DE LA RECHERCHE À L'INDUSTRIE

COMBUSTION MODELING IN LARGE SCALE VOLUMES

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BACKGROUND

Three Mile Island accident in 1979 had demonstrated and Fukushima accident in 2011 recalled that hydrogen combustion and explosion can have a dramatic effect on the nuclear power plants (NPPs).

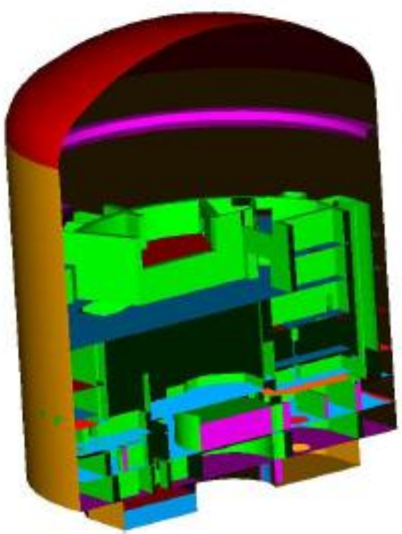
Analysis of such large scale scenarios is a relevant issue, which might be accessed through CFD modeling.

LARGE SCALE MODELING ISSUES

Various turbulent and chemical scales

Various gas dynamic and flame propogation regimes

Nuclear Reactor Containment: 50000-100000 m^3 with length scales between cm to meters



Hydrogen/Air/Steam premixed flame

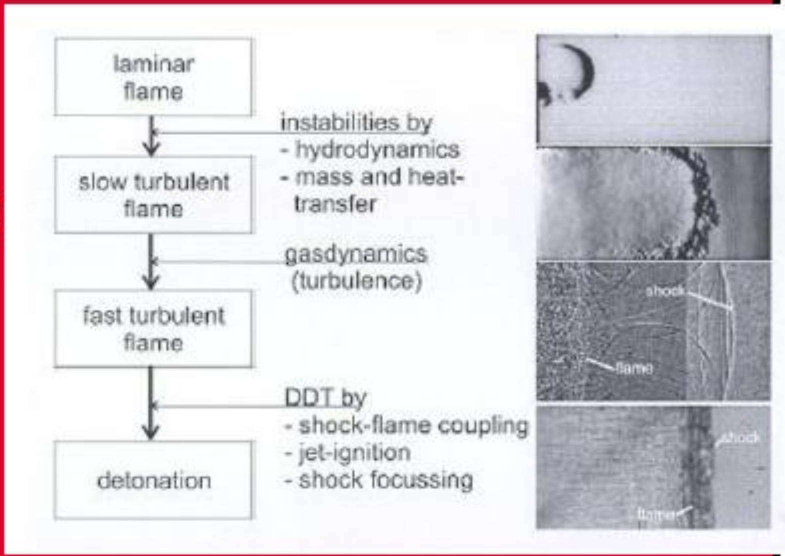
~ m/s

Strong Acceleration

~600 m/s

1-2 km/s

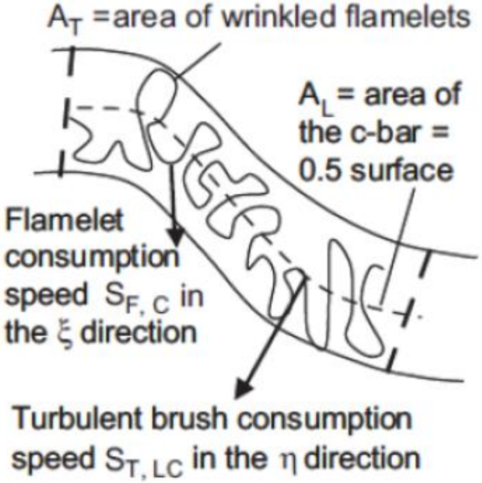
$\Delta p \sim \rho V_F^2$



LARGE SCALE MODELING ISSUES (2)

Modelling in nuclear reactor containment = 2 possible solutions

- Adaptative Mesh Refinement (AMR) [GAMEZO2008]
- Interface Propagation Model: $\Delta x >> \delta_L$ phenomena dealing with flame propagation are not modelled => Flame velocity correlation



$$\frac{S_T}{S_{L0}} = \frac{A_T}{A_L}\frac{\bar{S}_{F,C}}{S_{L0}} = \frac{A_T}{A_L} I_0.$$

$$\frac{S_T}{S_{L0}} = F(\Theta_T, \Theta_{F-ACC}, \Theta_{F-SC}, \Theta_{inst}, \ldots\ldots)$$

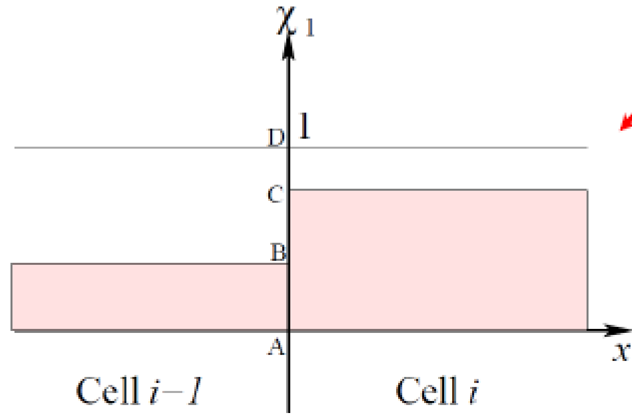
RDEM = Reactive Discrete Equation Method

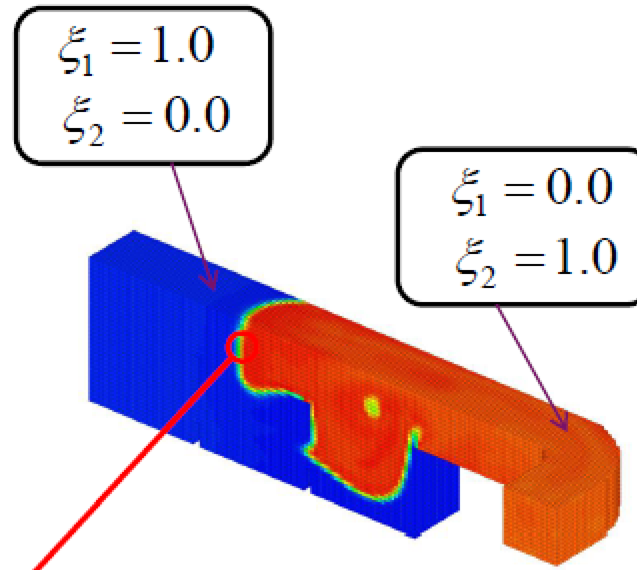
Two-phase Euler equations +

ξ_k - Volume fraction of phase k

$$\frac{\partial}{\partial t}(\xi) + \vec{D} \cdot \vec{\nabla} \xi = 0$$

$$\vec{D} = \vec{w} + K_0 \vec{n}$$





MODEL 1:

Model for the deflagration phase:

K_0 reaction wave velocity [BAUWENS2010]

$$K_0 = S_L^0 \Theta_{TH} \Theta_{TURB} \Theta_{WRIN}$$

3 contributions : thermodynamic, turbulence, flame wrinkling

$$\Theta_{TH} = \left(\frac{P}{P_0}\right)^{\alpha} \left(\frac{T}{T_0}\right)^{\beta}$$ [MALET2004]

$$\Theta_{TURB} = 1 + 1.334\gamma \Theta_{USER} \left(\frac{u'}{S_L^0}\right)^{0.55} \left(\frac{L_t}{\delta_L}\right)^{0.15} (\mathrm{Le})^{-0.3}$$ [BRADLEY1992]

$$L_t = 0.2\Delta \qquad u' = L_t \sqrt{2 S_{ij} S_{ij}} \qquad S_{ij} = \frac{1}{2}\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right]$$

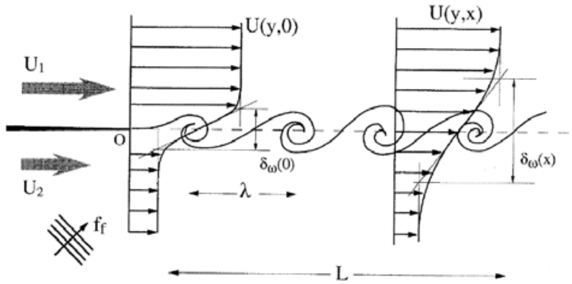
$$\Theta_{PLIS} = \left(\frac{R}{R_0}\right)^{1/3}$$ [GOSTINTSEV1987]

MODEL FOR K0: Lt VARIABLE IN 2D

MODEL 2:

$$K_0 = S_L^0 \Theta_{TH} \Theta_{TURB} \Theta_{WRIN}$$

$$\Theta_{TURB} = 1 + 1.334\gamma \left(\frac{\mathrm{u'}}{S_L^0}\right)^{0.55} \left(\frac{L_t}{\delta_L}\right)^{0.15} (\mathrm{Le})^{-0.3}$$



$$\delta_\omega(x) = \frac{\Delta U}{\max\limits_y \left(\frac{\partial U}{\partial y}\right)}$$

BROWN et ROSHKO 1974

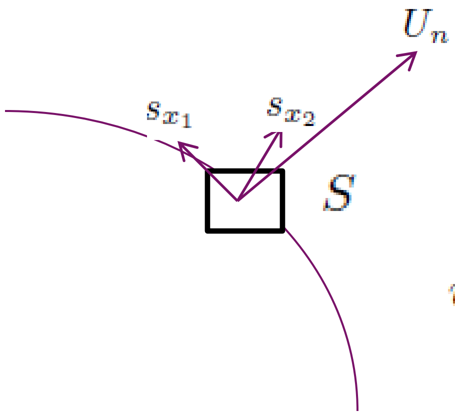
$$L_t = \frac{U}{\frac{dU}{dy}}, \quad \frac{dU}{dy} > \frac{U_c}{\Delta}$$

$$L_t = C_u \Delta, \quad \frac{dU}{dy} < \frac{U_c}{\Delta},$$

Cu = 1.0

MODEL 3:

$$K_0 = S_L^0 \Theta_{TH} \Theta_{TURB}$$ **!**



$$\Theta_{TURB} = 1 + 1.334\gamma \left(\frac{\text{u'}}{S_L^0}\right)^{0.55} \left(\frac{L_t}{\delta_L}\right)^{0.15} (\text{Le})^{-0.3}$$

$$u_n = u_{x_1} \cdot n_{x_1} + u_{x_2} \cdot n_{x_2} + u_{x_3} \cdot n_{x_3}$$

Uc

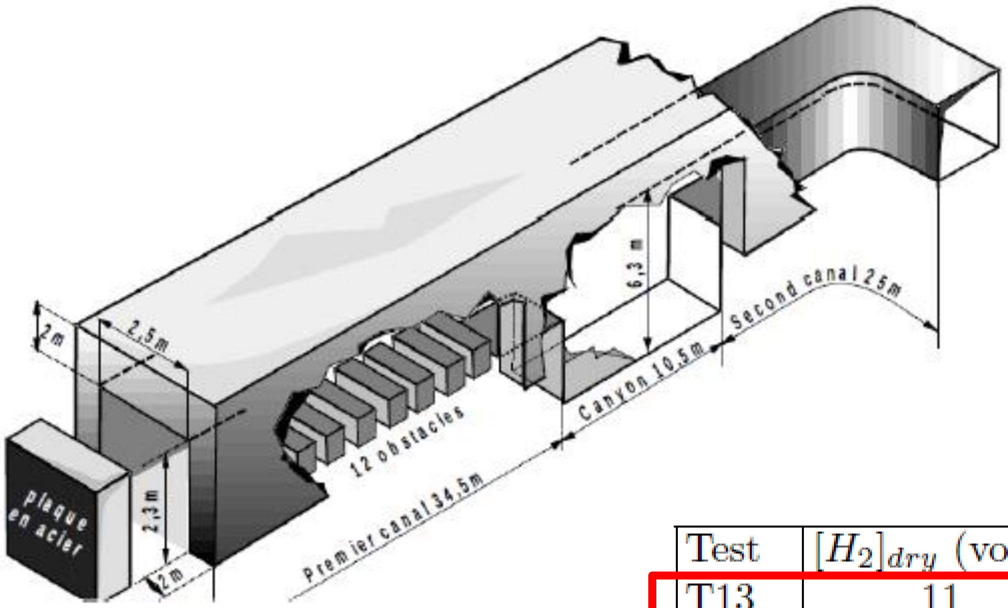
$$L_t = \frac{|U_n \cdot \vec{n}|}{||\vec{\nabla}_S \vec{U}||}, \quad ||\vec{\nabla}_S \vec{U}|| > \frac{b S_L^0}{\Delta}$$

where $\vec{\nabla}_S \vec{U} = \vec{\nabla} \vec{U} - \vec{n} \left(\vec{n} \cdot \vec{\nabla} \vec{U}\right)$

$$L_t = C_u \Delta, \quad ||\vec{\nabla}_S \vec{U}|| < \frac{b S_L^0}{\Delta},$$

Cu = 1.0

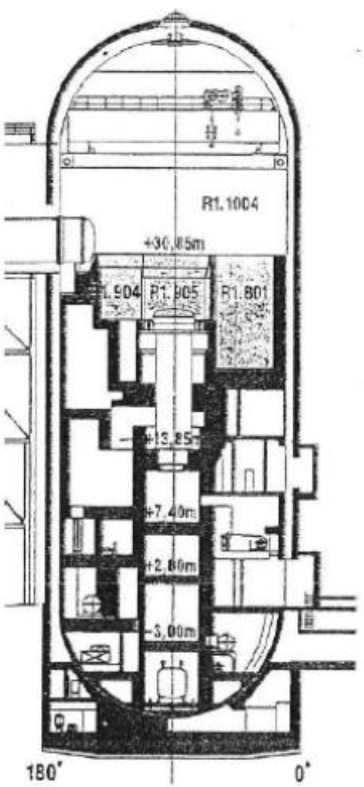
RUT FACILITY



Test	$[H_2]_{dry}$ (vol%)	$[H_2O]$ (vol%)	T (K)	Comment
T13	11	0	283	Fast flame
T22	14	0	283	DDT
T23	11.2	0	283	Fast flame
STM7	17.5	25.7	362	Fast flame
STM3	16.9	15.1	356	DDT
STM2	14.7	14.8	363	Fast flame
STH9	10.1	6.7	364	Slow flame

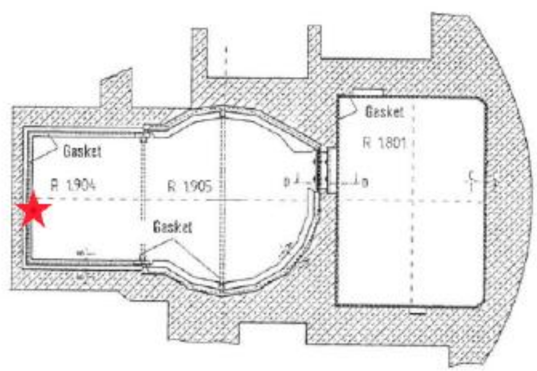
TMI →

HDR, FMGlobal and other FACILITIES

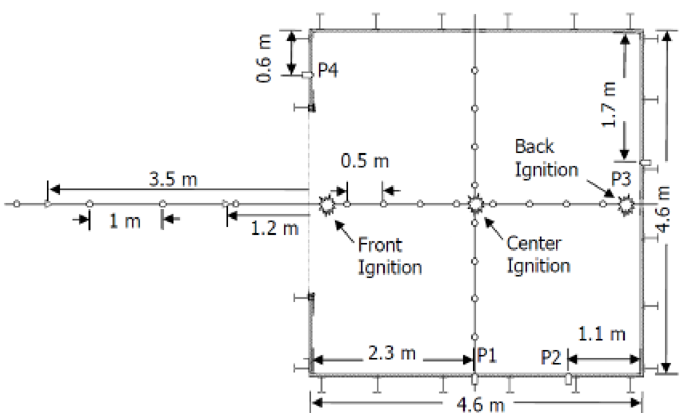


HDR

Room	Length (m)	Width (m)	Height (m)	Volume (m^3)
R1-904	5.5	5.5	4.65	140
R1-905	4.1	4.0	4.55	75
R1-801	7.0	5.5	9.50	330

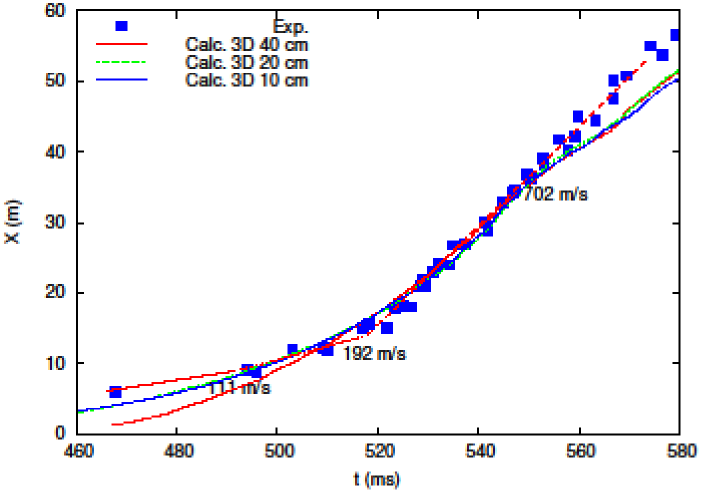


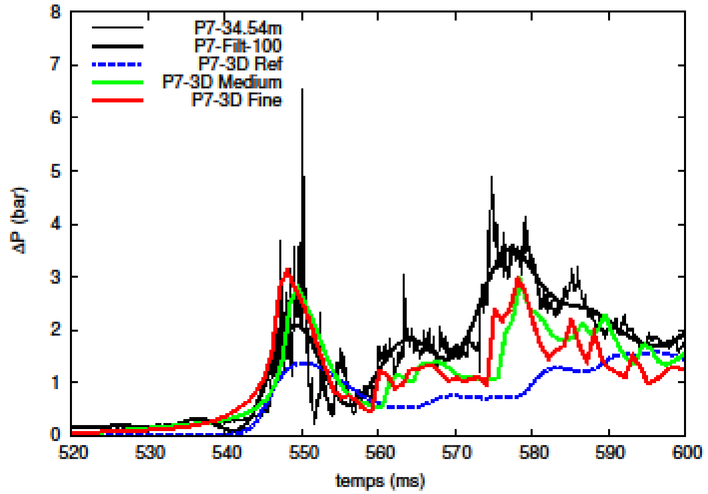
FMGlobal

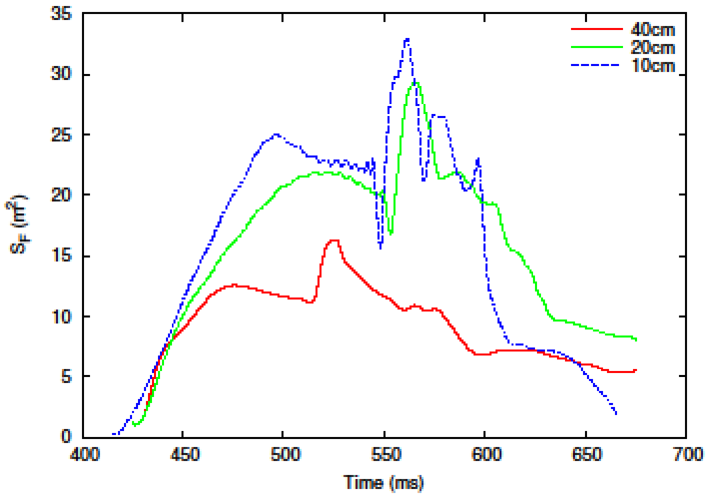


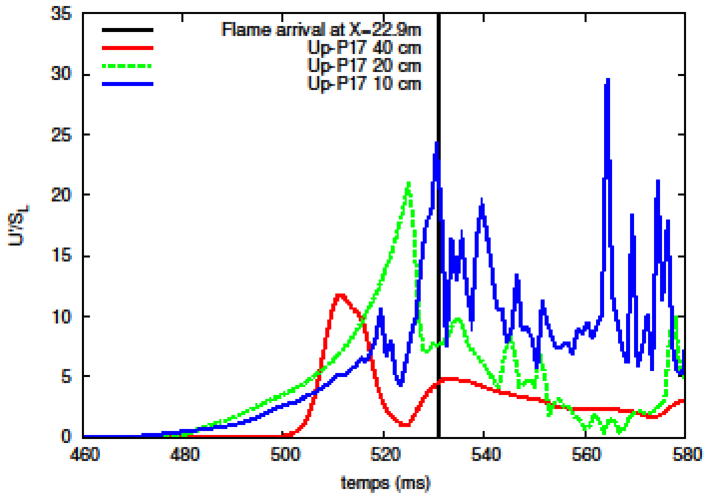
+ DRIVER, ENACCEF, BATELLE, THAI

STM7, MODEL 1: TD diagram, pressure, surface, u’

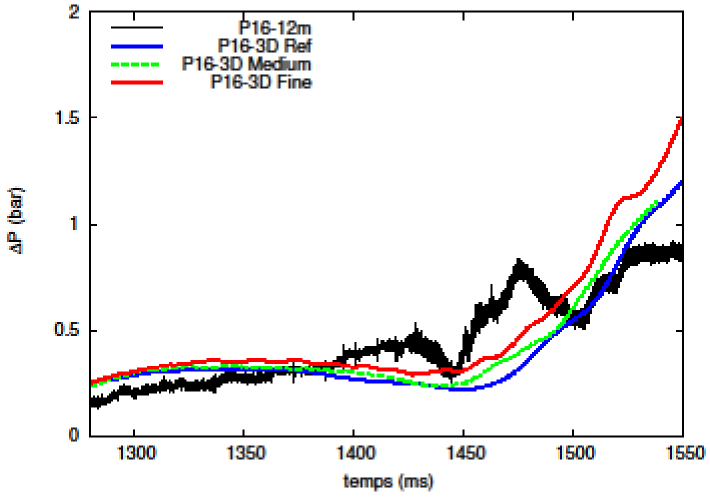


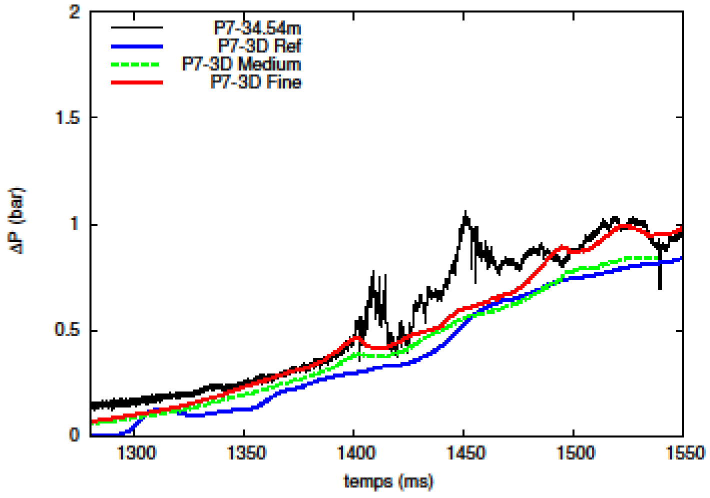


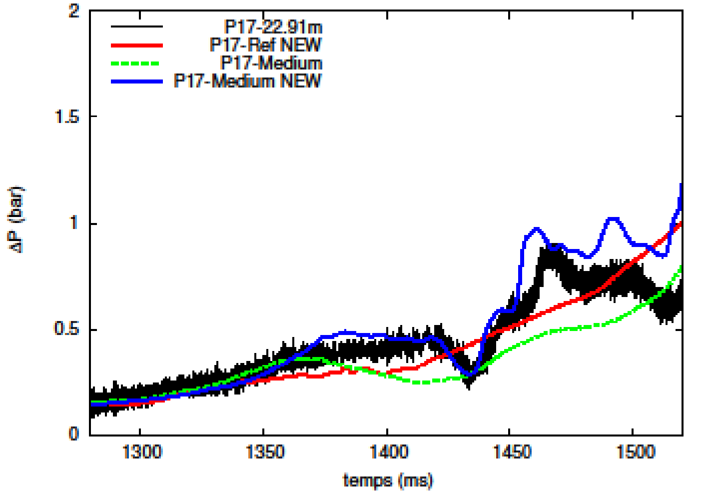


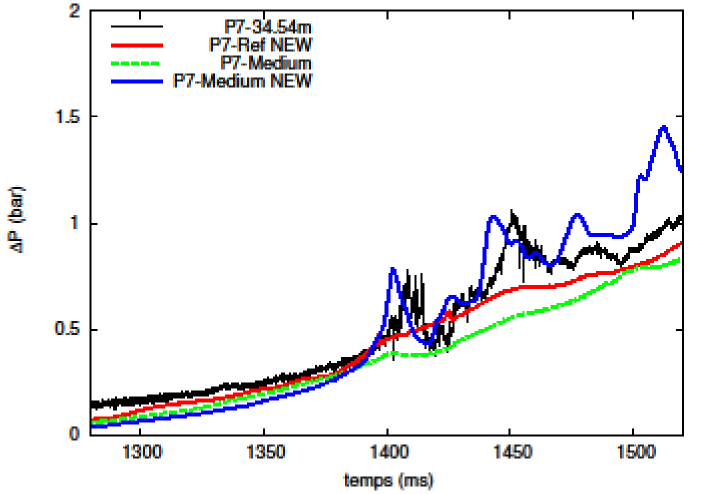


STH9, MODEL 1 and MODEL 2: Pressure curves

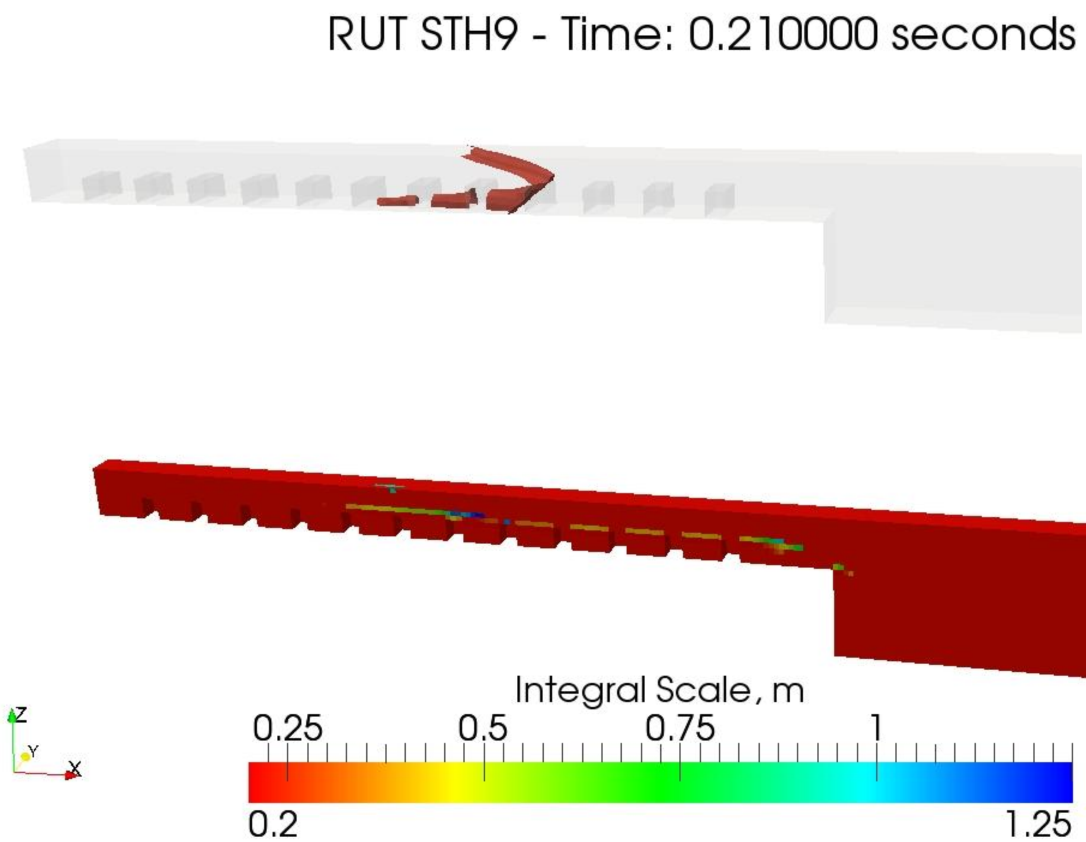


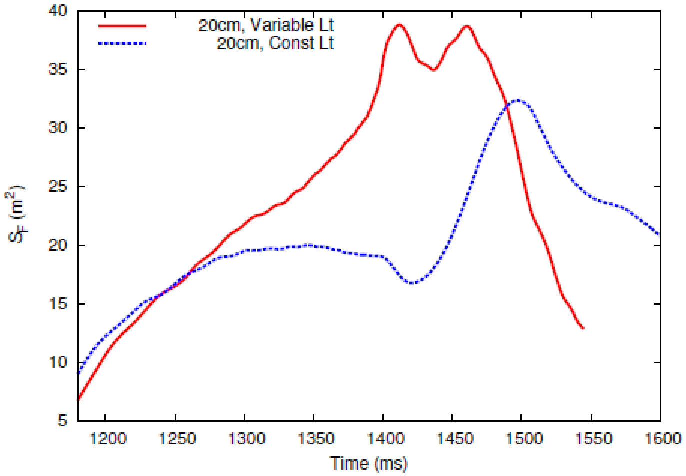






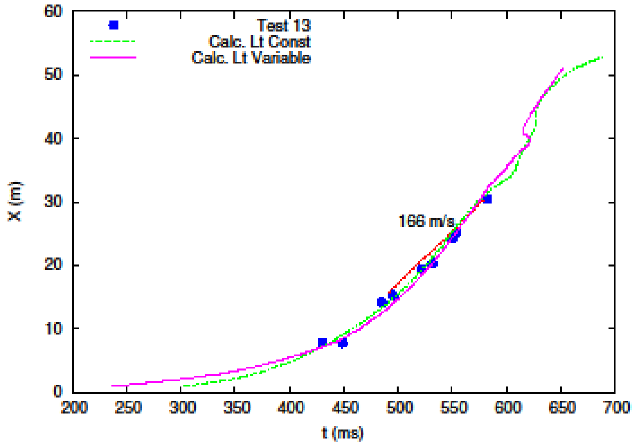
STH9, MODEL 2: Integral scale



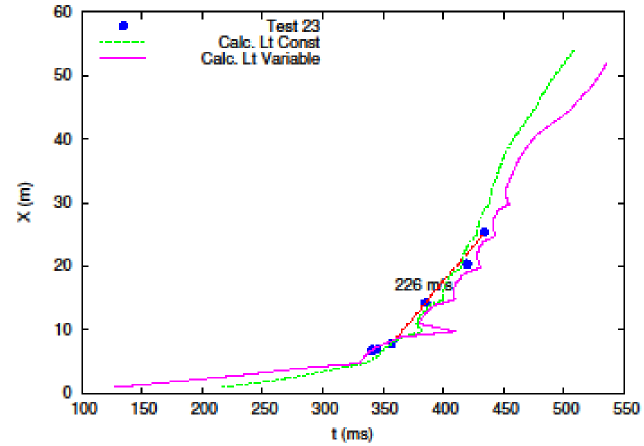


SOME OTHER RUT TESTS

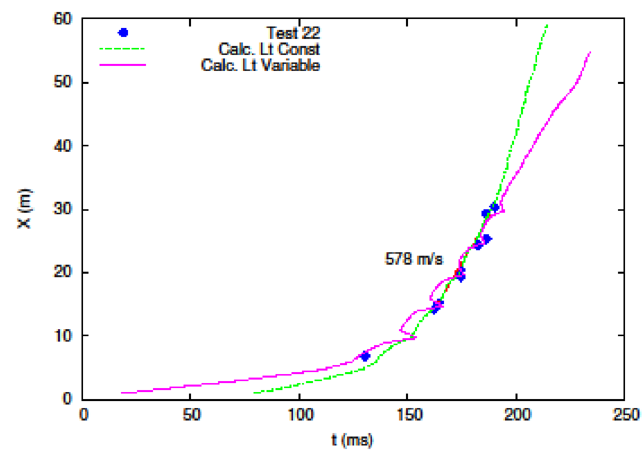
T13 ($X_{h2} = 0.11$):BR=0.3



T23($X_{h2} = 0.112$): BR=0.6

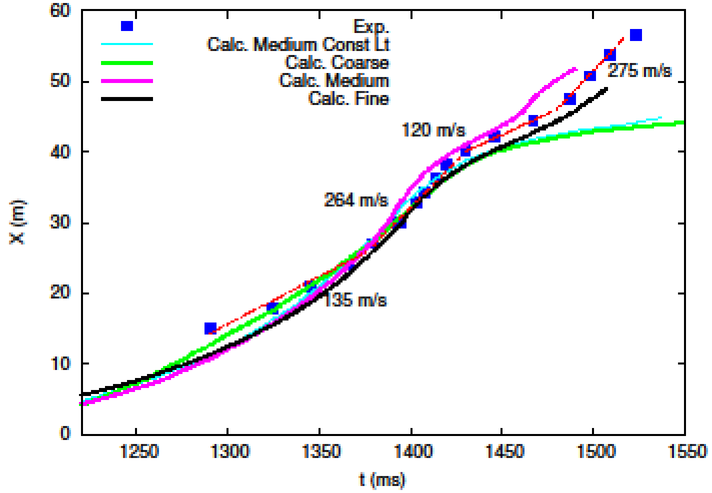


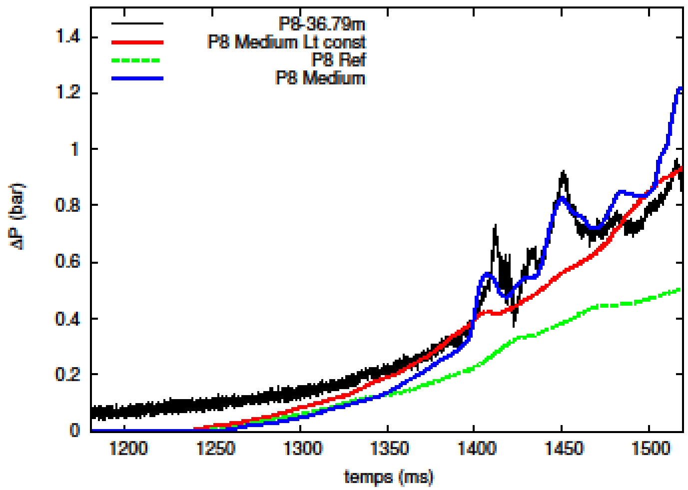
T22($X_{h2} = 0.14$): BR=0.6

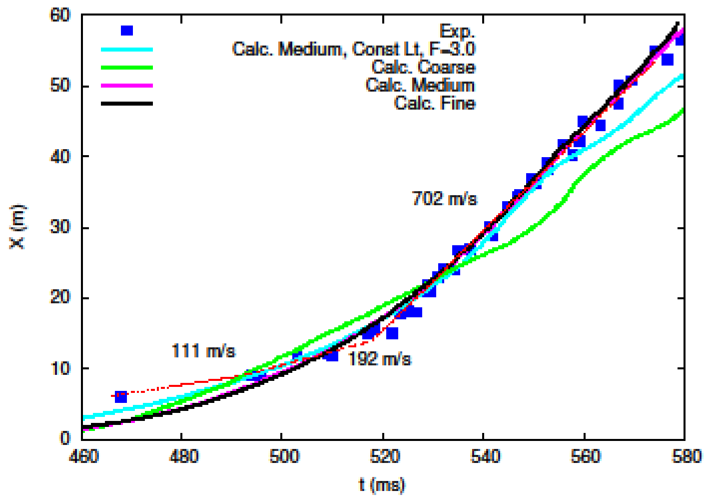


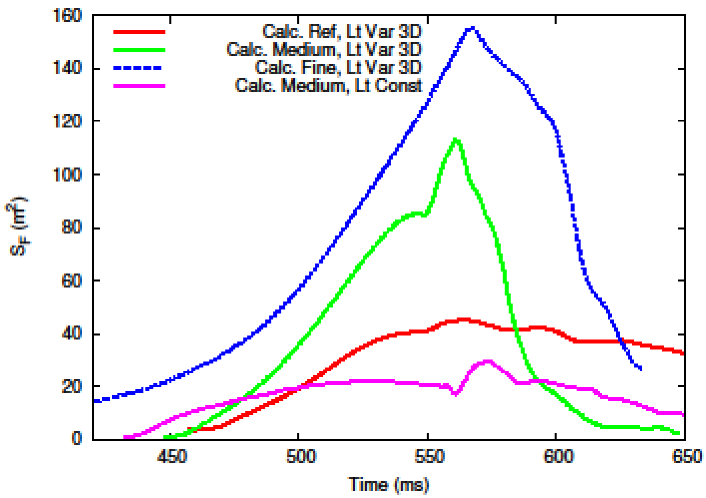
User factor in Model 1 was influenced by the hydrogen content.
Same is true for Uc parameter in Model 2.
Thus, in Model 3: Uc = f(S_L)

STM7 and STH9, MODEL 3: TD diagram and pressure



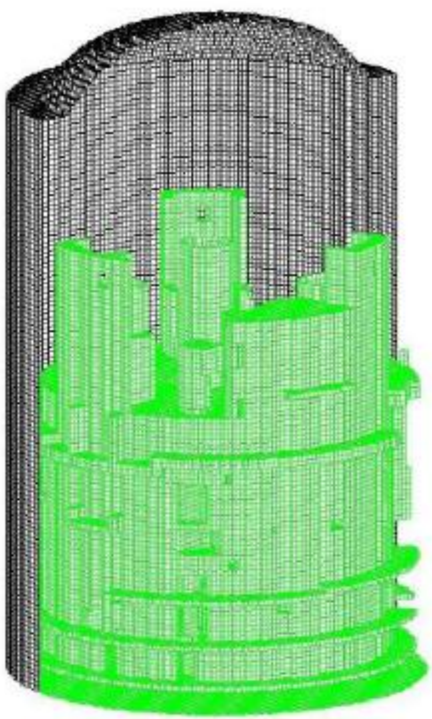




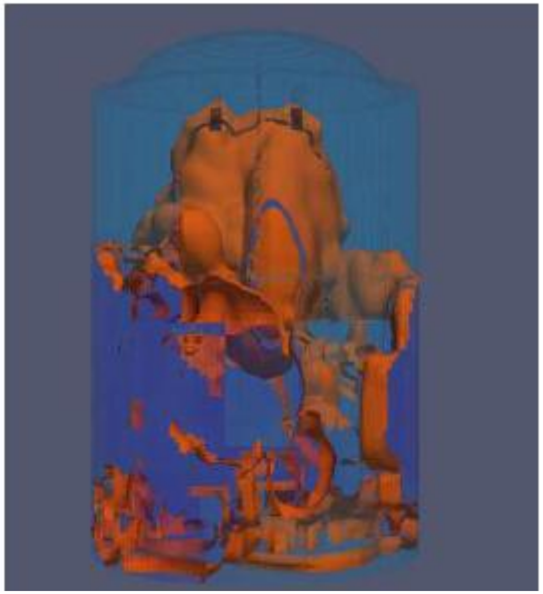


CONCLUSIONS

- **Hydrogen combustion in NPPs using RDEM with three K0 Models.**
- **Large set of experiments has been used to calibrate parameters of these models. Effects of geometry, BR, hydrogen/steam content, concentration gradients, etc. were considered.**
- **Modeling of severe accidental scenarios in real-scale NPPs is currently underway.**



Flame surface



500 kcells – 4 Mcells

Pressure