THERMAL ASSESSMENT OF THE CALIPSO IRRADIATION DEVICE FOR THE JULES HOROWITZ REACTOR

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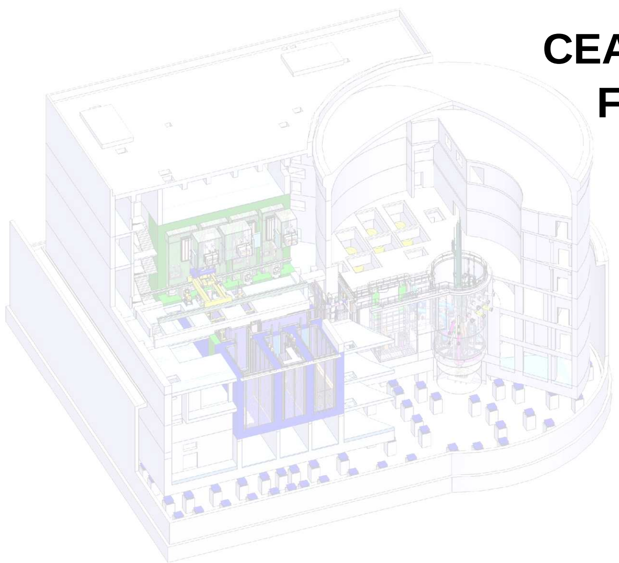

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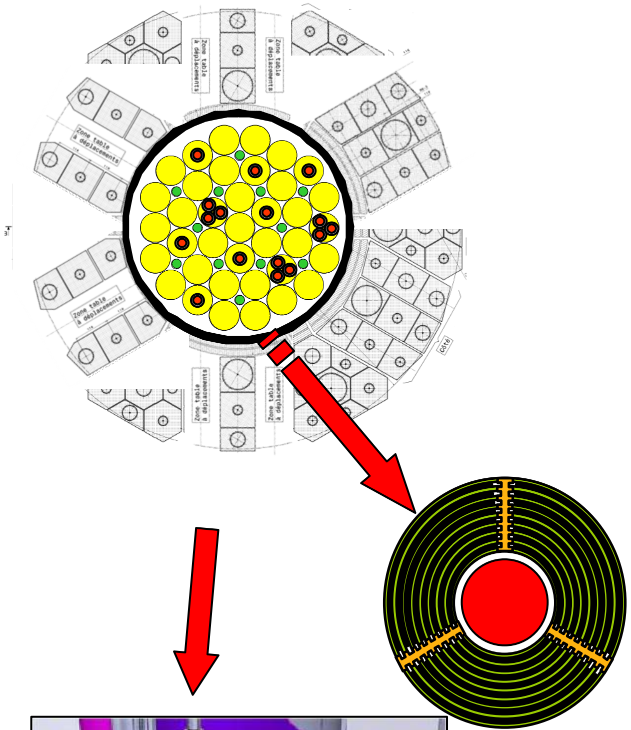
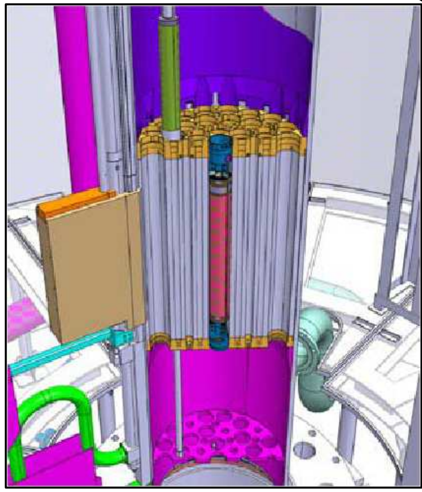
- **Good knowledge of the temperature of samples under irradiation in Material Testing Reactors is very important.**
  - Best results have been obtained up to now using a stagnant liquid metal like NaK as the fluid environment



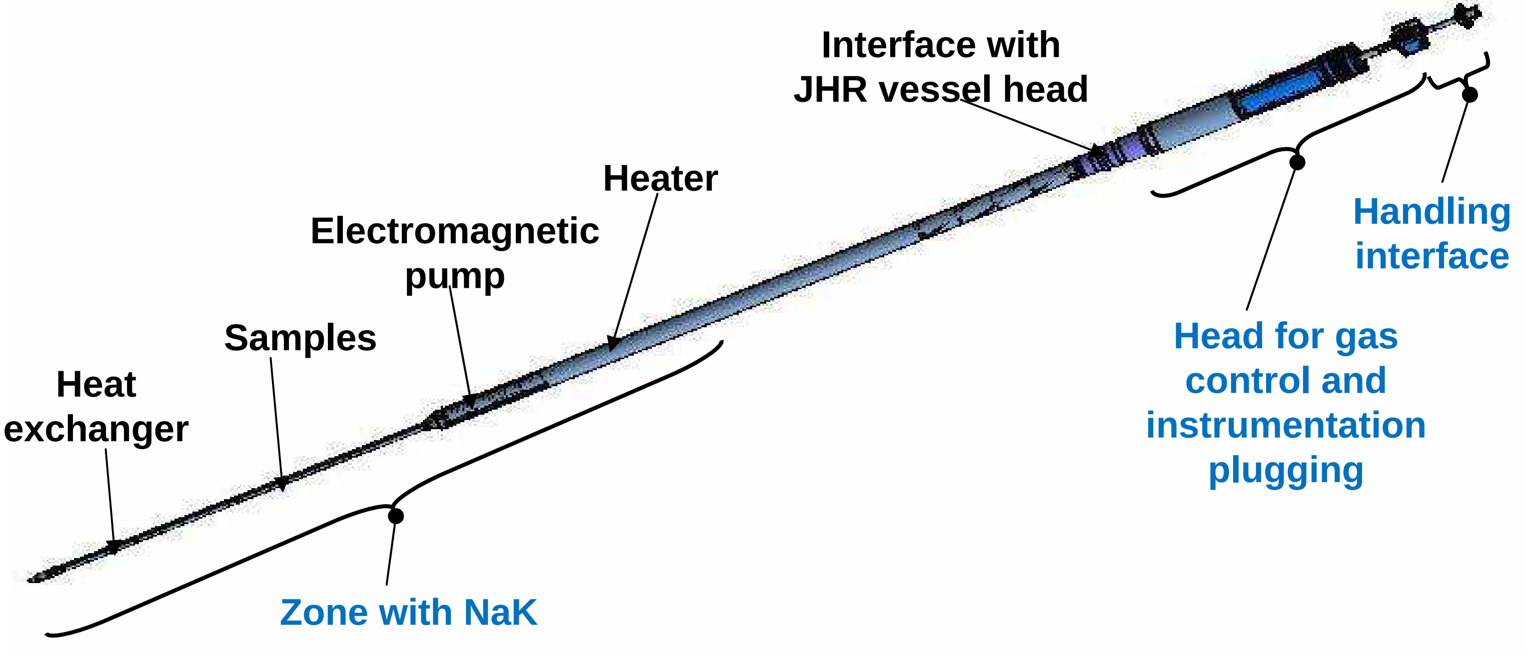
- **The search for a better temperature control and the reduction of experimental uncertainties requires having a liquid metal flowing around the samples**
  - This is the aim of the CALIPSO device, a NaK loop for material irradiation in the core of the Jules Horowitz Reactor (JHR)



- **Presentation of the thermal calculations with an optimized geometry**
  - General description,
  - Thermal modeling,
  - Main results.

General description : overall dimensions

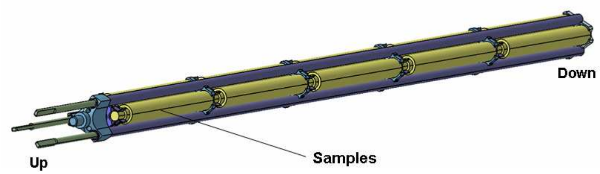
- **The containment rig is a double wall shell**
  - Total length : 6800 mm
- **Outer diameter in the lower part : 33 mm**
  - for heat exchanger and samples
- **Outer diameter above the fissile zone : 83 mm**
  - for electromagnetic pump and heater
- **Outer diameter above the interface with JHR vessel head : 138 mm**
  - for electrical connections, gas control and rig handling



General description : operating principle

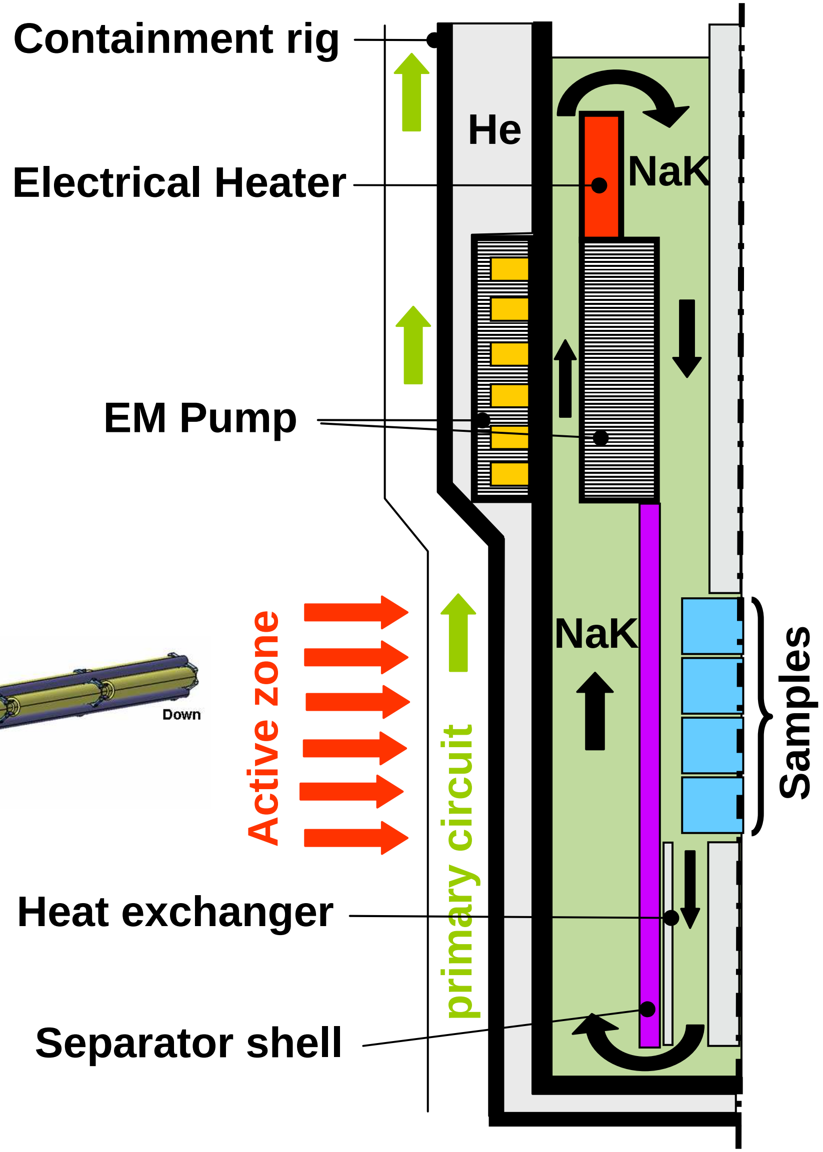
- **A 500 mm-long annular electromagnetic pump is located above the active zone in the containment rig**
  - The NaK in the pumping channel flows from the bottom to the top
  - NaK flow rate : up to 2 m^3/h,
  - pressure drop : 1.25 bar,
  - maximum NaK temperature : 450℃

- **An electrical heater is situated in the NaK just above the pump**
  - maximum power : 18 kW over 400 mm
  - to adjust the operating conditions in the sample zone
  - The NaK is heated before and after the flow reversal



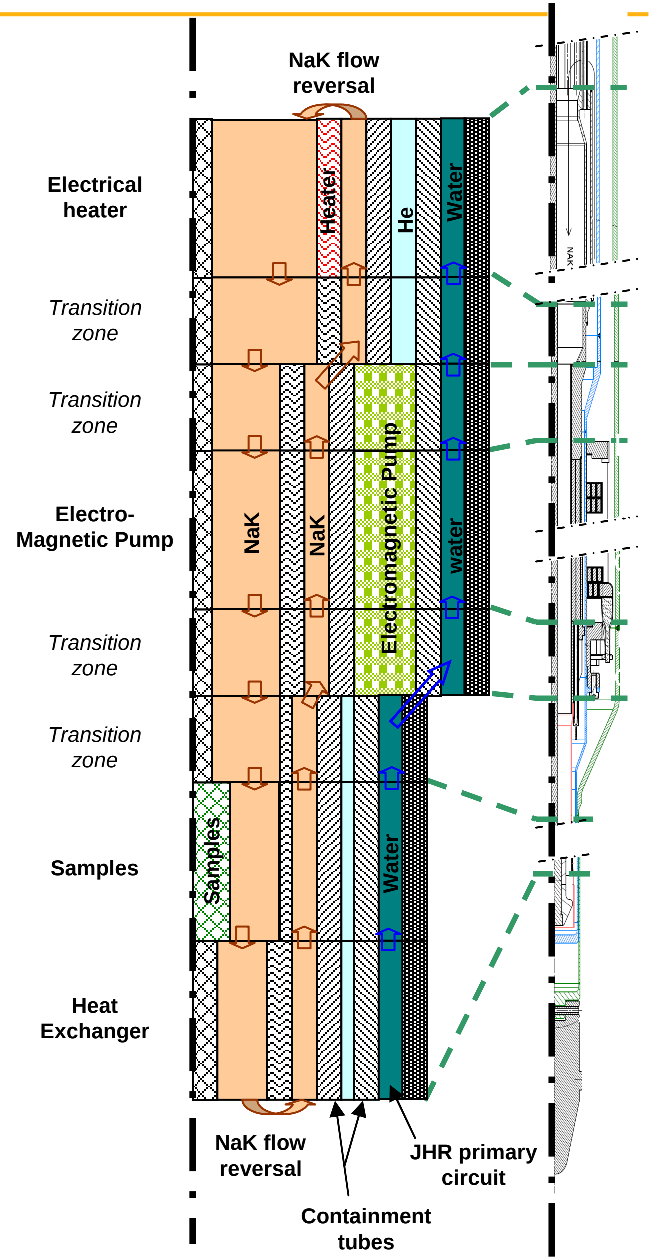
- **Energy transfer to the NaK due to nuclear heating occurs mainly in the active zone around the samples**

- **A heat-exchanger is located at the lower part of the sample-holder,**
  - To cool down the NaK by heat transfer with the reactor primary circuit



Thermal modeling : the REFLET code

- **The REFLET code was designed to perform steady state thermal calculations in axisymmetrical geometry**
  - Taking into account most of the specificities of irradiation test devices
  - Radial heat exchanges and energy transport in fluid flows are considered
  - Calculations of temperatures, heat fluxes and thermal balance
  - Very convenient for large exploration of operating range
- **Extensively used in the OSIRIS reactor for thermal prediction of experimental rigs and loops**
  - The calculation results in good agreement with experimental measurements
- **Modeling of 8 zones of different geometrical characteristics**
  - The main components and transition zones
  - Simplifications for the pump and sample zones



Thermal modeling : limit conditions

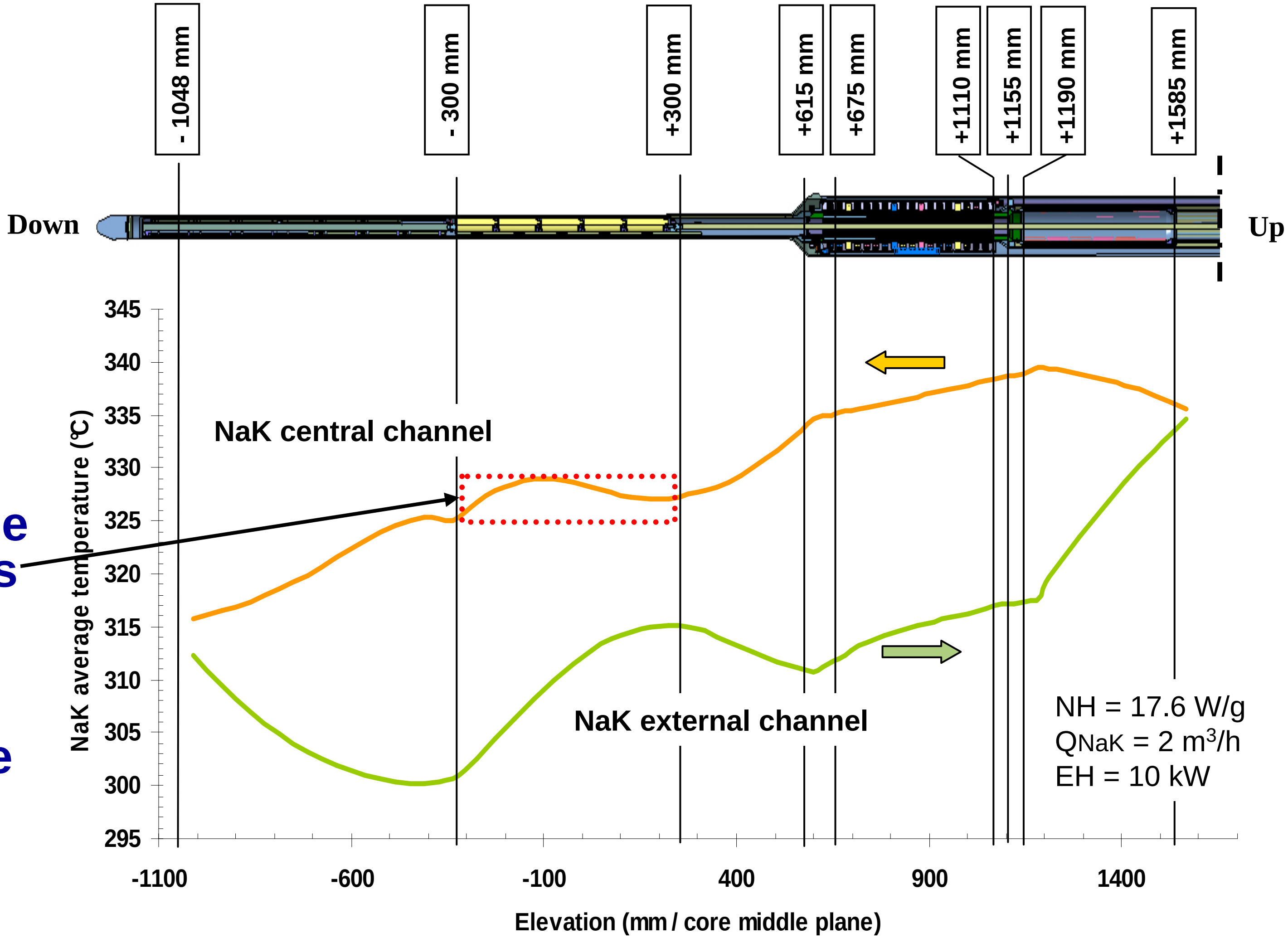
- **Nuclear heating**
  - Profile based on photonic calculations in the JHR core,
  - Similar in nature to a cosine shape in the active zone and an exponential shape above and below the active zone,
  - Different reactor power values, different locations of irradiation and calculation uncertainties
    - > **A wide range of values : 5 W/g – 21 W/g**

- **Heat exchange with the JHR primary circuit**
  - Inlet temperature : 30℃
  - Water speed : ~ 8 m/s
  - Heat transfer coefficient : ~ 3.5 10^4 W.m^{-2}.℃ $^{-1}$
    - > **Test device not very sensitive to the variations of the primary circuit conditions**

Results : quality criterion

- **To evaluate the thermal performance of the test device,**

- **Difference between the minimum and the maximum values of the NaK temperature in the central channel over the 550 mm of the sample zone,**

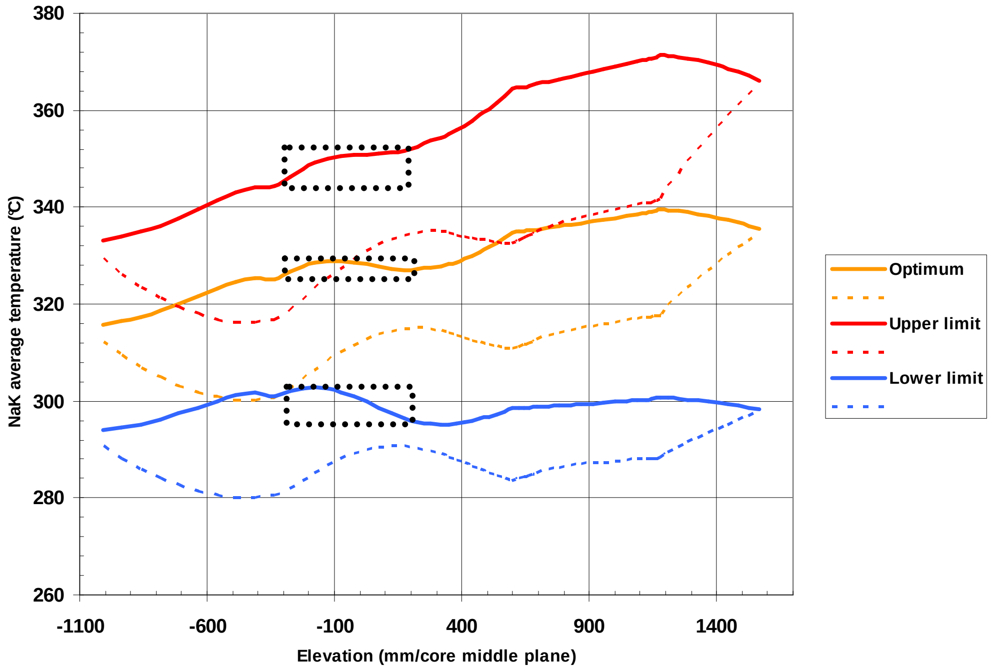


Temperature profiles in NaK at an optimum operating adjustment

Results : quality criterion

	Upper limit	Optimum	Lower limit
ΔT_{NaK} criterion	**7.5°C**	**2.2°C**	**7.5°C**
NaK mean temperature (over - 275mm and + 275 mm)	350°C	328°C	300°C
Power of electrical heater	13 630W	10 075W	5 925 W

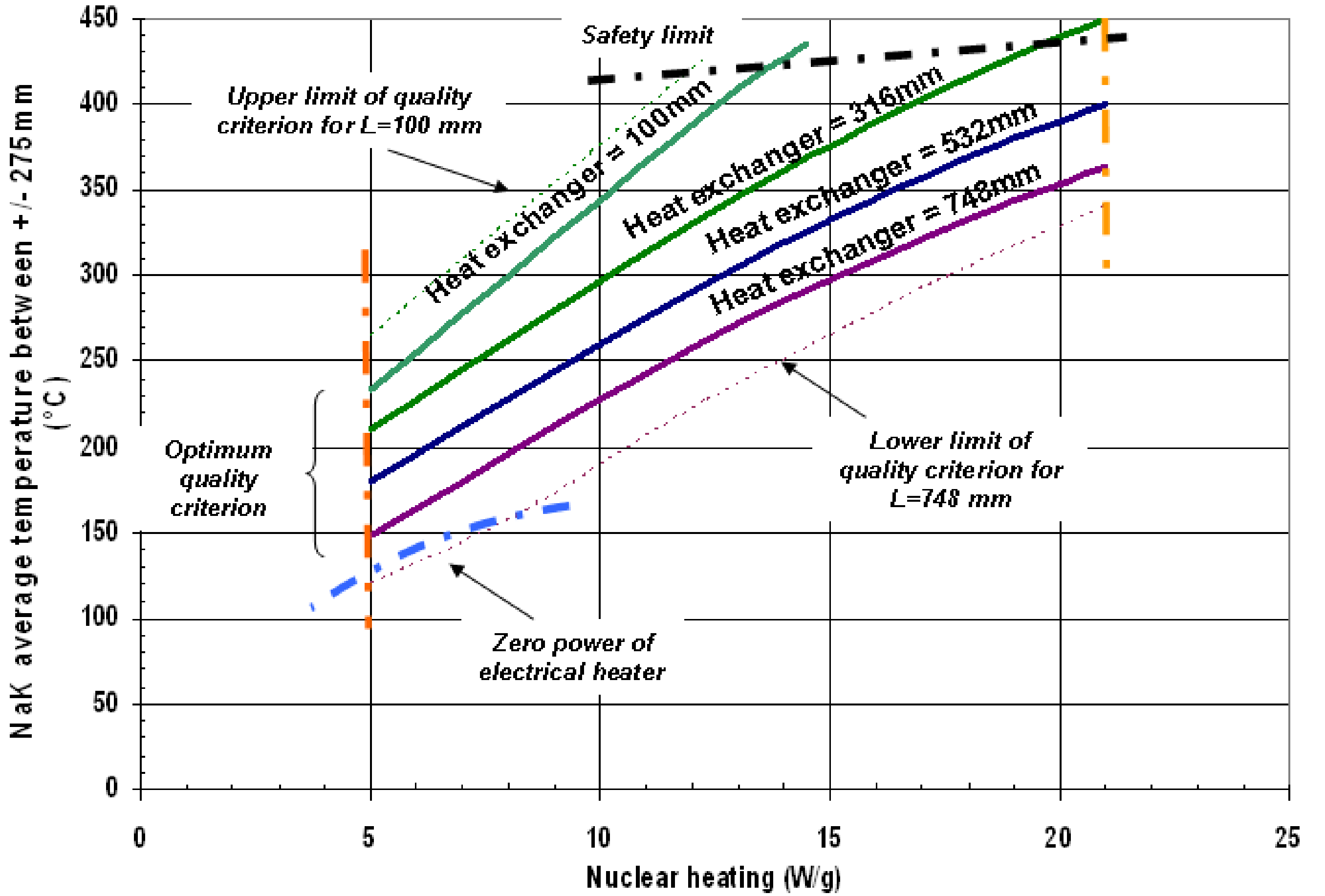
- **7.5℃ has been chosen as the limit of the optimum o perating zone regarding experimental targets**



Results : heat exchanger

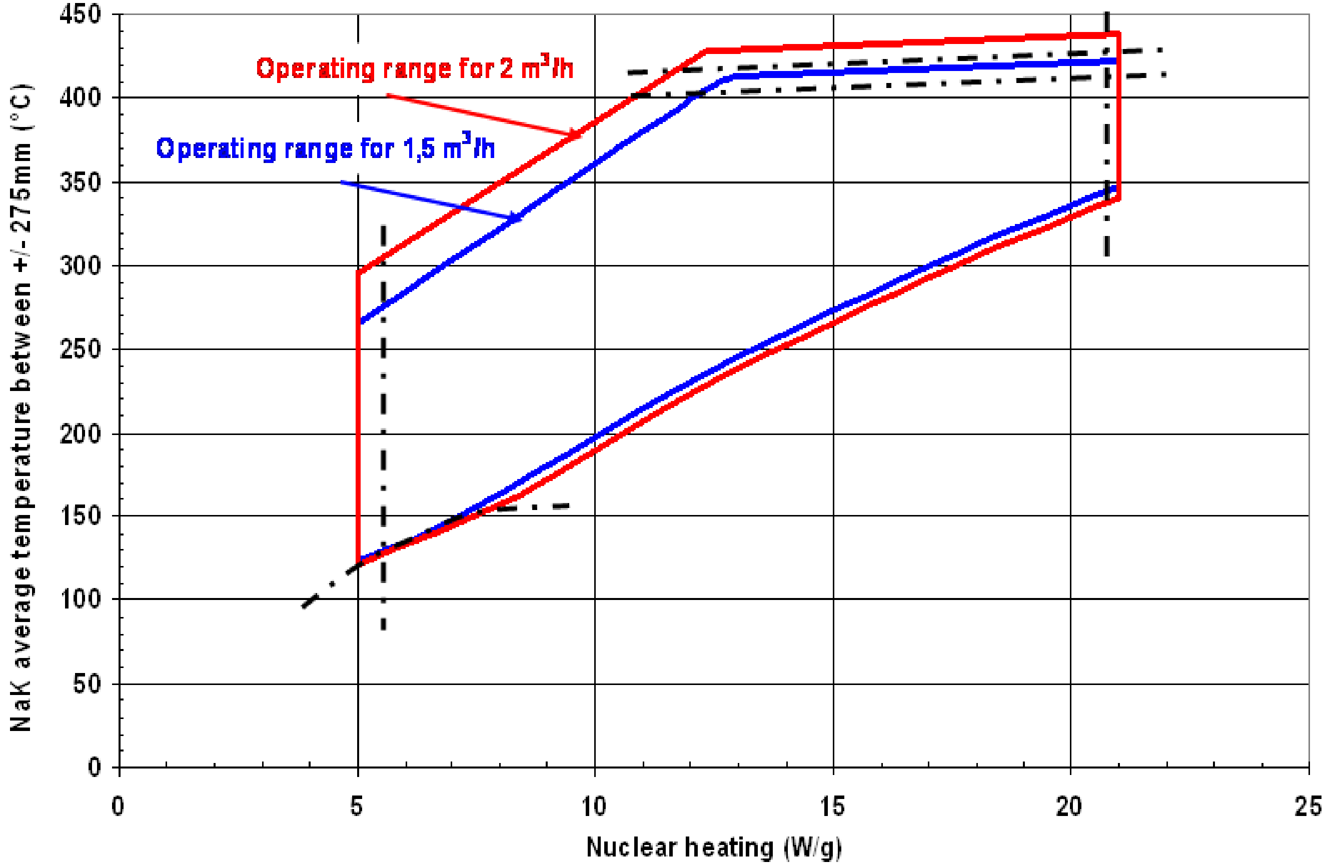
- **To adapt the NaK temperature level to the experimental needs (depending on the type and shape of samples), one can control heat loss to the primary circuit**

by adjusting the length of exchange in the bottom of the rig, i.e. the level of NaK flow reversal (adaptation done in hot cells before irradiation)



Results : NaK flowrate

- **Decreasing NaK flowrate reduces the optimum operating range**
  - It deviates outside of the limits (>7.5℃) for 1 m ^{3}/h
  - Higher flowrates than 2 m^3/h were not considered due to pump limitation



Results : management of temperature fluctuations

- **During reactor cycle, small variations of sample temperature can be compensated**
  - by controlling the electrical power of the heaters
  - while keeping the NaK flowrate constant at its nominal value

- **Fluctuation of ± 4% of nuclear heating**
  - leads to ~ 5°C variation of the NaK temperature,
  - easily managed by ~ 800 W power variation of the electrical heater
  - the quality criterion is only slightly affected.

	Nuclear heating	Electrical Power	NaK average temperature	ΔT_{NaK} criterion
Reference	17.6 W/g	10 073 W	328°C	2.2 °C
Nuclear perturbation	17.6 **- 0.7 W/g**	10 073 W	328 **- 6°C**	4.5 °C
Elec. heater adjustment	17.6 **- 0.7 W/g**	10 073 **+790 W**	328°C	5.3 °C
Nuclear perturbation	17.6 **+0.7 W/g**	10 073 W	328 **+4°C**	4.2 °C
Elec. heater adjustment	17.6 **+0.7 W/g**	10 073 **-751 W**	328°C	3.8 °C

- **Main results :**
  - Before irradiation :
    - > **Modulation of the heat exchanger length will give flexibility to CALIPSO to cope with the quality criterion while covering a wide range of nuclear heating and NaK temperature for different types of samples**
  - During irradiation :
    - > **NaK flowrate has to be kept constant : 1.5 m^3/h to 2 m^3/h are the optimal range,**
    - > **The electrical power of the heaters will be adjusted to compensate temperature changes due to nuclear heating fluctuation**

- **Future work :**
  - The manufacturing of an out-of-pile prototype is under way.
    - > **to qualify the performance of the main components**
    - > **to validate the thermal assessment of such a test device toward its licensing for irradiation in the JHR**