Development of Multi-dimensional RELAP5 and its Application

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at Sun Valley

by Lee, Sang-Yong
KOPEC
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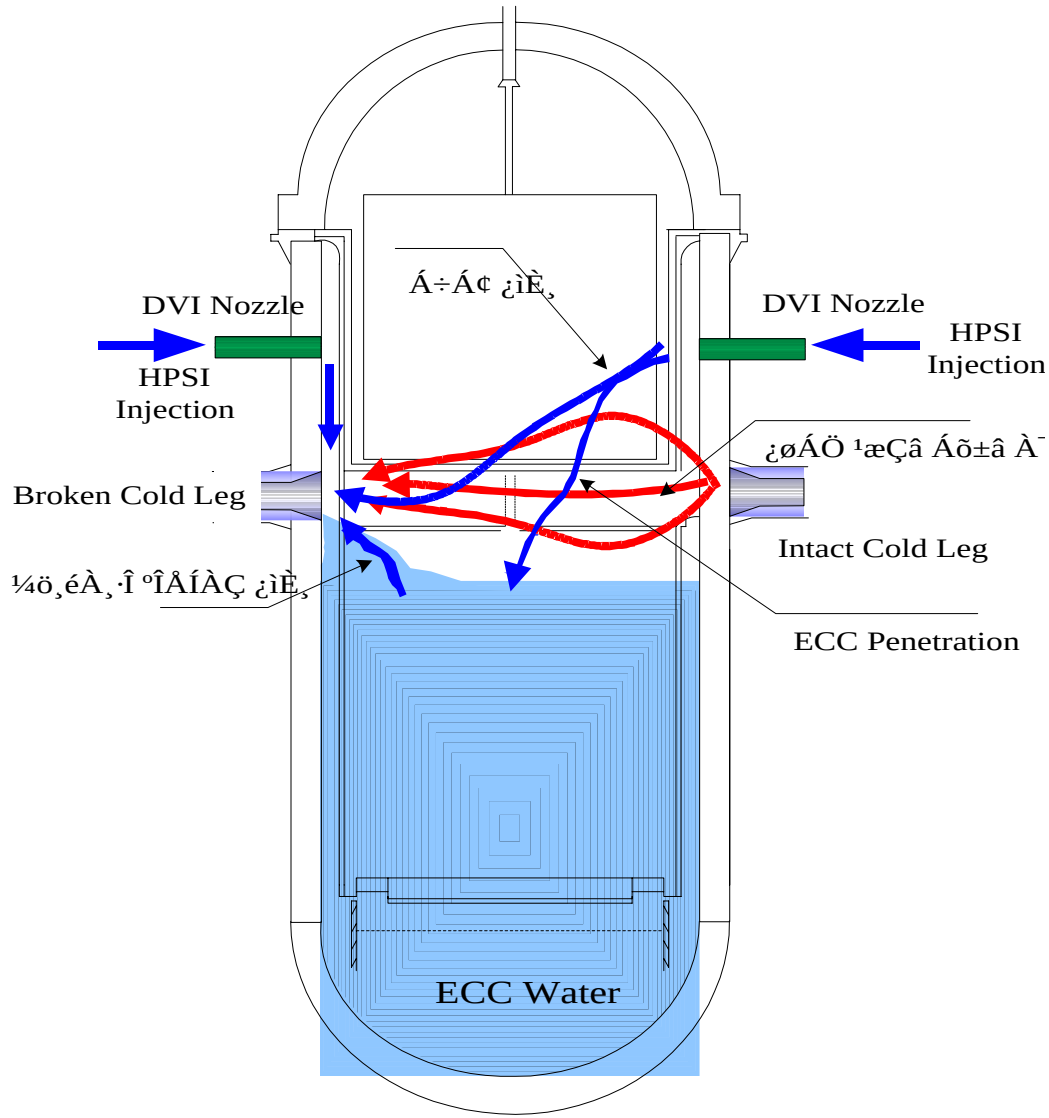
Why do we need RELAP5-MD ?

- Traditional application to LOCA
  - MD effects in D/C, Core, and Upper Plenum
- Application to the Direct Vessel Injection Plant
  - Cross Flow Model for Upper Downcomer is not enough
    - 2D distribution of vapor affects DVI flow
  - Global Circulation in D/C
    - affects wall nucleate boiling at the surface of vessel
  - Lower Plenum behavior affects D/C flow

What is DVI


DVI Nozzle
HPSI
Injection
Á÷Á¢ ¿ìÈ¸
DVI Nozzle
HPSI
Injection
¿øÁÖ ¹æÇâ Áõ±â À¯
Broken Cold Leg
Intact Cold Leg
¼öº¸À¸·Î ºÎÅÍÀÇ ¿ìÈ¸
ECC Penetration
ECC Water

How to do ?

- Full Momentum Convection Terms
  - explicitly
  - upwind scheme
- Friction Terms for cross flow junctions
- Directional Gravity Terms for Spherical Geometry
- Input Generator
  - pipe and multiple junction data generation
  - connectivity data generation
  - boundary condition generation
- Output Processing Technique Set-up
  - ORIGIN, TECPLOT

How to do ?

$$\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\phi}{r}\frac{\partial v_r}{\partial \phi}+v_z\frac{\partial v_r}{\partial z}-\underbrace{\frac{v_\phi^{\,2}}{r}}_{*}=$$

$$-\frac{1}{\rho}\frac{\partial p}{\partial r}+g_r+\nu\left(\nabla^2 v_r-\frac{v_r}{r^2}-\frac{2}{r^2}\frac{\partial v_\phi}{\partial \phi}\right)$$

$$\frac{\partial v_\phi}{\partial t}+v_r\frac{\partial v_\phi}{\partial r}+\frac{v_\phi}{r}\frac{\partial v_\phi}{\partial \phi}+v_z\frac{\partial v_\phi}{\partial z}+\underbrace{\frac{v_r v_\phi}{r}}_{*}=$$

$$-\frac{1}{\rho r}\frac{\partial p}{\partial r}+g_\phi+\nu\left(\nabla^2 v_\phi-\frac{v_\phi}{r^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \phi}\right)$$

$$\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\phi}{r}\frac{\partial v_z}{\partial \phi}+v_z\frac{\partial v_z}{\partial z}=$$

$$-\frac{1}{\rho}\frac{\partial p}{\partial z}+g_z+\nu\nabla^2 v_z$$

cylindrical

$$\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\phi}{r\sin\theta}\frac{\partial v_r}{\partial \phi}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\underbrace{\left(\frac{v_\theta^{\,2}}{r}+\frac{v_\phi^{\,2}}{r}\right)}_{*}=$$

$$-\frac{1}{\rho}\frac{\partial p}{\partial r}+g_r+\nu(\nabla^2 v_r-.....)$$

$$\frac{\partial v_\phi}{\partial t}+v_r\frac{\partial v_\phi}{\partial r}+\frac{v_\phi}{r\sin\theta}\frac{\partial v_\phi}{\partial \phi}+\frac{v_\theta}{r}\frac{\partial v_\phi}{\partial \theta}+\underbrace{\left(\frac{v_r v_\phi}{r}+\frac{v_\theta v_\phi\cot\theta}{r}\right)}_{*}=$$

$$-\frac{1}{\rho r\sin\theta}\frac{\partial p}{\partial \phi}+g_\phi+\nu(\nabla^2 v_\phi-.....)$$

$$\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\phi}{r\sin\theta}\frac{\partial v_\theta}{\partial \phi}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\underbrace{\left(\frac{v_r v_\theta}{r}-\frac{v_\phi^{\,2}\cot\theta}{r}\right)}_{*}=$$

$$-\frac{1}{\rho r}\frac{\partial p}{\partial \theta}+g_\theta+\nu(\nabla^2 v_\theta-.....)$$

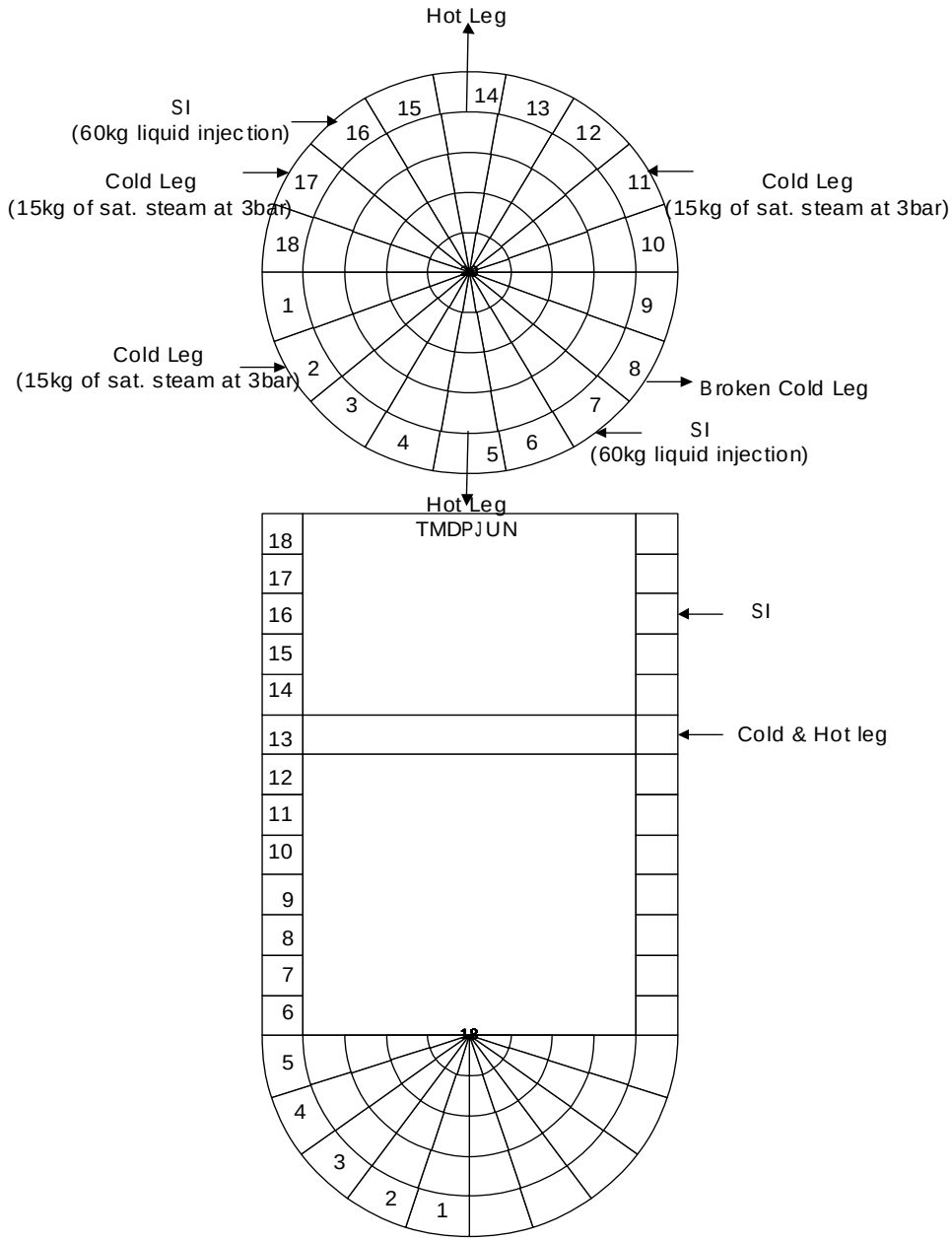
spherical

Test Calculations

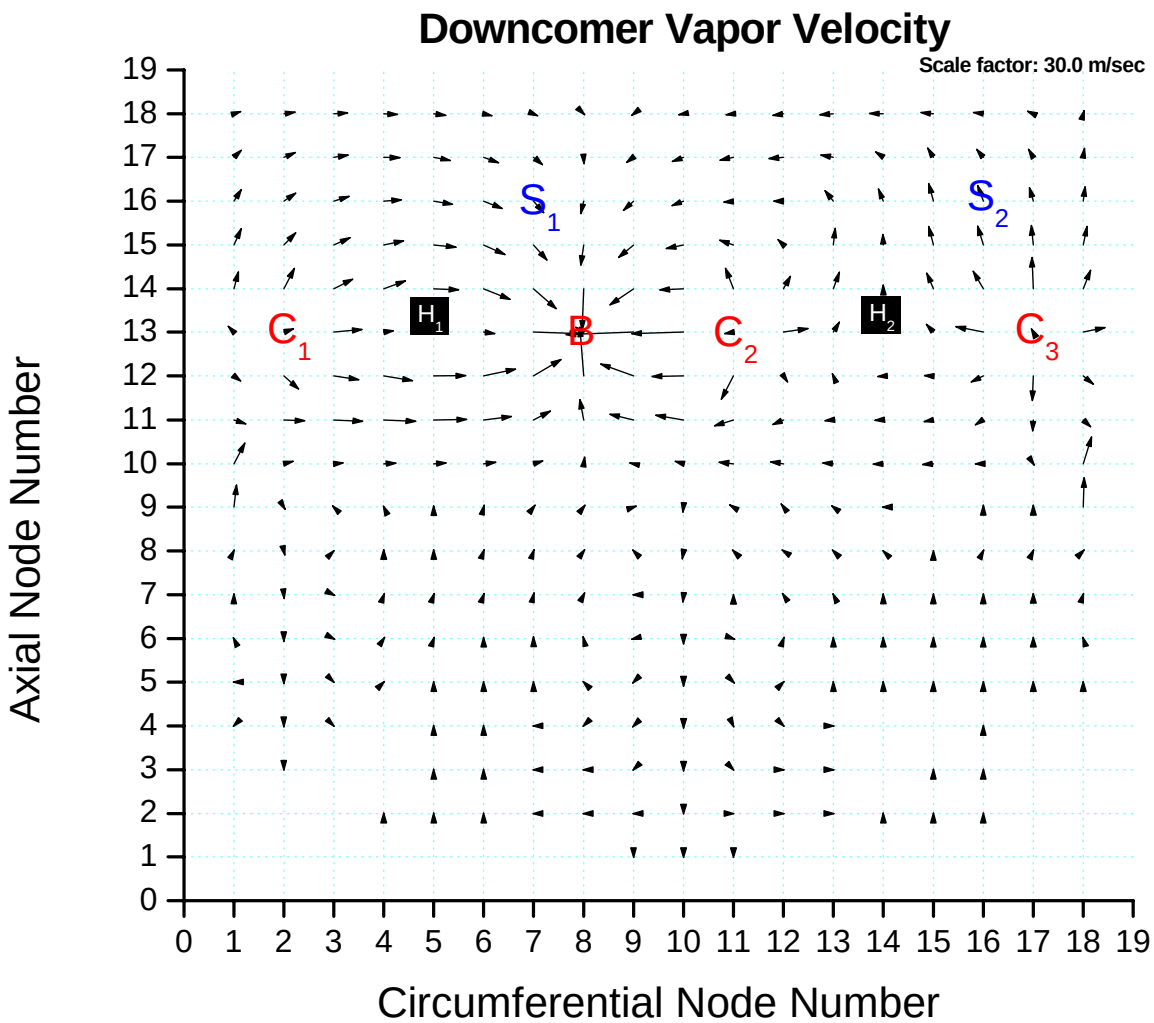
- Modeled APR-1400 to check
  - overall 3D calculation
  - 2D/3D combination
  - DVI modeling capability
  - D/C circulation
  - output processing technique set-up
- DIVA, MIDAS & scaled-up MIDAS to investigate
  - necessary DVI specific models
  - scale-up capability of RELAP5-MD
  - the implication of modified linear scale

Test Case #1

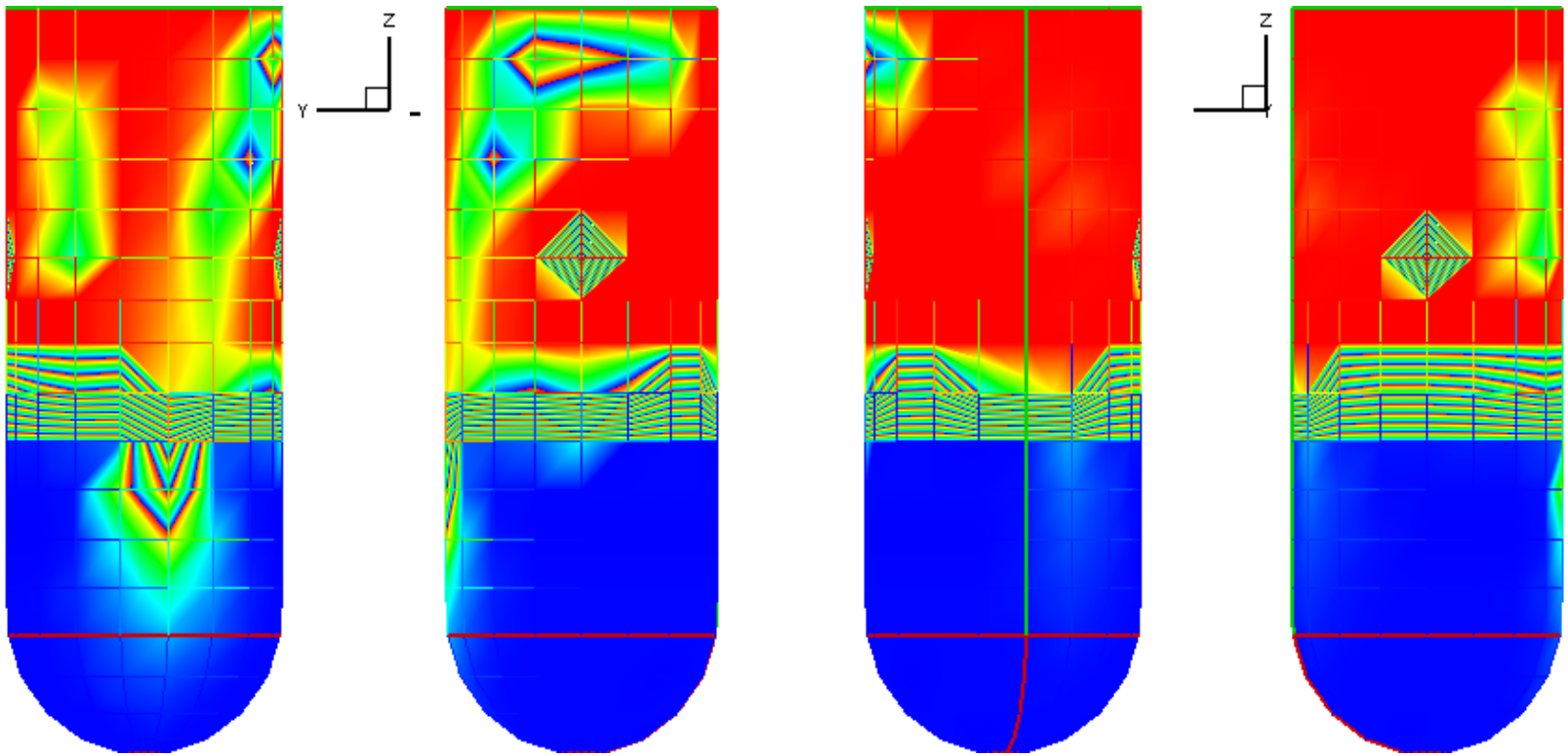
Modeled
APR-1400 D/C



Modeled APR-1400 D/C



Modeled APR-1400 D/C



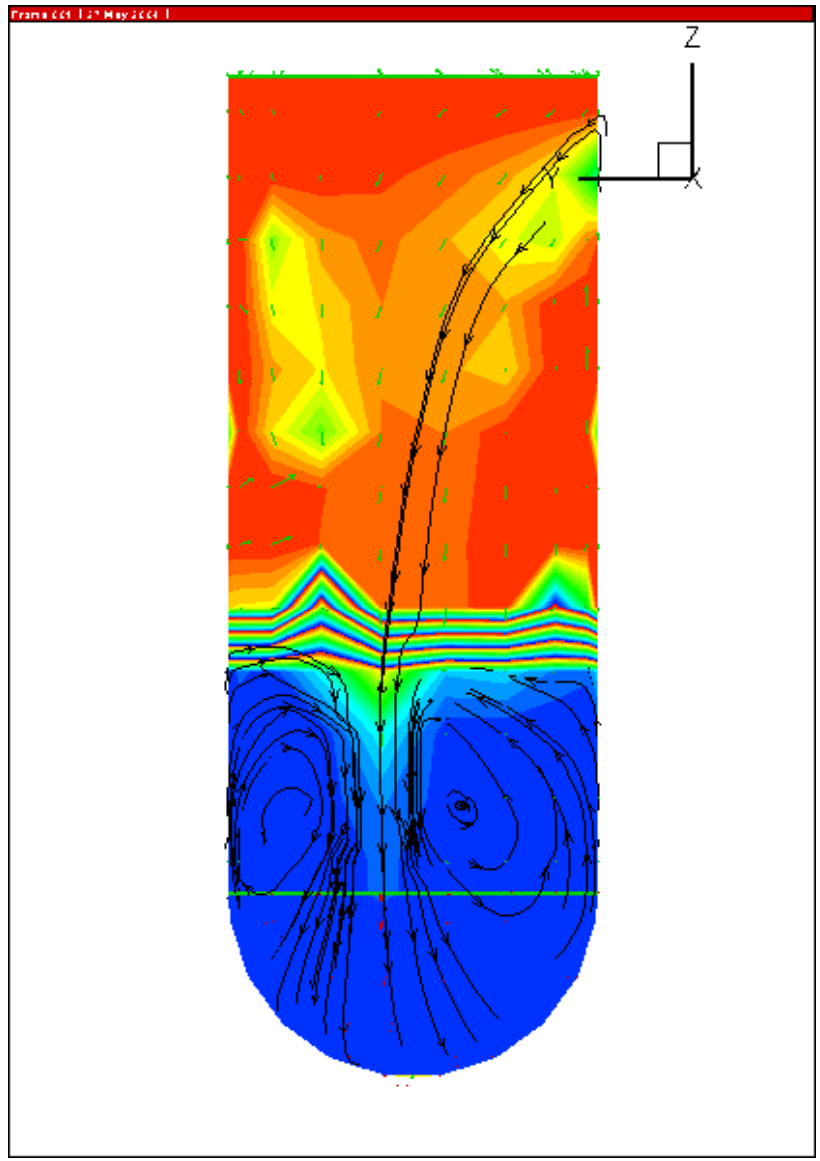
Downcomer Void Fraction Contour (550 sec)

Modeled APR-1400 D/C

Contour, Vector & Stream Line

reveal Global Circulation

in D/C and lower plenum



MIDAS Test Calculation

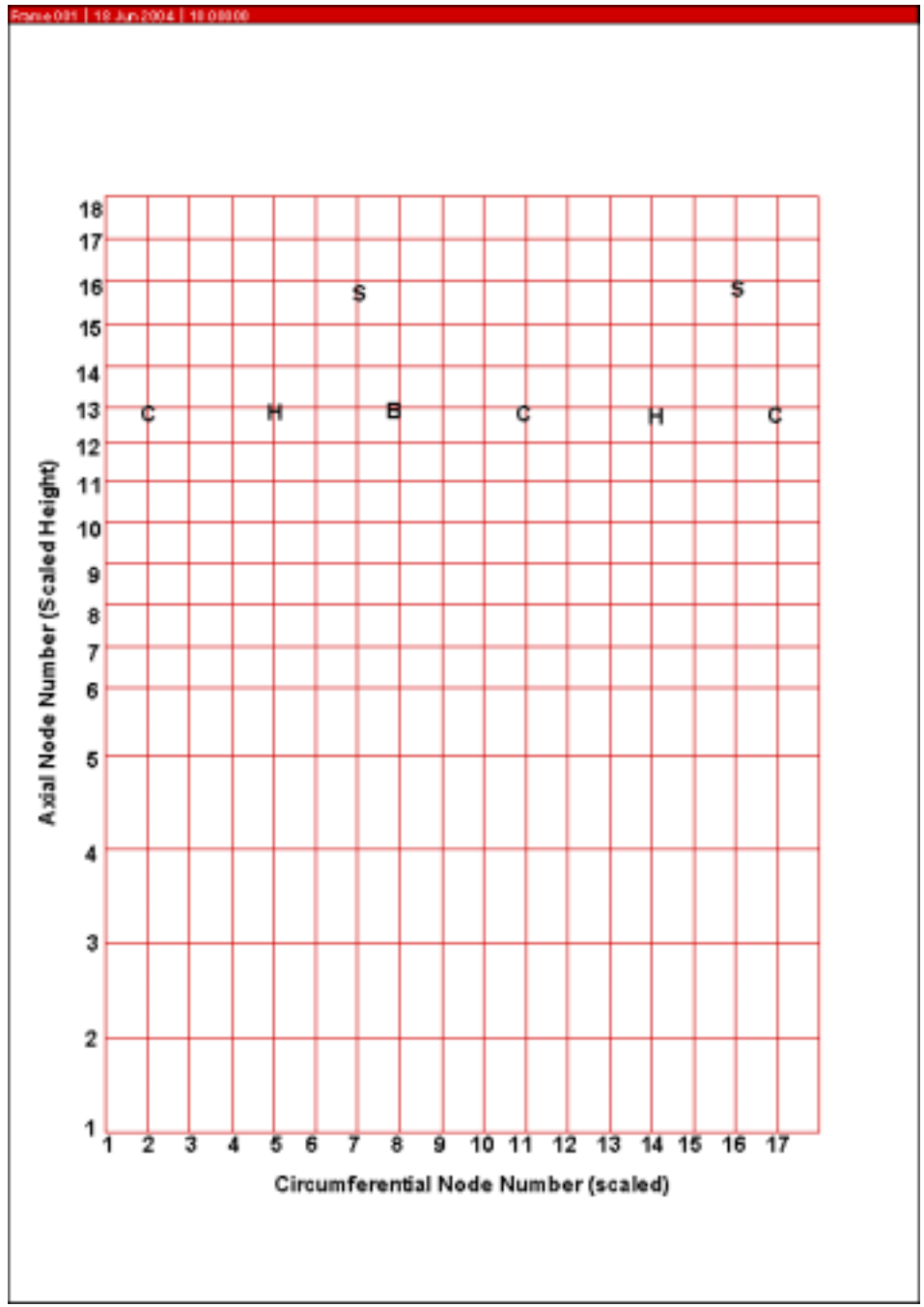
- 2D nodalization
  - 18 axial nodes and 18 circumferential nodes
- Flow Regime Map for Circumferential Junction
  - Horizontal to Vertical
- Simple Jet Model for SI
- special care for Break Junction
  - to reduce the user effects (=nodalization dependency)
  - no friction, junction length = gap width
- Scaled-up MIDAS test calculation
  - 4.93 modified linear scale

Nodalization for

DIVA

MIDAS

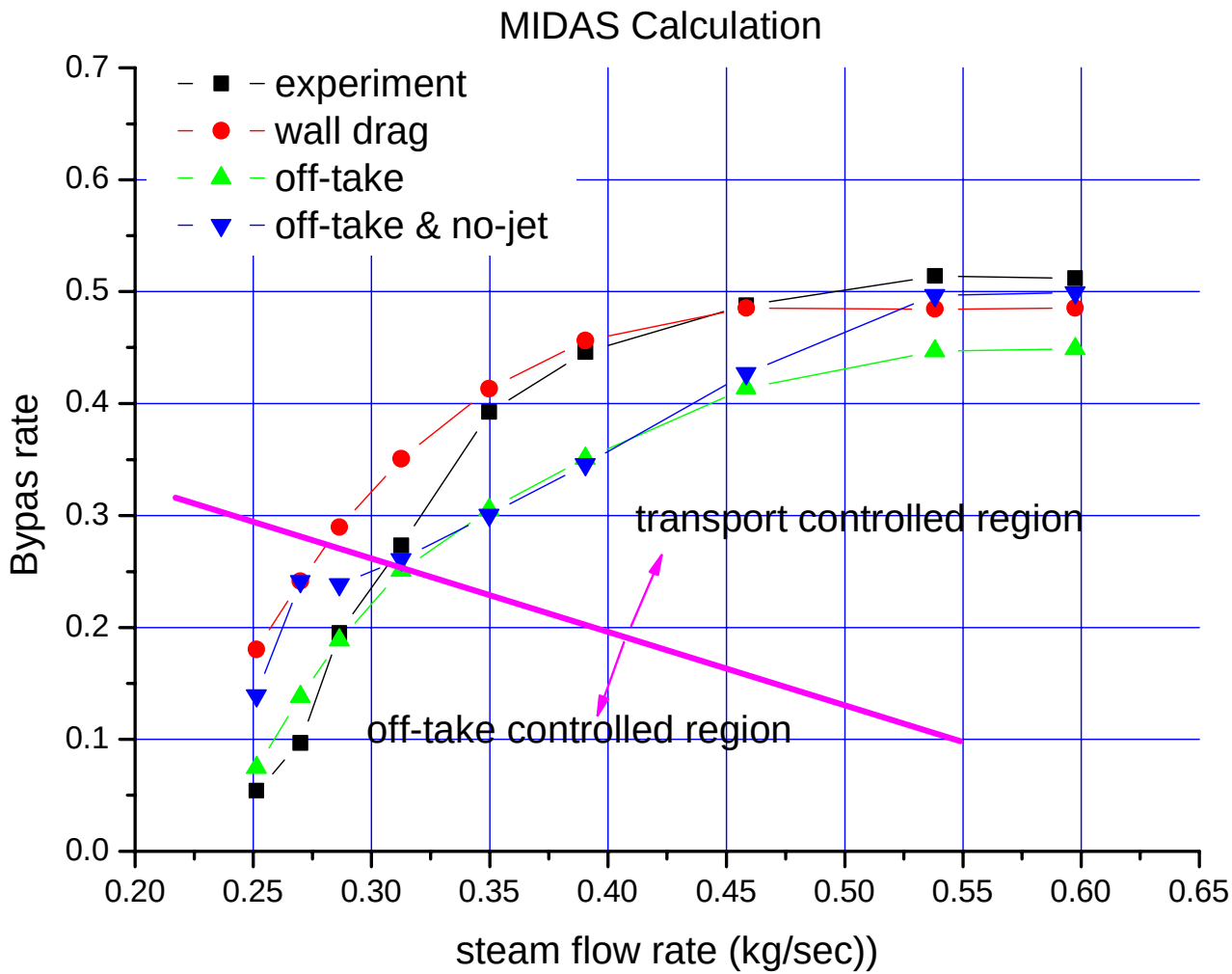
scaled-up MIDAS



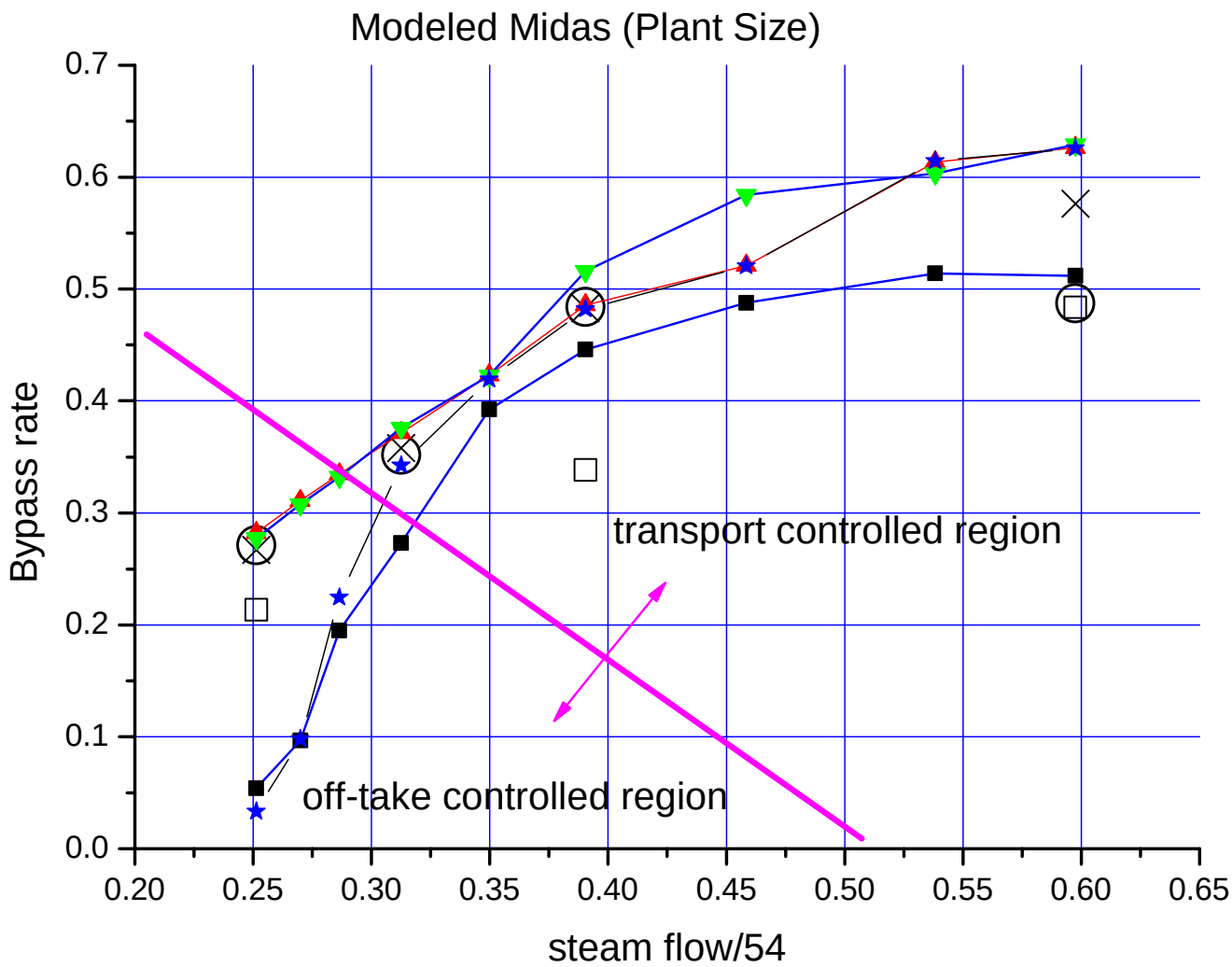
Major findings for MIDAS Test Calculation

- two distinct regions exist
  - off-take controlled region, transport controlled region
- test calculation shows
  - general scale-up capability in transport controlled region
  - some discrepancy in off-take controlled region
- at least three models are necessary
  - SI jet model, transport model, off-take model
- detailed investigation of critical velocity is necessary
- developed output processing technique is
  - valuable to get detailed ideas for future development

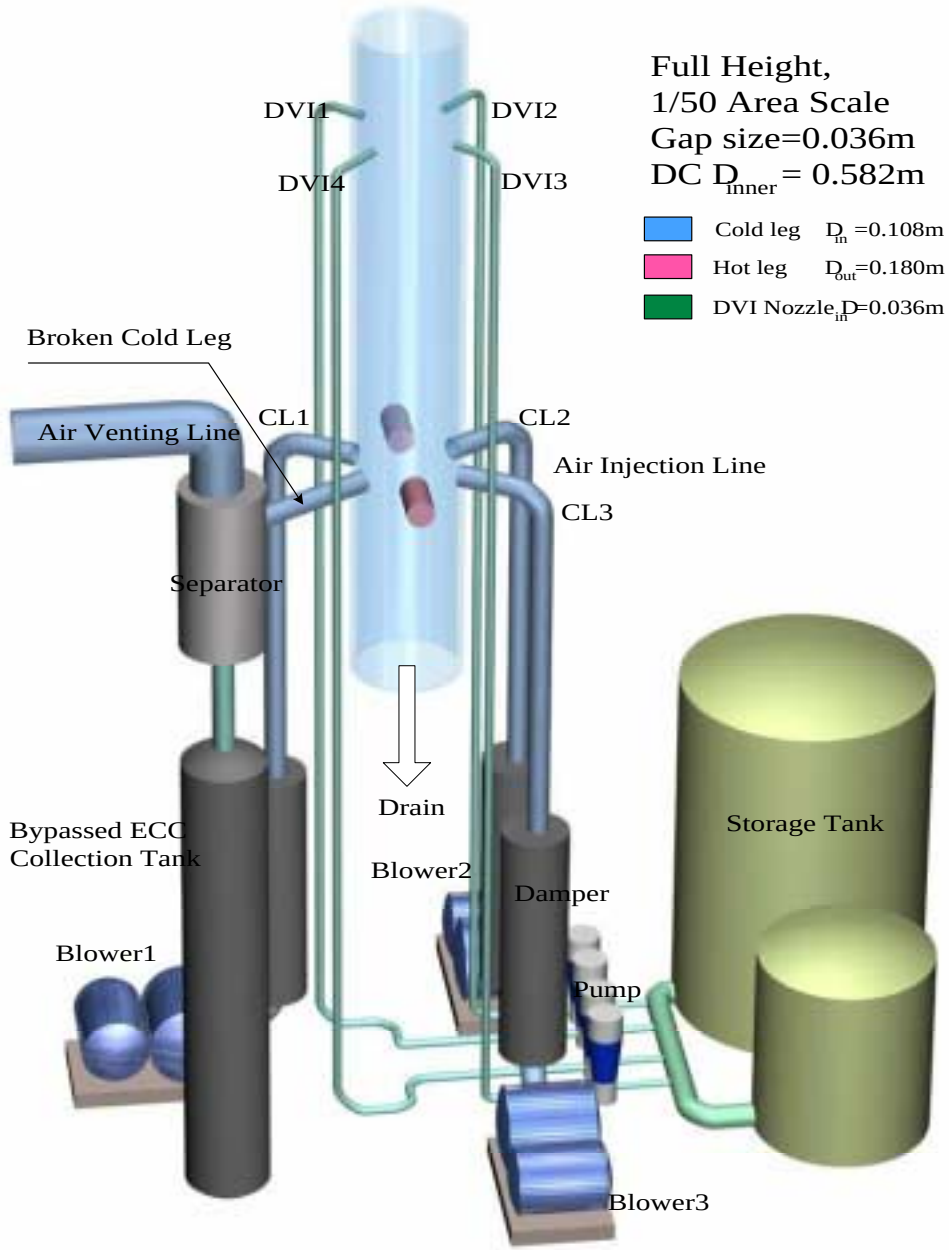
MIDAS Test Calculation



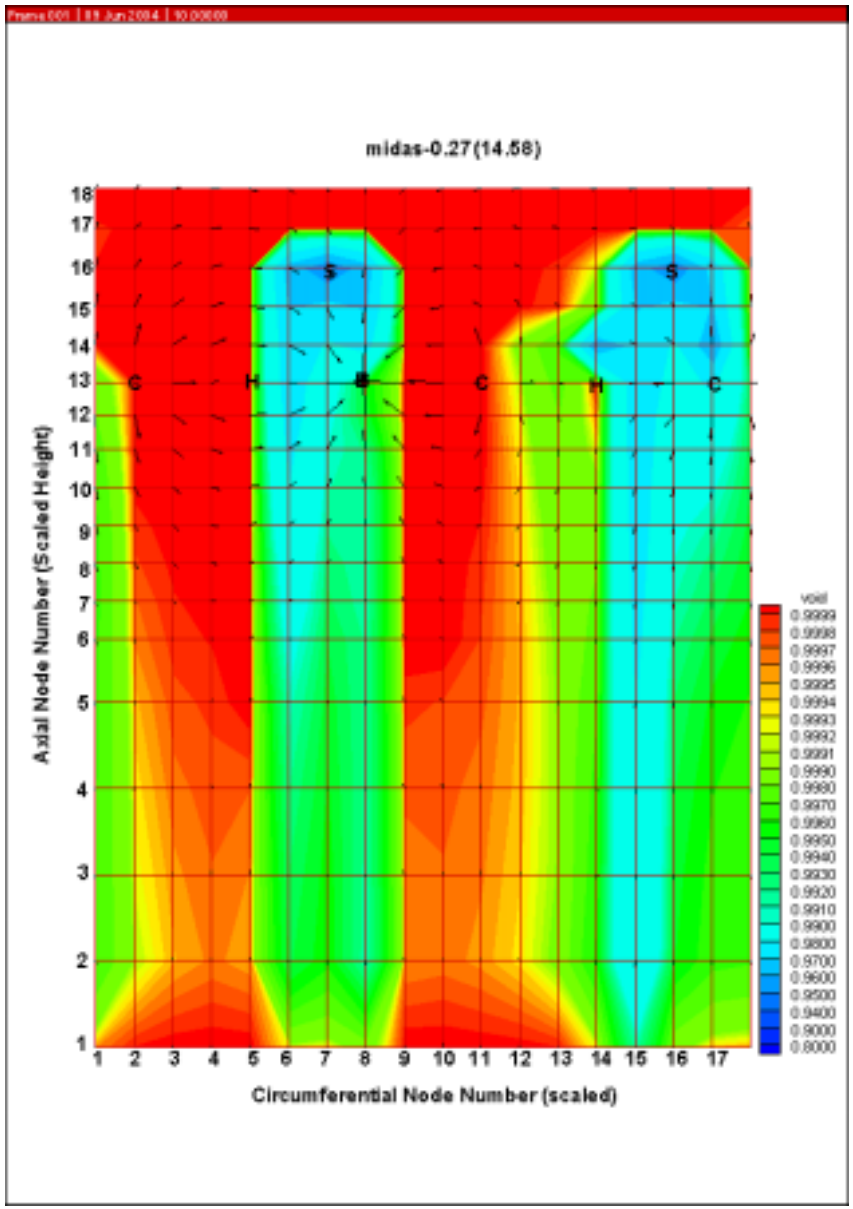
Modeled MIDAS Test Calculation



DIVA Test Calculation



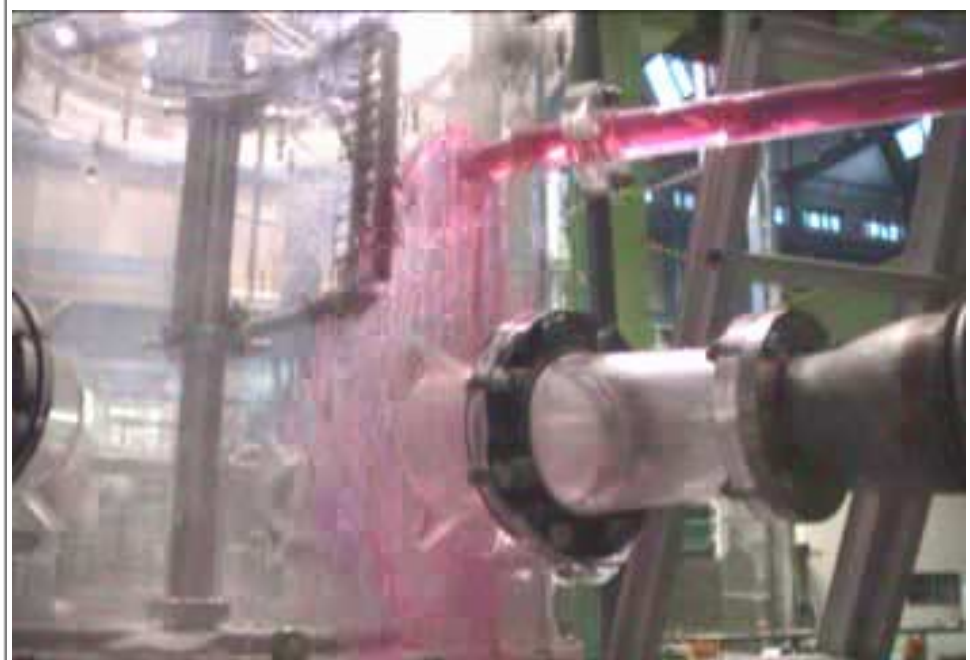
Results and Comparison (v_g=8m/s, v_f=0.91 m/s)



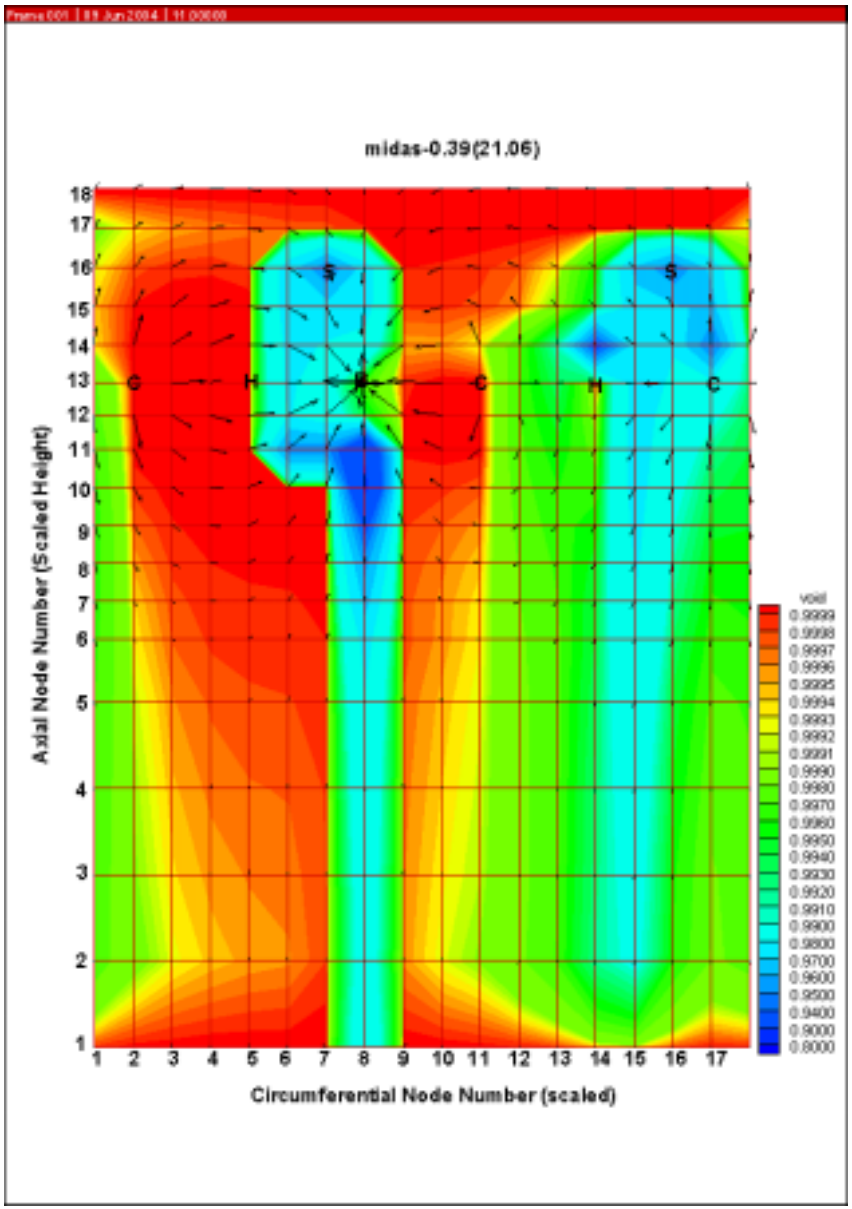
- reasonable prediction

  film width and shape

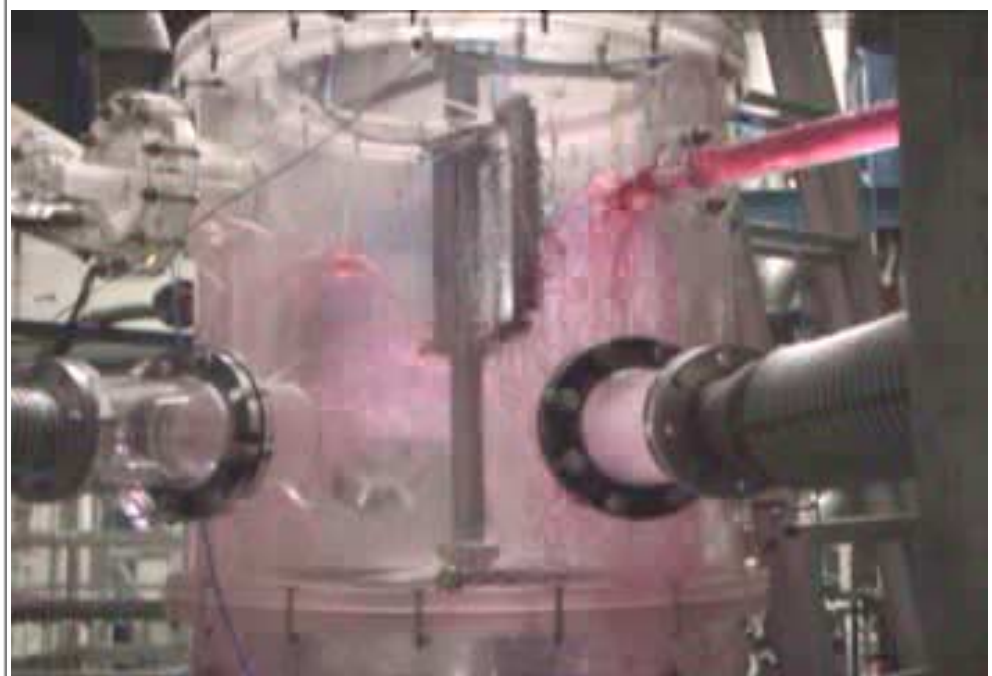
- relatively high down ward flow between HL and CL

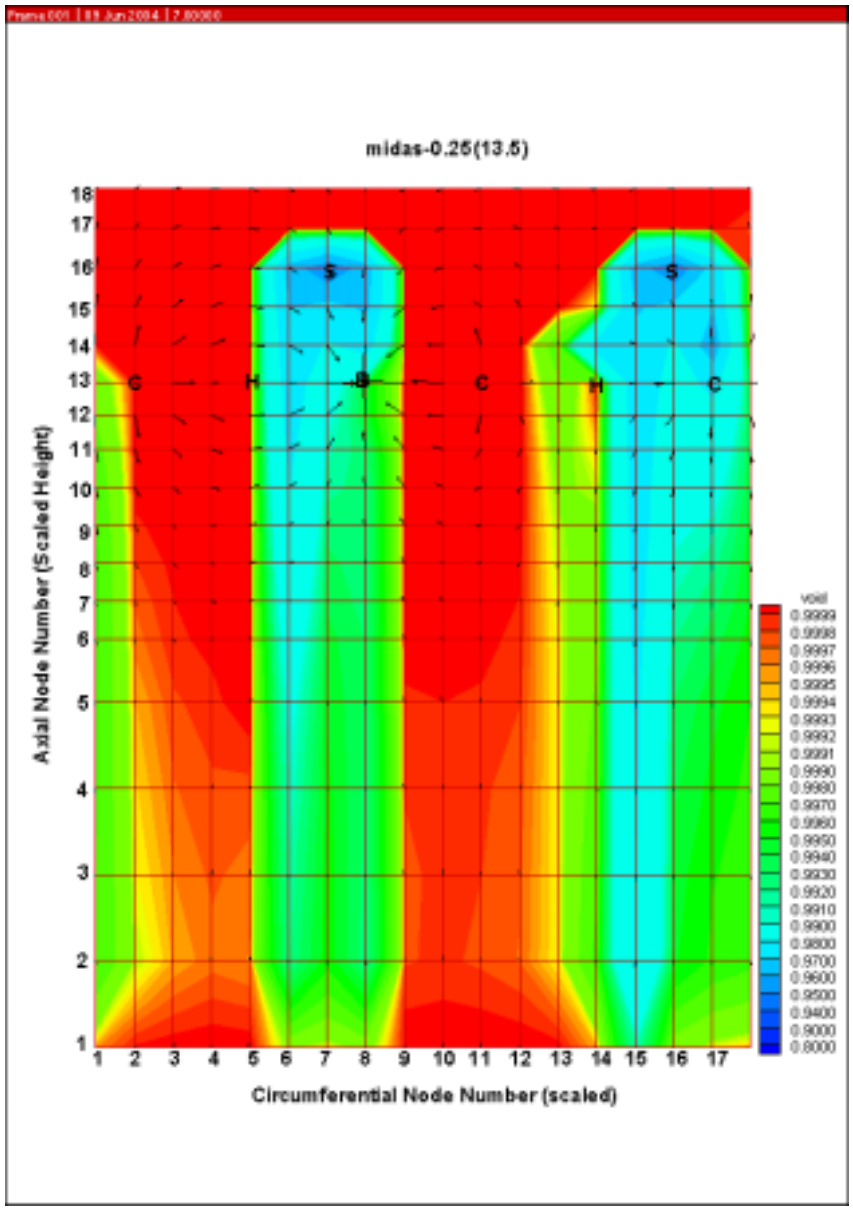


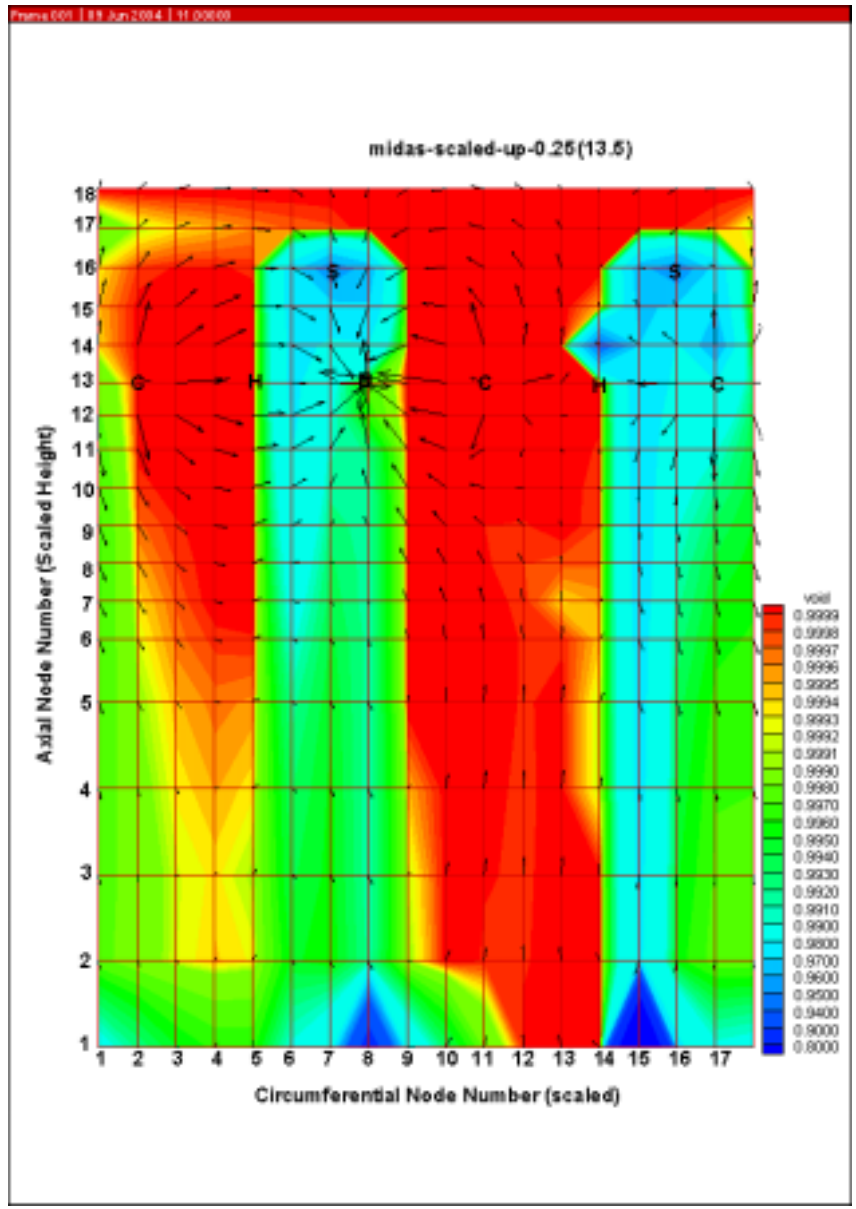
Results and Comparison (v_g=16 m/s, v_f=0.91 m/s)

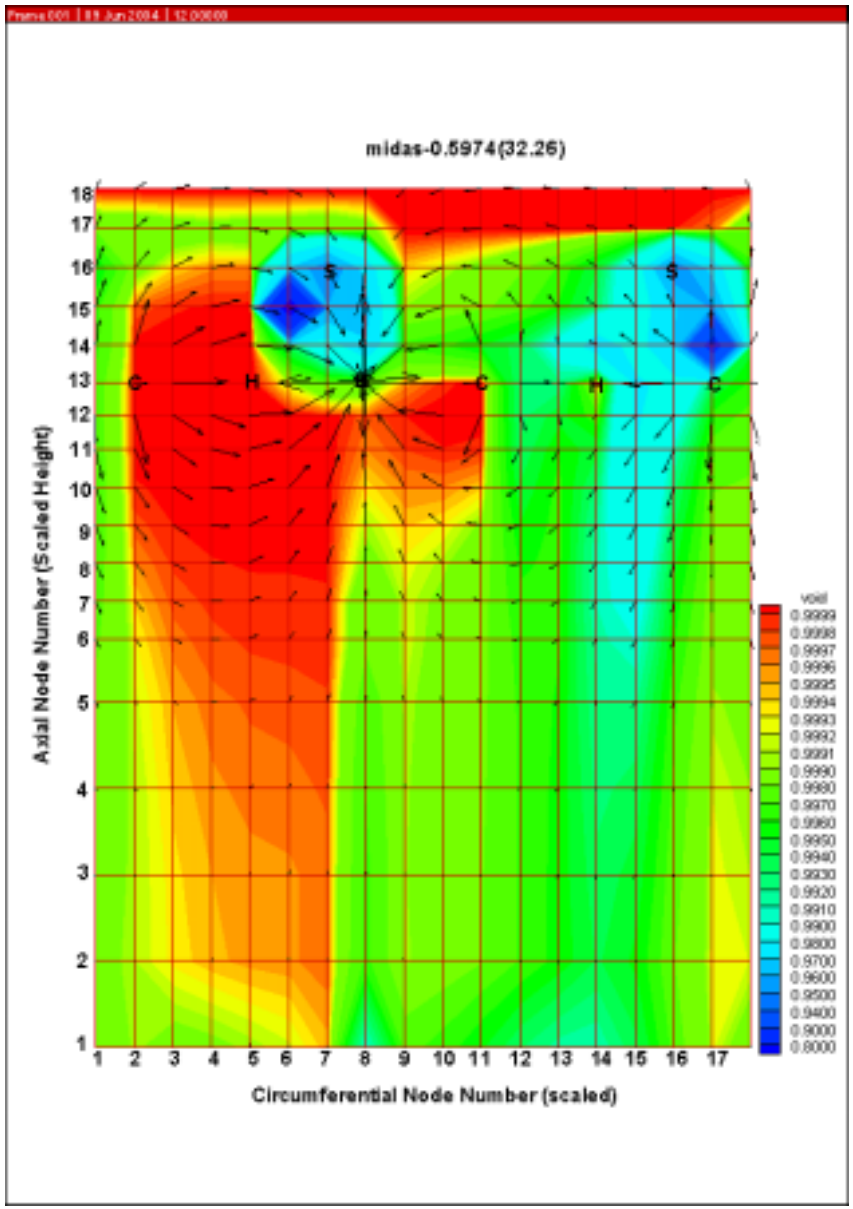


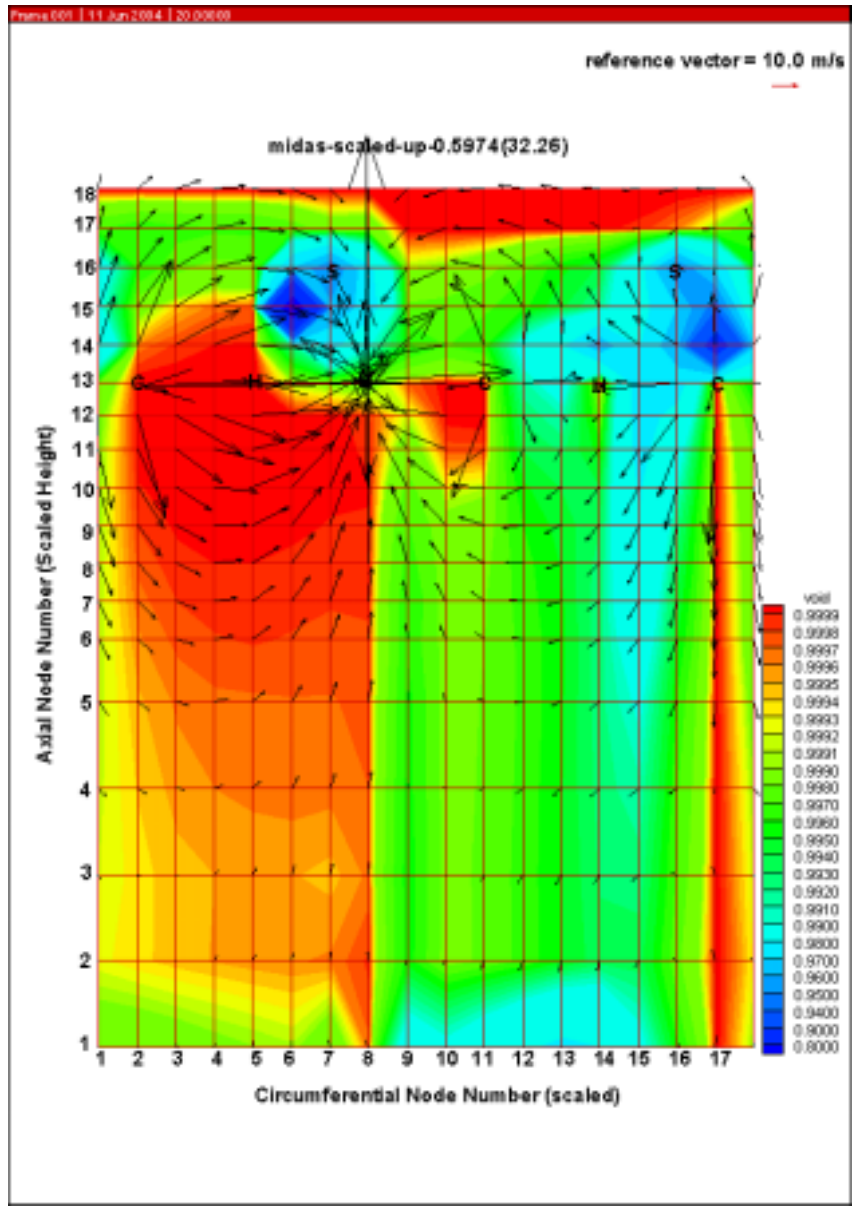
• reasonable prediction of water accujmulation at lower part of broken CL




midas-0.25(13.5)
Axial Node Number (Scaled Height)
Circumferential Node Number (scaled)
S
C
H
B
void


midas-scaled-up-0.25(13.5)
Axial Node Number (Scaled Height)
Circumferential Node Number (scaled)
S
C
H
B
void


midas-0.5974(32.26)
Axial Node Number (Scaled Height)
Circumferential Node Number (scaled)
S
C
H
void


reference vector = 10.0 m/s
midas-scaled-up-0.5974(32.26)
Axial Node Number (Scaled Height)
Circumferential Node Number (scaled)
S
C
H
void

Conclusion

- Development of RELAP5-MD
  - closed x-y geometry: OK
  - cylindrical geometry: OK
  - hemi-spherical geometry: OK
  - combination of hemi-spherical and cylindrical geometry: OK
- Successful Application
  - MIDAS, DIVA, Modeled APR-1400 D/C
  - Flexibility of Input Generator: OK
- Setup Output Processing Technique: OK
  - ORIGEN, TECPLOT
- Newly introduced TRACE ?
- Or Massively experienced RELAP5-MD ?

Conclusion

- MIDAS & DIVA Test Calculations show that
  - Jet Model is necessary
  - Off-take Model is necessary
  - Transport Properties should be adjusted
- Modeled APR-1400 Test calculation shows that
  - Global D/C circulation is possible
  - More realistic calculation(with core) is necessary