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



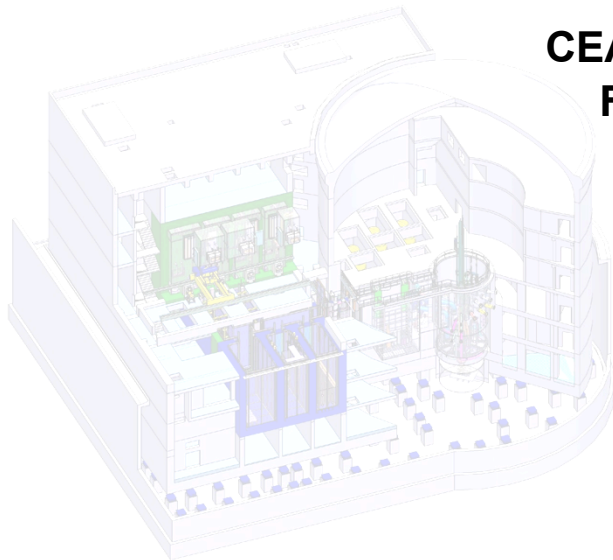
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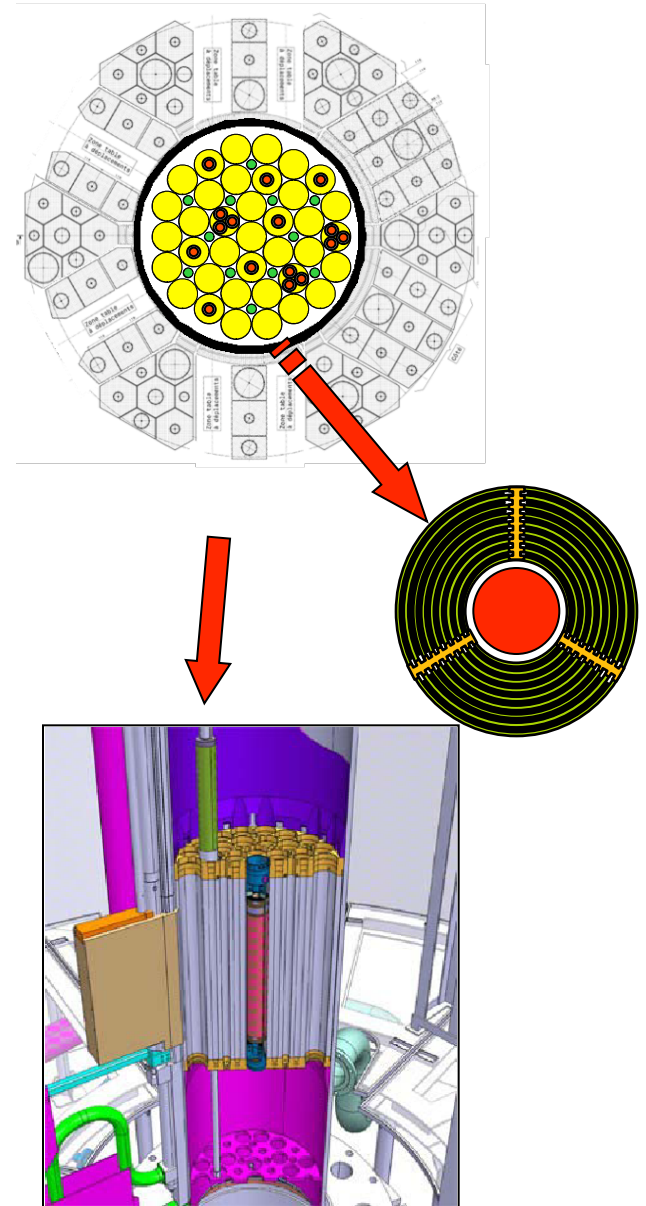


Introduction



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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.

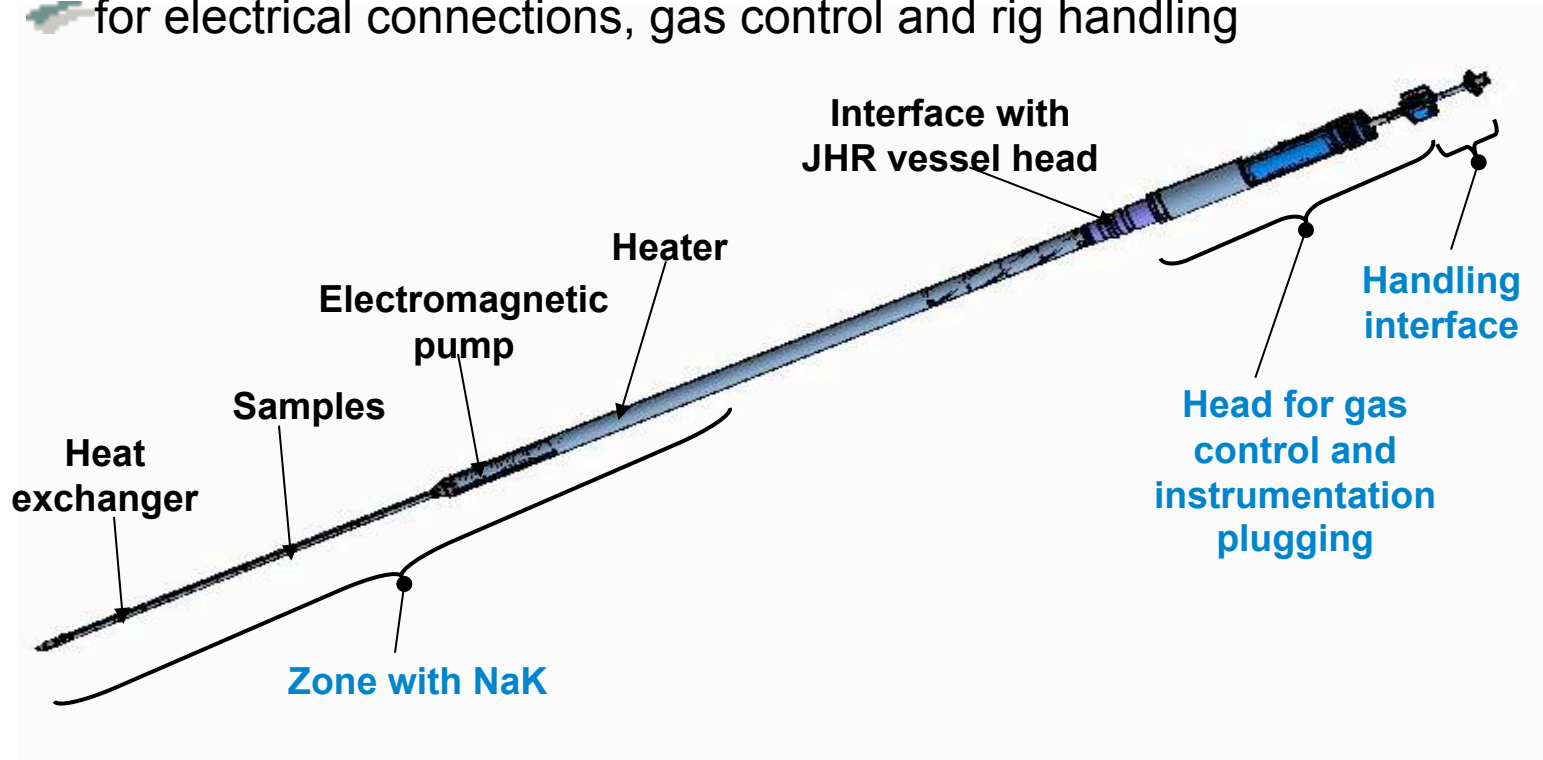


General description : overall dimensions



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- **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



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- **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 m³/h,

➤ pressure drop : 1.25 bar,

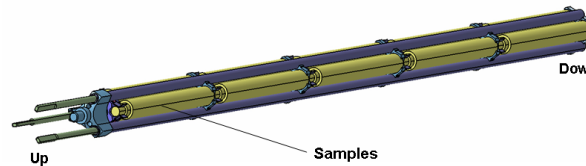
➤ maximum NaK temperature : 450°C

- **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

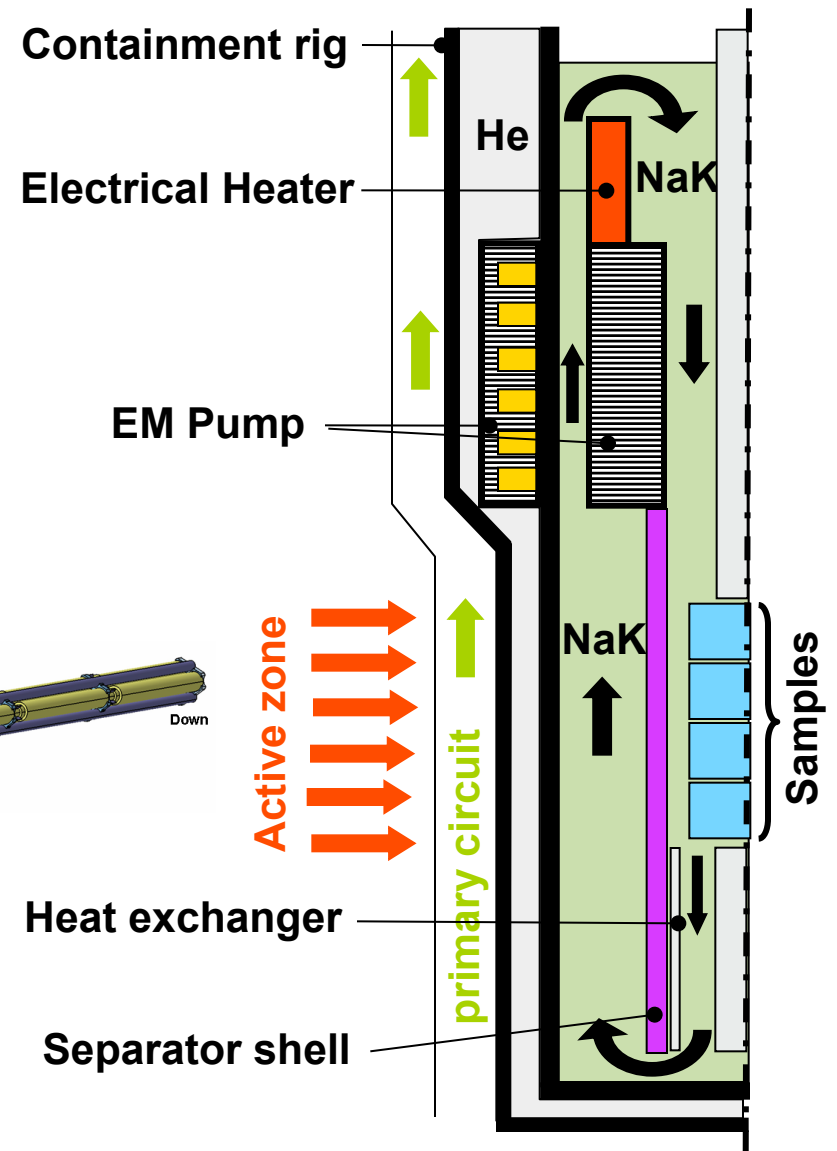
➤ The NaK is heated before and after the flow reversal



- **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



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- **The REFLET code was designed to perform steady state thermal calculations in axisymmetrical geometry**

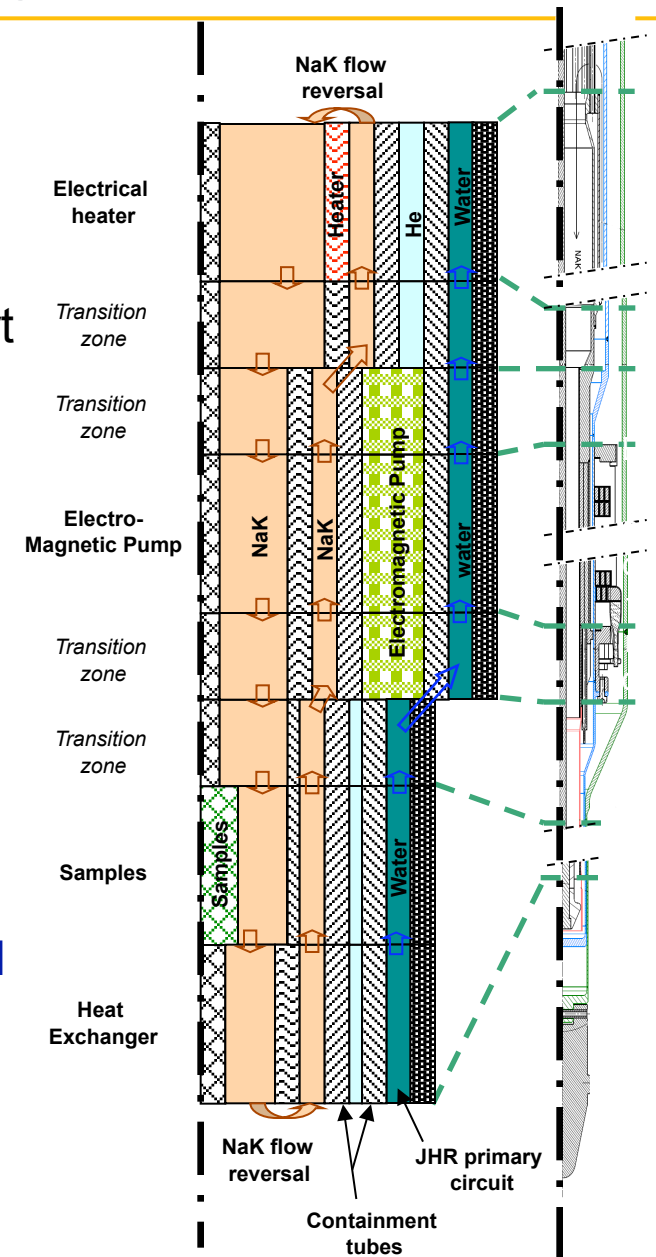
- Taking into account most of the specificities of irradiation test devices
- Radial heat exchanges and energy transport in fluid flows are considered
- Calculations of temperatures, heat fluxes and thermal balance
- Very convenient for large exploration of operating range

- **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



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- **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°C
- ☞ Water speed : ~ 8 m/s
- ☞ Heat transfer coefficient : ~ $3.5 \cdot 10^4 \text{ W.m}^{-2}.\text{°C}^{-1}$

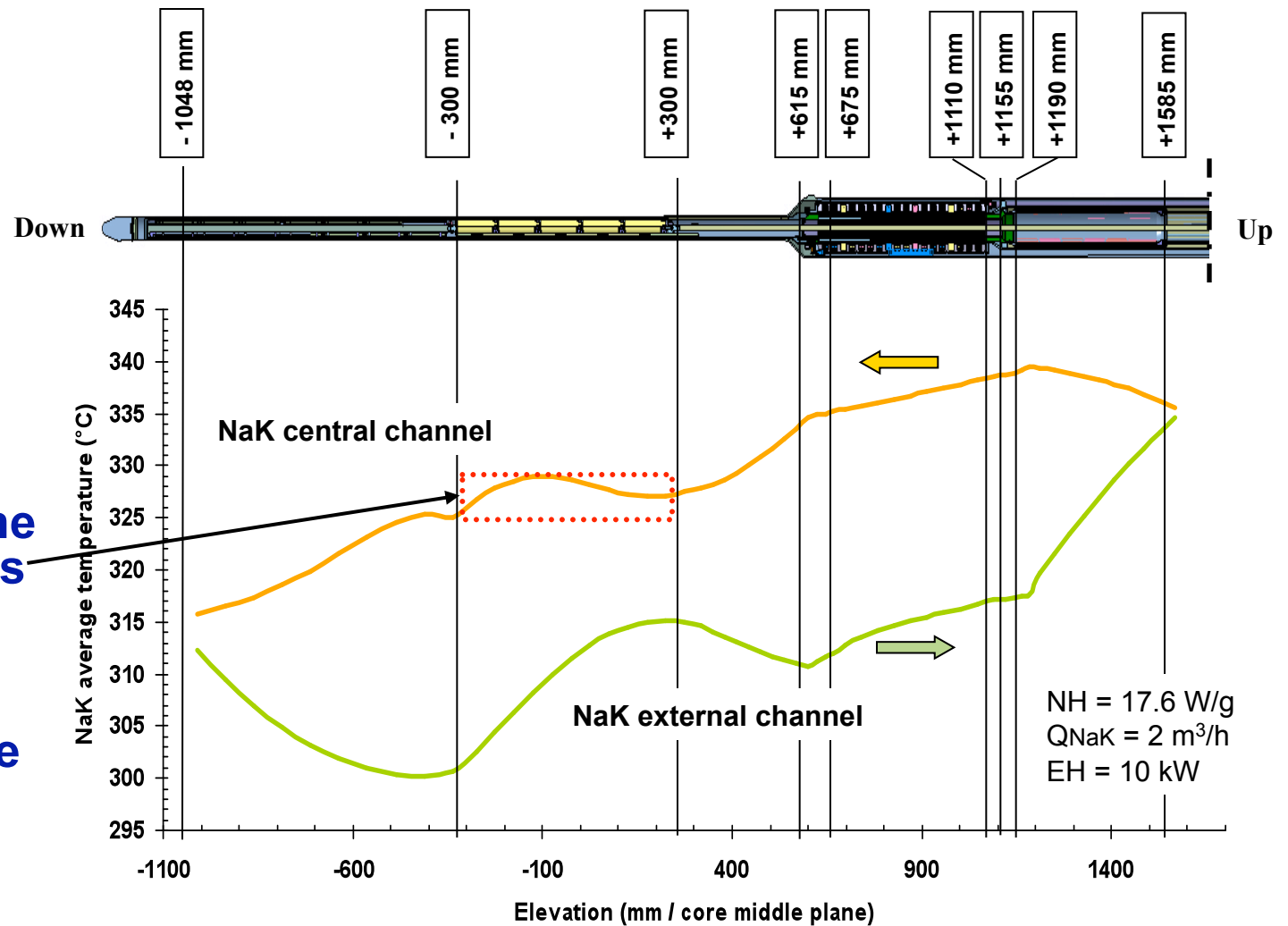
- > **Test device not very sensitive to the variations of the primary circuit conditions**

Results : quality criterion



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- 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

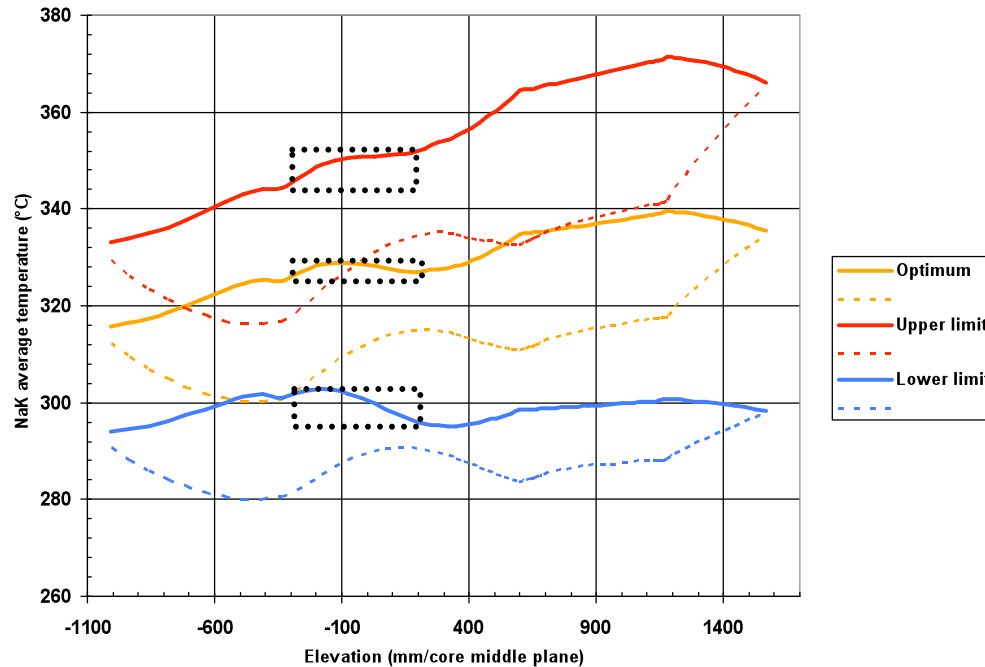
Results : quality criterion



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	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°C has been chosen as the limit of the optimum operating zone regarding experimental targets**



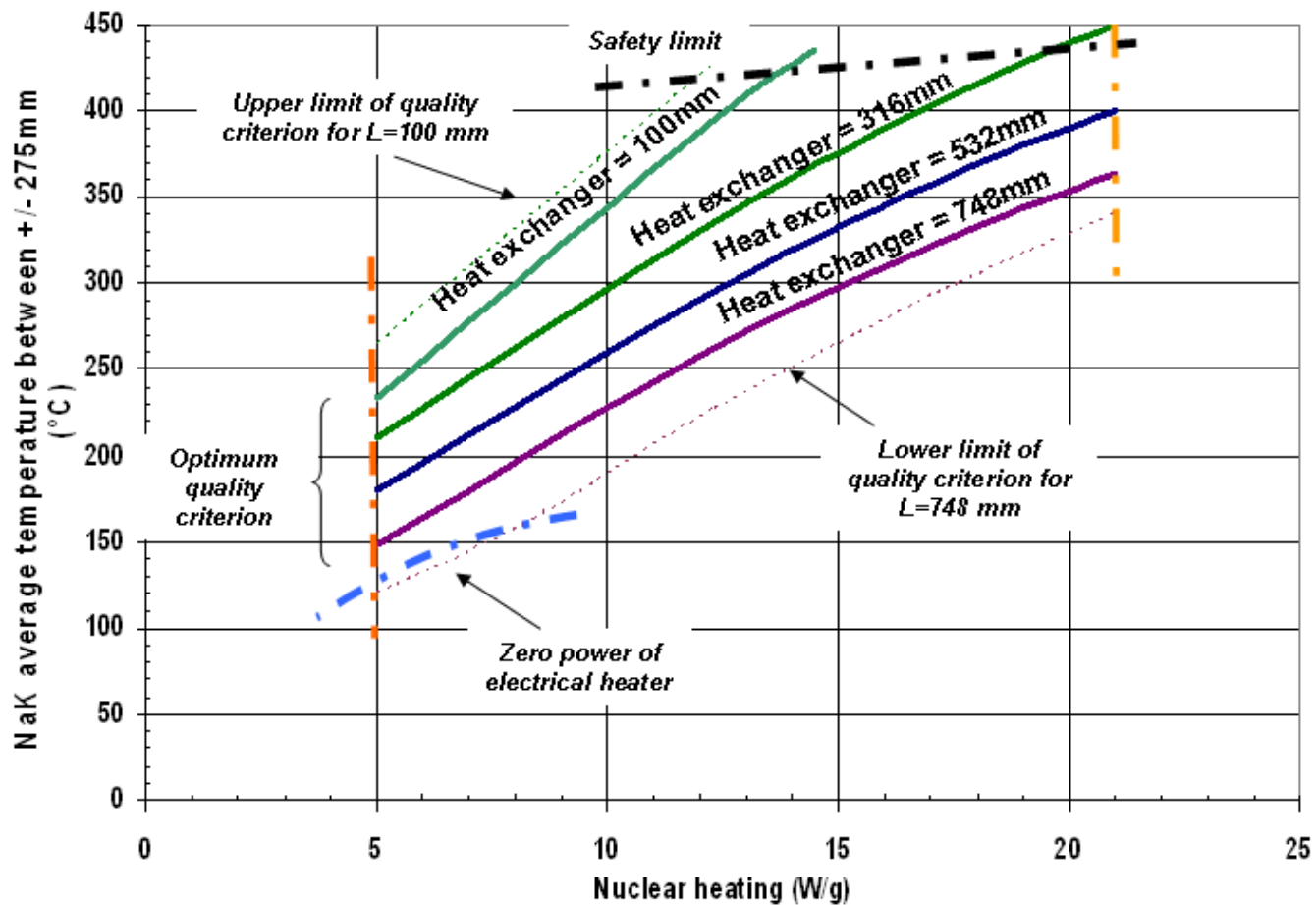
Results : heat exchanger



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- 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

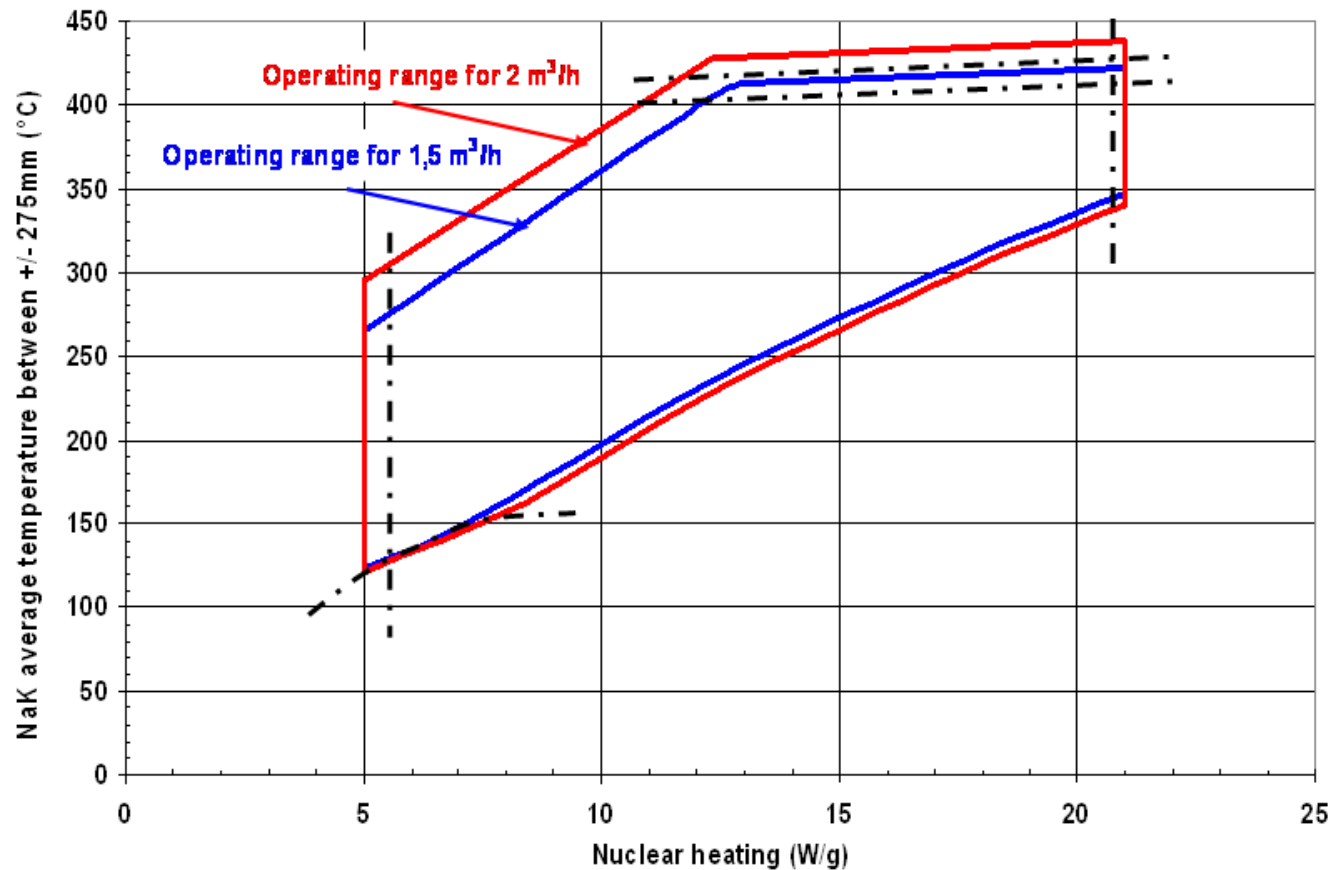


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- **Decreasing NaK flowrate reduces the optimum operating range**

It deviates outside of the limits ($>7.5^{\circ}\text{C}$) for $1\text{ m}^3/\text{h}$

Higher flowrates than $2\text{ m}^3/\text{h}$ were not considered due to pump limitation



Results : management of temperature fluctuations



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- **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 $\pm 4\%$ of nuclear heating**
 - leads to $\sim 5^\circ\text{C}$ variation of the NaK temperature,
 - easily managed by $\sim 800\text{ W}$ 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 m³/h to 2 m³/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**