Transient 3D heat transfer analysis up to Dryout in fuel rods

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In this research we analyze the coupled transient heat transfer problem consisting of a nuclear reactor's fuel rod and its intrinsic coolant channel, through the development of a computer code written in Fortran and based on the finite element method [1]. Our physical model has as basis a three-dimensional fuel rod coupled to a one-dimensional coolant channel. A homogeneous mixture is used to represent the two-phase flow in the coolant channel. The coupled heat transfer problem is solved in a segregated manner through an iterative method. As case studies, we present analyses concerning the behavior of the hottest fuel rod in a Pressurized Water Reactor, during a shutdown in which the residual heat removal system is lost (loss of the reactor's coolant pumps). These studies contemplate cases where the condition of the fuel rod's cladding is ideal or presents ballooning. Analyses are also performed for two circumstances of positioning of the fuel inside the rod: concentric and eccentric. We obtained as results that the eccentricity in the fuel of a fuel rod causes higher temperatures to appear on the side of the cladding to which the fuel dislocates. A situation that reverses in the fuel, with the temperature increasing in the opposite direction of the displacement. We also found that the ballooning causes local effects of critical consequence, with the melting temperature of the UO2 being exceeded even in cases of balloonings of modest dimensions. All the simulations presented the Dryout phenomenon at the same height of the fuel rod and at similar instants of time.

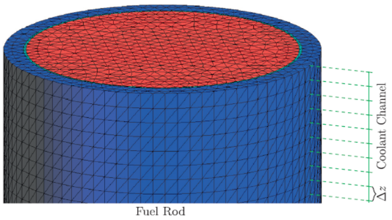

Figure 1. Discretization with Finite Elements

Figure 1 shows a typical finite element discretization used in the study. Figures 2, 3 and 4 shows results obtained in the simulation of eccentric fuels as well as for the case of balloning.

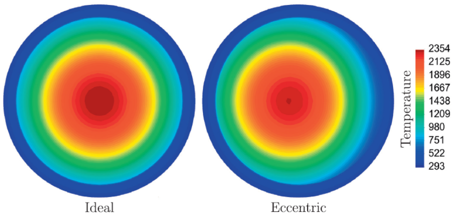

Figure 2. Transversal cuts of temperature distribution at steady state and half height (cases with concentric and eccentric fuels)

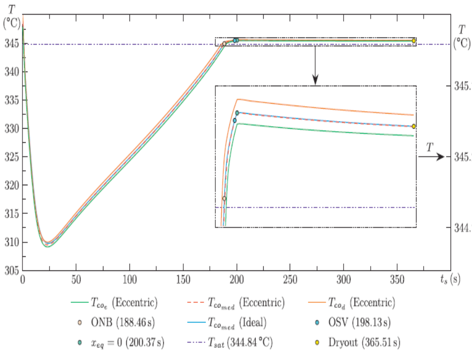

Figure 3. Temporal evolution of the cladding's outer surface temperature at the height in which the Dryout occurs (cases with concentric and eccentric fuels)

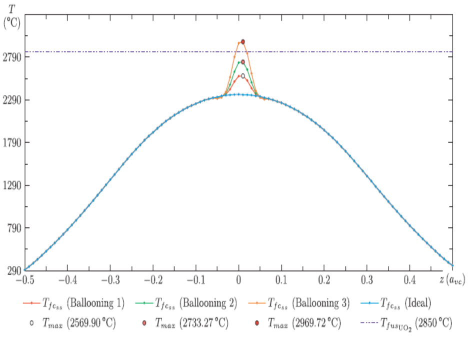

Figure 4. Distribution of temperature at the center of the fuel when steady state is reached (cases Ideal, Ballooning 1, 2 and 3)

References

[1] MARTINS, R.I.; AFFONSO, R.R.W.; MOREIRA, M.L.; DE SAMPAIO, P.A.B.; Transient 3D heat transfer analysis up to the state of Dryout in fuel rods, Annals of Nuclear Energy 115 (2018) 39-54.