Coolant-cladding interaction models in FINIX fuel behaviour module

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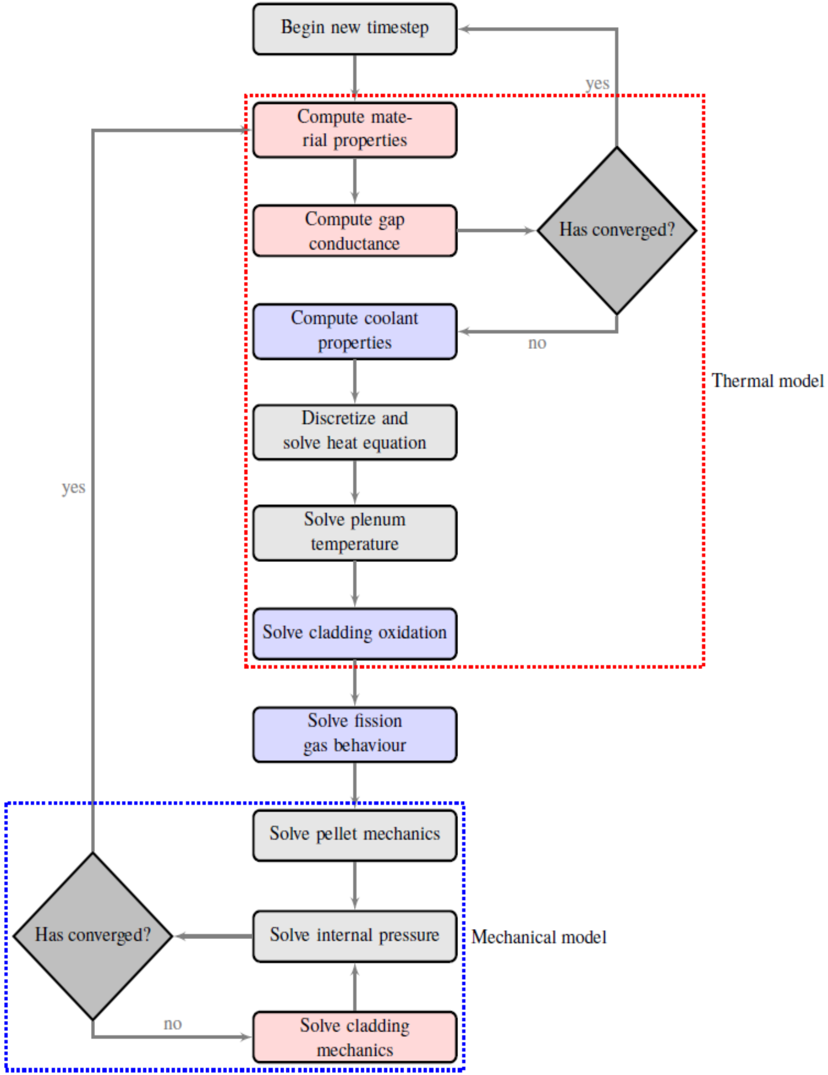
FINIX in a nutshell

- FINIX is a fuel behavior module developed at VTT since 2012[1].
- It's scope is between a dedicated fuel performance code and a thermal element.
- Designed to work both as a stand-alone code, and in coupled applications. Future development will focus on improving the coupled capabilities and optimization of FINIX.
- Uses the 1,5-dimensional finite-element method to solve the thermomechanical behavior of a fuel rod in both transient and steady-state scenarios.



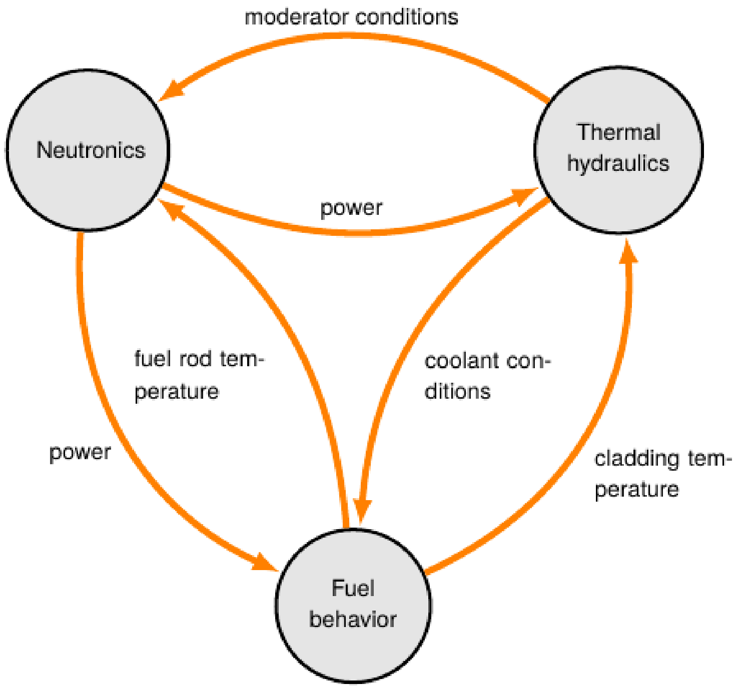
VTT's motivation in code development

- VTT is conducting most of the independent deterministic safety analyses in Finland, commissioned by the Finnish safety authority.
- Most of this analysis is performed with VTT's own tools, many of which originate from the 80's and 90's.
- The ageing of these tools and the retirement of their creators has led into loss of expertise, applicability, state-of-the-art and other challenges.
- These challenges are alleviated by investing in the development of new modular tools to provide new source-code level expertise.

Reactor solvers at VTT

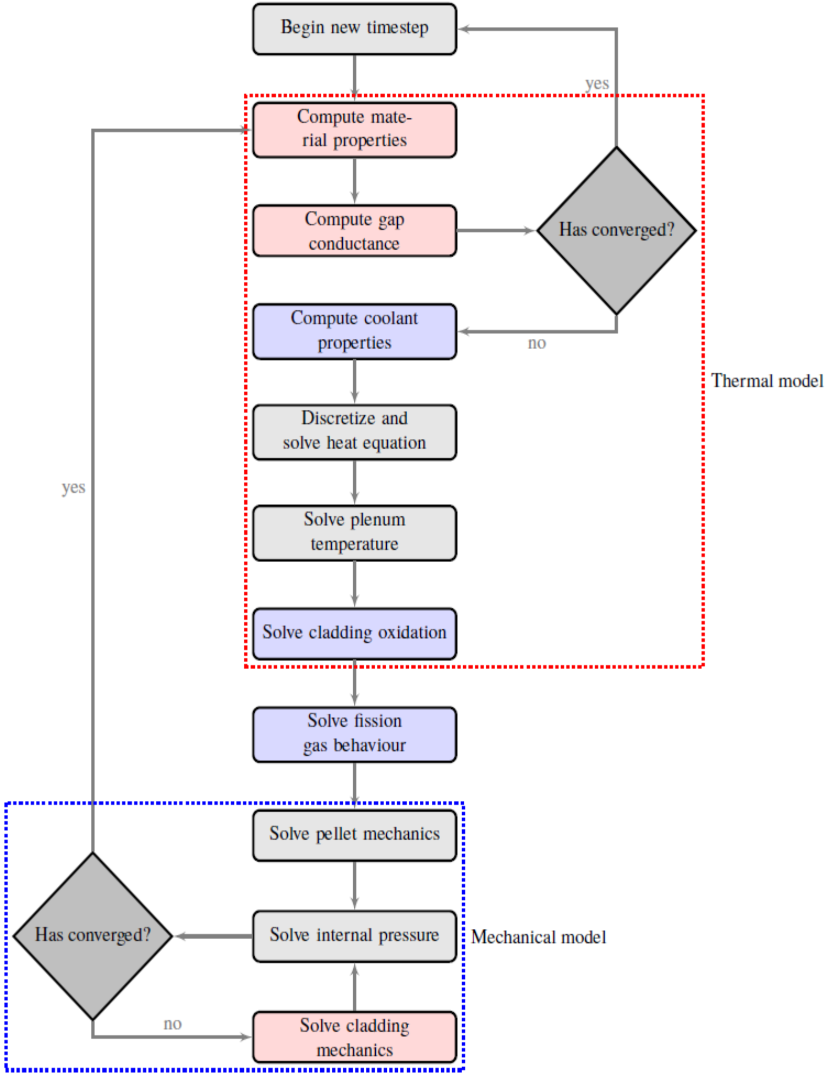
- **Serpent** Monte Carlo-neutronics code (2004 -)
- **FINIX** fuel behavior module (2012 -)
- **Ants** nodal neutronics code (2017 -)
- **Kharon** thermal hydraulics code (2017 -)

All of the aforementioned solvers are used in the new Kraken reactor analysis framework. Check out presentation by Ville Valtavirta on Thursday 31.10.



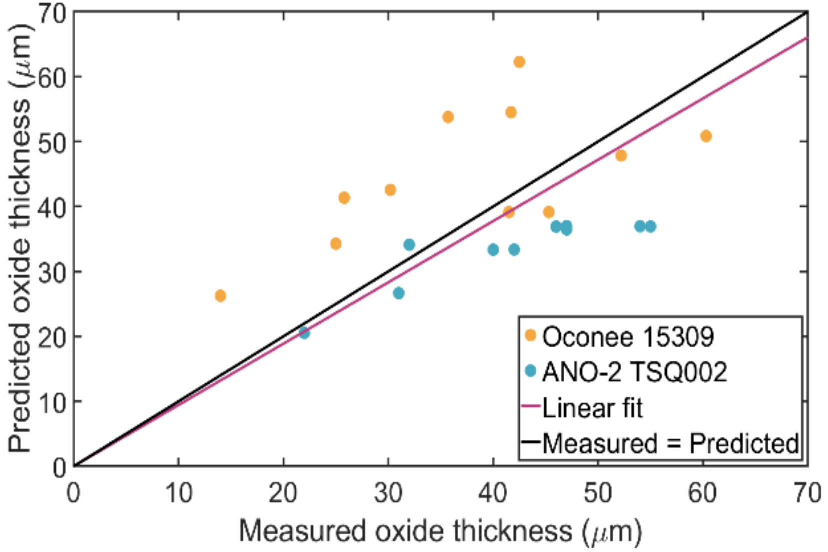
FINIX development

- FINIX development has so far focused on validation and verification of new and old models. The general aim of these updates has been to add depth and application range to fuel analysis performed with FINIX.
- Blue boxes represent the completely new models, whereas red boxes represent models that were updated.
- Several quality-of-life updates, such as restart feature have also been focus points in the past year.



FINIX development – oxidation model

- The implementation of oxidation model was necessary in order to model LOCA with FINIX, and to offer alternative tools for failure model analysis.
- Development of oxidation model offered a topic for the presenters Master’s thesis (University of Helsinki, 2019) [2].
- In order to enable the oxidation model to function properly, certain coolant properties had to be modelled as well, thus extending the topic of the thesis.



Modelling cladding oxidation

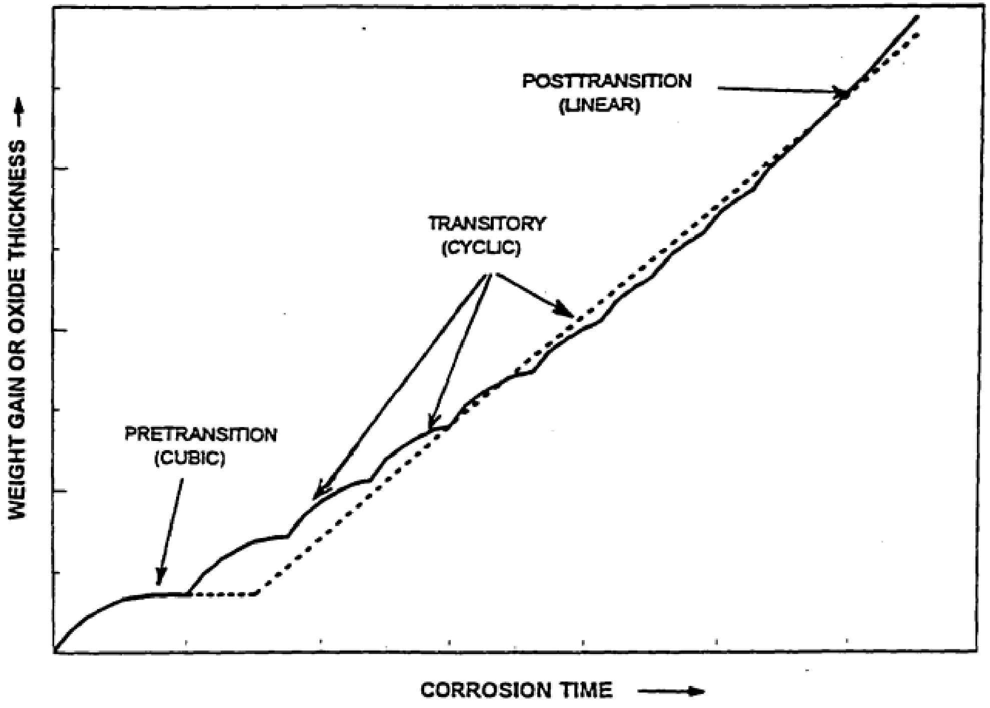
- Oxidation occurs both on the inner and outer surfaces of the fuel rod cladding. Inner surface oxidation of an intact fuel rod is caused by a near-instantaneous chemical reaction between the UO_2 pellet and the inner surface of the cladding when the pellet-cladding gap closes.

$$Zr + H_2O \rightarrow ZrO_2 + H_2$$

- Outer surface oxidation is a continuous stochastic process that depends mostly on the temperature of the cladding-coolant interface.

- This work focused on the oxidation of Zircaloys.

Modelling cladding oxidation



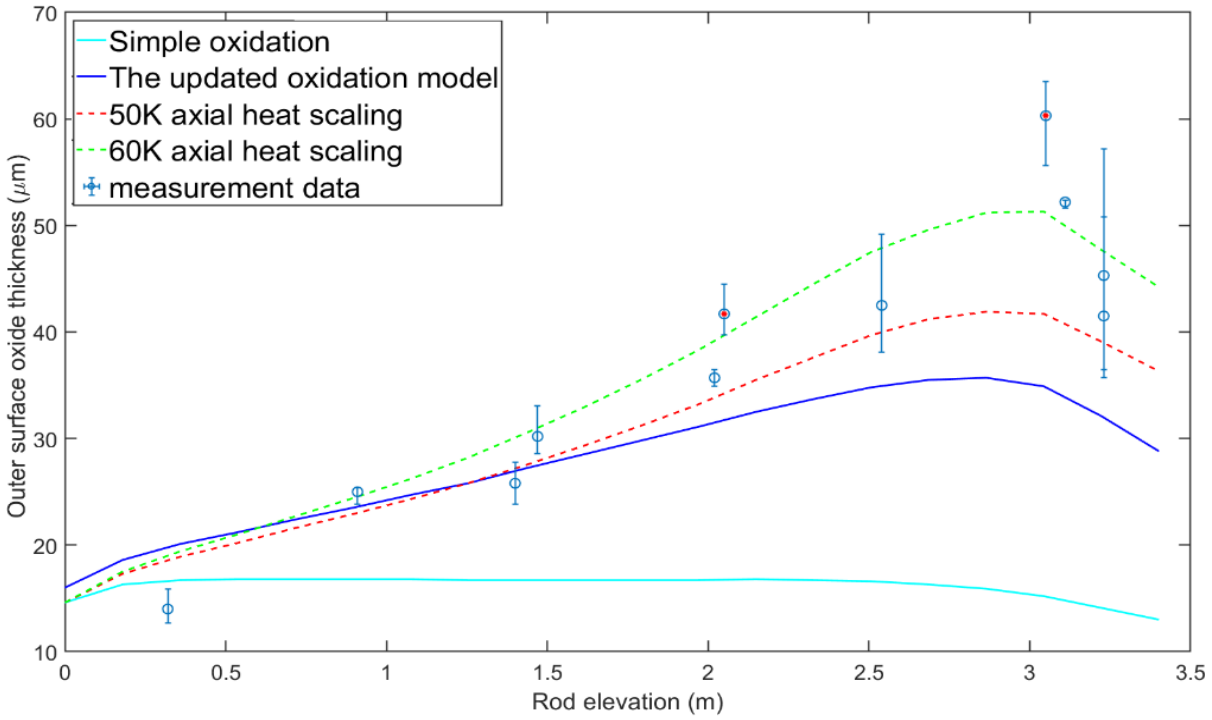
Initial oxidation model

- The initial attempt at modelling post-transition cladding oxidation with FINIX utilized a simple correlation by Joonas Kättö[3].

- The results weren't ideal, due to FINIX assuming a bulk coolant temperature instead of an axially increasing temperature distribution.

- In order to estimate the required temperature increase between the two ends of a fuel rod, three linear temperature scalings were used in initial attempts.

Initial oxidation results



Updated oxidation model

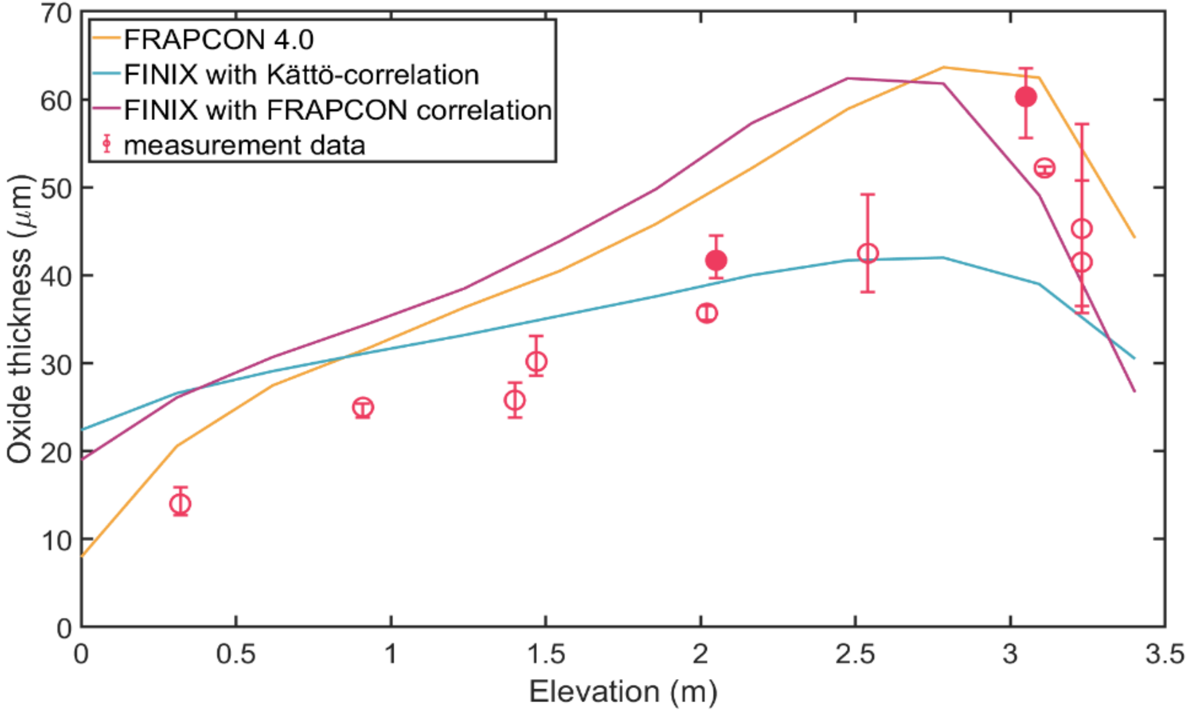
- The calculation of axial temperature distribution of coolant was then implemented in FINIX as an iterative solution.

- In order to calculate the heat capacity of the coolant and the heat flux from the cladding outer surface to the coolant, several industrial correlations for thermal properties of water coolant were implemented in FINIX.

- A few different mathematical models for heat transfer coefficient between the cladding and the coolant were tried out in order to provide a realistic temperature difference between the temperatures of cladding outer surface and coolant.

- FRAPCON-4.0 oxidation correlation[4] was tested alongside Kättö-correlation.

Final oxidation results



Conclusions

- FINIX is a fuel behaviour module used in the Kraken framework.
- The past development of FINIX has focused on the implementation of new models, whereas the future development leans towards optimizing the coupled applications.
- The implemenation of cladding oxidation model in FINIX necessitated the update of the models describing the coolant-cladding interface, due to insufficient axial temperature distribution of coolant prior to update.

References

[1]. T. Ikonen, H. Loukusa, E. Syrjälahti, V. Valtavirta, J. Leppänen, V. Tulkki, “Module for thermomechanical modeling of LWR fuel in multiphysics simulations”, Annals of Nuclear Energy, 111– 121, 84 (2014)

[2]. J. Peltonen, “Coolant-cladding interaction models in FINIX fuel behaviour module”, Master’s thesis, University of Helsinki Department of Physics, (2019).

[3]. J. Kättö, “Corrosion and its modeling in nuclear reactor fuel cladding”, Master’s thesis, Aalto University Department of Energy Technology, (2013).

[4]. K. J Geelhood, W. G. Luscher, P. A. Raynaud, I. E. Porter, “FRAPCON-4.0: A computer code for the calculation of steady-state, thermal-mechanical behavior of oxide fuel rods for high burnup”, Technical Report PNNL-19418, Pacific Northwest National Laboratory, (2015).