HEAT TRANSFER INSIDE A CALORIMETER DEDICATED TO GAMMA HEATING MEASUREMENTS IN MTR

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IGORR 2010

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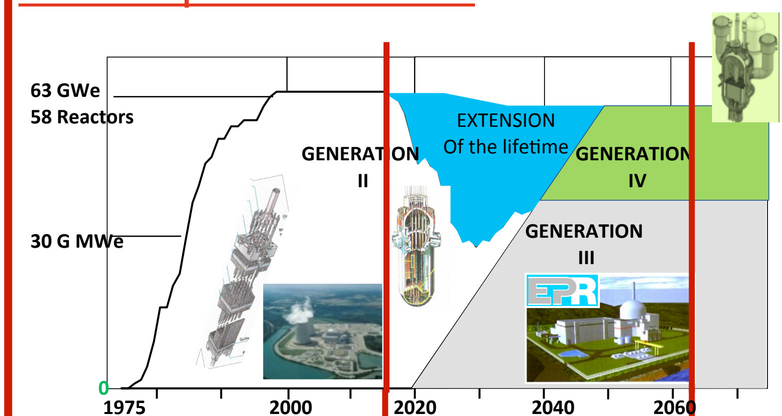
General Background

French power reactor



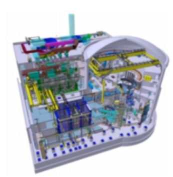
MTR in Europe

OSIRIS **(44 years , 70 MW)**

BR2 **(45 years, 60 MW)** ?

HFR **(47 years, 45MW)**

Halden **(51 years, 20MW)** ?



2015 JHR 2065

(Cadarache, 100MW)

Research needs on nuclear-material and -fuel

In MTR, ZPR, RR, …

Scientific aim : a better understanding of complex phenomena by increasing data accuracy

Challenges : new on-line and real time in-pile instrumentations and measurement methods

Scientific Background

A new French research programme between "l'Université de Provence " and the "CEA"

*IN-CORE :I*nstrumentation for *N*uclear radiations and *C*alorimetry *O*nline in *Re*actor : September 2009-September 2013

Région
Provence-Alpes-Côte d'Azur

l'Europe s'engage en Provence Alpes-Côte d'Azur avec le FEDER

Scientific and technological goals :

- **innovative device**
- **online parametric mapping of the JHR core channels**
- **coupling of several sensors dedicated to measurements of relevant physical parameters (gamma heating, neutron heating, neutron flux …).**

⟹ **Two kinds of experimental studies**

Under irradiation in OSIRIS for the first prototype, then in JHR

Without radiation for conception and optimization of gamma heating calorimeter

Radiometric Calorimetry:

Calorimeters used in nuclear science

4 categories

- **Radionuclide calorimeter containing a radioactive source :**
  activity, half time, desintegration energy, …
- **Beam calorimeter located in a particule collimated beam from an external source :**
  total power, absolute calibration of ionization chamber for instance
- **Local adsorbed dose calorimeter :**
  power deposited in a material specimen located an isotropic gamma field of an external source
- **In-reactor calorimeter :** measurements of various effects due to reactor radiation according to the internal material

Gunn et al.
NIM, 1964, 1970, 1976

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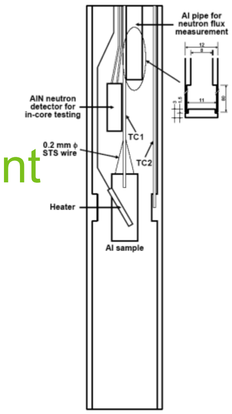
Two possible applications :

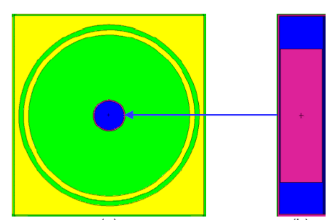
- Measurement of power deposition in specific materials
  - such as structural materials for engineering development

    for instance **Aluminium** for the designing of the moderator Cell of Cold Neutron Source of the Hanaro research reactor (Kim et al. IGORR 2005)



- Measurement of local doses of neutron and gamma rays
  - better knowledge of the core irradiation in specific location

    for instance power distribution and therefore heat deposition in two materials (**stainless steel and Molybdenum**) in position B6 of the SAFARI-1 reactor (Makgopa, ANIMMA 2009)



(a) (b)

Figure 2: (a) Top view of the calorimeter in core channel B6, (b) the calorimeter device with its core (purple), a gap filled with an atmosphere of air (blue) and a jacket [2].

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→ **Material choice depending on the targeted radiation**

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Heat transfers inside the calorimeter

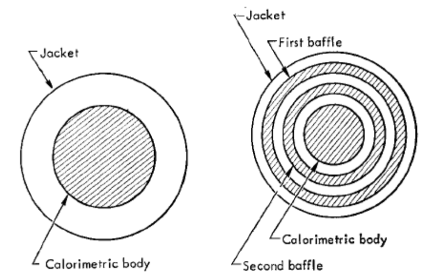
Different phenomena :

according to the kind of reactor
(natural or forced convective transfer)

according to the kind of material, to its surface aspect and to the temperature values
(thermal radiative transfer)

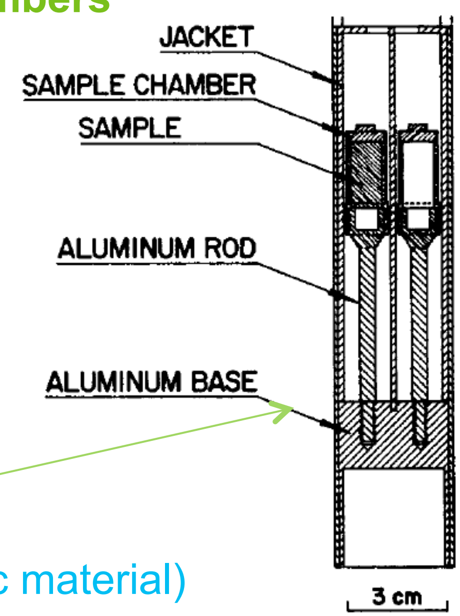
according to the kind of fluid inside the calorimeter and to the baffle numbers
(thermal conductive transfer)

Gunn 1970



and **depending on the thermal mode associated to the sensor**
(Adiabatic mode, isothermal
or mode with heat flow,
or pseudo-adiabatic mode)

And **according to the shape**
(one cell or
twin cell : empty + containing a specific material)



Gunn 1964

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The first thermal mode : Isothermal calorimeter or stationnary calorimeter

the calorimeter temperature = constant versus time

Local energy equation : Stationary Conduction

Thermally conductive solid body bounded by a fluid

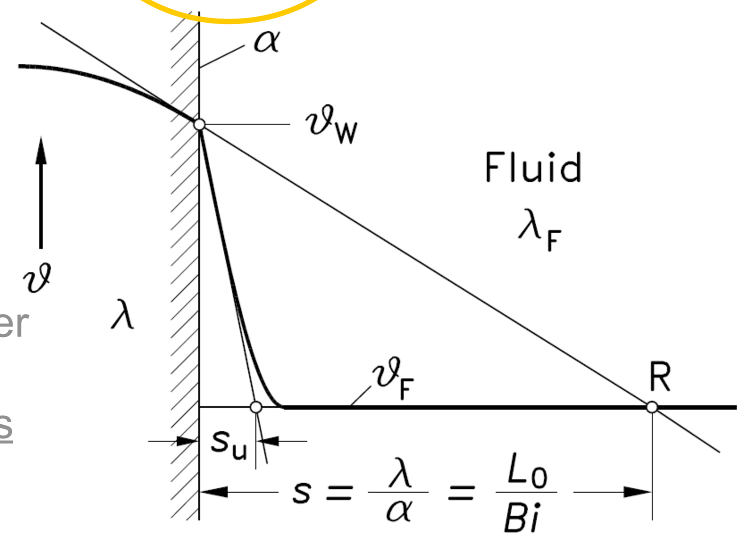
Inertia, Diffusivity, Source

$$\cancel{\varrho c(\vartheta)\frac{\partial \vartheta}{\partial t}} = \operatorname{div}\left[\lambda(\vartheta)\operatorname{grad}\vartheta\right] + \dot{W}(\vartheta, \boldsymbol{x}, t)$$

Convective boundary condition

$$-\lambda\left(\frac{\partial \vartheta}{\partial n}\right)_{\mathrm{W}} = \alpha\left(\vartheta_{\mathrm{W}} - \vartheta_{\mathrm{F}}\right)$$

α depends on the Nusselt Number given by a correlation versus the Prandtl number and the Reynolds number for forced convection



$$s_{\mathrm{u}} = \lambda_{\mathrm{F}}/\alpha = L_0/Nu$$

$$s = \lambda/\alpha = L_0/Bi$$

Temperature profile depending on the Biot Number and the Nüsselt Number

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The first thermal mode : Isothermal calorimeter or stationnary calorimeter

Overall heat transfer in that case

Deposited energy=Exchanged Energy

$$\text{dt} * \dot{Q} = kA\left(\vartheta_1 - \vartheta_2\right) \ \text{*dt}$$

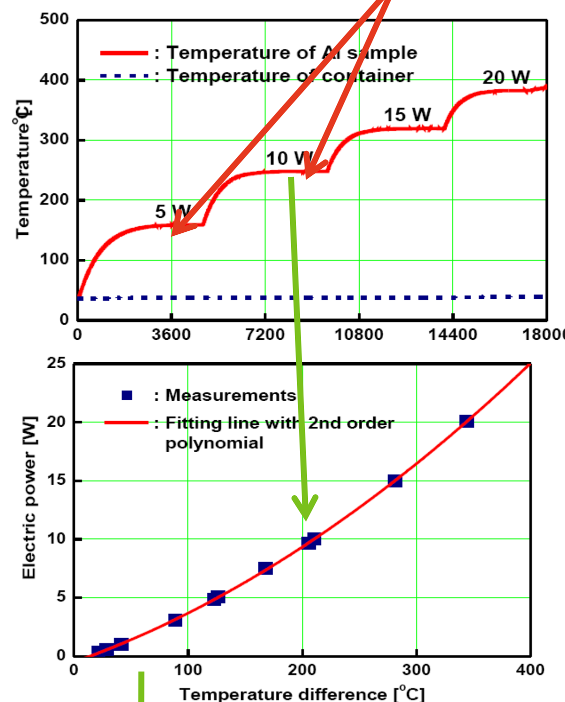
dt * $\dot{Q}$: heat flow

$(1/kA)$: resistance of overall heat transfer

Parameter determined by calibration experiments, for instance without radiation but by Joule effect induced by an electrical resistance

Parameter influencing the sensor sensitivity

the calorimeter temperature = constant versus time



Kim et al. IGORR 2005

non linear calibration curve : thermal radiative effect to take into account

The calibration curve fitting depending on the nature of heat transfer

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Other mode : The transitory mode

Non stationary heat transfer : Cooling curve (calorimeter is removed from the reactor core)

(Makgopa, ANIMMA 2009)

Cooling Step : Accumulated energy +Exchanged energy =0

$$\cancel{dt * \dot{Q}} = kA(\vartheta - \vartheta_2) * dt + m * dt * c(\vartheta)\frac{\partial \vartheta}{\partial t}$$

Plot of the cooling curve on semi-log scale, Determination of calorimeter pseudo-period T=(mc)/(kA)

(a pseudo period can be defined with the same exploitation of the heating curve)

Stationnary : deposited energy=Exchanged Energy

$$dt * \dot{Q} = kA(\vartheta_1 - \vartheta_2)$$

T=(mc)/(kA)

$$dt * \dot{Q} = \frac{m\,c}{T}(\vartheta_1 - \vartheta_2) * dt$$

Need of the calorific heat value

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A second thermal mode : Adiabatic calorimeter

Disadvantages :

needs of auxiliary equipment (fluid line including a vacuum pump) or needs of a more mechanical structure (multi-concentric baffles) to ensure a good thermal insulation

- no heat exchange between the calorimeter and its external surroundings

Deposited energy=Accumulated energy

$$\varrho c(\vartheta)\frac{\partial \vartheta}{\partial t} = \text{dt} * \dot{Q}$$

The knowledge of the value of calorific capacity is needed

Direct consequences :

- A better sensitivity

- A quick and/or high increasing of the temperature during the irradiation time

- A specific operating mode with short experiments by removing the sensor from the core

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Conclusions and Outlooks (1)

Actually a thermal study of a specific in-core calorimeter is realized

- A numerical model of heat transfers is validated by comparison with out of flux calibration experiments on CALMOS mock up in OSIRIS,

- The second numerical step will be dedicated to radiation conditions

- A calibration experimental set-up will be developed in order to perform thermal and hydraulic parametric studies under JHR conditions

-With these two complementary approaches, the conception and the optimization of one calorimeter for JHR core will be performed

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Conclusions and Outlooks (2):

- "CARMEN", an innovative nuclear emissions measurements device for online core channels mapping, adapting the current OSIRIS technology (CALMOS) to operate in JHR conditions:
  - Implementing additional detailed instrumentation for nuclear radiations
  - Strengthening the signal treatment and modeling domains, in order to combine the measurements

Improving the quantity and quality of online information: At the current stage: photon measurements (gamma heat and flux), thermal neutron flux and fast neutron flux

- Main project milestones (up to sept. 2013)
  - A first device evolution, CARMEN-1, to be tested in OSIRIS in 2011
  - CARMEN-2, taking benefits from the CARMEN-1 feedback, to be designed for JHR conditions