg counter-current flow

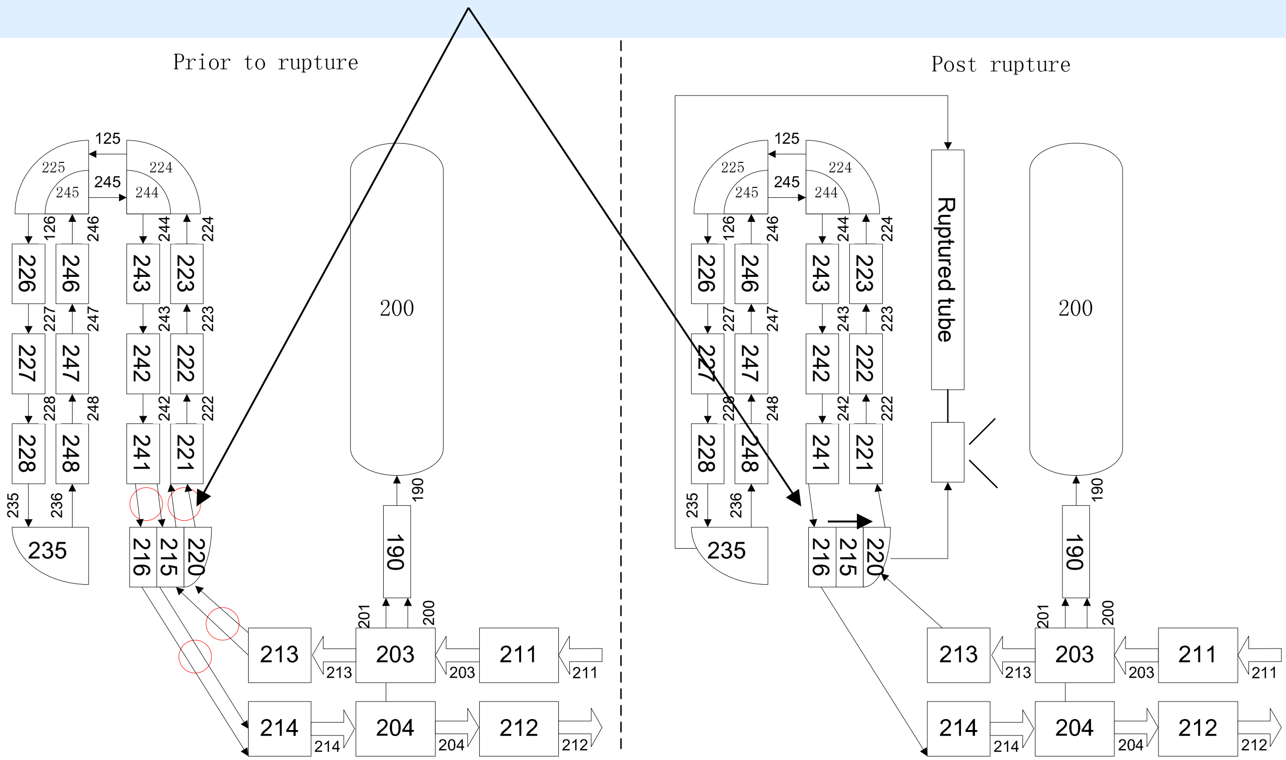
Scenario description

- Prior to tube rupture
  - Hotleg counter-current flow is established
  - A degraded tube is induced to creep failure at top of tubesheet
- Post tube rupture
  - Rupture flow enlarged by crack opening process
  - Flow reversal at hotleg lower part due to suction from SG
  - SG tube recirculation caused by suction from ruptured tube
  - Gas mixing and mixture pulled into ruptured tube



# Assumptions in MELCOR simulation

- Prior to rupture, **pairs of flow paths** are used to simulate counter-current flow and SG inlet plenum mixing
- Rupture area develops from 0 to 50% tube cross sectional area in about 1 minute
- When MELCOR predicts flow reversal in the hotleg lower part, **each pair of flow paths** are merged into one to avoid unphysical local circulation flow



# MELCOR prediction of post-tube-rupture flow pattern

## Hotleg lower part

- Cold gas flow is reversed and replaced by hot gas

## SG inlet plenum

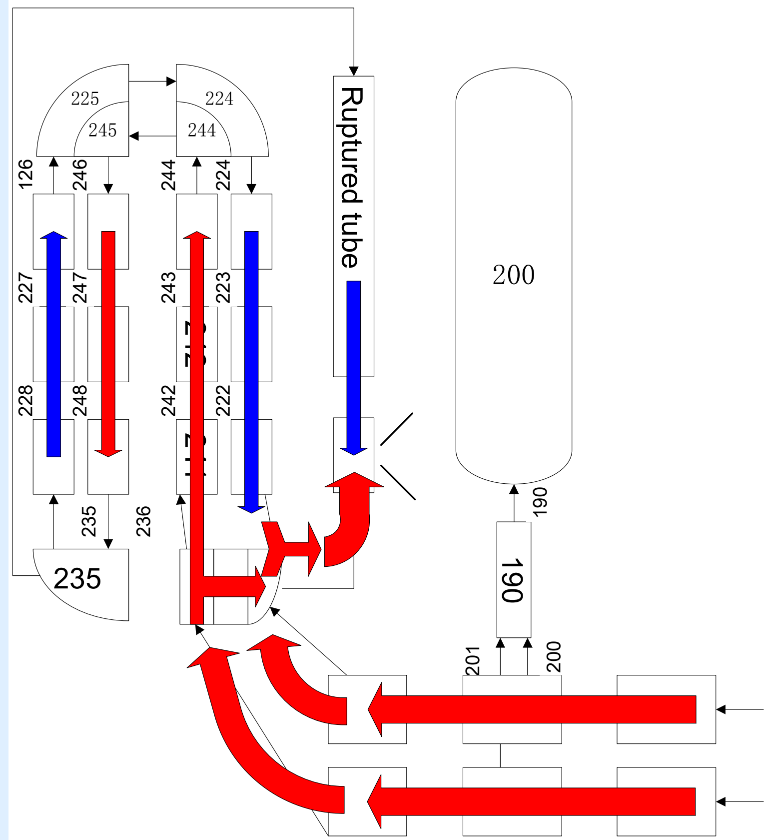
- Hotleg gas mixed with recirculating gas

## SG tubes

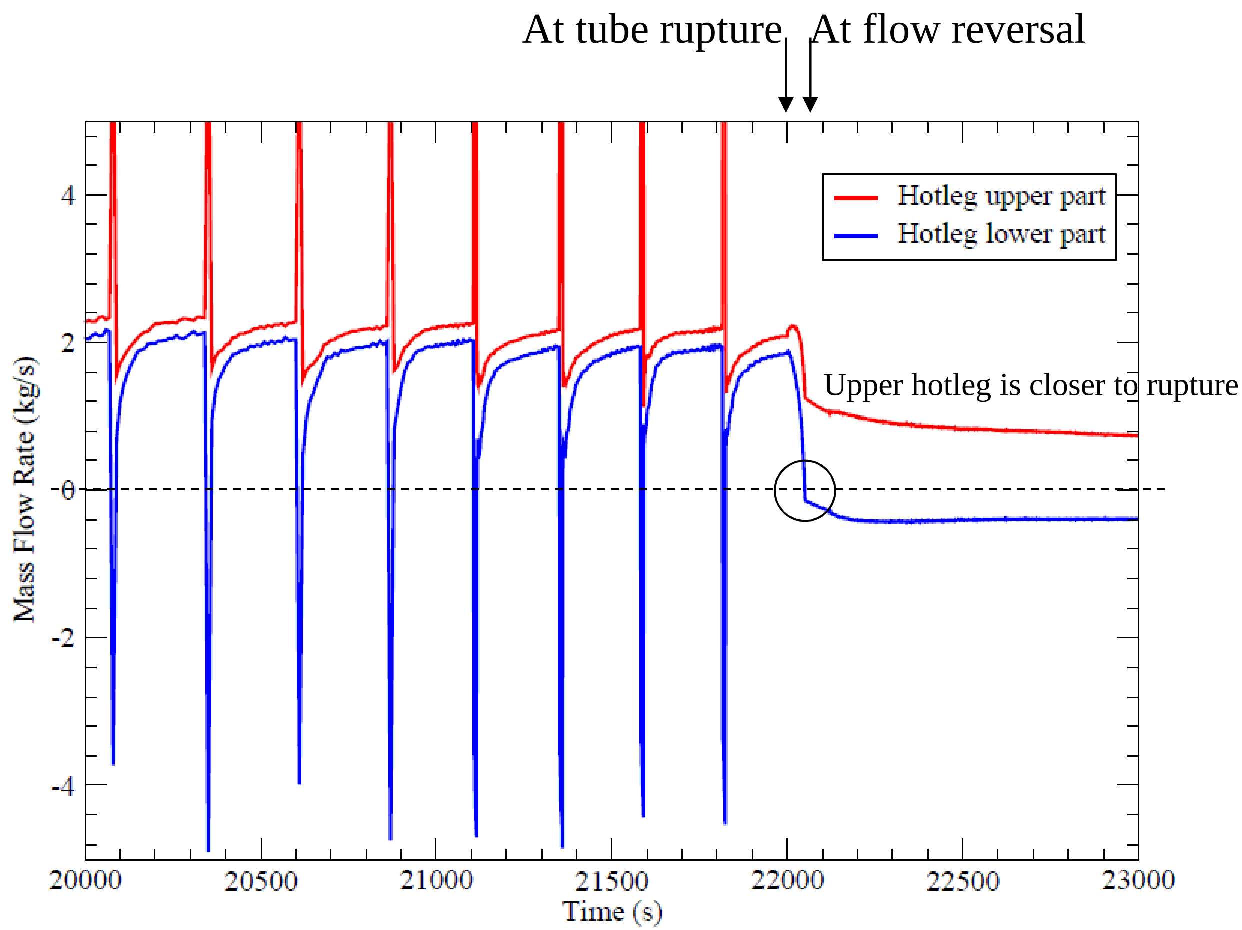
- Recirculating flow caused by suction from both ends of ruptured tube

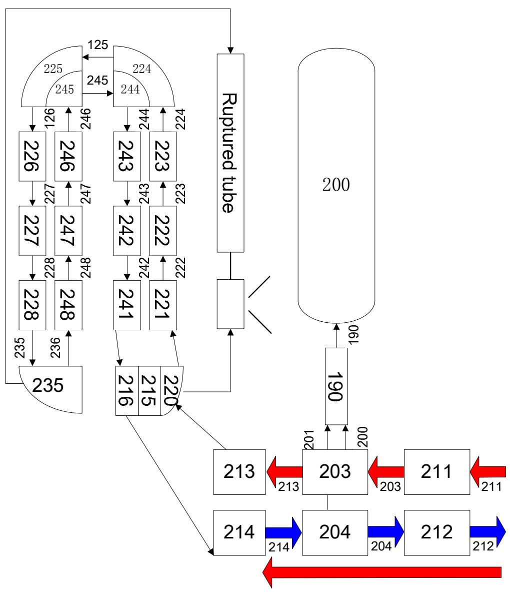
## Ruptured tube

- Incoming hot gas from inlet plenum, cold gas from outlet plenum

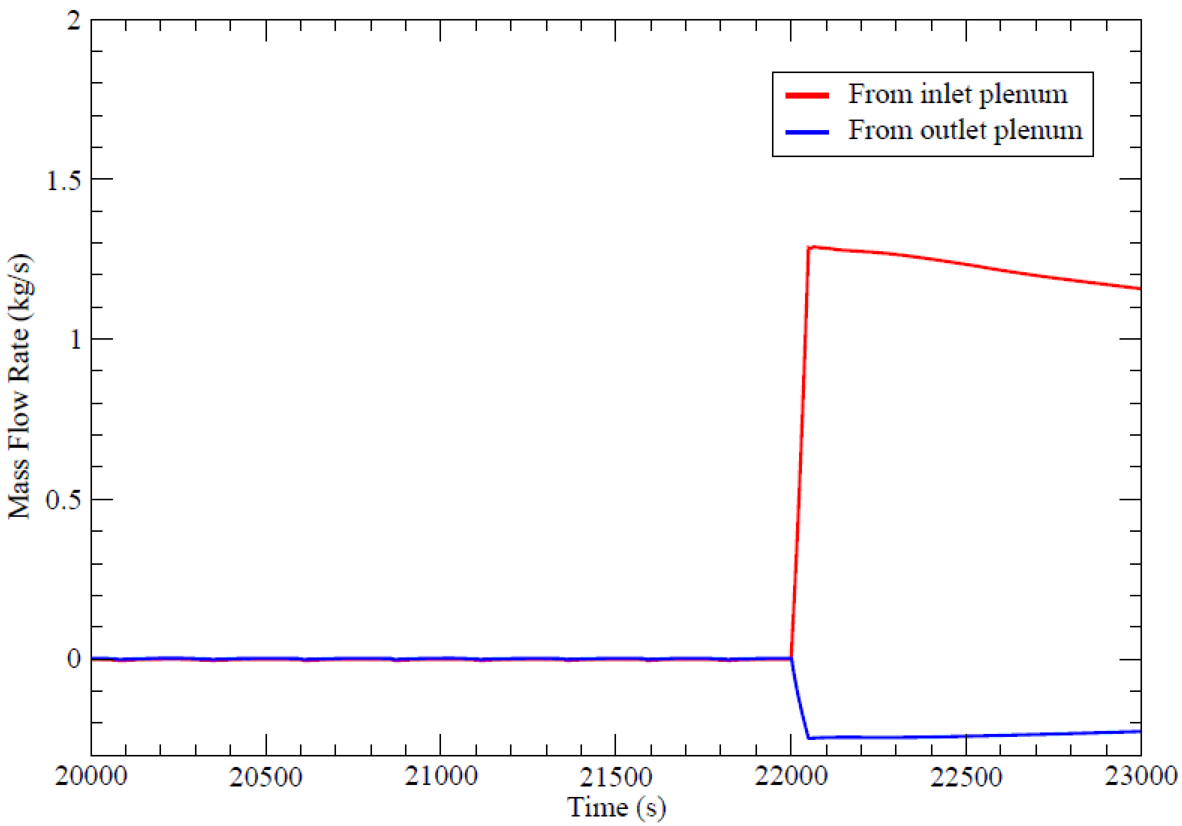


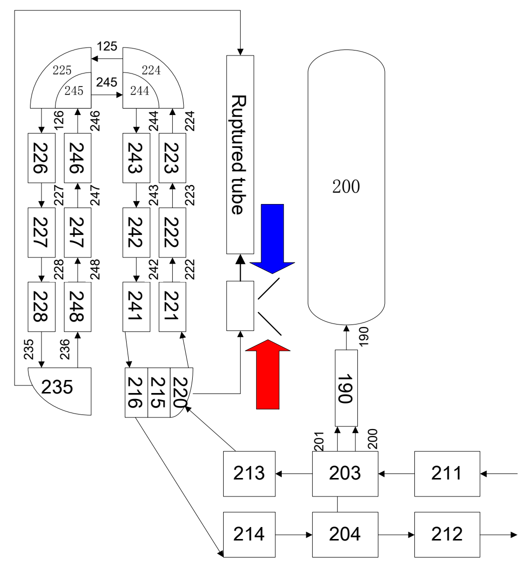
# Flow reversal in hotleg lower part, when rupture area develops to above 40% tube cross sectional area



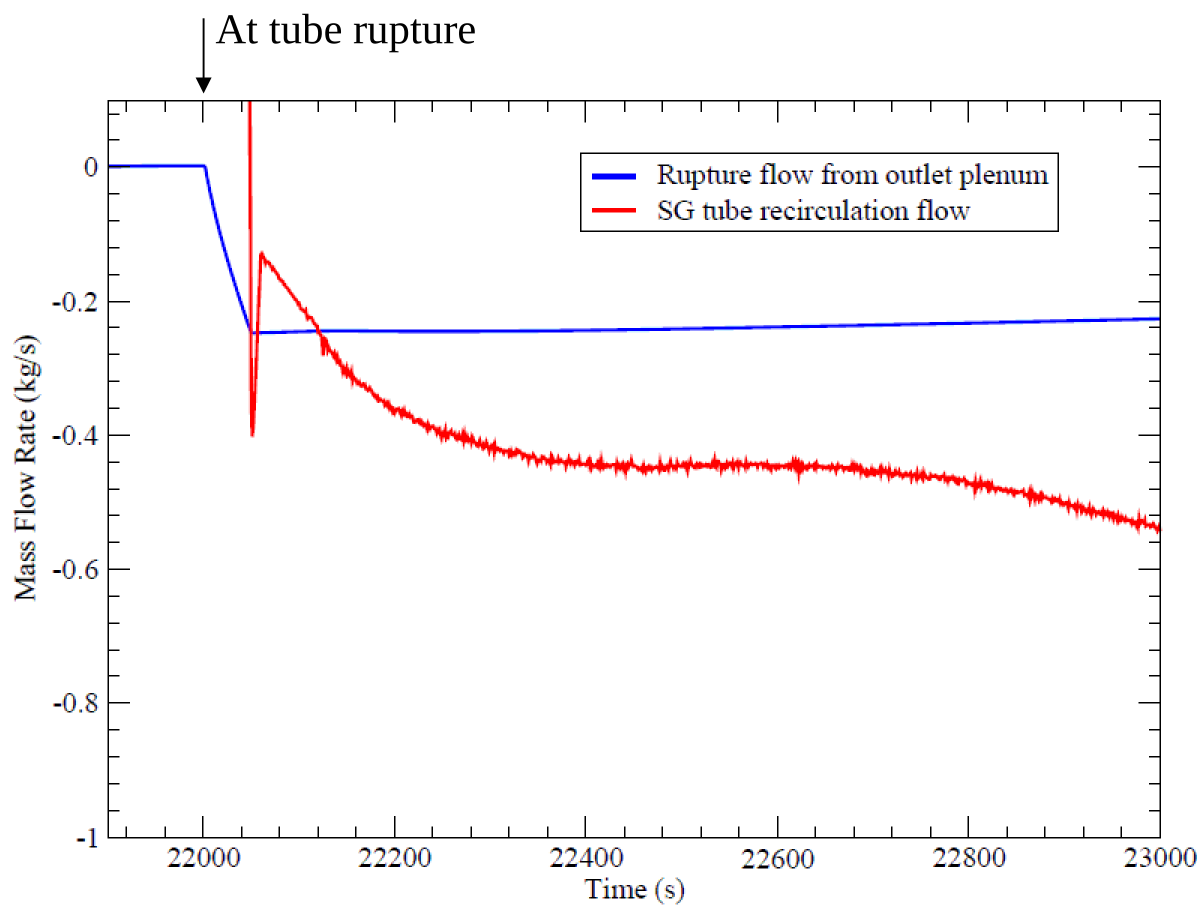



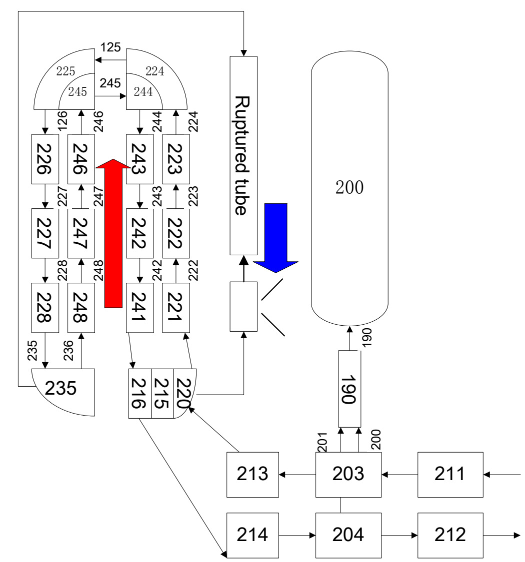
# Rupture flow rate, originated from SG inlet and outlet plenums



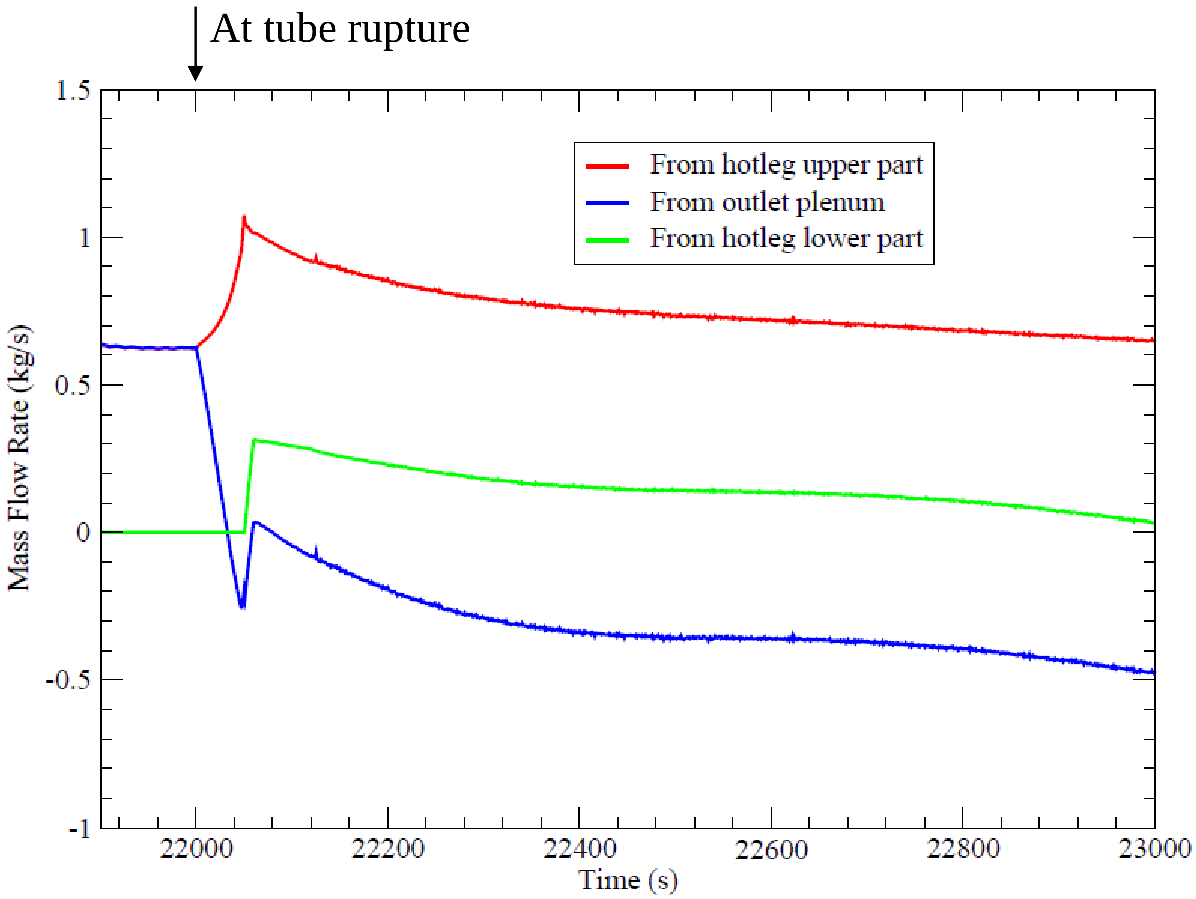



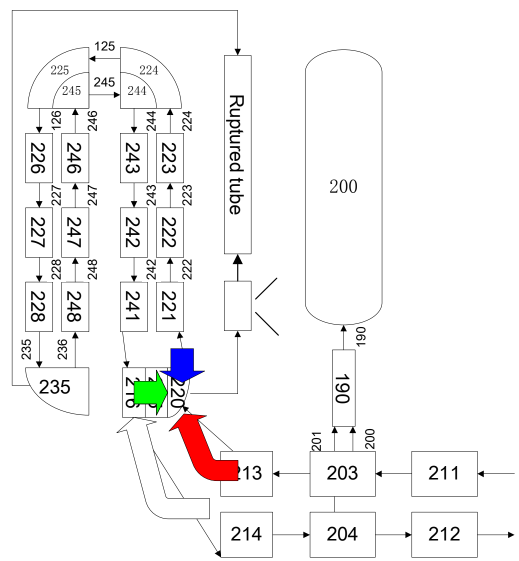
# SG tube recirculation flow: a recirculation ratio about 2, increasing with time due to increase of incoming gas temperature



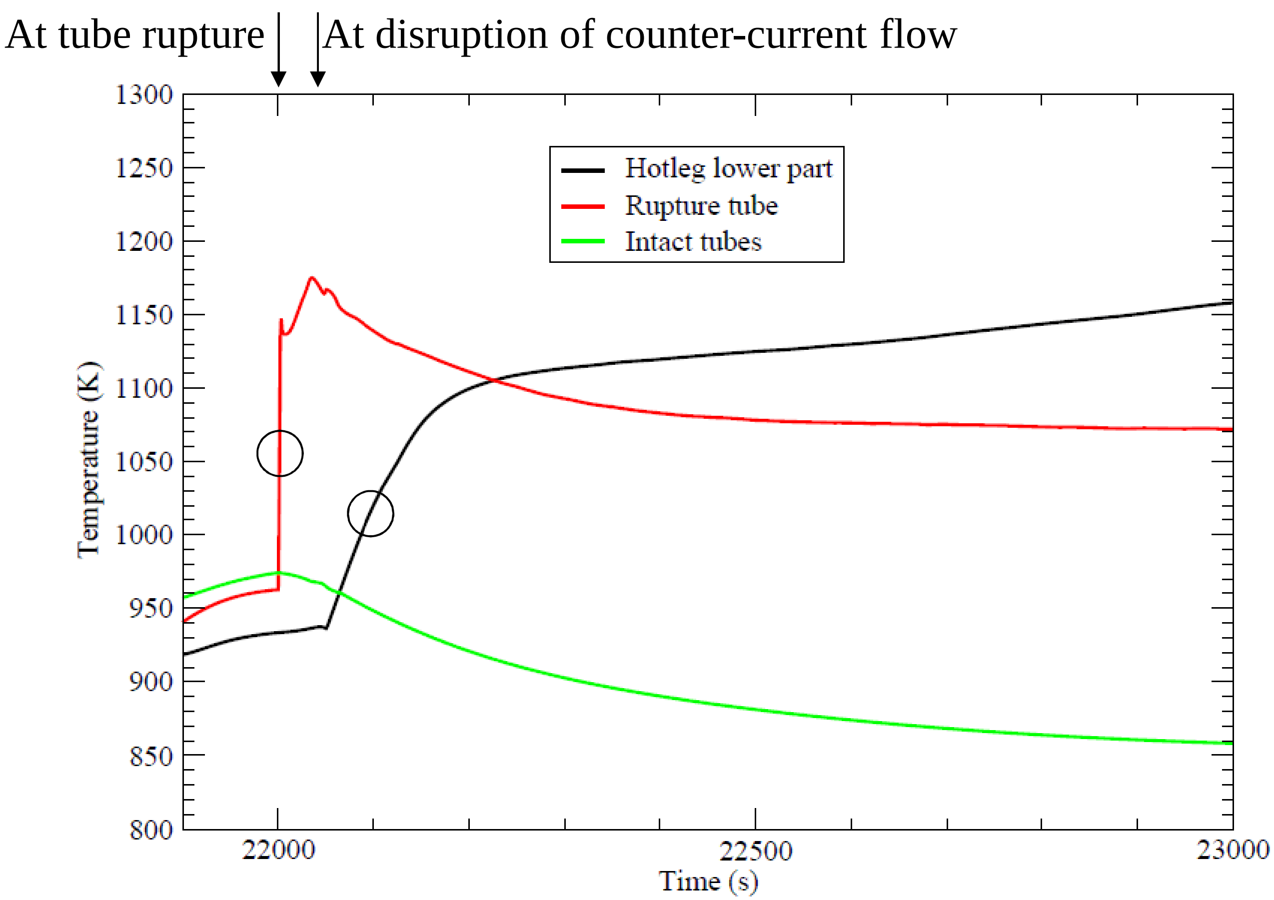
# SG inlet plenum mixing, governing rupture flow temperature



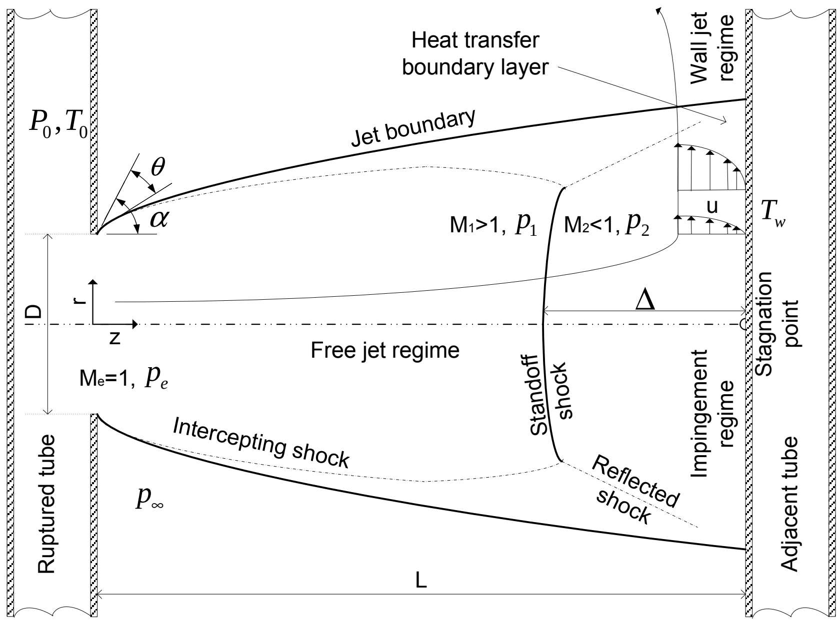
# Gas temperatures:

## Temperature jumps caused by tube rupture and disruption of counter-current flow



# Brief introduction to jet impingement heat transfer

Impingement of high energy jet issuing from induced rupture may heat up and affect creep behavior of adjacent tube




P=pressure
T=temperature
M=Mach number
D=rupture size
L=tube-to-tube distance

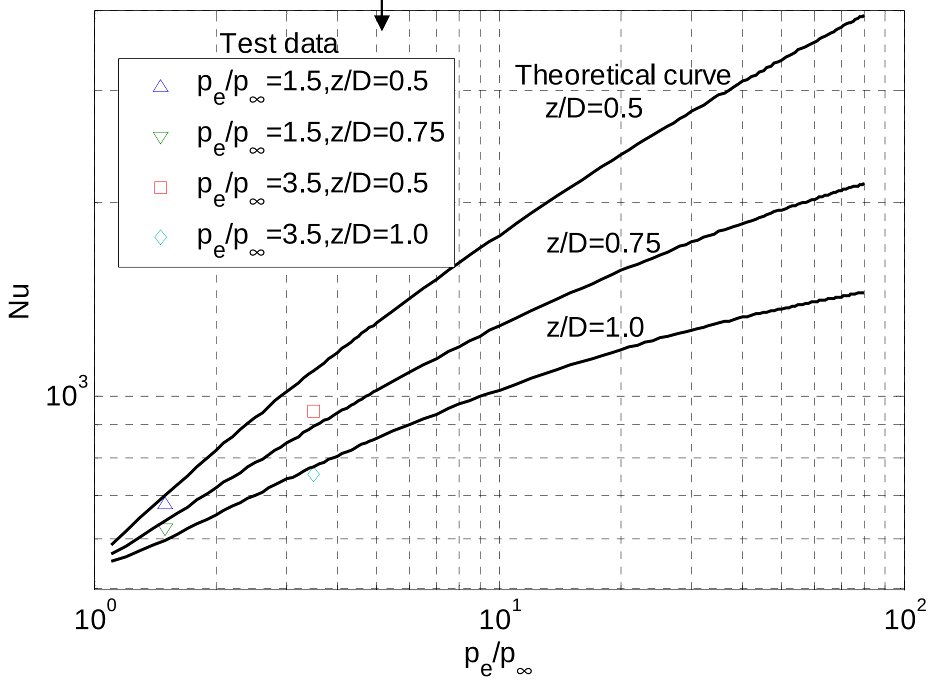
## Flow structure of impinging jet

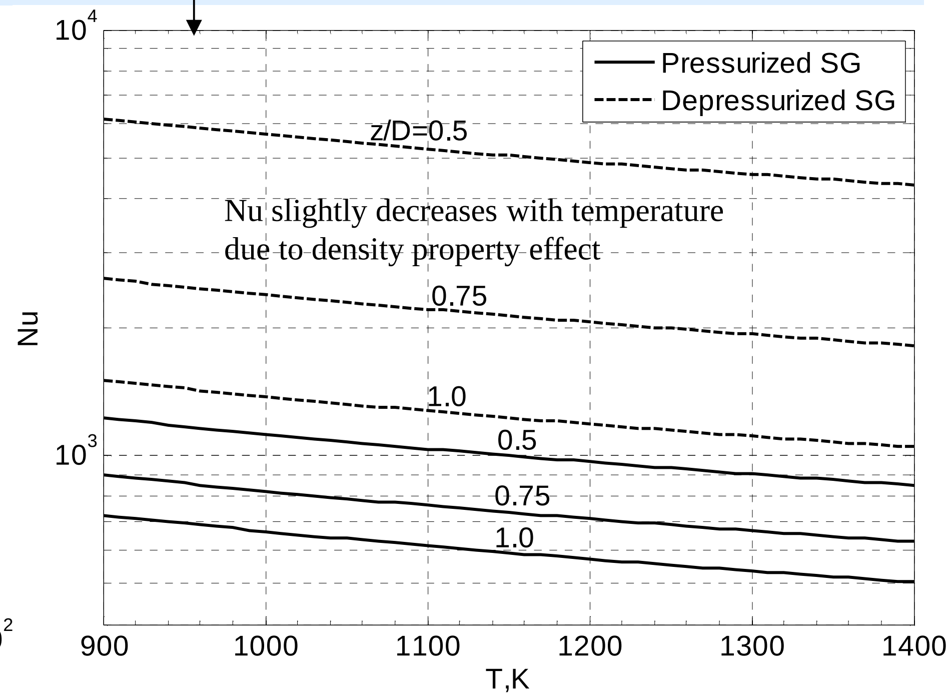
- Development of jet boundary
- Gas undergoes expansion and acceleration
- Pressure loss through passing normal shock
- Heat transferred via a viscous boundary layer

# A mechanistic jet impingement heat transfer model is developed

$$Nu = \frac{\Pr^{1/3}(D\sqrt{RT}/\nu)^{1/2}}{(r_L/D)^{1/2}}\left[\frac{1}{2}\ln\left(\frac{p_{sp}}{p_\infty}\right)\right]^{1/4}$$

- Heat transfer increases with larger pressure ratio and smaller nozzle to surface spacing
- Dependent variables can be provided by MELCOR
- Being validated by experiments and applied to induced SGTR conditions



# Summaries

- MELCOR modeling experience was developed for post-tube-rupture scenarios
- Disruption of hotleg counter-current flow is predicted by MELCOR
  - To occur at rupture area about 40% tube cross sectional area
  - To alter SG inlet plenum mixing and recirculation
- Validated CFD predictions are needed to determine mixing parameters for MELCOR modeling
- A jet impingement heat transfer model is developed and may be implemented into MELCOR to evaluate heatup and creep behavior of an adjacent tube impinged by the rupture flow