FACULTY OF MECHANICAL ENGINEERING
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Model of cooling nuclear fuel rod in the nuclear reactor

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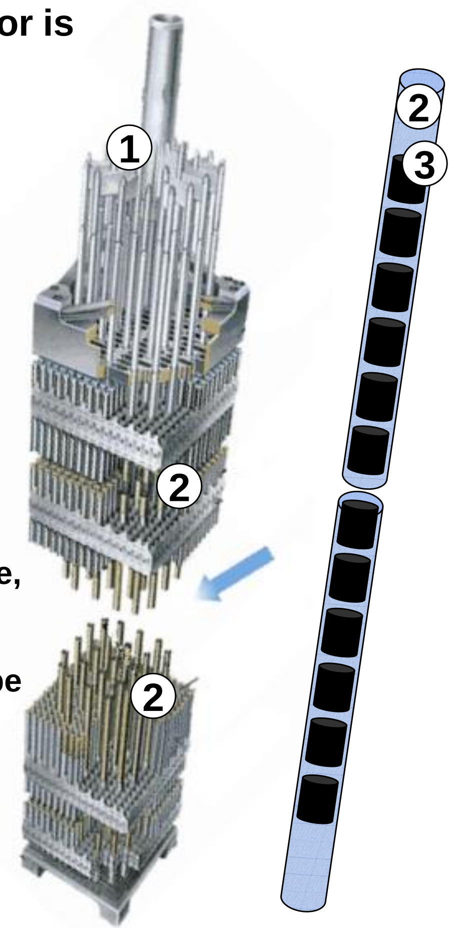
Several basic requirements for nuclear fuel rod

- it must provide that the thermal output of the nuclear reactor is achieved
- it must provide that fuel is spent under reliable and safe operation
- phase transitions must not be accompanied by major changes within the given temperature range
- fuel must be resistant to excessive increments in radiation
- the design must provide:
  - reliable fastening and spacing of fuel elements,
  - stable and secure position of the fuel cluster in the reactor core,
  - minimum resistance in coolant flow,
  - reliable and safe operation at all operation modes with no shape change or compromise of hermeticity,
  - option to remove a damaged fuel bundle,
  - option to install sensors for measurement of temperature, flow and neutron fields,
  - design must allow effective serial production



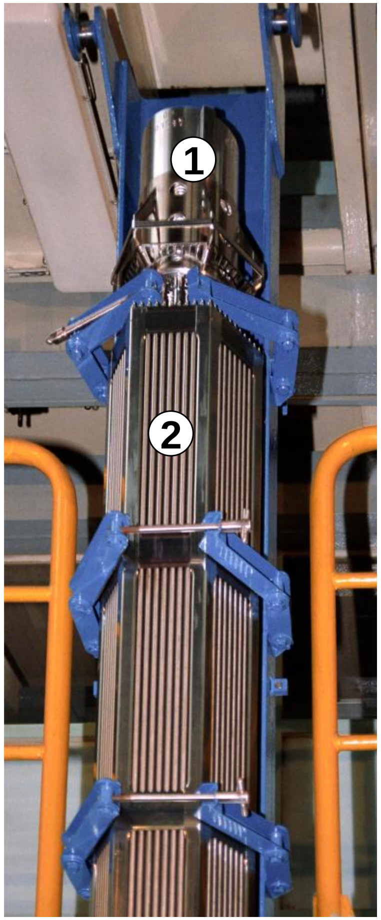
Nuclear fuel rod of VVER 1000

- **JE Temelín**

reactor core ➔ height = 3,53 m, diameter = 3,16m

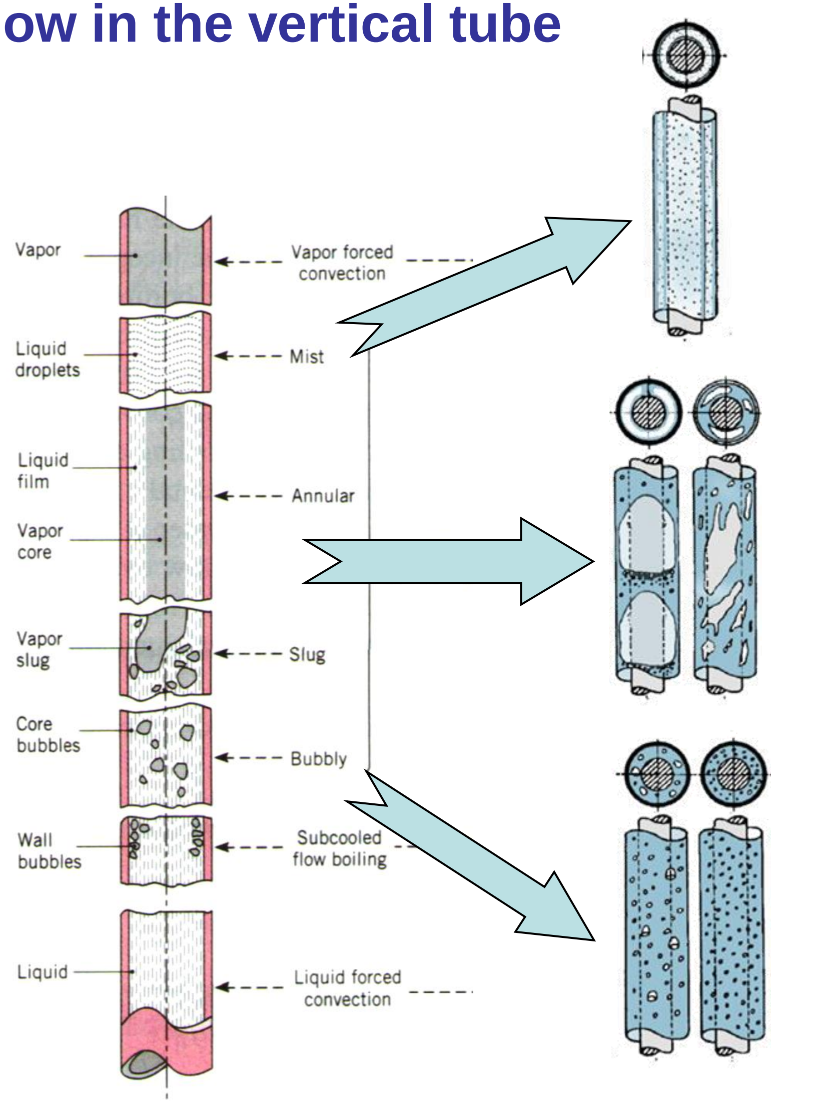
1 fuel cluster ➔ 312 fuel rods
18 regulations rod
1 central metering pipe

163 fuel clusters ➔ ➔ ➔ 50 856 fuel rods



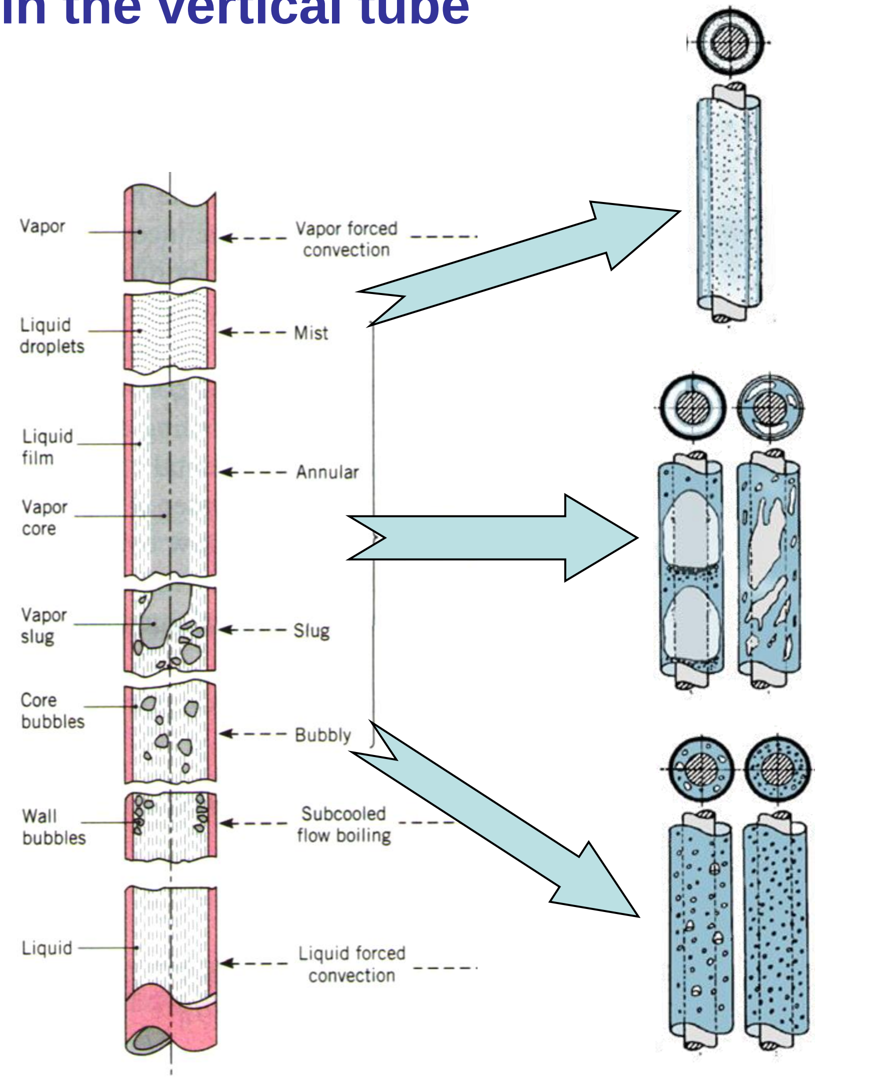
Classification of two-phase flow in the vertical tube

- **Liquid region** – *region of the coolant in liquid phase.*
- **Boiling region** – *transitory (boiling) region – both phases are present here, liquid and gas.*
    - **Bubbly flow regime** – *individual bubbles concentrate into larger steam bodies.*
    - **Slug flow regime** – *flow of large bubbles which occupy most of the annular channel section*
    - **Annular flow regime** – *gas phase occupies the central part of the annular channel section. Liquid phase generates a thin film on tube wall.*
    - **Mist flow regime** – *steam flow with discrete liquid drops.*
- **Vapor region** – *region of the coolant in the gas phase.*



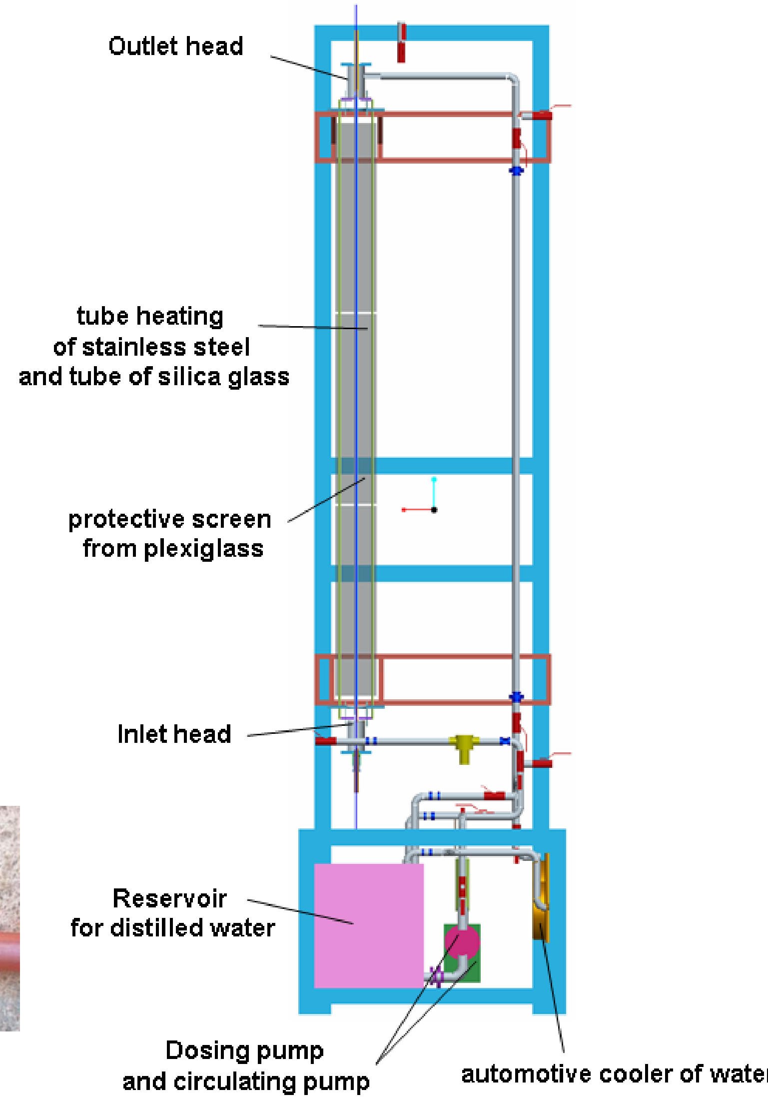
Type of heat transfer crisis in the vertical tube

- **Heat transfer crisis in an area with low steam content**
  - This crisis type most often occurs in high density of heat flow and in high flow rates of coolant.
  - This crisis is characterized by accumulation of a large quantity of bubbles in the vicinity of the heat-transfer surface; this prevents cooling of the surface with the liquid phase of the coolant.
  - Another typical symptom is a rapid rise of wall temperature
- **Heat transfer crisis in an area with high steam content**
  - This type occurs at lower density of the heat flow and lower flow rate of coolant.
  - A typical symptom is a layer of liquid at the wall; this layer is being disturbed which leads to local vaporization.
  - The presence of the steam phase plays a key role towards impairment of heat transfer; this causes temperature to rise.



Experimental apparatus

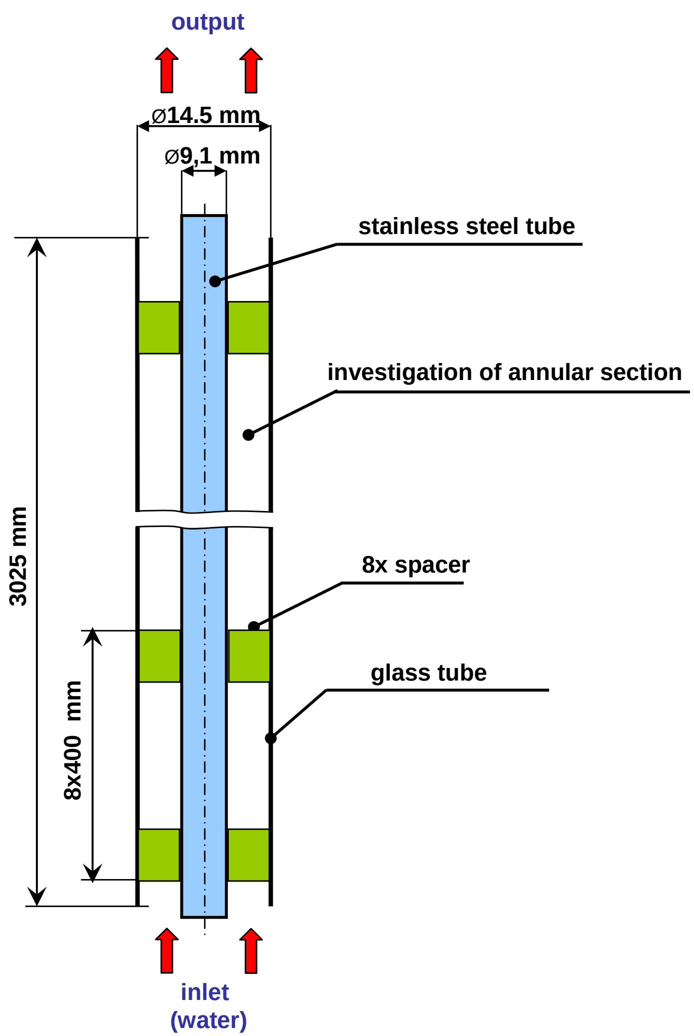
- **The special experimental apparatus is primarily used for research in the domain of heat transfer at models of nuclear reactor fuel rods**
- **The main topic is generation of gas bubbles that affect flow and heat transfer from the heated wall into ambient environment**
- **This knowledge assists in detailed understanding of the issues related to operation of nuclear equipment and, jointly, facilitates education of young staff in the domain of nuclear power engineering**

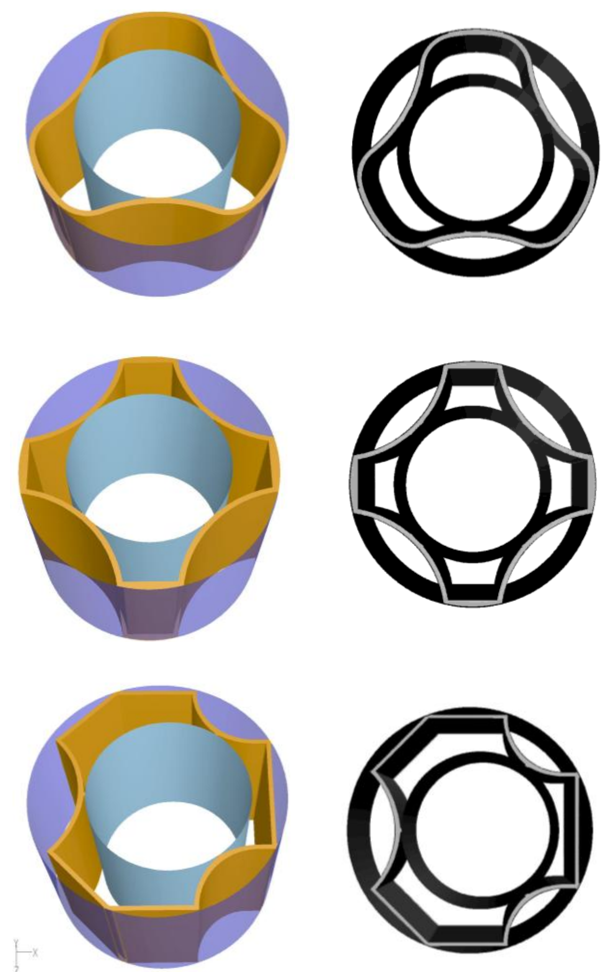


principle heating stainless steel tube

Welding aggregate SELCO ETG 602

Model of nuclear fuel rod and designed spacers





VAR 01

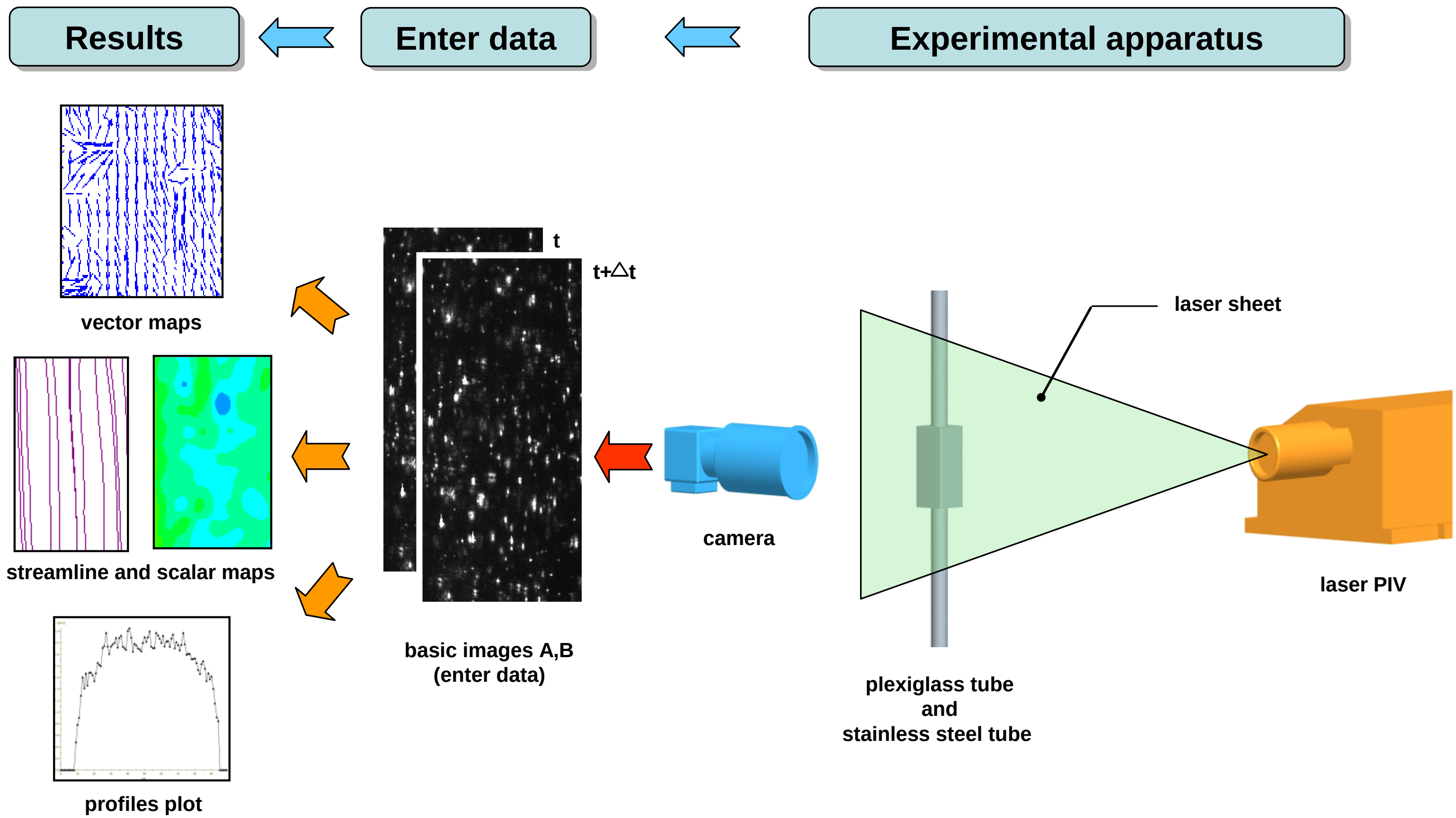
VAR 02

VAR 03

Possibilities activity in the experimental apparatus

- **Measurement velocity profile via PIV**
  - by mass flow rate
  - by design features of spacers
- **Measurement thermal flow field via method PLIF**
  - by mass flow rate
  - by design features of spacers
- **Measurement cooling graph according temperature in the fuel rod**
  - by surface temperature
  - by mass flow rate
  - by design features of spacers
  - by connecting thermocouple with surface of stainless steel
- **Compare hydrodynamic properties for design features of spacers**
  - by mass flow rate
  - by surface temperature

Measurement of Velocity Profile via PIV (Particle Image Velocimetry)



Using apparatus of PIV (Particle Image Velocimetry)

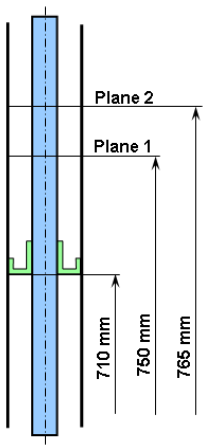
- **Laser:**
  - NewWave Research Model 25 300
    Solo 200XT-15Hz from company Dantec
    - power laser 300-400
    - Δt – between double shots 15μs
    - frequency for scan double shots 7,4Hz (T = ~0.135s)
    - series 300 double shots for postprocessing

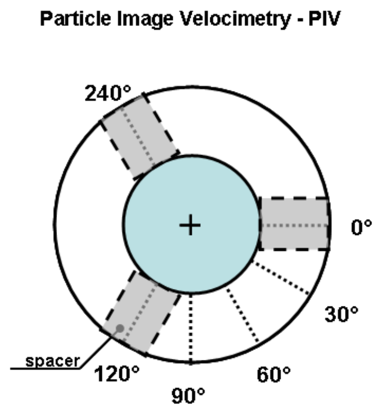
- **Using lens:**
  - telecentric lenses Navitar ELWD
    Macro Invaritar from company Melles Griot
  - Nikon AF Micro Nikkor 60 f/2.8D

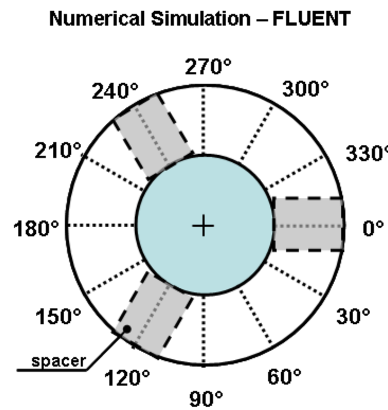
- **CCD camera:**
  - Flow Sense 4M 1/2" from company Dantec

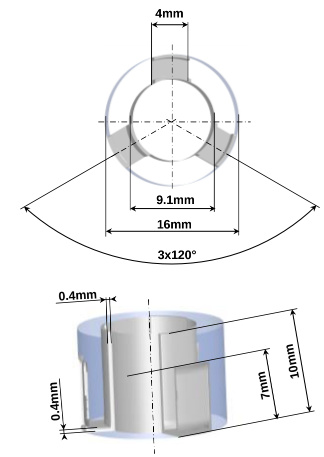
- **Software:**
  - Dantec Dynamic Studio v. 2.30

Velocity profiles from PIV and Numerical simulation (FLUENT)

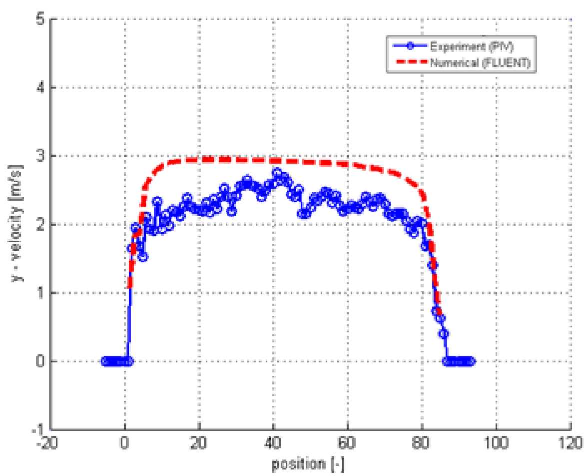




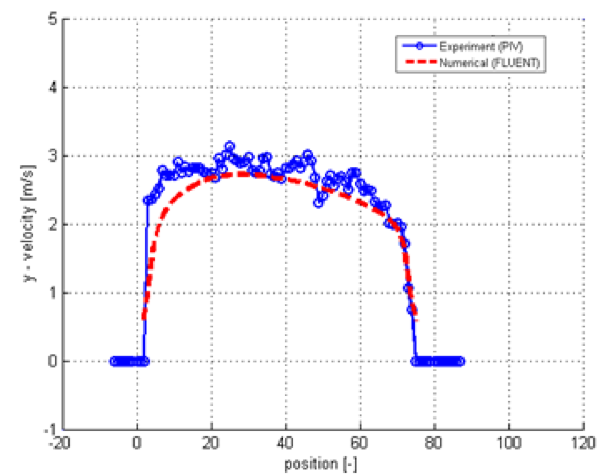




spacer



velocity profil – 000 – 750

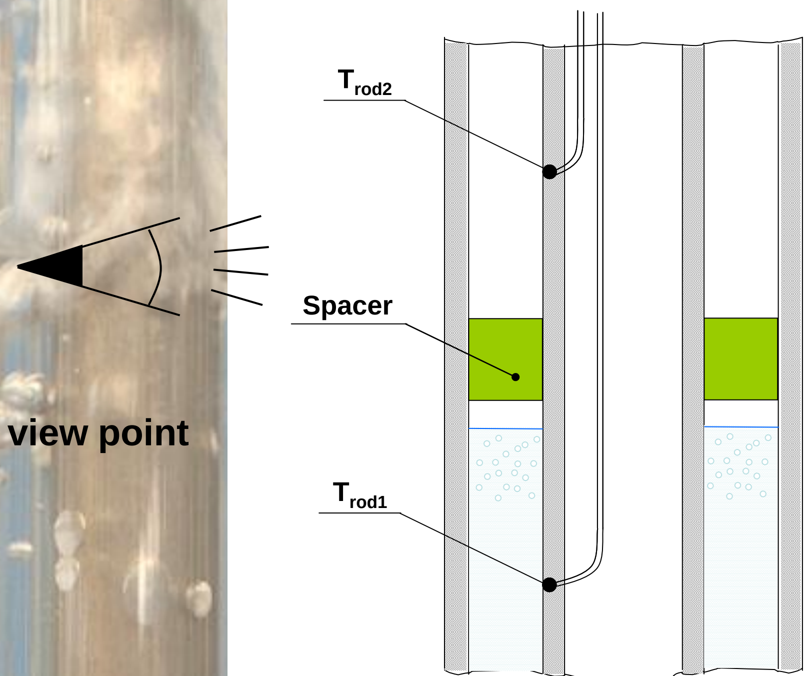


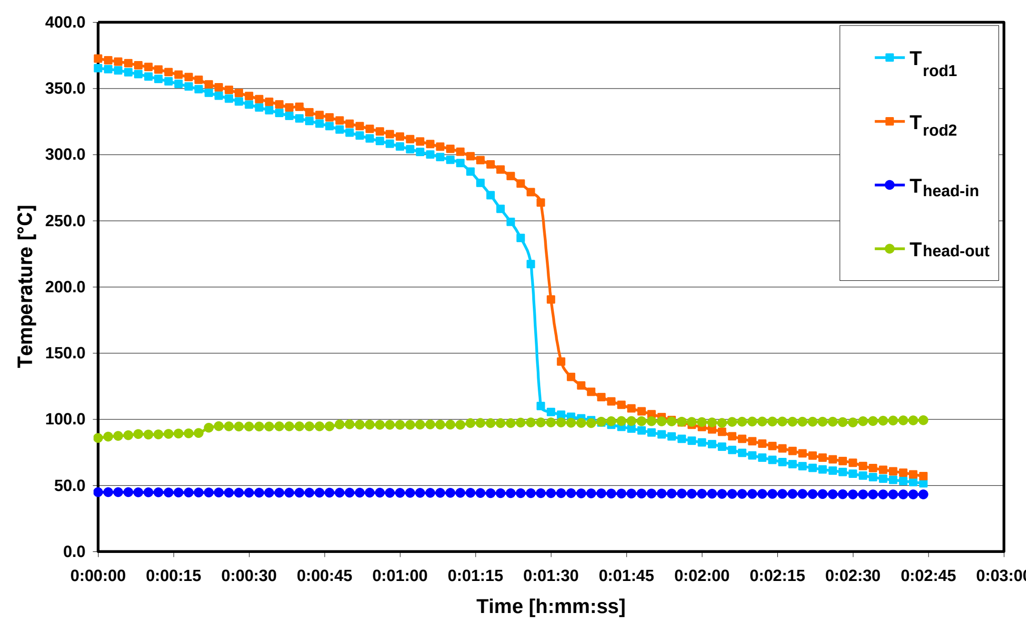
velocity profil – 060 – 750

Principle of surf. temperature measurement in vertical tube

- thermocouple is put in hole of stainless steel and after is holder by silver solder to wall of stainless steel tube
- thermocouple measurement surface temperature in the stainless steel tube in dependence on time

spacer VAR 01





Preview of cooling nuclear fuel rod video (1)

Camera:

Casio Exilim Pro EX-F1
600 frame per second
resolution 432x192 pixels

Preview of cooling nuclear fuel rod video (2)

Camera:

Casio Exilim Pro EX-F1
600 frame per second
resolution 432x192 pixels

Flow direction

output

input

Discussion a conclusion

- this topic describe information about experimental apparatus at the Department of Power System Engineering (KKE) at the University of West Bohemia in Pilsen
- experimental apparatus describe phenomena, which it's based two-phase flow (vapor + water) with heat transfer in the vertical tube
- this topic shows possibilities measuring and activities in the experimental apparatus
  - measurement velocity profile via PIV
  - thermal field via method PLIF
  - measurement surface temperature
  - record from camera with high speed frames
- next activities via numerical simulation
  - flow field in vertical tube (velocity profile, intensity turbulence, …)
  - boiling process
  - cooling fuel rod with spacer
- compare and validation results for presented activities between experimental measuring and numerical simulation

Thank you for your attention.

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