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Heat transfer in a disc wedged between two fuel element plates

Determine a criterion for re-use of the fuel elements that are offloaded – what is the possible effect of the maximum possible obstruction after restart. What size obstruction (if any) is acceptable in an element and still safe to use that element?

Assumptions

Assume an obstruction that is cylindrical in shape, with L defined by the width of the cooling channel between fuel plates in a position where the fuel plate makes the most heat and D varied to determine the overall size and mass of the obstruction (see figure 1).

Consider this for two cases – (1) the obstruction is an aluminum disc, and (2) the obstruction is a disc made entirely of fuel meat.

Heat is conducted into the disc from both circular surfaces directly through the solid contact between fuel plate aluminum cladding and the surface of the cylinder. For the case of a disk of fuel, it is assumed that the disk has the same constituents as NBSR fuel meat, and that heat is generated in the disk at the same rate as the fuel in the adjacent plates.

The cylindrical surface of the inclusion is constantly cooled by the normal coolant flow. The average flow through an element cooled by the outer plenum is 267 GPM (6400 GPM, 24 elements), distributed through 18 coolant channels. For the case of an aluminum obstruction, the disc is heated by a constant 137 W/cm^2 from the fuel element. For the case of a fuel meat obstruction, heat is generated from the obstruction itself by a constant 5400 W/cm^3 , as well as from the fuel element (see figure 2).

Analysis

For the case of an aluminum obstruction, the heat into the obstruction equals the 137 W/cm^2 multiplied by the area of the disc times two surfaces (assume the disc contacts fuel element on each side of the gap). The heat removed from the obstruction is determined by the heat transfer to the D_2O flowing across the cylinder. The disc diameter is increased and obstruction heat in and heat out calculated until the inlet heat exceeds heat being removed. At this point, boiling onset occurs, and obstruction temperature rapidly rises resulting in melting of the obstruction and the fuel element cladding.

For the case of a fuel meat obstruction, the meat itself generates heat as well as the fuel element. The heat generated is 5400 W/cm^3. The diameter of the obstruction is increased until the surface temperature of the disk is well above the D_2O saturation temperature at which point convection heat transfer is impeded by water vapor resulting in a rapid temperature rise and melting of the obstruction and fuel element cladding.

Results

For the case of an aluminum obstruction, a disc 0.295 cm thick and 1.4 cm in diameter (mass = 1.23 g) will result in insufficient heat removed and melting of aluminum obstruction and fuel element cladding.

For the case of a fuel meat obstruction, a disc 0.295 cm thick and 0.2 cm in diameter (mass = 0.03 g) will result in insufficient heat removed and melting of aluminum fuel element cladding.

Note that if the obstruction were spherical (not a 0.28 cm thick disc), the equivalent diameter of the smallest obstruction (fuel meat case) is 0.4 cm, which is larger than the width of a channel.

Conclusion

It is unlikely that an aluminum obstruction would become wedged in a fuel element gap. It is also unlikely that a spherical fuel meat obstruction would become wedged in a fuel element gap. However, it is possible that a fuel meat disc could become wedged in a fuel element gap as its diameter is less than the gap. These estimates are very conservative in that we assume the obstruction is located at the hot spot in the core, and that any obstruction would likely have an irregular shape with more surface area available for heat transfer to the D_2O.

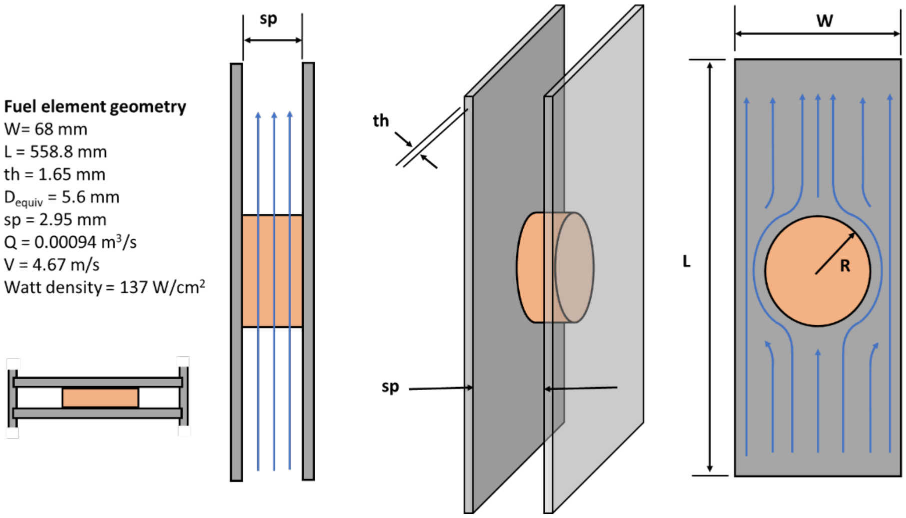

Figure 1.

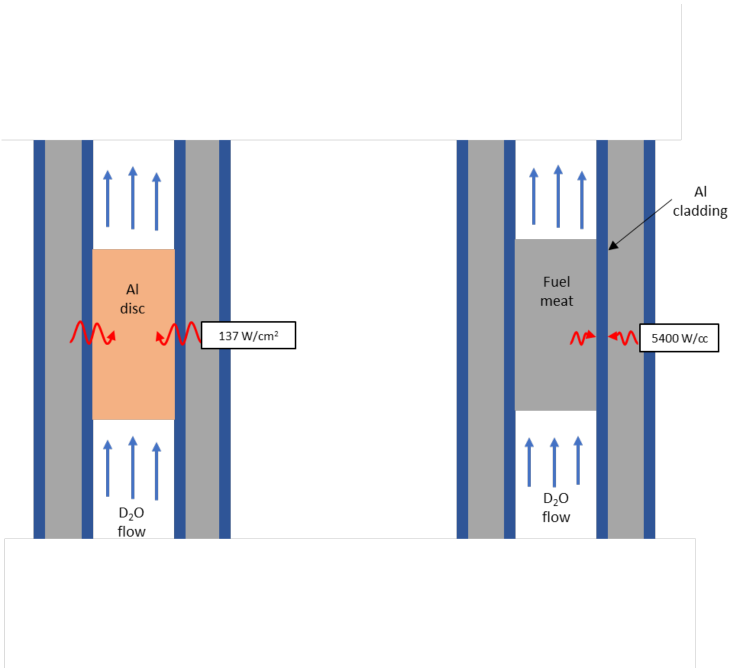

Figure 2.

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Heat Transfer in a Disk of Fuel Wedged between Two NBSR Fuel Plates

The temperature distribution within a long cylinder with a uniform volumetric heat source is [1]:

$$T(r) = T_S + Sr^2/4k \tag{1}$$

where: S = Volumetric heat source

T_S = temperature at the outer surface

k = thermal conductivity.

Assuming the disk is reconstituted fuel meat (80% Al, 20% U_3O_8 by volume) wedged between fuel plates at a hot spot we have:

$S = 5400$ W/cc $= 5.4 \times 10^9$ W/m^3,

$k = 0.8 \times 235 + 0.2 \times 0.3 = 188$ W/m-K

See the attached spreadsheet for calculations.

Heat Transfer in a Disk of Aluminum Wedged between Two NBSR Fuel Plates

As aluminum does not generate heat as fuel wedged in a fuel element would, calculated aluminum heat rise can be expressed as:

$$Q = m * c_p * \Delta T \tag{2}$$

Where Q is the heat flux x disc area x 2 (heat from both sides):

Heat flux = $q'' = 137$ W/cm^2

$A = \pi * r^2_{disc}$

Heat is removed from the same aluminum obstruction by D_2O flowing over it. The heat removed is expressed as:

$$Q = h * A * \Delta T \tag{3}$$

Where:

$$A = \pi * d_{disc} * th \tag{4}$$

$$h = \frac{k * Nu}{d_{disc}} \tag{5}$$

Heat removed from the aluminum disc is subtracted from heat input from the fuel element. As aluminum disc diameter increases, so does heat into the disc. When heat into the disc becomes greater than heat removed by the D_2O, D_2O becomes two phase with a rapid rise in aluminum temperature.

Note that if one calculates an effective equivalent Q per unit volume (as with the fuel meat case), the result from that calculation yields the same resulting aluminum disc diameter – 1.4 cm.

See the attached spreadsheet for calculations.