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School on Physics, Technology and Applications of Accelerator Driven Systems (ADS)

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Engineering Design of the MYRRHA (Practicum: Thermal analysis of a fuel element)
Part VIII

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CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

Practicum :

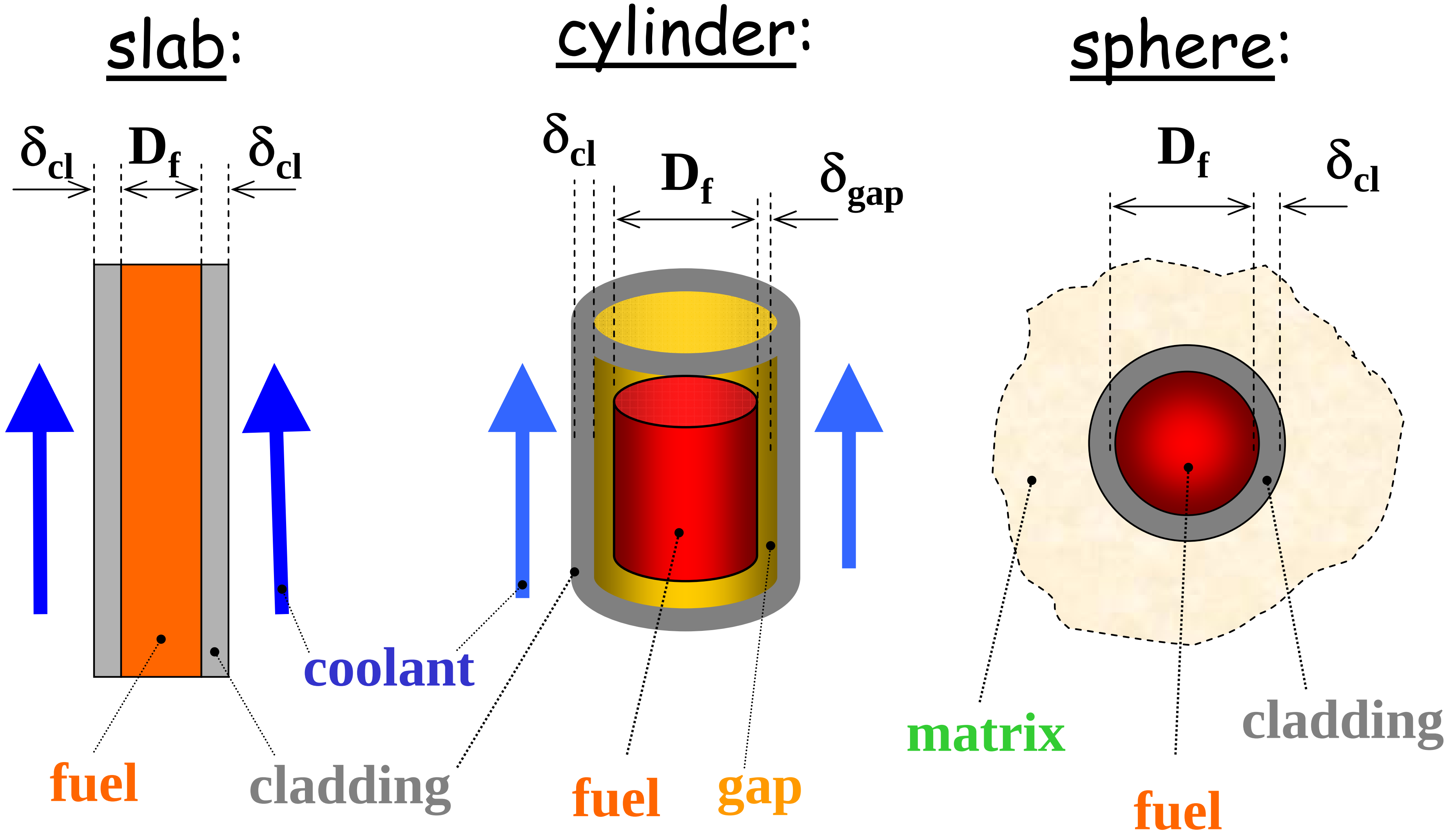
Thermal analysis of a fuel element

Prepared by Prof. V. Sobolev

Institute of Nuclear Materials Science

Belgian nuclear research Centre, SCK·CEN

Different geometries of a fuel element



Safety requirements for fuel element design

- Non-melting of fuel: $T_{fuel} < T_{fuel\ melt}$
- Non-melting of cladding: $T_{clad} < T_{clad\ melt}$
- Chemical resistance of cladding to fuel and to coolant: $\Delta\delta_{cl} < 5\ \%$
- Mechanical resistance of cladding to stresses caused by internal and external pressures, by temperature changes, by swelling and creep, and by PCMI.

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Input information for design

- **Materials** and their **properties**
- Expected local **peak power** in fuel
- **Allowed** operation **temperatures**
- **Coolant** type and temperature

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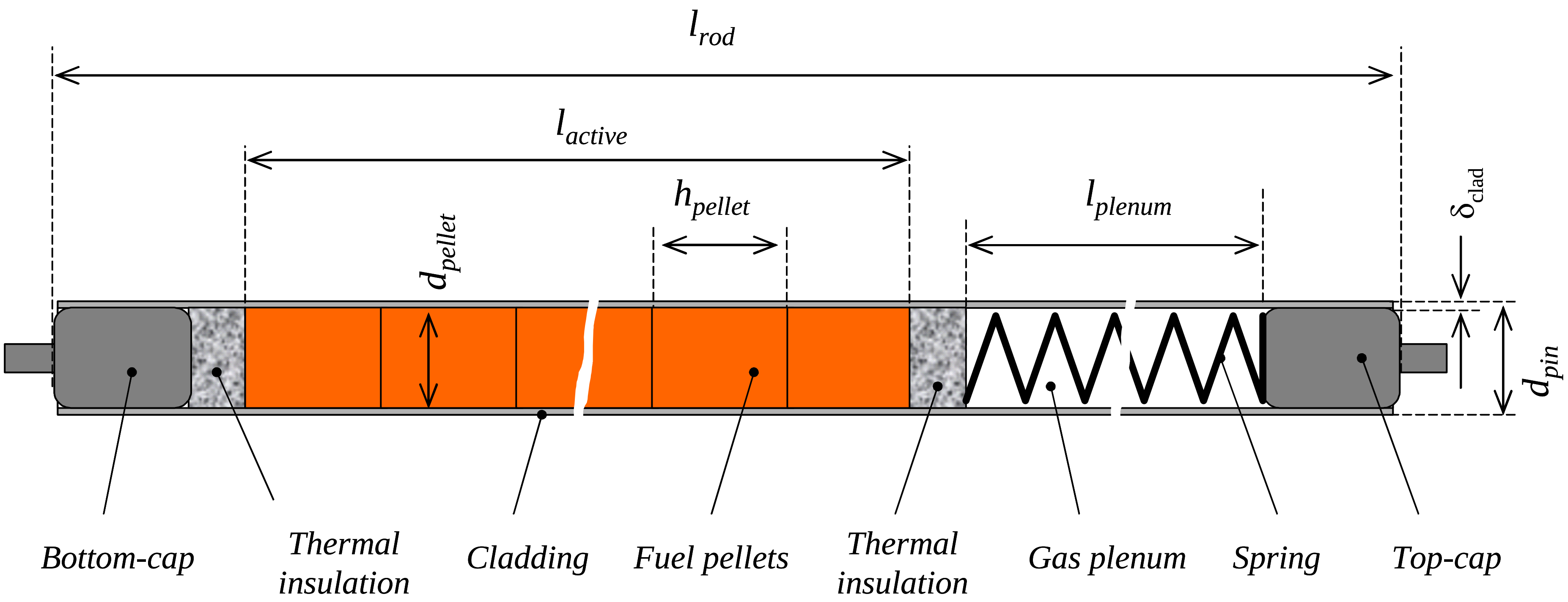
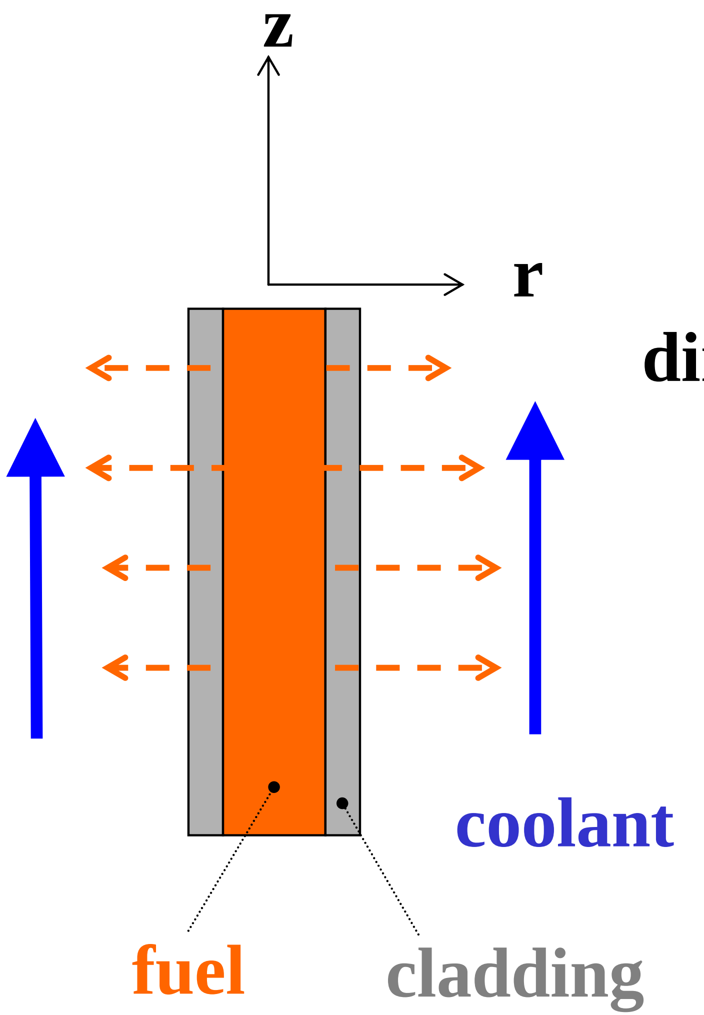
Typical fuel rod

Main elements



Heat transfer by thermal conductance and convection:



$$\nabla\left(k\cdot\nabla T\right)+q'''=0$$

If heat is transferred only in one direction (r) and solids are isotropic then:

$$\frac{d}{r^n dr}\left(k\cdot r^n\cdot\frac{dT}{dr}\right)+q'''=0$$

***n* = 0 for slab; *n* = 1 for cylinder; *n* = 2 for sphere.**

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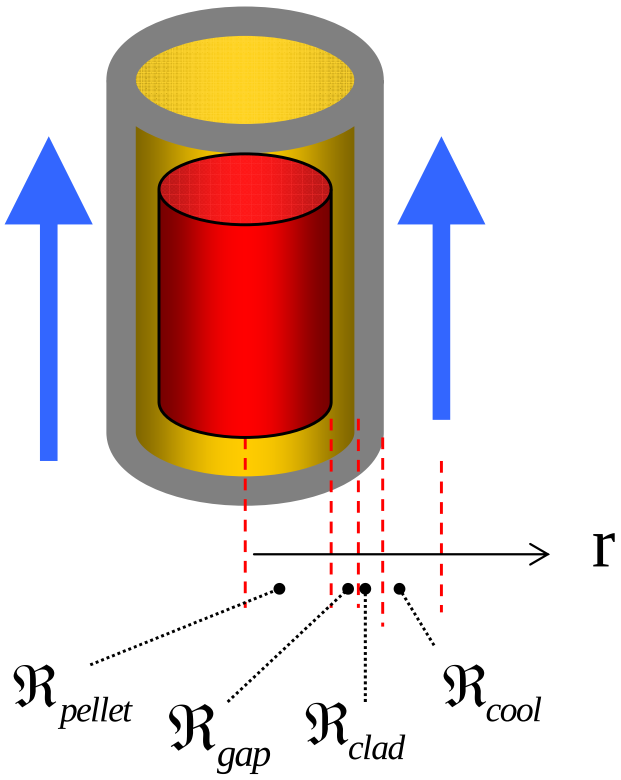
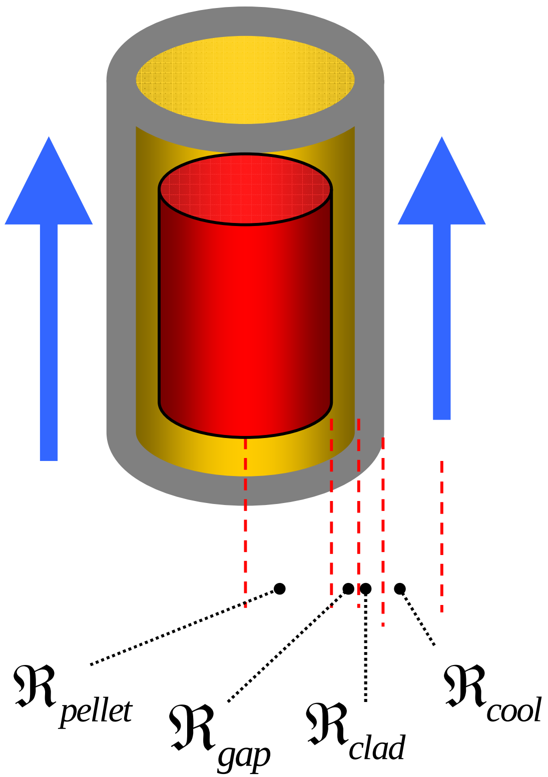
Radial temperature differences in a cylindrical fuel element



$$\begin{cases} \dfrac{d}{r\cdot dr}\left(r\cdot k\cdot\dfrac{dT}{dr}\right)+q'''=0 \\ \left.\dfrac{dT}{dr}\right|_{r=0}=0 \\ h\cdot\left(\left.T_c\right|_{r=R_{co}}-T_{cool}\right)=\left.q''\right|_{r=R_{co}} \end{cases}$$

Radial temperature differences in a cylindrical fuel element

$$\Delta T_{fc-coolant} = \sum_i \Delta T_i \approx q'_f \cdot \sum_i \Re_i$$



$$\Delta T_{co-coolant} \approx q'_f \cdot \frac{1}{\pi \cdot D_{co} \cdot h_{coolant}}$$

$$\Delta T_c \approx q'_f \cdot \frac{1}{\pi \cdot k_c} \cdot \ln\left(\frac{D_{co}}{D_{ci}}\right)$$

$$\Delta T_g = q'_f \cdot \frac{1}{\pi \cdot \langle D_g \rangle \cdot h_g}$$

$$\Delta T_f = q'_f \cdot \frac{1}{4\pi \cdot \langle k_f \rangle}$$

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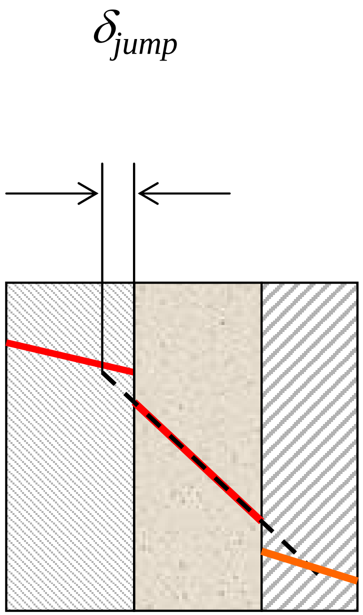
Gap thermal resistance



no contact

$$\Re_{gap} \approx \frac{\delta_{gap} + \delta_{jump\,clad} + \delta_{jump\,pellet}}{k_{gas\,effective}}$$

in contact

$$\Re_{gap} \approx \frac{C \cdot \sqrt{\langle \delta r \rangle_{clad} \cdot \langle \delta r \rangle_{pellet}}}{p} \cdot \left(\frac{k_{pellet} + k_{clad}}{k_{pellet} \cdot k_{clad}} \right)$$

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Cold and hot gap size

- In order to avoid PCMI :

$$D_f \leq D_{ci} \qquad at\ DBC$$

where

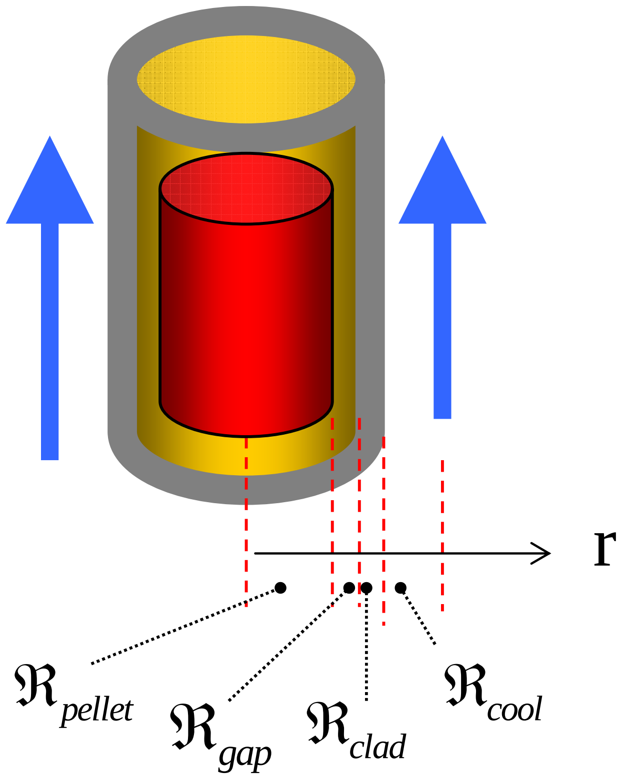
$$D_f(T) = D_f(T_0) \cdot \left(1 + \varepsilon_{T\,f}(T)\right)$$

$$D_{ci}(T) = D_{ci}(T_0) \cdot \left(1 + \varepsilon_{T\,c}(T)\right)$$

$$\delta_g(T) = D_{ci}(\langle T_c \rangle) - D_f(\langle T_f \rangle)$$

Exercise 1:

Cylinder:

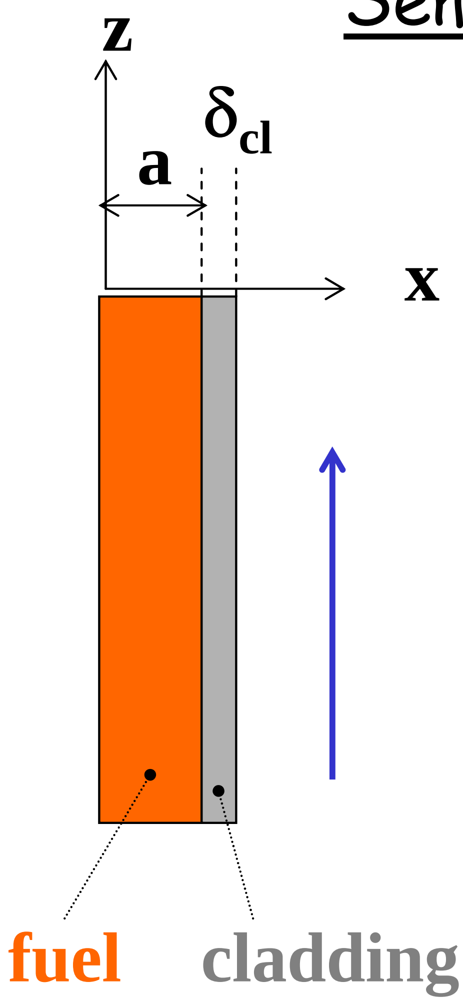


$$\begin{cases} \dfrac{d}{dr}\left(r \cdot \dfrac{dT_f}{dr}\right) + \dfrac{q''' \cdot r}{k_f} = 0 \\ \left.\dfrac{dT_f}{dr}\right|_{r=0} = 0 \\ \left.T_f\right|_{r=R_{fo}} = T_{fo} \end{cases}$$

$$T_{fc} = ?$$

Exercise 2:

Semi-slab:



$$\frac{d^2T_f}{dx^2} + \frac{q'''_f}{k_f} = 0 \qquad \left(\frac{dT_f}{dx}\right)_{x=0} = 0$$

$$\frac{d^2T_c}{dx^2} = 0 \qquad T_f\Big|_{x=a} = T_c\Big|_{x=a}$$

$$-\left(k_c \frac{dT_c}{dx}\right)_{x=a} = -\left(k_f \frac{dT_f}{dx}\right)_{x=a} = q'' = q''' \cdot a$$

$$\frac{\Delta T_{UO_2}}{\Delta T_{UC}} \equiv \frac{\left(T_{fc} - T_{co}\right)_{UO_2}}{\left(T_{fc} - T_{co}\right)_{UC}} = ?$$

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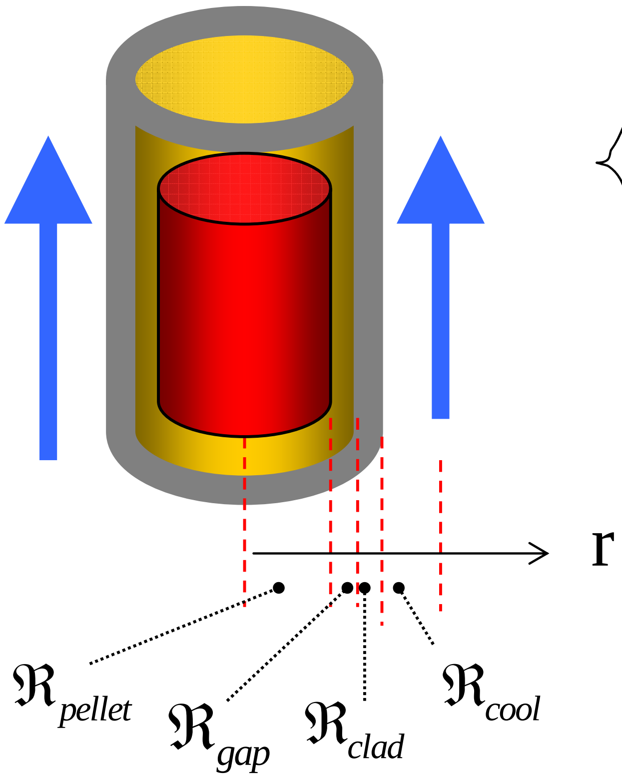
Exercise 3:

Cylinder:



$$\begin{cases} \dfrac{d}{dr}\left(r \cdot \dfrac{dT_f}{dr}\right) + \dfrac{q''' \cdot r}{k_f} = 0 \\ \left.\dfrac{dT_f}{dr}\right|_{r=0} = 0 \\ h \cdot \left(T_c\big|_{r=R_{co}} - T_{cool}\right) = q''\big|_{r=R_{co}} = \dfrac{q'}{2\pi \cdot R_{co}} \end{cases}$$

$$\langle T_f \rangle = f\left(q'\right) = ?$$