THE STAT7 V1.1 CODE FOR STATISTICAL PROPAGATION OF UNCERTAINTIES IN STEADY-STATE THERMAL HYDRAULICS ANALYSIS OF RESEARCH REACTORS

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ABSTRACT

STAT7 is a steady-state, single-phase thermal hydraulics (TH) software for plate fueled research and test reactors that supports statistical propagation of uncertainties of fabrication tolerances and other key reactor parameters in analysis using Monte Carlo method. Application of the software includes the reactor conversion from highly enriched to low-enriched uranium fuel of U.S. High Performance Research Reactors (USHPRR) such as MITR-II. STAT7 can calculate multiple histories of datasets that includes flow rate of coolant and bypass channels and temperature distribution of the coolant and fuel plate with or without fins. Furthermore, it can predict operational safety margins for the onset of nucleate boiling or onset of flow instability, including statistical uncertainties. The statistical sampling and TH capabilities of STAT7 have been validated and verified against hand calculations, other codes, and experimental data. STAT7 has been actively employed in various TH analyses to support MITR-II LEU conversion, such as TH impact assessment of fuel specification and mixed HEU-LEU transition analysis [1].

MOTIVATION

- In the HEU-to-LEU reactor conversion, analyses of TH safety limits and the operational margins of the new LEU design are important to protect the reactor against high fuel plate temperatures due to critical heat flux or departure from nucleate boiling or onset of flow instability.
- In the fuel design phase, an assessment of the TH impact on the safety limits and operational margins from fuel fabrication tolerance is necessary.
- These types of investigations typically require multiple runs of computer simulations for parametric studies and sensitivity analysis.
- In response, the STAT7 computer code has been developed for statistical propagation of uncertainties in steady-state thermal hydraulics analysis of research reactors

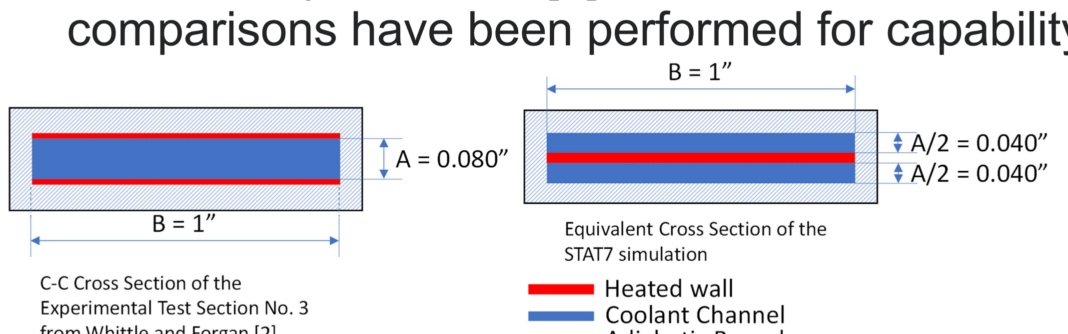
STAT7 V1.1 CODE CAPABILITIES

No.	Capabilities
1	Statistical Sampling
2	TH Calculation per Channel
3	Finned Plate Option
4	Bypass Option
5	End-channel treatment
6	ONB Calculation
7	OFI Calculation

- STAT7 uses a Monte Carlo approach to model common fabrication parameters and other key reactor analysis uncertainties required for research and test reactor TH analyses.
- STAT7 accommodates flexibility in analyzing many realistic aspects of reactor fuel managements for the plate-type fuels with simple input settings.
- STAT7 automates multiple runs of the steady-state TH calculations with (or without) statistical prediction of safety limits such as onset of nucleate boiling (ONB) and onset of flow instability (OFI).
- STAT V1.1 update (from V1.0) provides one major bug fix (correction in bypass flow rate calculation for finned fuel assembly) and one major new calculation capability (No. 7 – OFI Calculation).
- Verification and Validation methods for capabilities no. 1 and 2 (random number generator and water properties fit functions) have been updated to test the capabilities directly from the implementation by employing of the Fortran to Python interface generator, "F2PY", which is a utility provided by the "NumPy" Python library.

VERIFICATION AND VALIDATION: OFI CALCULATION

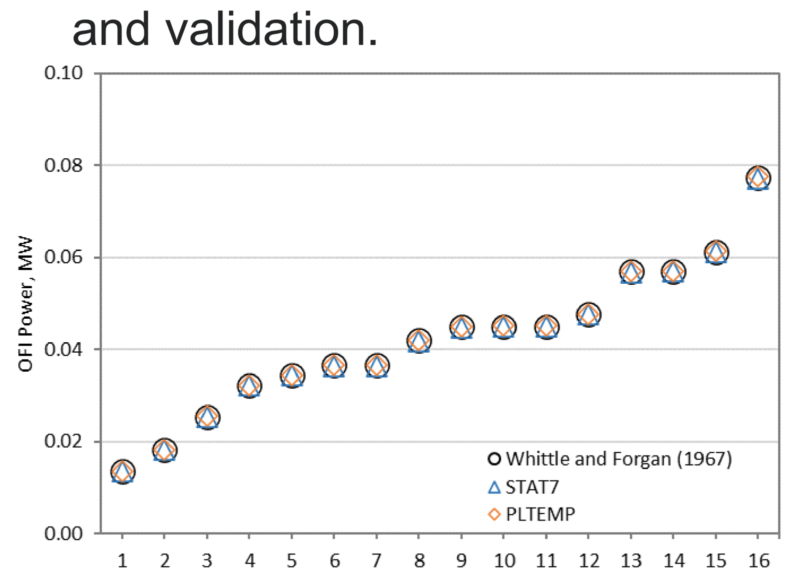
- Code-to-experiment [2] and code-to-code (against PLTEMP/ANL V4.3) comparisons have been performed for capability 7, Onset of flow instability.



Test Section Configurations

- A total of 16 experimental datasets from four different test sections have been extracted from [2] for the code verification and validation.

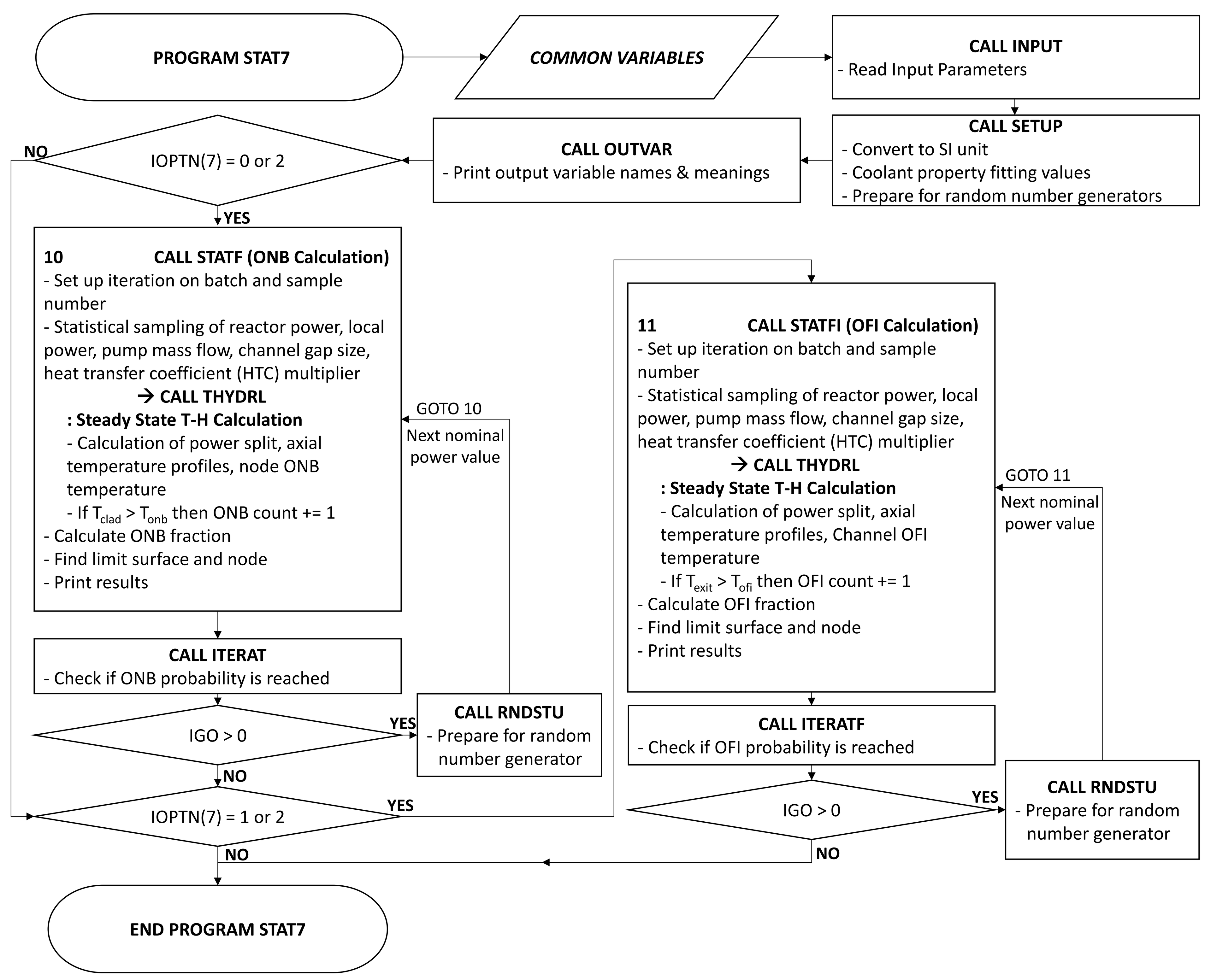
Thermal hydraulic parameters			Max. relative difference, %
Node-to-node comparison for all channels		Coolant temperature	0.06
		Cladding temperature	0.50
		Fuel peak temperature	0.35
		ONB temperature	0.06
		HT coefficient	0.75
		Heat flux	0.08
		Pressure	0.03
Flow rates	Core region	Channel 1	0.07
		Channel 2	0.07
		Channel 3	0.05
		Channel 4	0.07
		Channel 5	0.02
	Bypass channel		0.13



OFI Verification and Validation Results

- The maximum relative error of code-to-experiment was 0.32% (STAT7 vs. Exp.), and that of code-to-code was 0.59% (STAT7 vs. PLTEMP).

MAIN STRUCTURE OF THE STAT7 CODE

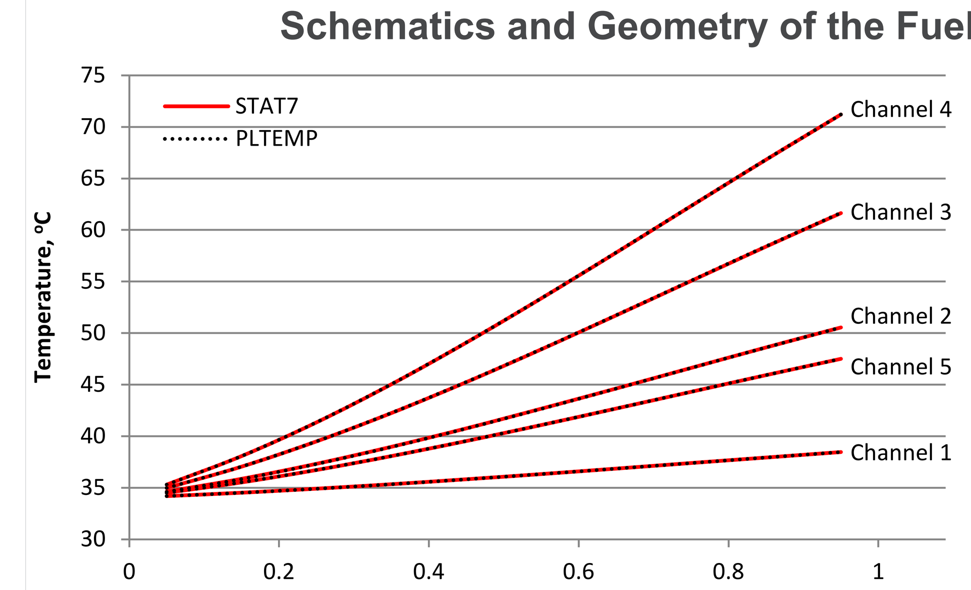


VERIFICATION AND VALIDATION: COMBINED CAPABILITIES

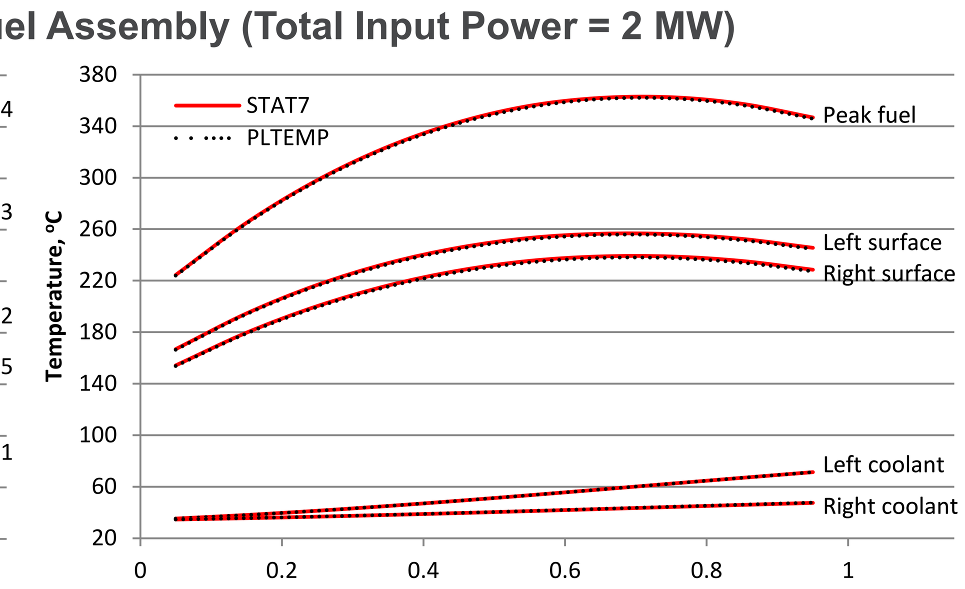
- Code-to-code comparison has been performed for combined capabilities No. 1 – 6 against PLTEMP/ANL V4.3

Group	Parameters	Values
FUEL	Number of fuel assemblies	1
	Number of fuel plates	4.0
	Fuel length, m	1.0
	Fuel width, m	0.4
	Fuel thickness, m	0.01
	Fuel thermal conductivity, W/mK	50.0
	Clad thickness (one side), m	0.005
	Clad thermal conductivity, W/mK	100.0
FIN	Groove depth/Fin height, m	0.002
	Width of groove tip/Fin width, m	0.002
	Groove width, m (STAT7)	0.002
	Number of fins in an internal channel (PLTEMP/ANL)	200

Schematics and Geometry of the Fuel Assembly (Total Input Power = 2 MW)



Coolant Temperature Profiles



Temperature Profiles Corresponding to Fuel Plate #4

CONCLUSIONS

- STAT7 is an easy-to-use steady-state TH analysis tool with statistical uncertainty propagation that is developed to support LEU conversion for research reactors with plate-type fuels.
- All the STAT7 V1.1 code capabilities have been validated and verified.

REFERENCES

[1] D. J. Allen, "Impact Assessment for the MIT Research Reactor Low Enrichment Uranium Fuel Fabrication Tolerances," M.S. Thesis, Massachusetts Institute of Technology, May 2020.

[2] R. H. Whittle and R. Forgan, "A Correlation for the Minima in the Pressure Drop versus Flow-rate Curves for Sub-cooled Water Flowing in Narrow Heated Channels," Nucl. Eng. and Des., 6, 89-99 (1967).