Numerical Simulation of the Laminar Hydrogen Flame in the Presence of a Quenching Mesh

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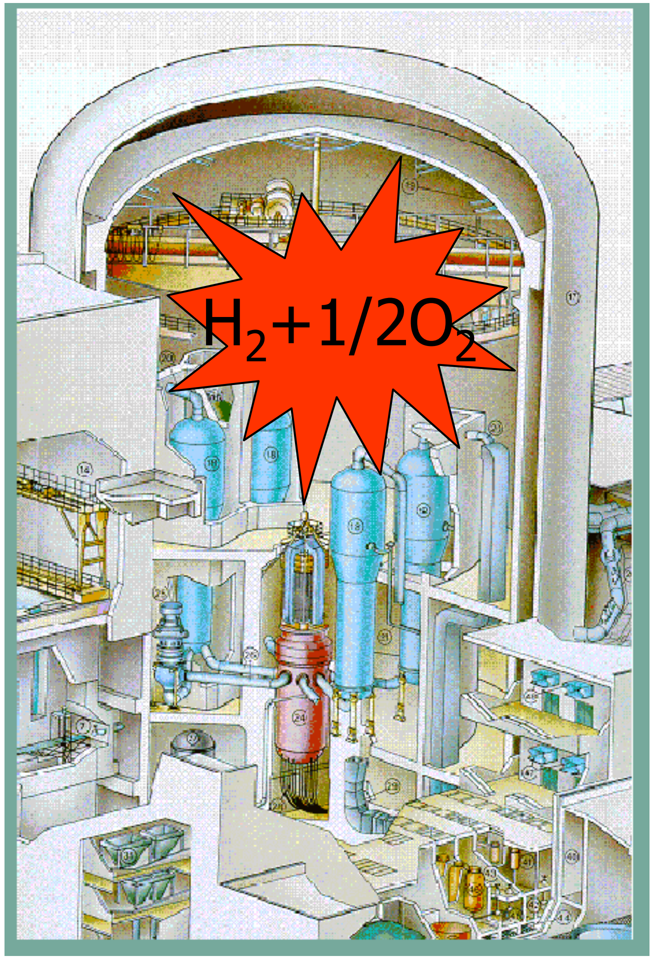
Introduction.

Severe accident

$Zr+2H2O \Rightarrow ZrO2+2$**H2**

Release of steam and hydrogen into the reactor building, forming an explosive mixture

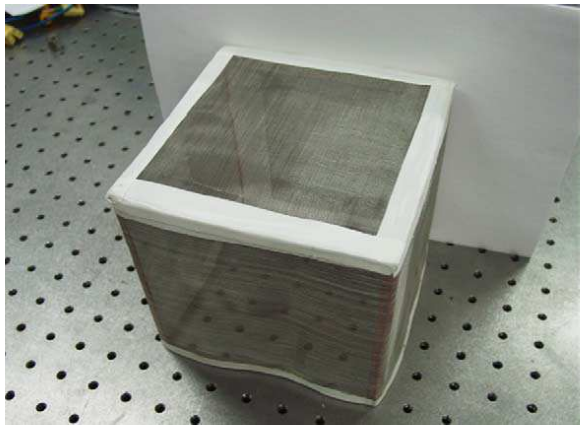


Introduction.

There is a need for mitigation measures against hydrogen risk in a nuclear power plant.

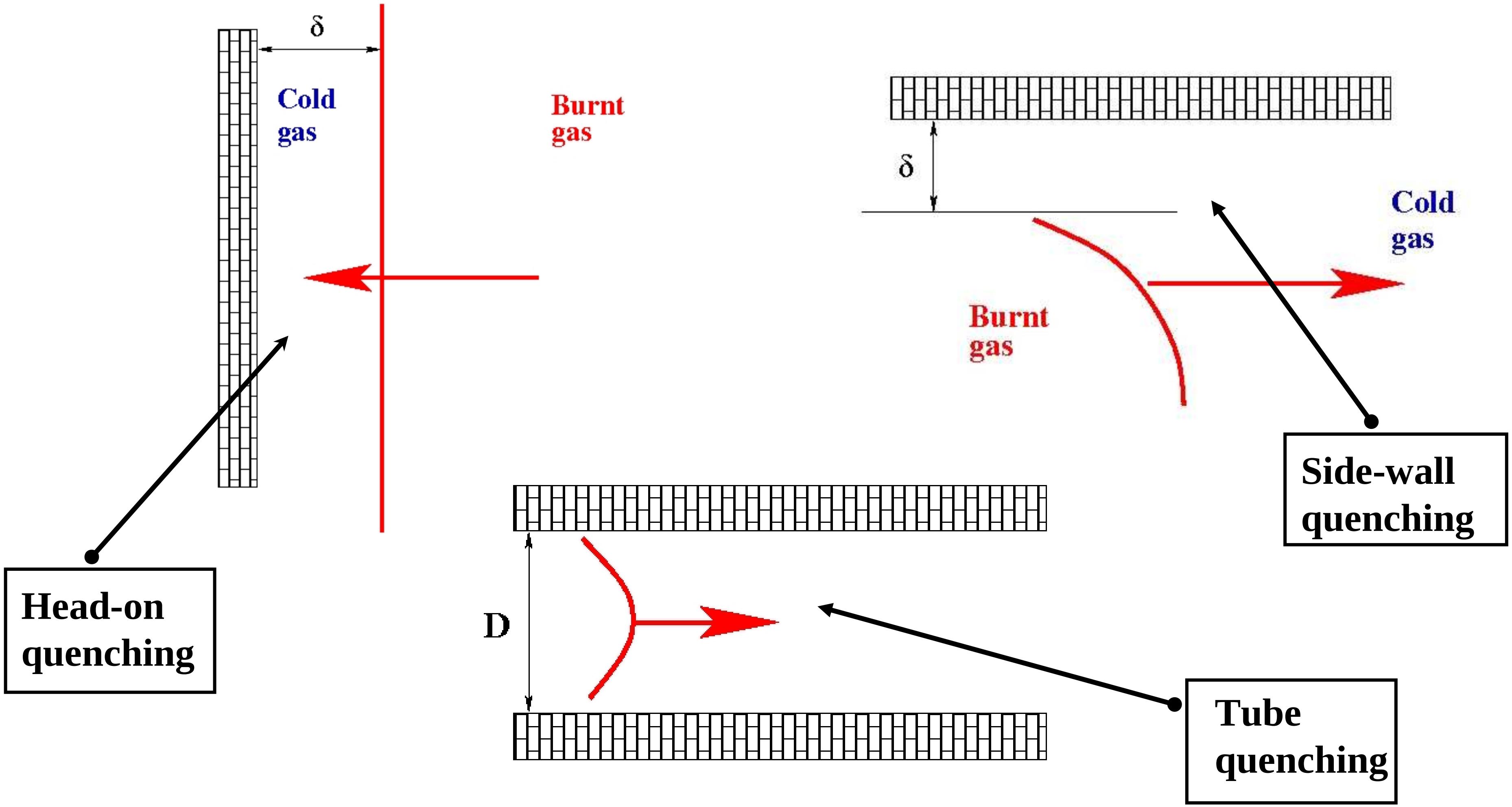
In a number of NPP Passive Autocatalytic Recombiners (PAR) are installed

The installation of a quenching mesh between the compartments or the enclosure of equipment by the quenching mesh has been suggested [1] as a measure to prevent flame propagation



[1] Song J., Kim S., Kim H., On some salient unresolved issues in severe accidents for advanced light water reactors, Nuc. Eng. Des., 235, 2005, pp. 2055-2069

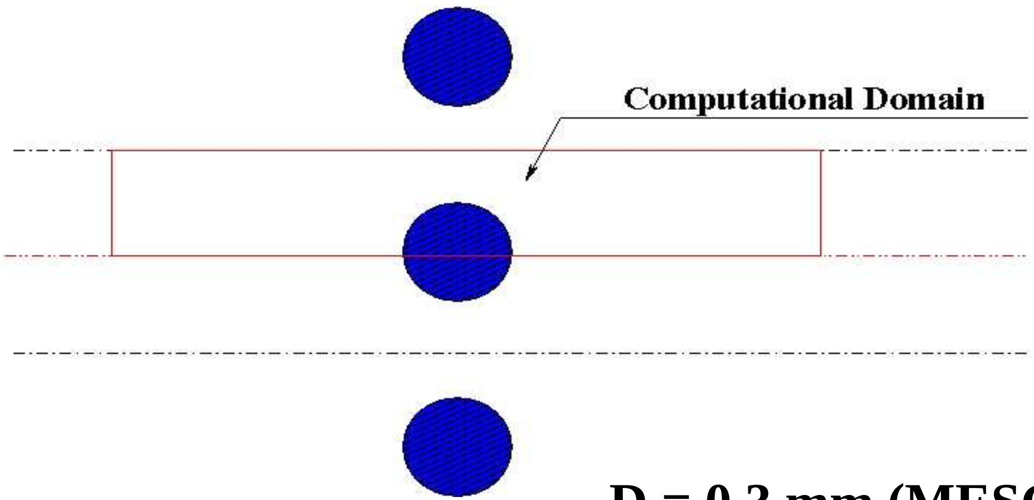
Typical situations studied in the past



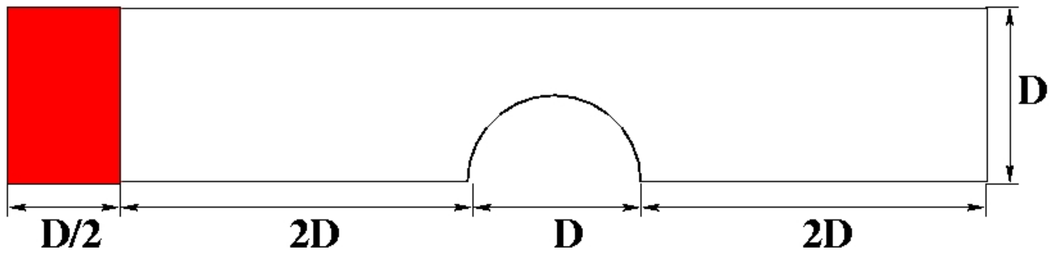
Flame-Mesh interaction is a combination of the above situations.

We assume

- Two-dimensional laminar flame
- Stoichiometric H2-Air mixture
- Initial T=300 K, P=1 atm
- Mesh temperature is constant in time



D = 0.3 mm (MESG)



▪ Governing Equations

$$
\begin{cases}
\dfrac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0 \\
\dfrac{\partial \rho y_i}{\partial t} + \nabla \cdot (\rho \vec{u} y_i) = \nabla \cdot \{D_i \nabla (y_i)\} + \dot{\omega}_i \\
\dfrac{\partial \rho \vec{u}}{\partial t} + \nabla \cdot (\rho \vec{u} \otimes \vec{u} + pI) = \nabla \cdot \vec{\vec{\tau}} + \rho \vec{g} \\
\dfrac{\partial \rho e}{\partial t} + \nabla \cdot (\rho \vec{u} h) = \nabla \cdot (\vec{\vec{\tau}} \cdot \vec{u} - \vec{q}) + \rho \vec{g} \cdot \vec{u} - \dot{\omega}_T
\end{cases}
$$

where

$$p = \rho \frac{R_u}{W} T \qquad \dot{\omega}_T = \sum_{i=1}^{N} \Delta h_{f,i} \dot{\omega}_i$$

$$e(T) = \int_0^T c_v dT + \frac{1}{2} \vec{u} \cdot \vec{u}$$

Combustion Modelling

- *One Step Global Reaction Mechanism*

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$\begin{cases} \dot{\omega}_{H2} = -2W_{H2}\dot{\omega} \\ \dot{\omega}_{O2} = -W_{O2}\dot{\omega} \\ \dot{\omega}_{H2O} = 2W_{H2O}\dot{\omega} \end{cases}$$

Laminar 'Arrhenius' rate:

$$\dot{\omega}_{Arr} = C_f \left(\frac{\rho_{H2}}{W_{H2}}\right)\left(\frac{\rho_{O2}}{W_{O2}}\right)\exp(-T_a / T)$$

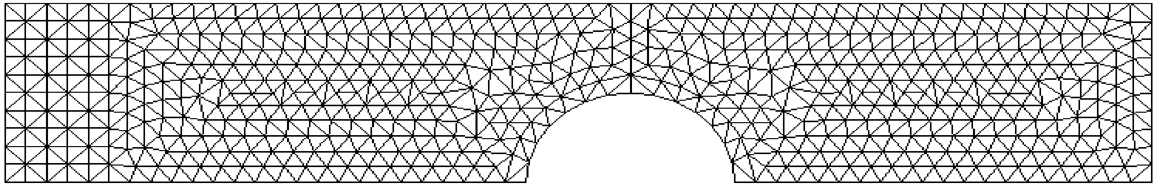
Quenching Criterion:

$$T_q = T_{adiab} - \frac{T_{adiab}^2}{T_a}$$

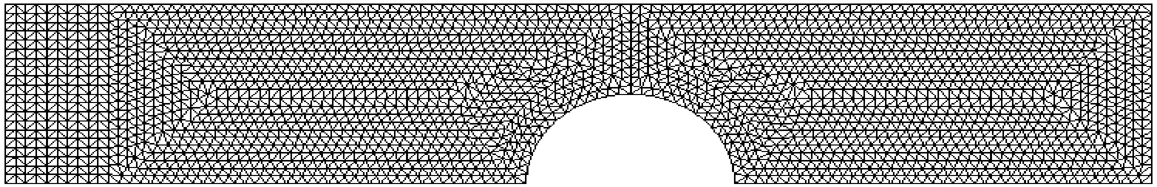
$$\dot{\omega} = \dot{\omega}_{Arr} H(T - T_q)$$

Numerical method and grids used for computation

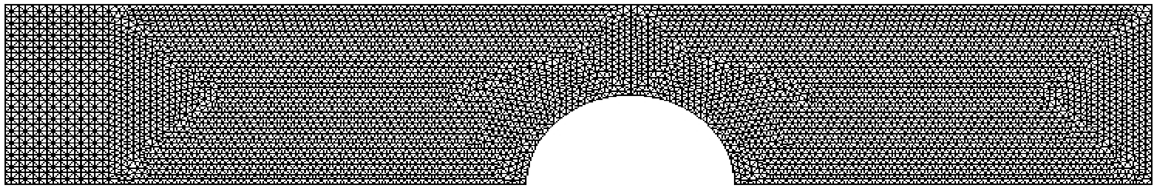
- **Finite Volume discretisation**
- **Shock-Shock approximate Riemann Solver (convective)**
- **« Diamond » method (diffusive terms)**



1134 elem., dx=0.02 mm



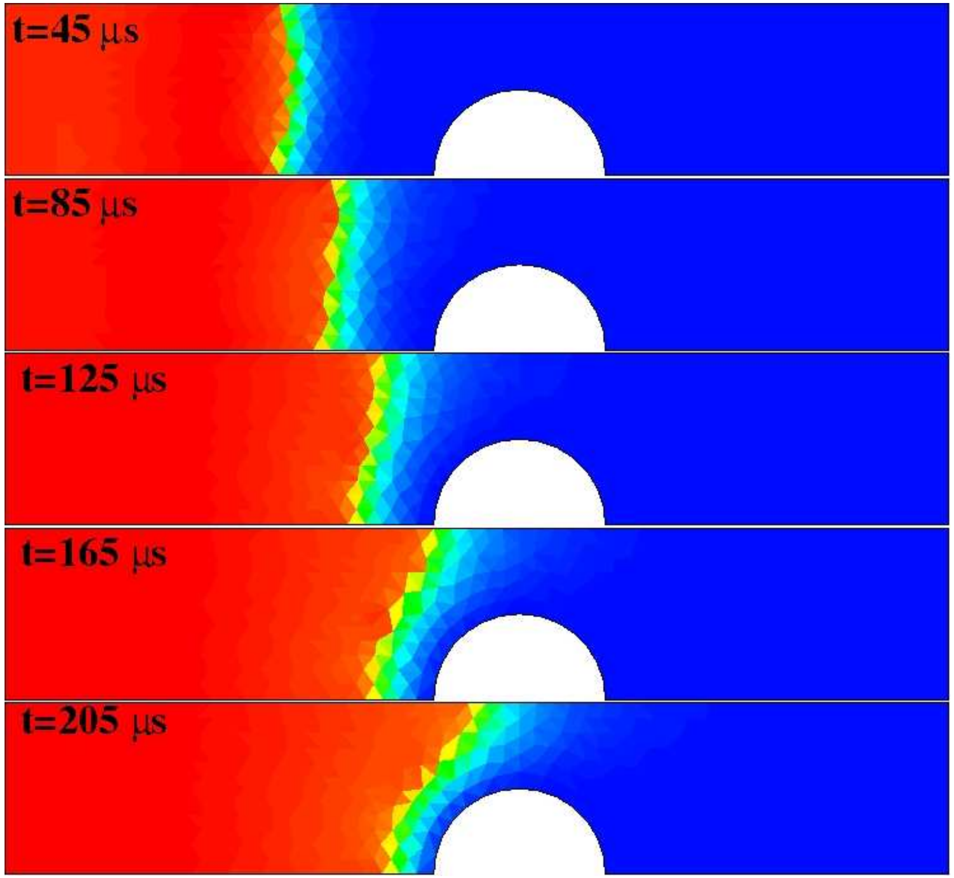
4548 elem., dx=0.014 mm



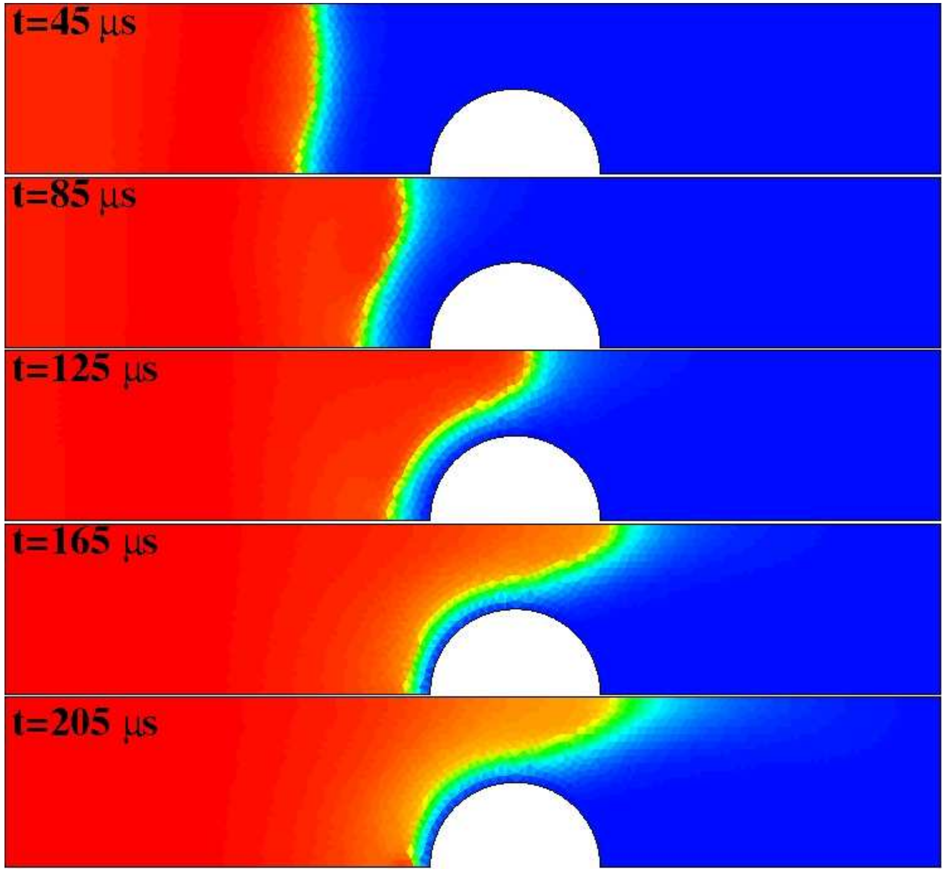
10354 elem., dx=0.0092 mm

Temperature contours on the

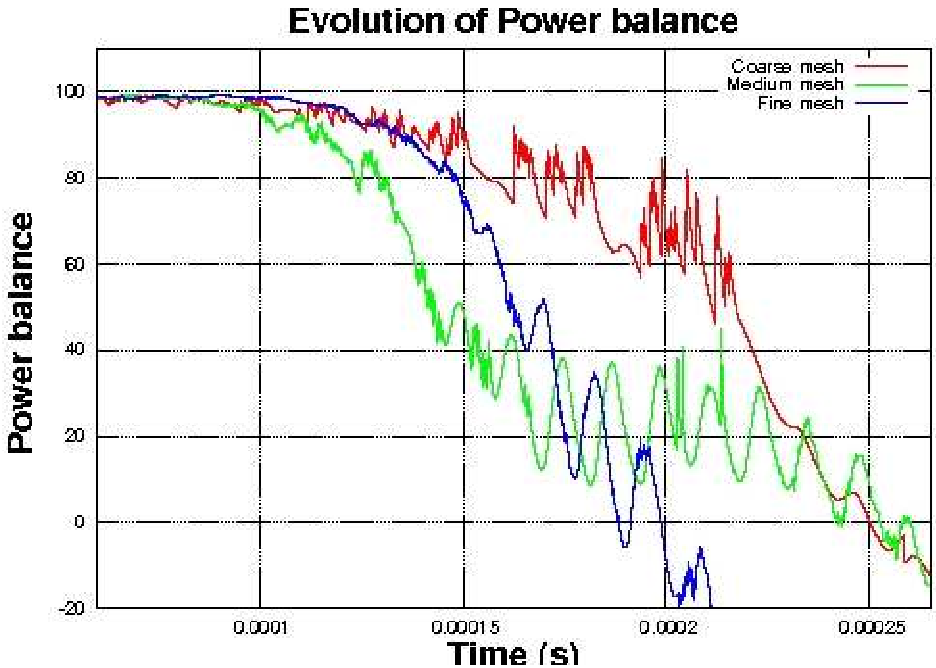
coarse mesh



medium mesh

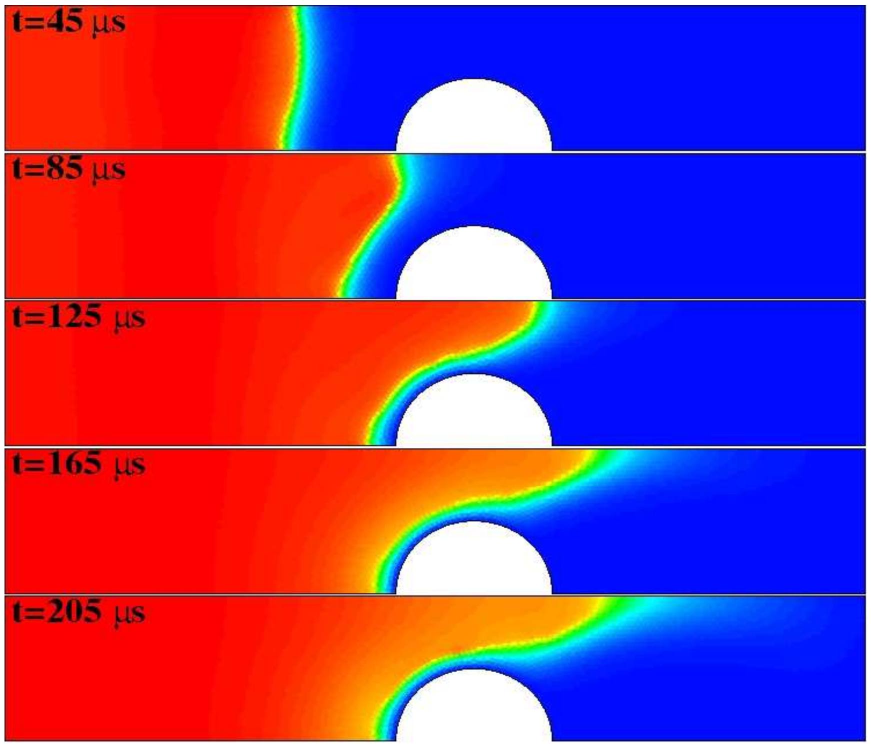


Numerical results



$$\frac{Q_{gener} - Q_{lost}}{Q_{gener}} \times 100\%$$

Temperature contours



Temperature evolution with time

Conclusions.

- *Thermal criterion is used for flame quenching*
- *quenching Peclet number* $Pe = \frac{S_L D}{\alpha} \approx 25$
- *Which role is played by active radicals recombination during diffusion near wall is not clear*
- *Turbulent flame quenching studies are suggested as a future work*