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Preliminary Simulations using Bison: P2M Simulation Exercise Phase 2.1

December 2023

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P2M Simulation Exercise Phase 2.1

Idaho National Laboratory

Outline

- Models and Assumptions
- AN3 Preliminary Results
- AN10 Preliminary Results
- Summary and Discussion
- Future Work

Code General Information

Organization	Idaho National Laboratory
Code and Code Version	Bison (git hash 6ba5c98ba0, Oct 18, 2023)
Dimension	2D(r,z)
Thermal Analysis	Transient
Thermal Conductivity Model	NFIR [1]
Pellet-clad Gap Heat Transfer Model	Toptan [2,3]
FGR Model	SIFGRS [4]
Fission Gas Axial Transfer Model	Khvostov [5] (Planned)
Fuel gas-induced Swelling Model	SIFGRS [4]
Fuel Pellet Fragmentation Model Impacting FGR	Microcracking [6]
Previous simulations of AN3 and AN10 bump tests	AN3* [7]

[1] A. Marion (NEI) letter dated June 13, 2006 to H. N. Berkow (USNRC/NRR). Safety Evaluation by the Office of Nuclear Reactor Regulation of Electric Power Research Institute (EPRI) Topical Report TR-1002865, "Topical Report on Reactivity Initiated Accidents: Bases for RIA Fuel rod Failures and Core Coolability Criteria". http://pbadupws.nrc.gov/docs/ML0616/ML061650107.pdf, 2006.

[2] A. Toptan, D. J. Kropaczek, and M. N. Avramova. Gap conductance modeling II: optimized model for UO_2-zircaloy interfaces. *Nuclear Engineering and Design*, 355:110289, 2019. doi:10.1016/j.nucengdes.110289.

[3] A Toptan, D J Kropaczek, and M N Avramova. Gap conductance modeling I: theoretical considerations for single- and multi-component gases in curvilinear coordinates. *Nuclear Engineering and Design*, 353:110283, 2019. doi:10.1016/j.nucengdes.2019.110283.

[4] G. Pastore, L. Luzzi, V. Di Marcello, and P. Van Uffelen. Physics-based modelling of fission gas swelling and release in UO_2 applied to integral fuel rod analysis. *Nuclear Engineering and Design*, 256:75–86, 2013.

[5] G. Khvostov, W. Wiesenack, M. A. Zimmeraman, and G. Ledergerber. Some insights into the role of axial gas flow in fuel rod behaviour during the LOCA based on Halden tests and calculations with the FACLON-PSI code. *Nuclear Engineering and Design*, 241:1500-1507, 2011.

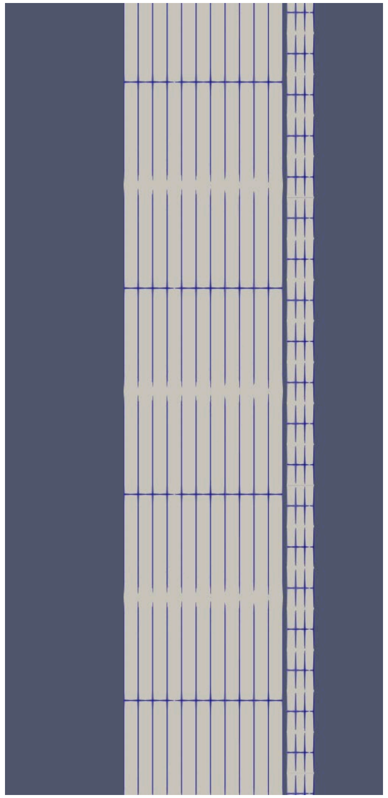
[6] G. Pastore, D. Pizzocri, S. R. Novascone, D. M. Perez, B. W. Spencer, R.L. Williamson, P. Van Uffelen, and L. Luzzi. Modelling of transient fission gas behaviour in oxide fuel and application to the Bison code. In *Enlarged Halden Programme Group Meeting, Røros, Norway, September 7-12*, 2014.

[7] R.L. Williamson, K.A. Gamble, D.M. Perez, S.R. Novascone, G. Pastore, R.J. Gardner, J.D. Hales, W. Liu, and A. Mai. Validating the Bison fuel performance code to integral LWR experiments. *Nuclear Engineering and Design*, 301:232–244, 2016. doi:10.1016/j.nucengdes.2016.02.020.

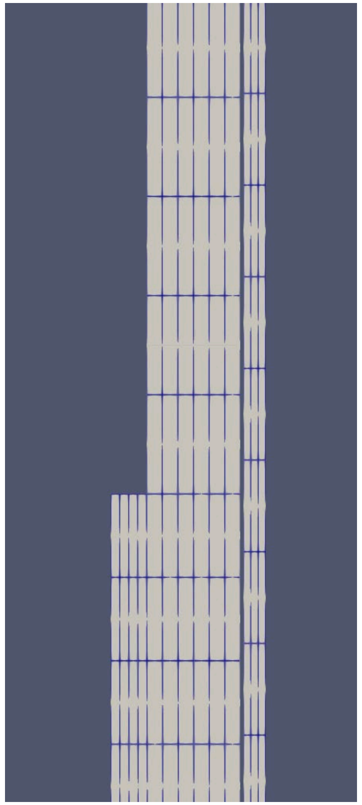
***The documents provided in this benchmark have different details not provided as provided in previous benchmark in which AN3 was selected.**

Approach to Refabrication in Bison

- Currently, no easy way to transfer calculated results to a mesh with different dimensions.
  - Father/mother rod to bump test
- Gas within the rod is refabricated given the gas composition, pressure, temperature, and volume.
  - Impacts gap conductance and the initial moles of gas available for subsequent plenum pressure calculations.
  - Ability to provide continuous sweeping of gas.



Base Irradiation



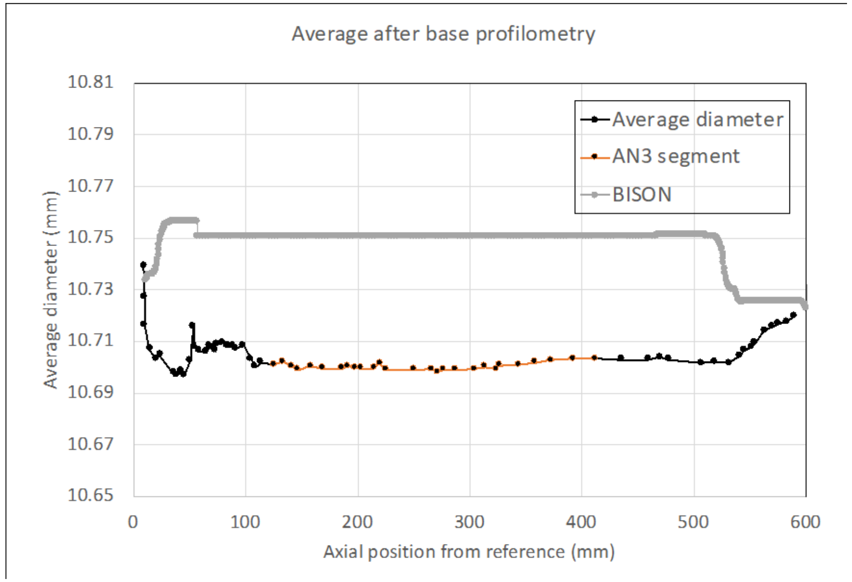
Base Irradiation and Bump

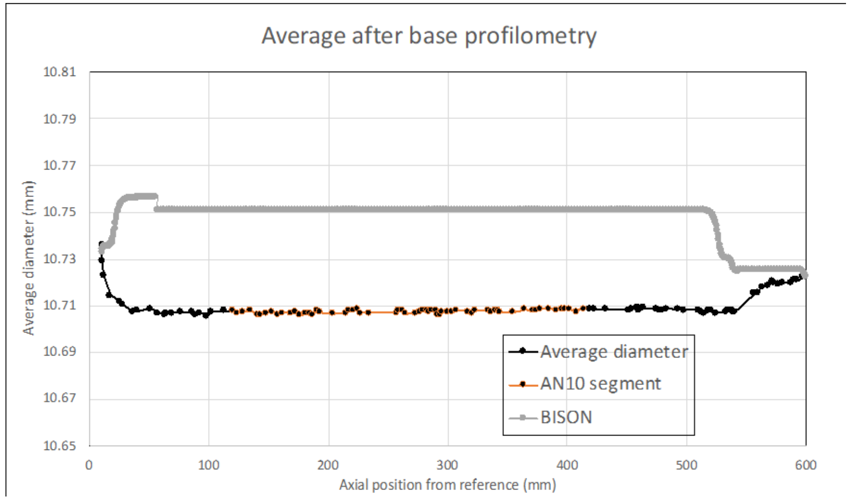
AN3 and AN10: Models and Assumptions

- Base irradiation results are obtained from a 2D(r,z) smeared pellet geometry simulation of the father rod.
  - Dishes and chamfer volumes added to plenum volume
  - Natural and insulator pellets modeled but with same outer diameter
  - Cladding liner not modeled
- Bump test results are obtained from a 2D(r,z) smeared pellet geometry simulation of the bump test dimensions including the base irradiation.
  - Insulator pellets not modeled
  - Cladding liner not modeled
  - Initial volume at beginning of bump test ensured to be as tabulated
- 11 QUAD8 elements in radial direction of fuel and 3 QUAD8 in the cladding

AN3 and AN10: Preliminary Baseline Results

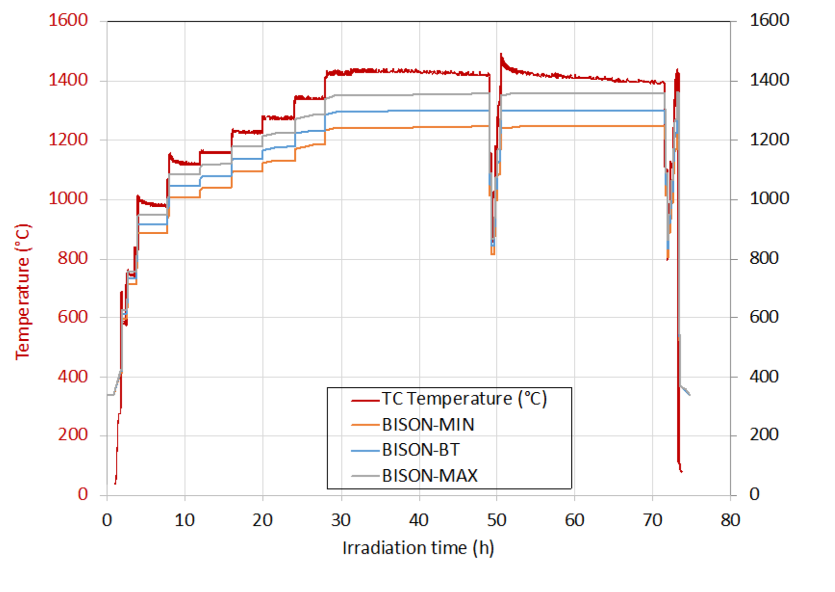
Description	AN3-BASE	AN3-Measured	AN10-BASE	AN-10 Measured
Fuel stack length (mm)	506.7	502.04	506.7	502
Final pressure at 0°C (bar)	28.6	25.7	28.6	27.3
FGR (%)	0.51	0.2	0.51	0.2
Average fuel rod burnup (MWd/kgU)	39.4	36.32	39.4	36
Final free volume (cm^3)	4.66	5.27	4.66	5.12
Grain size at r/r0=0 at x=344 mm (μm)	9.392	(-)	9.392	(-)
Grain size at r/r0=0.91 at x=344 mm (μm)	9.36	(-)	9.36	(-)

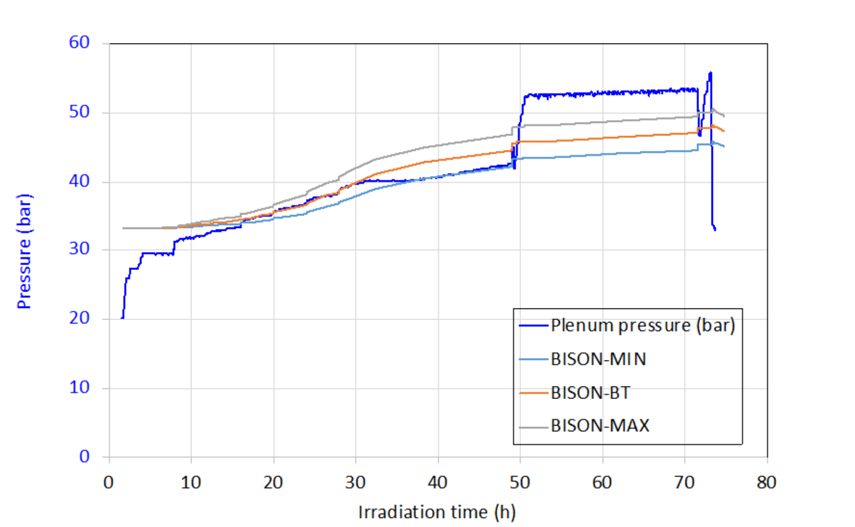


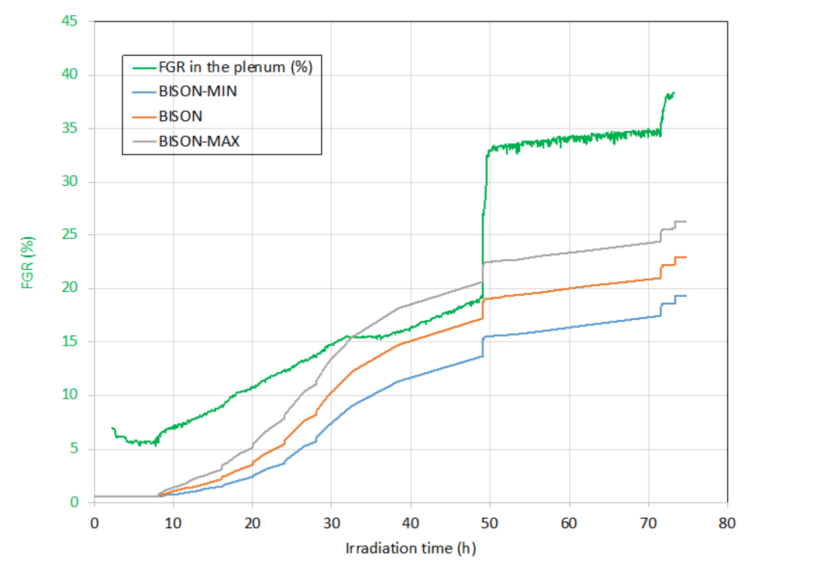


AN3: Preliminary Ramp Results

Description	AN3-BT	AN3-MIN	AN3-MAX	Measured
Fuel stack length (mm)	288.2	288.2	288.9	286
Final pressure at 0°C (bar)	21.18	20.15	22.15	27.6
FGR (%)	22.88	19.32	26.28	35.5
Average fuel rod burnup (MWd/kgU)	40.04	40.03	40.05	36.319
Final free volume (cm^3)	6.11	6.16	6.06	6.2
Grain size at r/r0=0 at x=234 mm (μm)	39.70	30.24	104.08	(-)
Grain size at r/r0=0.26 at x=234 mm (μm)	31.14	23.88	41.22	(-)
Grain size at r/r0=0.91 at x=234 mm (μm)	9.36	9.36	9.36	(-)

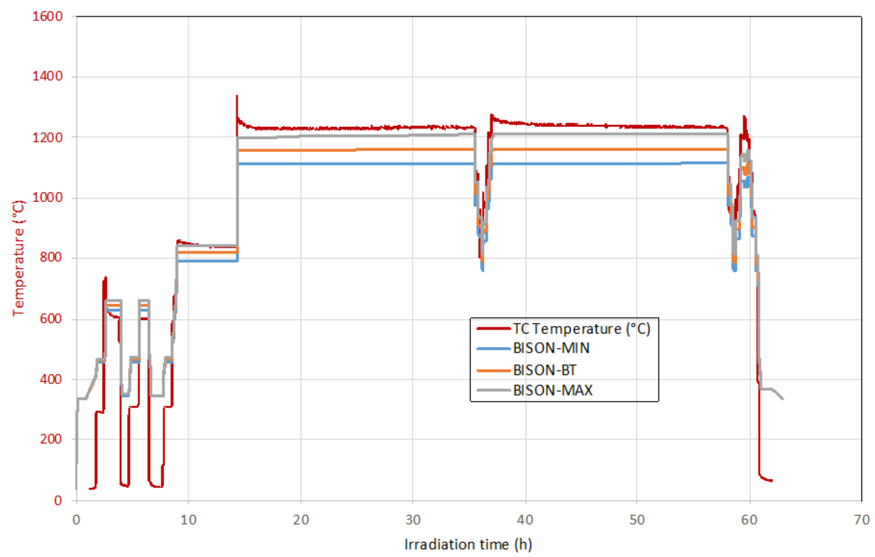


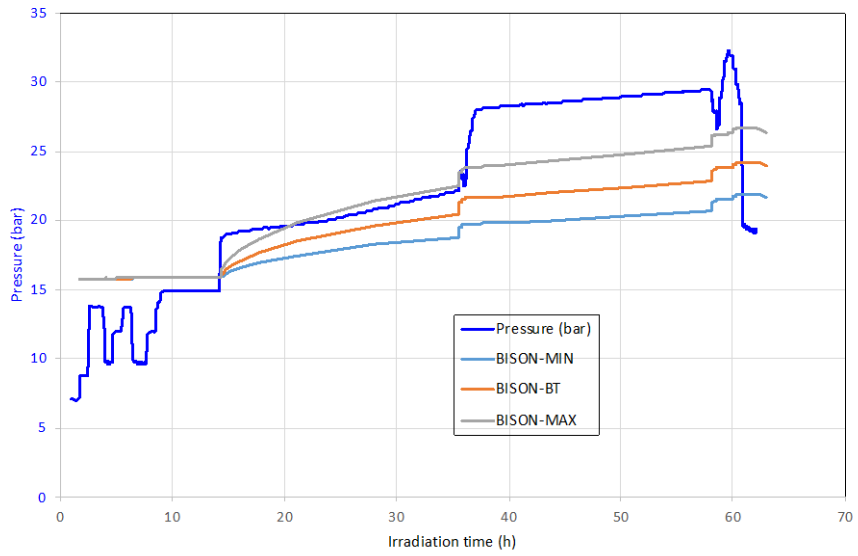


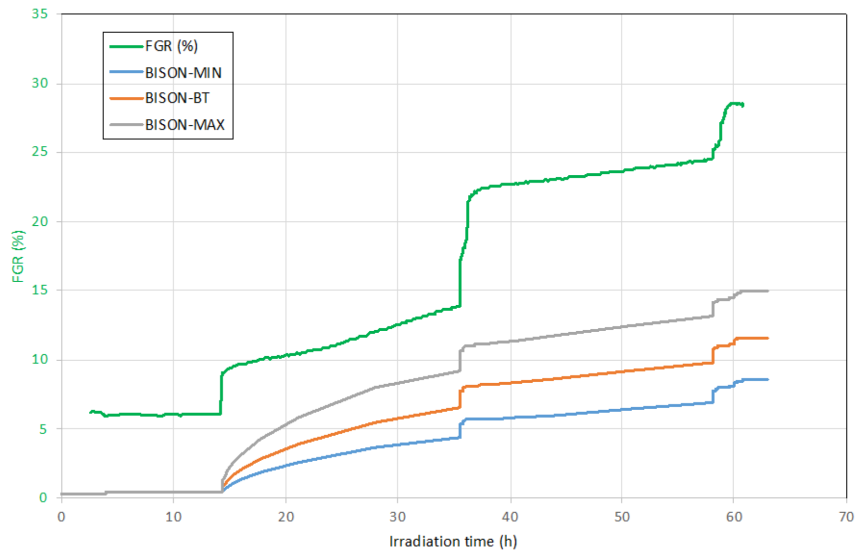


AN10: Preliminary Ramp Results

Description	AN10-BT	AN10-MIN	AN10-MAX	Measured
Fuel stack length (mm)	294.4	294.5	294.4	292
Final pressure at 0°C (bar)	10.71	9.7	11.79	16.42
FGR (%)	11.65	8.57	14.97	26.9
Average fuel rod burnup (MWd/kgU)	40.53	40.52	40.53	36.649
Final free volume (cm^3)	6.36	6.41	6.28	6.05

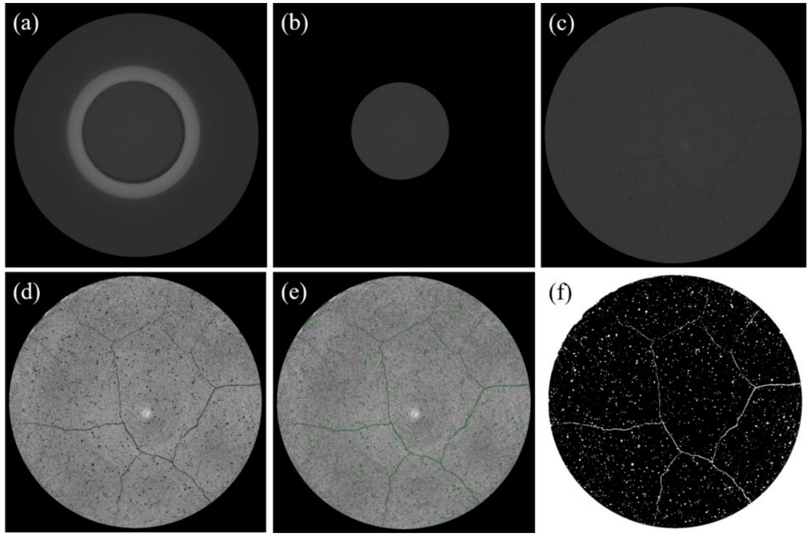


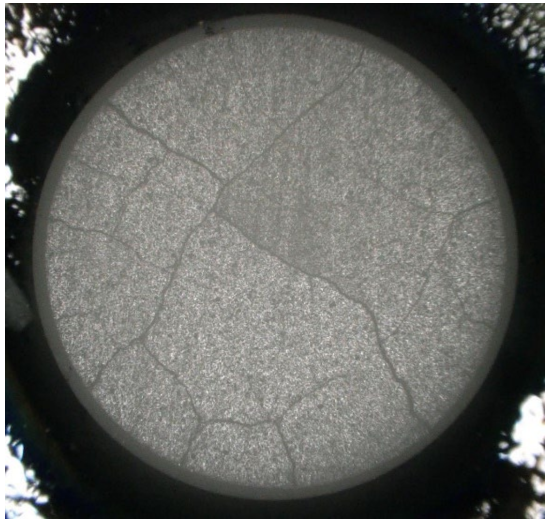


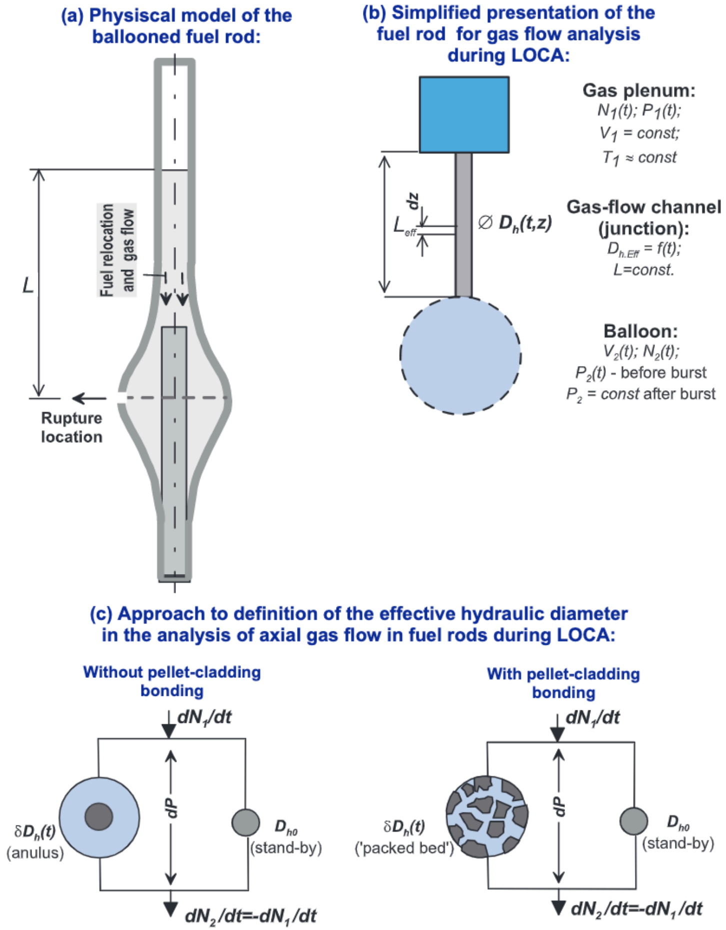


Discussion on Axial Gas Communication

- Prior to fuel cladding contact gas can freely communicate through the fuel to clad gap.
- After contact is established gas flow is slower as it must utilize the available pathways within the fuel.
- Empirical model that treats gas flow as two parallel paths
- Using out of pile experiments to determine permeability values based upon x-ray tomography.







Summary

- An overview of the assumptions made in modeling the benchmark cases was provided.
- Preliminary results for AN3 and AN10 were presented.
- Some discrepancies identified between the values in the supplied PDF and the output Excel files.
- Discrepancies have been identified in Bison predictions early in the bump test.
- Bison is underpredicting FGR, pressure, and temperature during the later stages of the bump tests.

Future Work

- Revisit initial conditions of refabrication.
- More rigorous evaluation of new gap conductance model.
- Extract xenon wt% profiles.
- Finish implementation of axial gas communication model and incorporate into the analyses.
- Finish P2M-Q1 simulations.
- Complete population of benchmark spreadsheets and submit to organizers.

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