DE LA RECHERCHE À L'INDUSTRIE

LOW MACH NUMBER FLOWS IN PLATE-TYPE FUEL CORES

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PURPOSE

- Plate type fuel reactors
- Practical studies
- Porous code using Rieman solver : FLICA4
- Source terms
- Application to safety calculations
- Limitations of the Godunov's schemes for low velocity real flows

PLATE TYPE FUEL REACTORS

- Experimental reactors

Orphée, Saclay France

McMaster Nuclear Reactor, Canada

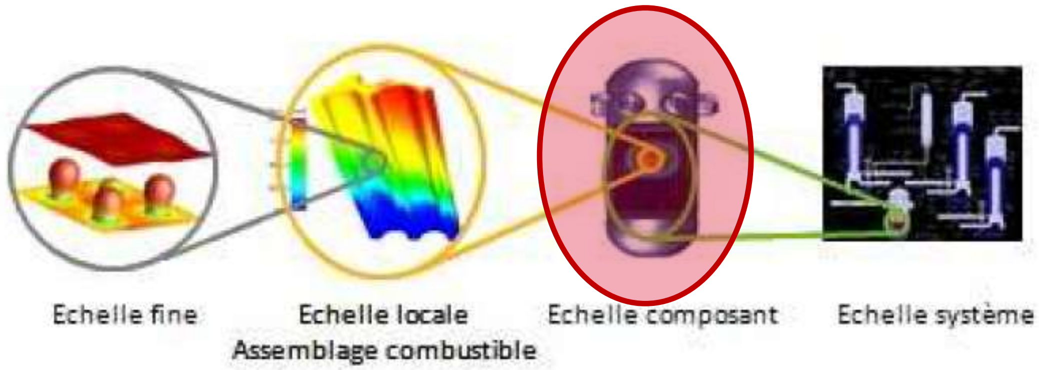
- Nuclear Naval propulsion reactors

PLATE TYPE FUEL REACTORS

- Low velocity : up to 10 m/s
- Wall-bounded flows with inlet and exit plenum
- ~ 2000 parallel channels
- numerous singularities:
    - Section flow variations
    - Singularities (local pressure drop)
    - Vapor phase apparition and disparition

PRACTICAL STUDIES

- Design and safety studies
- Large volume of transients (10 to several hundreds of seconds)
- Need to know for each case the DNBR = how close/far from critical point at which the heat transfer from the fuel decreases rapidly and the fuel cannot be properly cooled down
- The code should be able to predict accurately flow locally at the hot spot and at the same time flow distribution and power between all of the different elements of the core

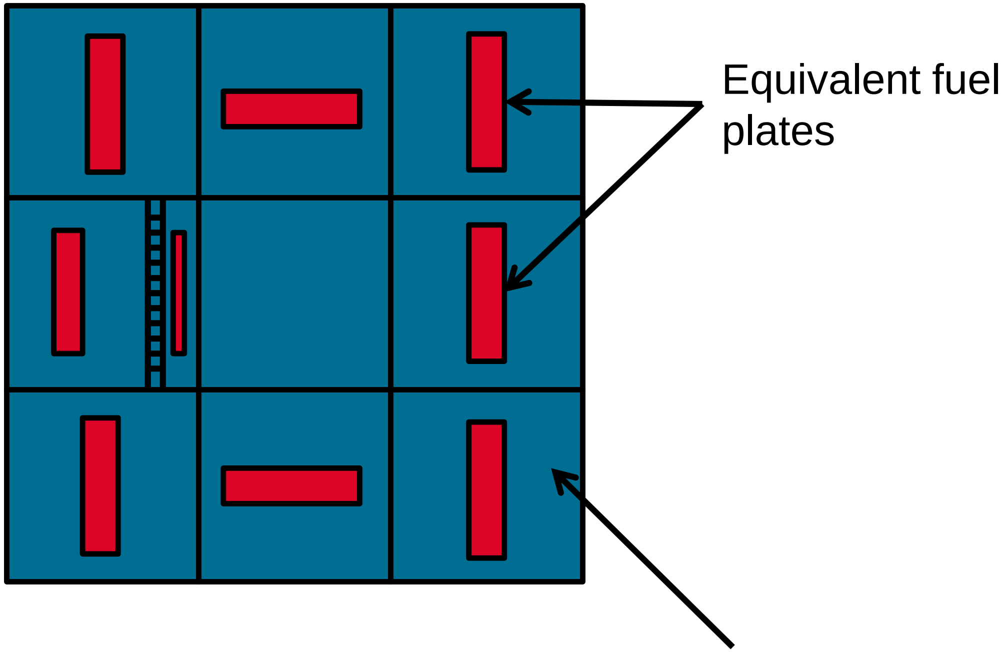


A POROUS BODY MODEL CODE : FLICA4 (CEA)

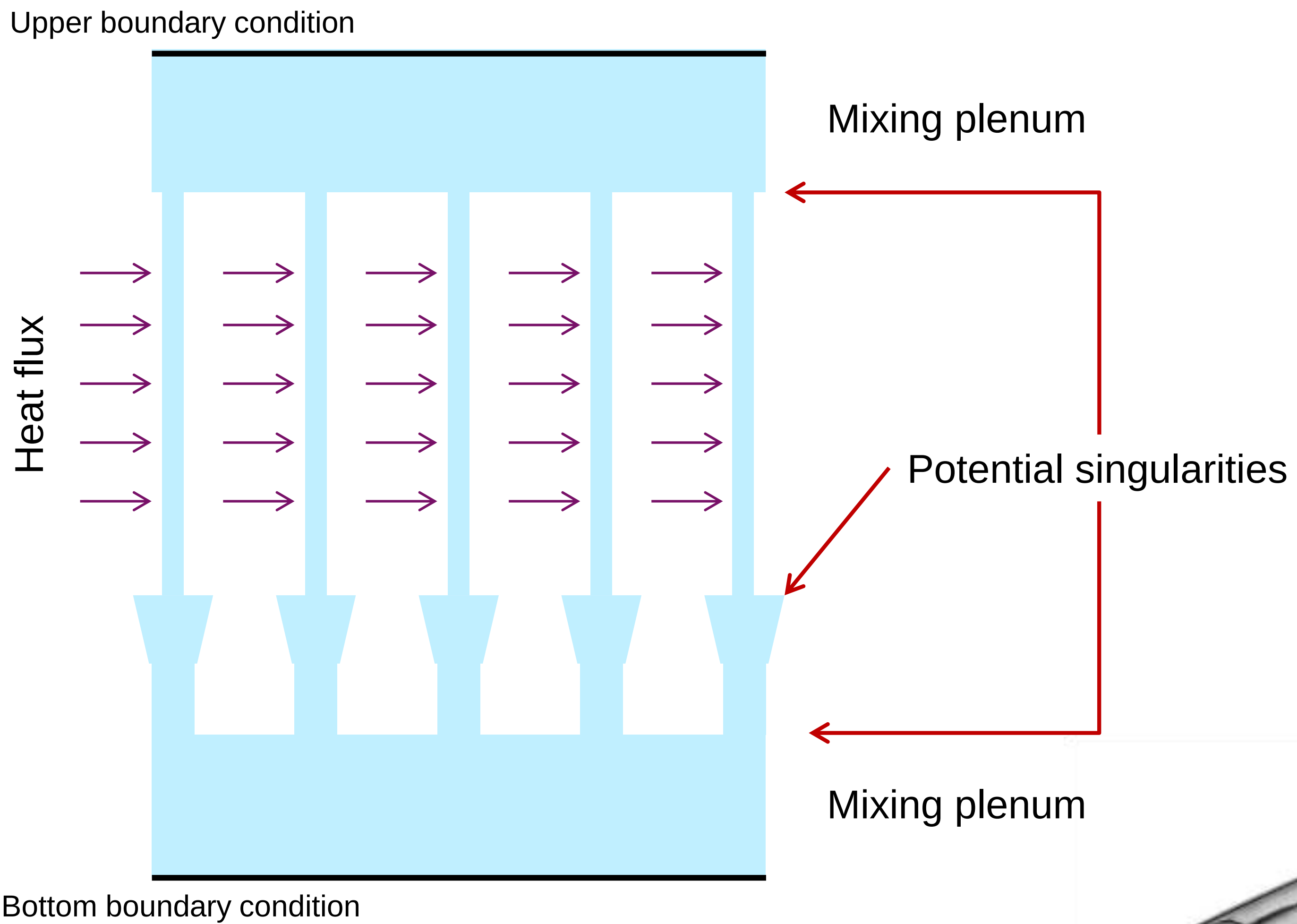
- Two-phase flow code : porous body model
- Subchannel approximation
- 2D mesh is extruded to produce 3D mesh
- 3D flow
- Rieman solver
- Real fluid (tabulated properties)
- Navier-stokes equations:
  - 1 equation for mixture mass conservation
  - 1 equation for mixture momentum conservation
  - 1 equation for mixture energy conservation
  - 1 equation for vapor mass conservation
- Dirichlet boundary conditions:
  - Enthalpy/temperature and velocity/mass flux on one hand
  - Pressure on the other hand

EXAMPLES OF PRACTICAL FLOWS

Orphée, Saclay France



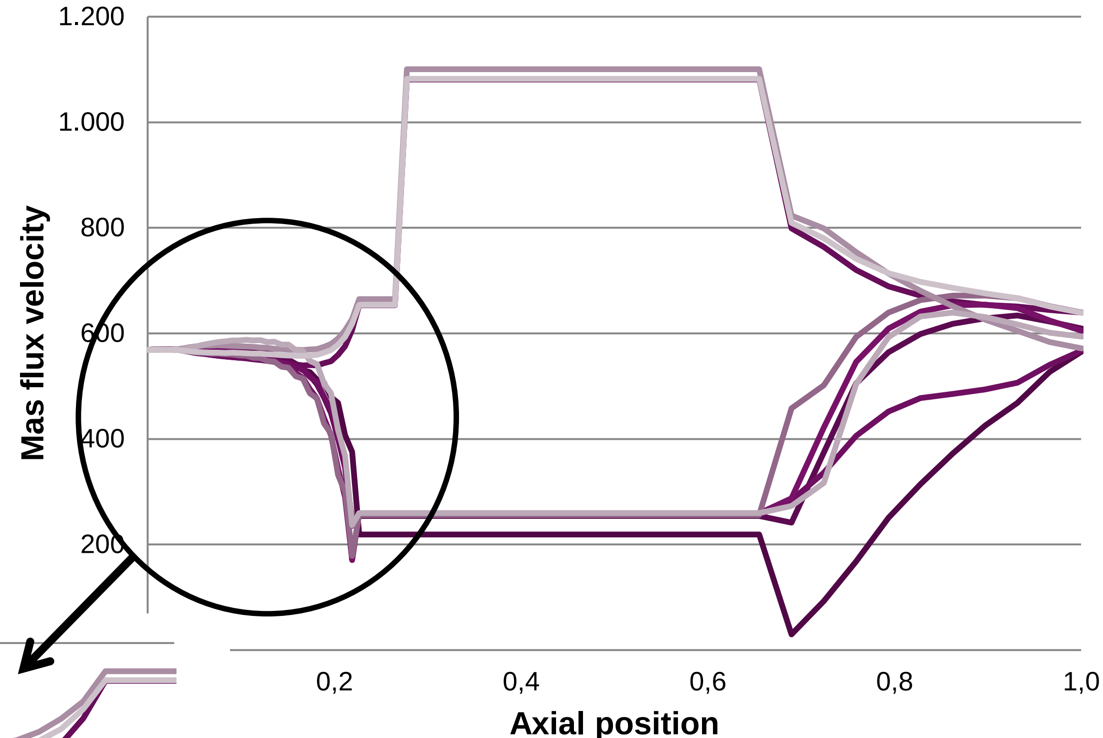
Because the meshing in a code such as FLICA4 is not flexible, the real core would be modeled with this type of akward meshing

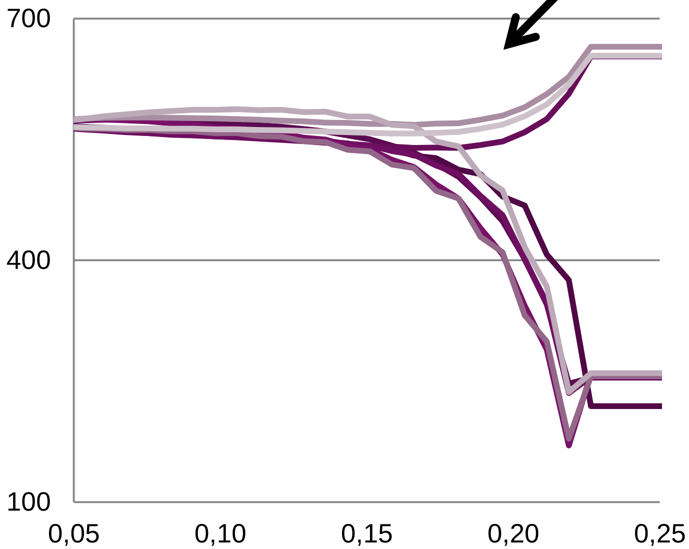


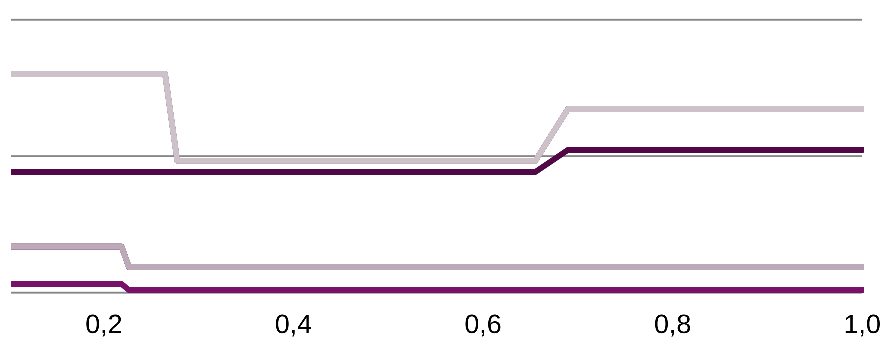

McMaster Nuclear Reactor, Canada

RESOLUTION OF THE FLOW

- Section reduction acts as a flow obstacle
- At low Mach number, with porosity discontinuities, how to solve for the velo







SOURCE TERMS WITH RIEMANN SOLVERS AT LOW VELOCITY

- Boundary conditions = need for specific formulation at low Mach number
- Vapor generation
- Pressure drop localized within the flow
- Sudden area variation

➔ all of the above can generate checkerboard oscillations downstream of the source localisation

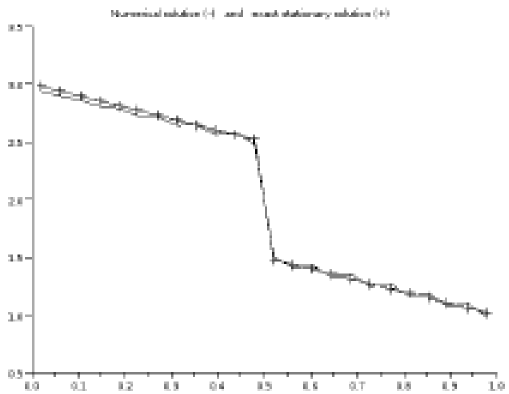
SOURCE TERMS WITH RIEMANN SOLVERS AT LOW VELOCITY

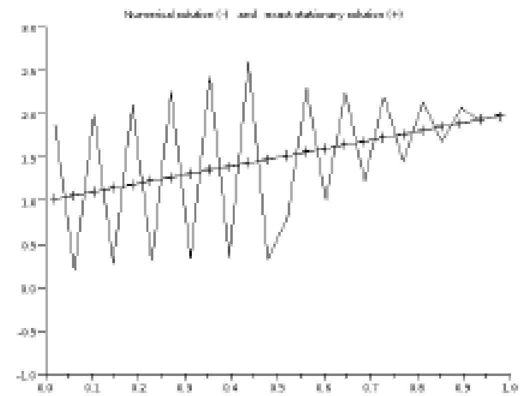
Exemple of a singular pressure drop at the half-height
Resolution in a 1D channel with frictionnal pressure drop
Improvement thanks to specific formulation of boundary conditions for low Mach Number (Dellacherie)

pressure

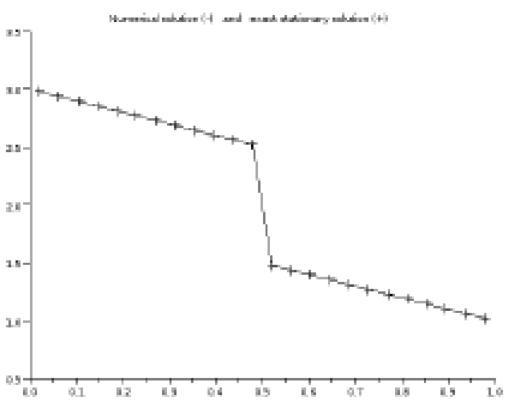
velocity

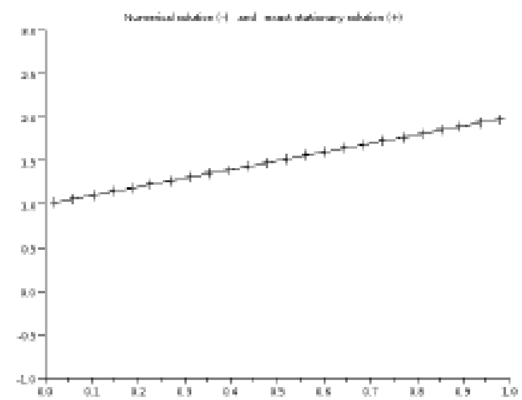
Initial boundary conditions





Low Mach formulation





CONCLUSIONS

- Design studies and safety analysis studies require a large quantity of transient calculations of two-phase flow that can only be feasible with subchannel codes, capable of handling 2 mm to 10 cm wide meshes
- Plate-type fuel reactors are specific since the flow is distributed between wall-bounded assemblies
- Several discountinues sources are to be accounted for, mainly sharp porosity variations and pressure singularities at specific locations (both disontinuities can arise at the same location)
- 3D flows need to be accurately solved to correctly predict mass flow in each fuel assembly
- Rieman solver in these types of low velocity flows can exhibit checkboard oscillations
- Separate effects of discontinuities can be lowered with specific low Mach correctors, however, combination of several effects anihilates the positive effects of correctors

THANKS

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Thank you for your attention