TRACE Fuel Rod Model Improvements

Information Systems Laboratories, Inc.

Presented at

Nuclear Regulatory Commission
TRACE/SNAP User Workshop
Columbia, Maryland
March 26 – March 29, 2018

Objective

Describe prior shortcomings and recent improvements for modeling fuel rods with TRACE. The exercises that follow will familiarize you with the new models and demonstrate the improvements described here.

Outline

Shortcomings of the legacy TRACE fuel rod models and top-level view of improved modeling results

Summarized from S. Bajorek, “Fuel Rod Model Evaluation,” and J. Spore, “Fuel Rod Model Improvements, TRACE Coordination Meeting, May 20, 2015.

Listing of TRACE input changes related to the fuel rod model improvements

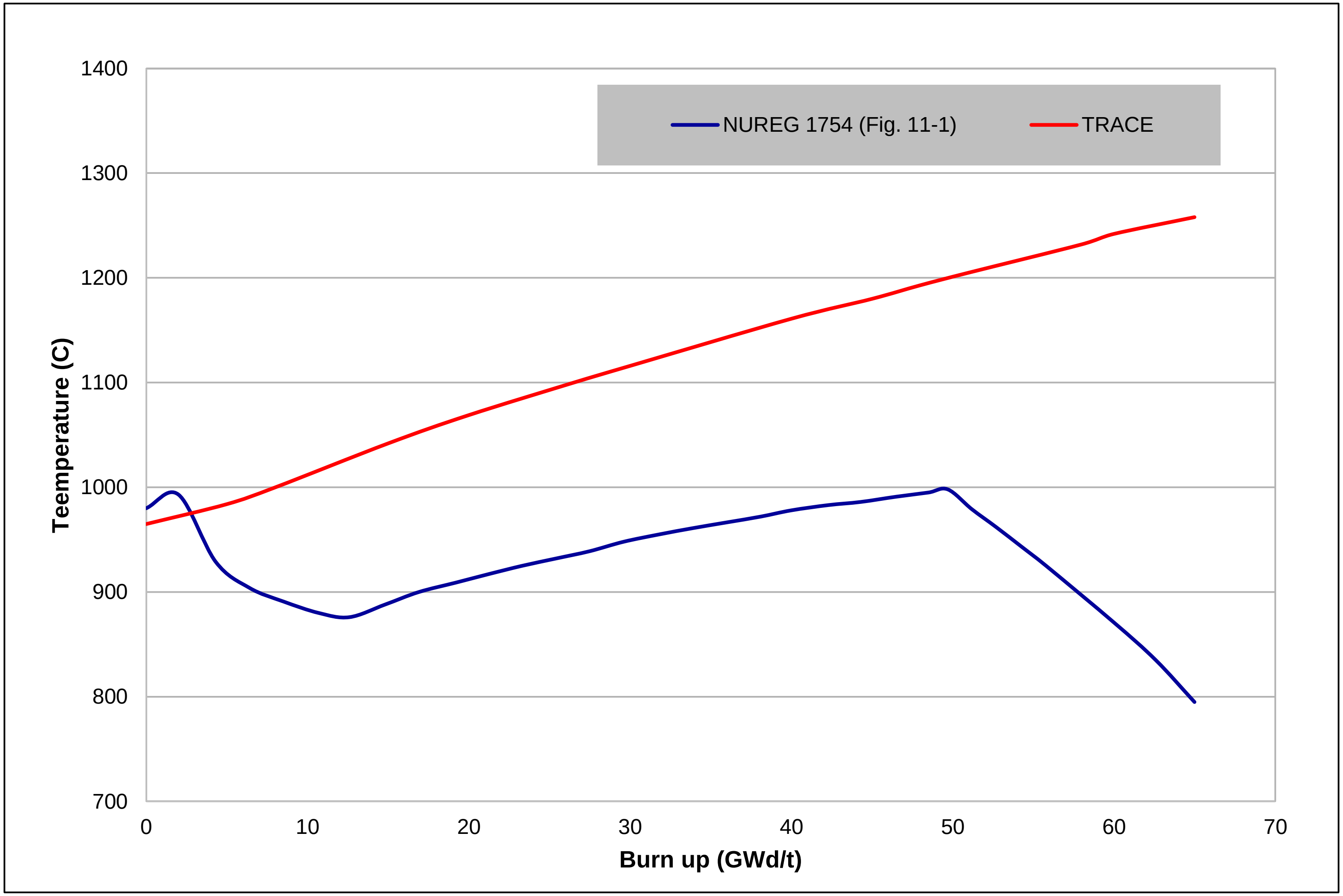
Limitations of Legacy Fuel Rod Models

The following slides show results of the legacy fuel rod models in TRACE

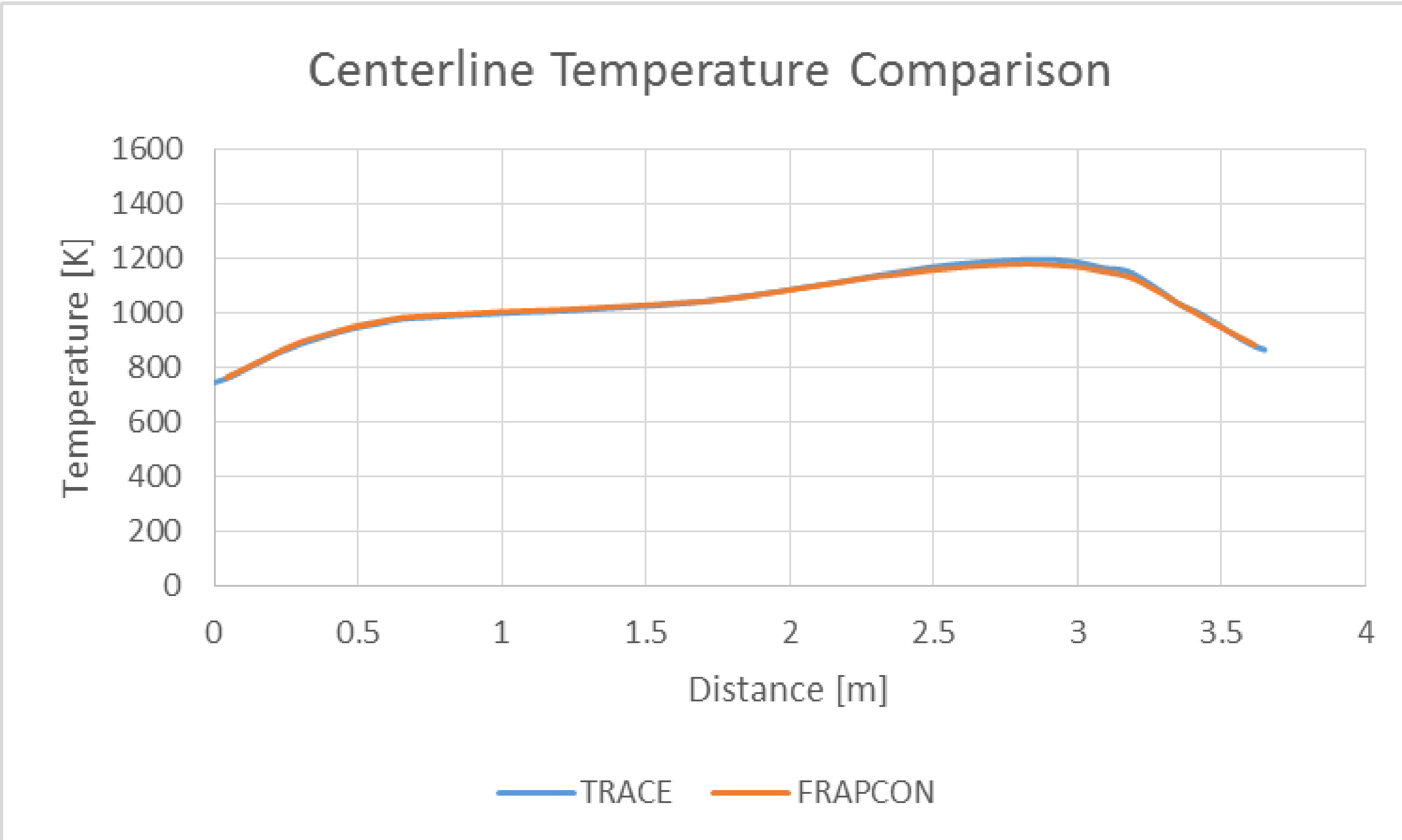
Given the results:

What are the important figures of merit?
Do the results align with your expectations?
What other effects might you observe?
What might you try to improve the results or confirm the source of the problem?

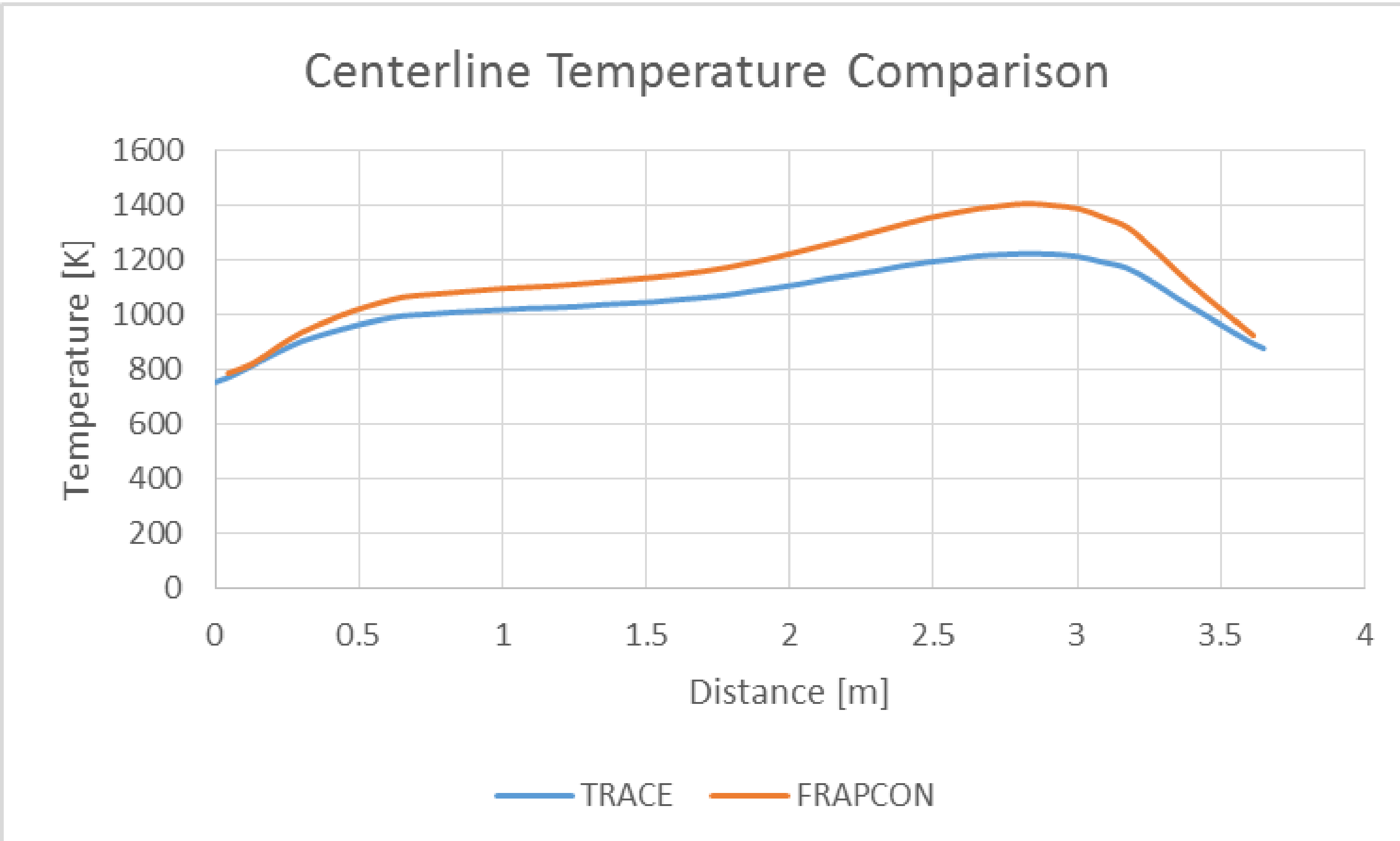
Fuel Centerline Temperature vs Burnup 2012, Comparison of TRACE and FRAPCON Calculations



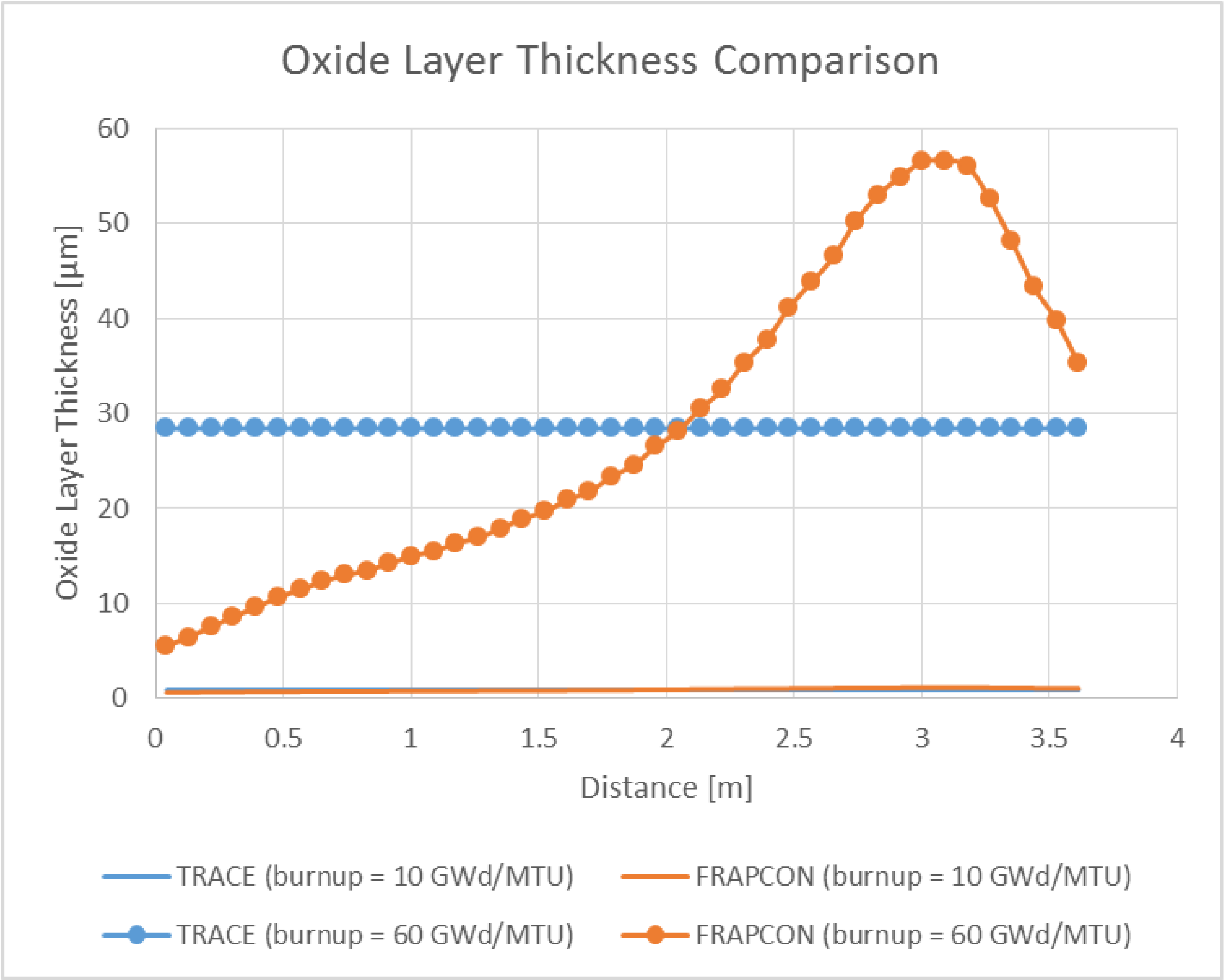
Fuel Centerline Temperature vs Core Axial Level at Low Burnup 2014, Comparison of TRACE and FRAPCON Calculations



Fuel Centerline Temperature vs Core Axial Level at High Burnup 2014, Comparison of TRACE and FRAPCON Calculations



Oxide Layer Thickness vs Core Axial Level and Burnup 2014, Comparison of Values Used in TRACE and FRAPCON Calculations



Limitations of Legacy Fuel Rod Models

Users of early versions of TRACE 5.0 reported difficulties in obtaining an accurate and consistent set of fuel rod conditions at steady state:

Fuel centerline temperatures
Fuel average temperatures
Pellet-to-cladding gas gap conductances

Evaluations in 2012 and 2014 showed the difficulties resulted from limitations of TRACE assumptions:

Single values for initial oxide thickness, fuel swelling, and cladding creepdown parameters

One-dimensional (axial) array for burnup parameter; uniform burnup value assumed radially within the pellet

2015 TRACE Version 5.910 Included Most Model Revisions Recommended by the 2014 Study

Initial oxide thickness parameter can now be specified using an axial array rather than as a single value

Fuel swelling and cladding creepdown parameters can now be specified as axial arrays rather than as single values

Burnup parameter can now be specified using a 2D array (axial and radial within the pellet) rather than using a 1D array (axial, and assuming uniform radially within the pellet)

The following slides show the improved results obtained with TRACE Version 5.910

Fuel Centerline Temperature vs Core Axial Level at High Burnup 2015, Comparison of TRACE and FRAPCON Calculations

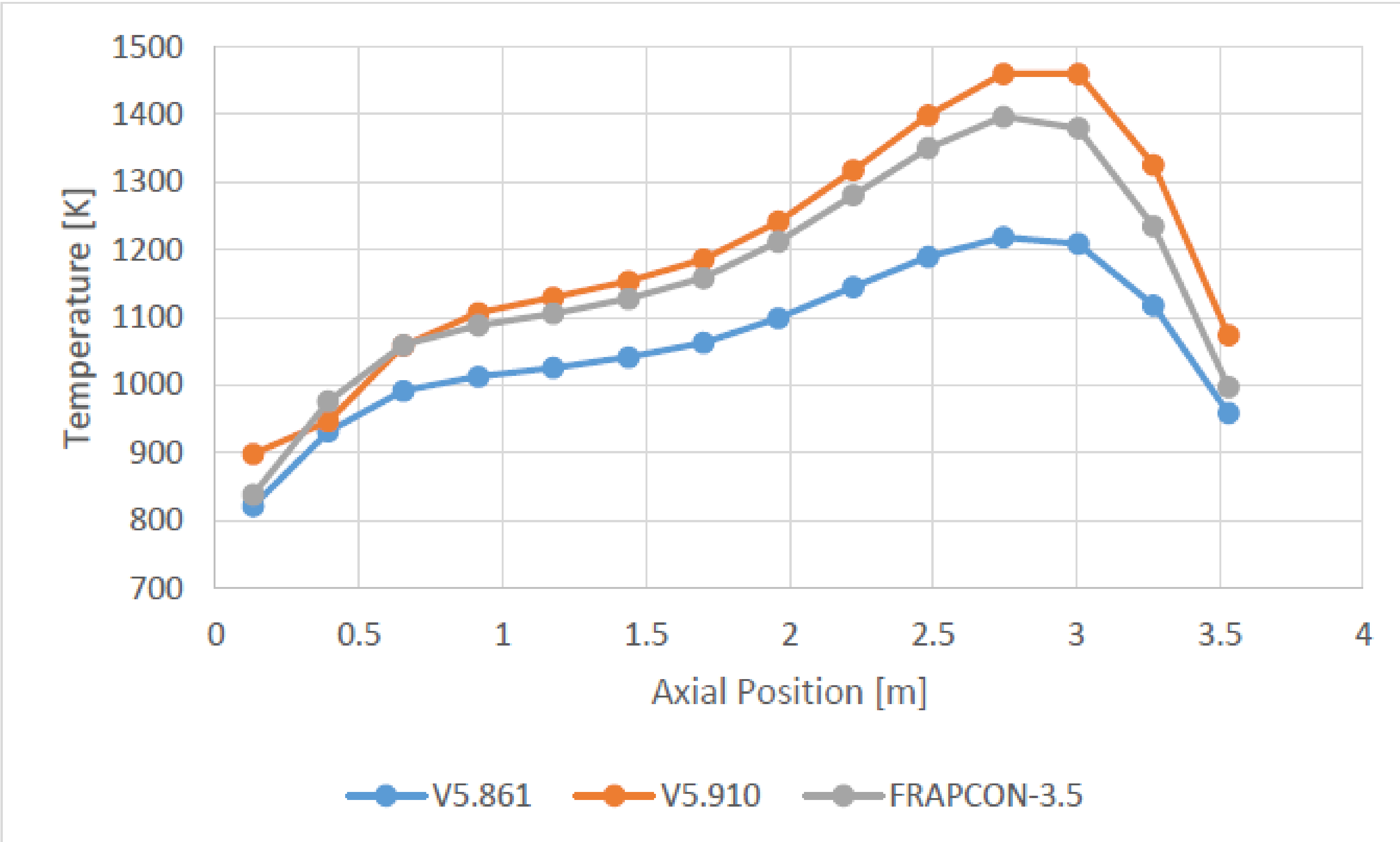


Figure 15: Fuel Centerline Temperature, Burnup = 60 GWd/MTU, 5 Radial Fuel Nodes

Fuel Average Temperature vs Core Axial Level at High Burnup 2015, Comparison of TRACE and FRAPCON Calculations

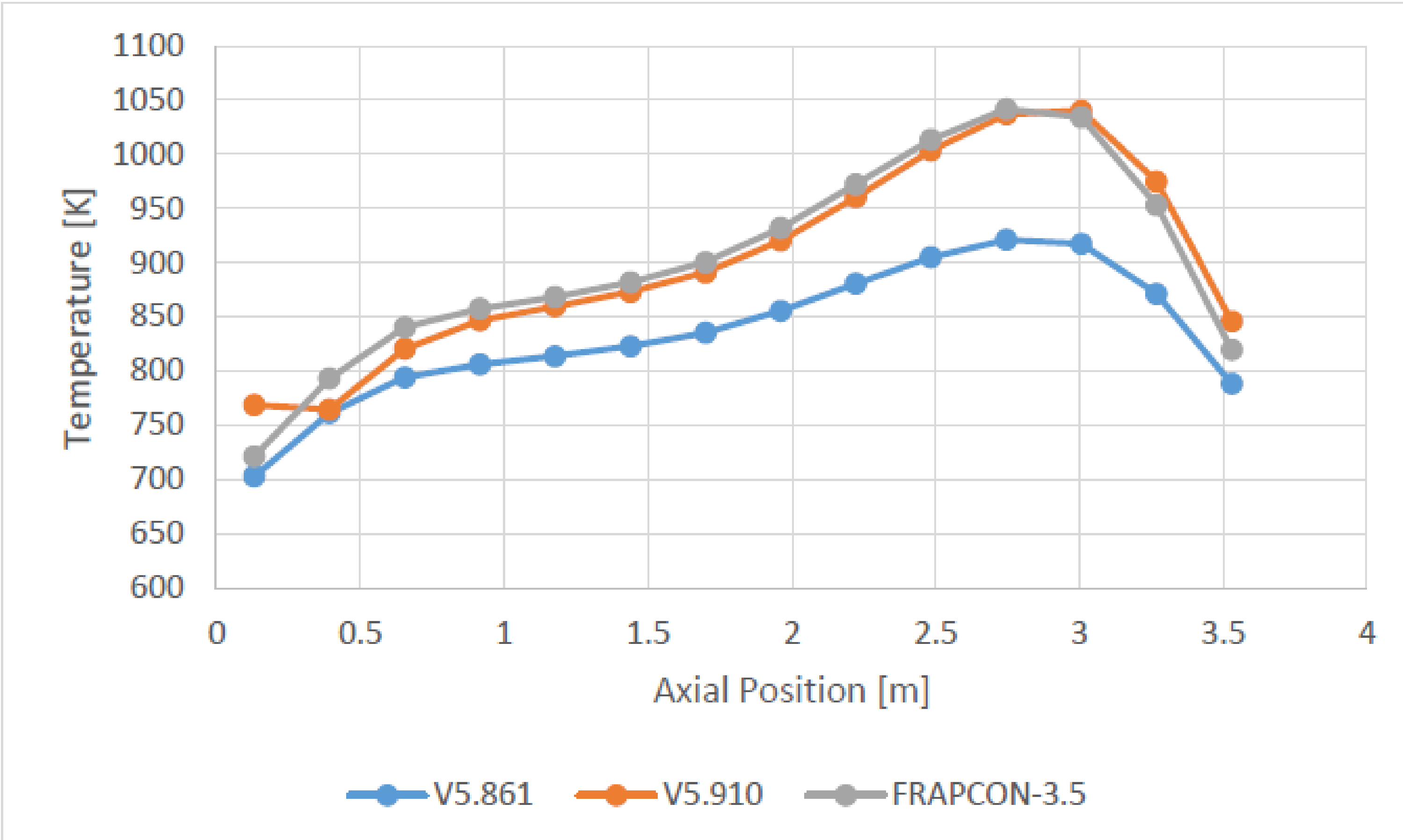


Figure 22: Average Fuel Temperature, Burnup = 60 GWd/MTU, 5 Radial Fuel Nodes

Fuel Centerline Temperature vs Core Axial Level at Low Burnup 2015, Comparison of TRACE and FRAPCON Calculations

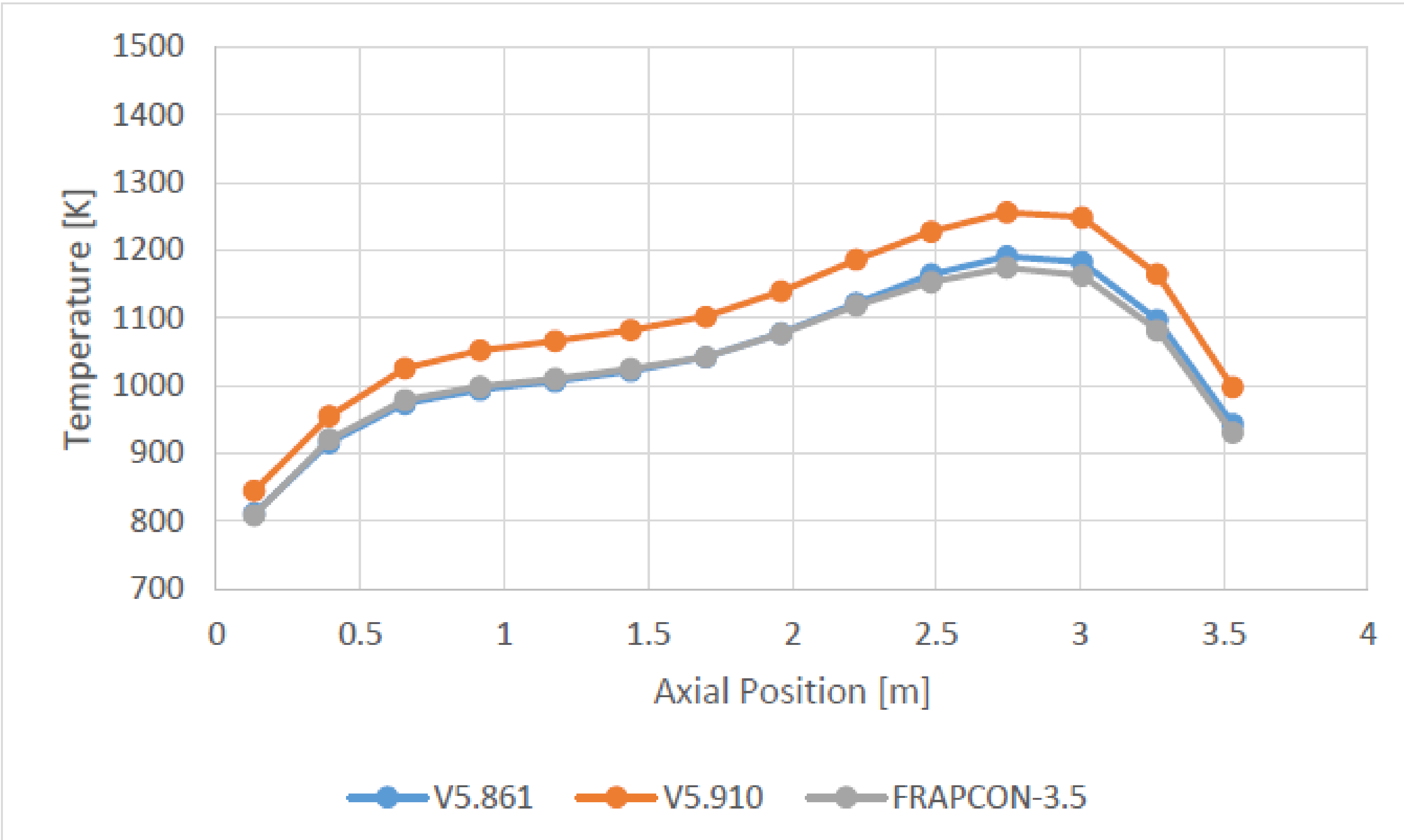
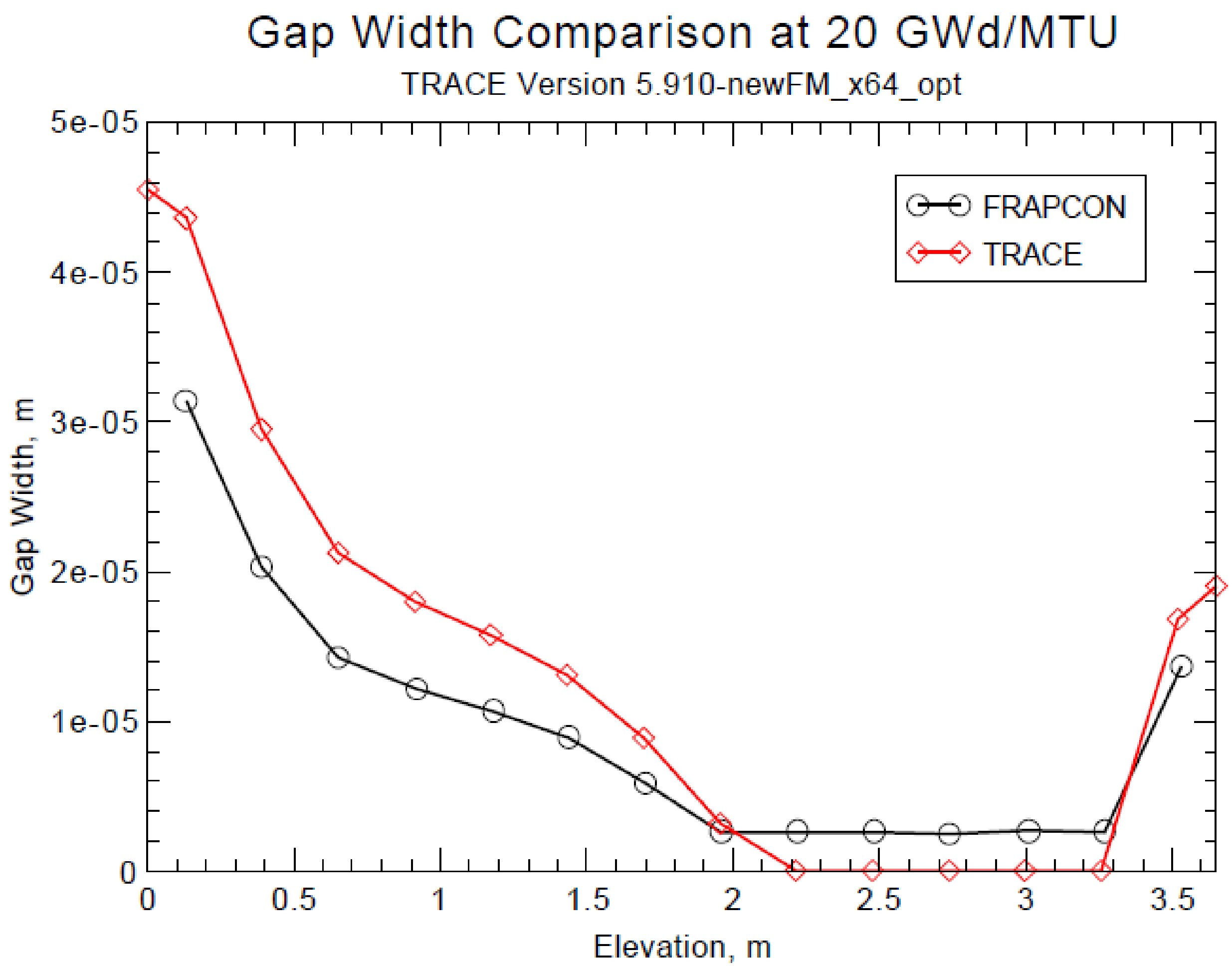


Figure 13: Fuel Centerline Temperature, Burnup = 10 GWd/MTU, 5 Radial Fuel Nodes

Fuel Gas Gap Width vs Core Axial Level at 20GWd/MTU Burnup 2015, Comparison of TRACE and FRAPCON Calculations



Additional Model Revisions Were Included in TRACE Version 5.1064

1. A fix to the second-order finite element evaluation of the fuel thermal conductivity has been implemented
2. To satisfy a user request, a new plot parameter (PlotGapEffDim) has been added to facilitate comparison of the fuel rod heat transfer processes. The added plot parameter is the term (based on gap width and differential temperature) that is divided into the gap conductance (kGap) to obtain the gap heat transfer coefficient (hGap). The new parameter aids in comparing the effective fuel rod gap and surface convective heat transfer coefficients.
3. The user may now input a crud layer on the outer surface of fuel rod heat structures. The crud layer reduces the effective surface thermal conductivity based on its thickness and assumed thermal conductivity. This capability may also be used on the surfaces of non-fuel rod heat structures.
4. The TRACE Zirconium surface emissivity model has been replaced with the FRAPCON emissivity model

Documentation of New Fuel Rod Models

(The Most Current Manuals, Supplied in the Workshop Materials, are for TRACE Version 5.1051)

- The basis for the fuel rod models, including the recent revisions, is provided in Section 8 (beginning on Page 481) of the TRACE Theory Manual
- Input specifications for the HTSTR component, including the recent fuel rod model revisions, are provided in the TRACE User Guide Volume 1, beginning on Page 557. Also see the NAMELIST variable input description starting on Page 122. Note that input revisions related to the fuel rod model improvements are included in the revisions identified by change bars.
- Modeling guidelines for the HTSTR component, including fuel rod heat structures, are provided in the TRACE User Guide Volume 2, beginning on Page 134.

TRACE Input Revisions Related to the Improved Fuel Rod Models

- The top-level choice for fuel rod modeling is made using NAMELIST input
- Legacy fuel rod models are used unless either LEGACYFRM is set to false or DETAILEDFRM is set to true.
  - See Pages 128 and 153 of TRACE User Guide Volume 1.
  - DETAILEDFRM=true option allows modeling fuel rods at the highest level of detail

TRACE Input Revisions Related to the Improved Fuel Rod Models

- For LEGACYFRM = false, the following NAMELIST options are activated:
  - FRGASP=true (activates the fuel rod gas pressure model)
  - CALCSWELLDEN=true (FRAPCON-based fuel swelling and densification models are used)
  - SEPARATEROUGH=true (cladding and fuel roughness are input separately)
  - USE_MODNFI_K=true (use the modified NFI correlation for fuel conductivity)
  - RADHTEMIS=1 (the heat structure material property emissivities are used at the surface nodes)

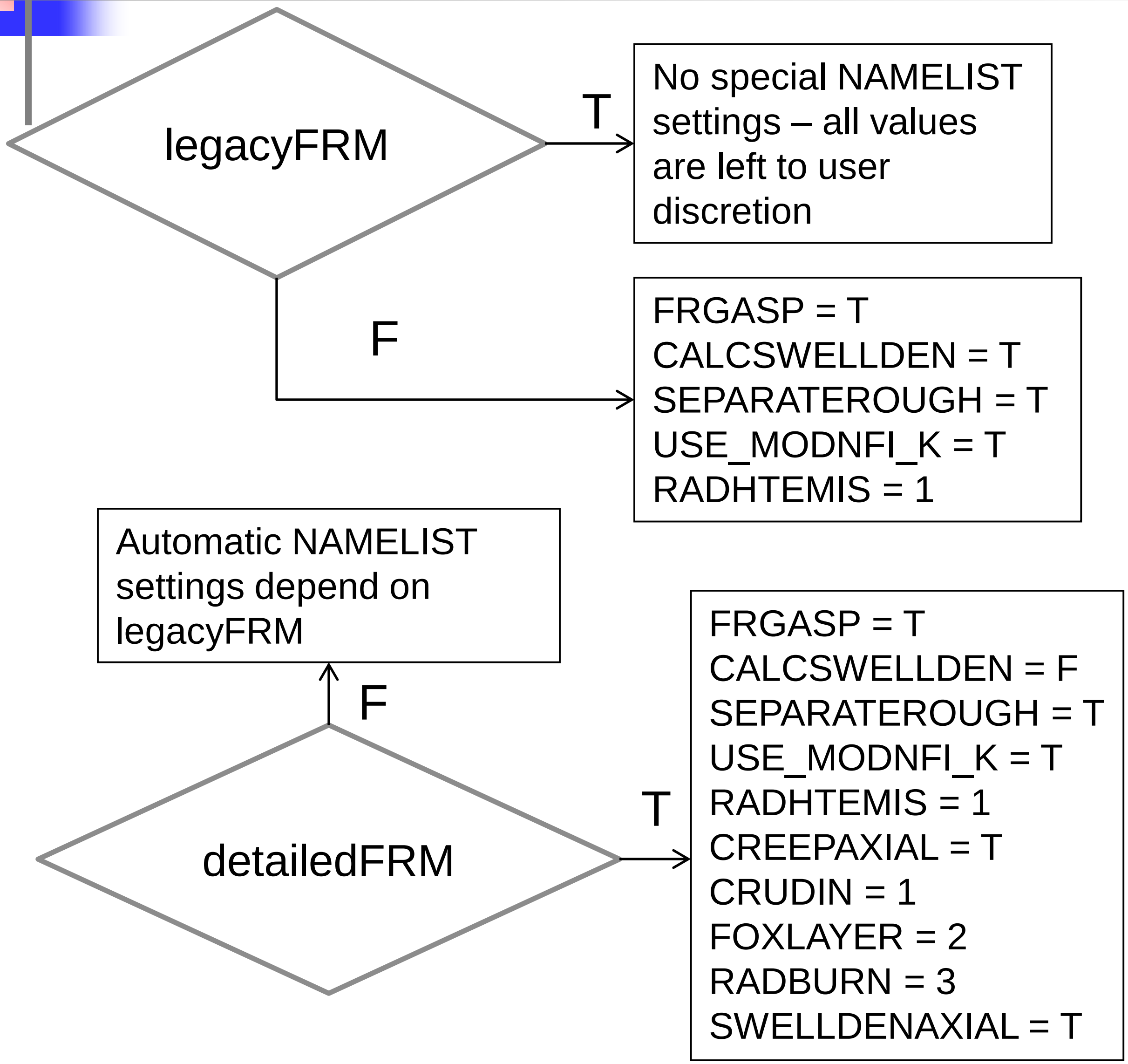
TRACE Input Revisions Related to the Improved Fuel Rod Models

- For DETAILEDFRM=true, the following NAMELIST options are activated:
  - CALCSWELLDEN=false (user input for fuel swelling and densification is used)
  - CREEPAXIAL=true (user input for cladding creepdown must be input for each fuel rod at each axial level)
  - CRUDIN=1 (a crud layer is modeled on the outside surface of each heat structure, extra input is required)
  - RADHTEMIS=1 (the heat structure material property emissivities are used at the surface nodes)
  - FOXLAYER=2 (axially-varying initial oxide layer allowed, extra input required to specify layer thickness at each axial level)

TRACE Input Revisions Related to the Improved Fuel Rod Models

- For DETAILEDFRM=true, the following NAMELIST options are activated: (continued)
  - FRGASP=true (activates the fuel rod gas pressure model)
  - RADBURN=3 (a generalized 2D axial-and-radial array of burnup values is input for each fuel rod)
  - SEPARATEROUGH=true (cladding and fuel roughness are input separately)
  - SWELLDENAXIAL=true (axial fuel swelling and densification arrays are required input for all fuel rod heat structures)
  - USE_MODNFI_K=true (use the modified NFI correlation for fuel conductivity)

Clarification of TRACE NAMELIST Settings Affecting Fuel Rod Models



Note: Setting legacyFRM = F and detailedFRM = T at the same time would require inconsistent NAMELIST settings. This is not allowed and will result in an input error.

Summary and Conclusions

Fuel rod model improvements have resulted in significantly better TRACE simulation capabilities

Many complex input revisions affect new fuel rod model implementation

2nd Order finite element solution for heat conduction is recommended (vs. finite volume)

The exercises that follow will familiarize you with use of the new fuel rod models