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CMPXLATT – WESTINGHOUSE AUTOMATED TESTING TOOL FOR NODAL CROSS SECTION MODELS

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ABSTRACT

The procedure for evaluating the merits of different nodal cross section representation models is normally both cumbersome and time consuming, and includes many manual steps when preparing appropriate benchmark problems. Therefore, a computer tool called cmpXLatt has been developed at Westinghouse in order to facilitate the process of performing comparisons between nodal diffusion theory results and corresponding transport theory results on a single node basis. Due to the large number of state points that can be evaluated by cmpXLatt, a systematic and comprehensive way of performing verification and validation of nodal cross section models is provided. This paper presents the main features of cmpXLatt and demonstrates the benefits of using cmpXLatt in a real life application.

Key Words: Nodal Cross Section Models, Verification and Validation, Software Module Testing

1. INTRODUCTION

A common practice of evaluating the merits of different nodal cross section representation models is to pre-select some typical unit-assembly configurations and to compare nodal simulation results for these assembly setups at various conditions against corresponding reference transport calculation results. Unfortunately, the process of setting up such unit-assembly test cases is both cumbersome and time consuming as they normally are generated manually by hand thereby potentially restricting the number of state parameter combinations evaluated in such test cases. The lack of an automated test process for the qualification of nodal cross section models has led Westinghouse to develop the computer tool cmpXLatt with the main objective of facilitating the process of performing comparisons between nodal diffusion theory calculations and corresponding transport theory calculations on a single node basis.

The main feature and advantage of cmpXLatt (abbreviation for “compare CROSS with Lattice code”) is that it is built upon the nodal data link code CoreLink, an interface and data transfer code between the lattice code and the Westinghouse boiling water reactor (BWR) nodal core simulator POLCA7 [1]. As a result the reading and processing of relevant lattice code output files by cmpXLatt is straightforward since the low-level functionality of CoreLink is utilized. Consequently, the same procedure and computer codes as used for standard nodal cross section generation may be used to generate the lattice code reference solution of selected test cases. By reading the lattice code output files containing the reference solution, cmpXLatt will

automatically recognize which state points have been evaluated in the two-dimensional unit-assembly calculations and will automatically run POLCA7 on these same assembly states for the considered node. Based on these simulations, cmpXLatt will make appropriate comparisons of k-infinity between the nodal results and corresponding reference lattice code results and will print out relevant statistics based on these comparisons. In other words, one of the most significant advantages of cmpXLatt is that a fairly large number of state points can be evaluated by the system with no additional user inference as cmpXLatt automatically recognizes which state points are available in the reference solution to perform nodal simulations on.

By running cmpXLatt on the same state points used for generating nodal cross section data (in this context also called cell data) to POLCA7 and by including this additional computational step as part of the standard cell data generation procedure, one automatically verifies that correct nodal data have been provided to the nodal simulator. By choosing state points different from those used in standard cell data generation gives a validation basis for the nodal cross section model to quantify its accuracy and relevance.

In this paper the main features of the computer tool cmpXLatt are discussed. The paper is organized as follows. In Section 2 details about the procedure for setting up test cases using cmpXLatt is provided whereas in Section 3 a real life application of cmpXLatt is presented demonstrating the benefits of using cmpXLatt. Finally, in Section 4 some concluding remarks are given including future visions of cmpXLatt usage.

2. SETTING UP TEST CASES WITH CMPXLATT

In order to parse lattice code output files and to correctly identify the state points of various nuclear data blocks present in these files, standard cell data generation computer codes need to be employed in generating the reference solution provided to cmpXLatt. In this regard one may set up two types of comparisons in the tests evaluated by cmpXLatt:

- Verification tests – if the **same** state points exist in the lattice code output files as used for generating cross section data to the nodal simulator then **verification** is considered. Consequently, these state points, which are equal to the cell data table entry points in the cell data file, are referred to as verification state points.
- Validation tests – if **different** state points exist in the lattice code output files compared to those used for generating cross section data to the nodal simulator then **validation** is considered. Consequently, these state points, which are **not** equal to the cell data table entry points in the cell data file, are referred to as validation state points.

Verification test cases are mainly performed as a part of the standard cell data generation procedure in order to obtain a quality assurance record on nodal data provided to the nodal simulator POLCA7. Running cmpXLatt on such lattice code output files is straightforward as these files are anyway generated in these standardized lattice calculations to be read by the link code CoreLink. Consequently, an indication of the correct implementation of the POLCA7 nodal cross section model is obtained in a rather automated fashion.

Validation test cases are mainly set up in order to challenge the nodal cross section model performance for typical as well as extreme state points expected to be encountered in the reactor core. Based on the statistics generated by cmpXLatt one tries to find any weaknesses in the predictive capability of the model by systematically quantifying the accuracy of the nodal simulator for such core states on a single node basis. These validation activities are typically performed when new models are introduced to be used in specific nodal simulation applications. Therefore, the main characteristics of these reactor core applications will dictate the assembly and core states to be considered in these validation tests, i.e. the state points evaluated in the validation tests are currently chosen manually based on engineering judgment.

In order to run POLCA7 in a single node mode, a so-called wrapper code called CROSS is utilized by cmpXLatt. CROSS is an interactive single-node two-group nodal simulation tool which combines all the necessary routines and modules of POLCA7 to simulate spatially homogeneous unit-assembly depletion and branch cases similar to those spatially heterogeneous cases employed to generate cross section data (i.e. equivalent parameters) for POLCA7 with a lattice code.[1] A typical application of the simulation tool CROSS can be found in Ref. [2].

The cmpXLatt code uses low-level functionality of CoreLink in order to parse output files of various supported lattice codes (i.e. PHOENIX4, HELIOS and CASMO-4), and generates a set of CROSS (i.e. POLCA7 single node) run cases based on the reactivity points found in these lattice code files. CROSS is subsequently executed within cmpXLatt for these run cases. Various kinds of branch cases are supported by cmpXLatt to be evaluated (for all available coolant density histories) reflecting the underlying nodal cross section representation model, which include:

- Reference depletion case, typically corresponding to 40 or 50 % void history.
- Momentaneous coolant density branch cases.
- Control rod insertion branch cases.
- Spacer grid insertion branch cases.
- Fuel Doppler temperature branch cases.
- Zero xenon spectrum branch cases.
- Soluble boron branch cases.
- Combined spacer grid and control rod insertion branch cases.
- Combined control rod insertion and fuel Doppler temperature branch cases.
- Combined control rod insertion and zero xenon spectrum branch cases.
- Combined control rod insertion and soluble boron branch cases.
- Heterogeneous bypass soluble boron branch cases.
- Heterogeneous bypass water branch cases.
- Combined heterogeneous bypass soluble boron and water branch cases.

[1] Unit-assembly (with reflective boundary conditions) lattice calculations using a neutron transport code are normally performed considering a radial slice of an assembly including half of its inter-assembly gaps with the size consistent with the assembly pitch and height of 1 cm. Such a radial slice is referred as an assembly "cell".

The user may choose which of the above branch cases to be executed by cmpXLatt via various options specified in the cmpXLatt input file. The option "all" executes all the supported types of branch cases. However, the prerequisite for such desired evaluation is that **appropriate branch case data are available in the lattice code output files, i.e. an appropriate reference solution containing such branch case data has been prepared**. The contents of a typical cmpXLatt input file is shown in Fig. 1.

If desired, it is fairly easy to include and implement new types of branch cases to be evaluated in cmpXLatt as this software is implemented using the Tcl scripting language. However, support for generating such branch cases as well as correct parsing of them have to be implemented in the employed cross section generation procedure.

Once the lattice physics reference solution has been generated and corresponding fuel input data (i.e. geometrical data and cell data with nodal cross section data) have been provided to the nodal simulator, one is ready to execute cmpXLatt on the desired branch cases specified in the cmpXLatt input file.

3. APPLICATION OF CMPXLATT

For the sake of demonstration, a real life application of cmpXlatt is presented here in terms of an analysis to qualify a newly developed water density and soluble boron heterogeneity cross section model incorporated in POLCA7 and POLCA-T [3]. This so-called "heterogeneity model" (see Ref. [4]) has been developed to be applied in specific types of BWR transients with severe spatial dependence on the soluble boron and water density distribution in the reactor core with a large impact on the core reactivity (e.g. anticipated transients without scram (ATWS)).

The qualification work of this heterogeneity model with cmpXLatt was performed for hot voided and non-voided saturated conditions. The various tests were evaluated in terms of various branch calculations employing different combinations of relevant state parameters at different fuel exposures for core conditions expected to be encountered during considered transient events (i.e. ATWS in this case). Only fuel exposures up to the burn-up point where burnable absorbers (BAs) are depleted out were considered in the study (i.e. 0 – 20 MWd/kgHM), mainly because in this burn-up range the considered fuel type is expected to drive the reactivity in the core.

Two sets of cell data files with three different standard cell data files in each such set were prepared for use in the qualification work. For each set of files, three different values of the homogeneous soluble boron concentration perturbation (i.e. ΔC_{hom} = 1000, 1500 and 3000 ppm) were utilized in the boron branches with each such boron perturbation associated to a different cell data file. Furthermore, for the first set of cell data files these soluble boron branch cases (i.e. both heterogeneous and homogeneous) were conducted for all coolant density histories (abbreviated "B all ρ_{his}") whereas in the second set of files such branch cases were only performed for the reference coolant density history corresponding to 40 % void history (abbreviated "B ref. ρ_{his} "). Therefore, a total of 6 different cell data files were prepared to be used in the qualification exercise.

The obtained numerical results are reported in terms of the burn-up averaged k-infinity error and corresponding standard deviation in units of [pcm]. The maximum and minimum k-infinity errors over the considered burn-up range are also provided (also in units of [pcm]). These statistics are directly taken from cmpXLatt output file. In Fig. 2 an example of such a cmpXLatt output file is shown for a subset of evaluated branch case types.

In the subsequent sections all temperatures are reported in units of [C] whereas water densities are given in units of [g/cm^3].

```
# --------------
# Fuel Type Name
# --------------
Fuel Type:         429


# ------------------------
# Lattice Code Input Files
# ------------------------
Base History File: ../phx/work/forslupt/FT429-27375/p7-429-00.dat
Void History File: ../phx/work/forslupt/FT429-27375/p7-429-??.dat

# -------------------------------------
# CROSS Version, Input File and Options
# -------------------------------------
Cross Version:     4.14.0
Cross Driver:      /dvl/users/forslupt/script/bin/run_cross.4.14
Source File:       source-429.txt
Print File:        print.txt
Hold Xenon:        yes

# -----------
# Report File
# -----------
Report File:          429-cmpxlatt.rpt

# -------------------------
# Print and Compare Options
# -------------------------
#
# Possible values for Compare: refdepl cooldns crod sgrid
#                              doppler zeroxe boron sgcrod
#                              crdopp crxenon crboron
#                              hetbor hetdns hetbordns all
# ---------------------------------------------------------
Compare:           all


# Possible values for Print:   kinf
# ---------------------------------
Print:             kinf
```

Figure 1. The contents of a typical cmpXLatt input file.

3.1. Verification of the heterogeneity cross section model

By considering the state points of the cell data file in the reference solution (i.e. states of nodal data table entry points), a verification of the correct model implementation as well as nodal data transfer is obtained. Consequently, very small errors are expected for these verification cases. In this regard, a burn-up averaged k-infinity error less than 10 ± 20 pcm and a maximum k-infinity error below 50 pcm are considered acceptable.

One should note that even if each cell data file used in this qualification contains a complete set of cross section data needed by the nodal simulator with corresponding state parameter combinations, only state points concerning conditions with water density and soluble boron variations were included in the statistics reported here. In Table I the number of such state points (i.e. $N_{tot}^{states} = N_{mom}^{states} \times N_{bup}$) for each branch case type evaluated is summarized. Consequently, a total of 5104 state points were included in the verification analysis for cell data files with boron branches for all coolant density histories whereas 2842 state points were included for cell data files with boron branch cases only for the reference coolant density. The total execution times of cmpXLatt in terms of the mean CPU time[2] for each set of cell data files are also shown in Table I with all calculations performed on an Intel(R) Xeon(R) Dual-Core CPU 5160 @ 3.00GHz hardware architecture running SLES9 Linux distribution. These results demonstrate the efficiency of using cmpXLatt in qualification analyses as the elapsed real time is here assumed to be close to the CPU time due to the relatively small amount of I/O tasks performed by cmpXLatt.

Table I. Number of state points evaluated in the verification analysis for each set of cell data files.

Branch case type	**Number of state points**		**Total CPU time [s]**	
	B all ρ_{his}	B ref. ρ_{his}	B all ρ_{his}	B ref. ρ_{his}
Coolant water density variations	1044	1044		
Bypass water density variations	1044	1044		
Homogeneous soluble boron variations	1044	261		
Heterogeneous soluble boron variations	1044	261		
Heterogeneous soluble boron and bypass water density	928	232		
Total for all branch case types	5104	2842	236.35	137.04

[2] Here the mean CPU time refers to an average value for the three cell data files included in a set.

```
------------------- Begin of Quality Assurance Record -------------------
Lattice code and version: PHOENIX4 2.3.2
Cross section library   : PHOENIX LIBRARY: 25 JUL 1997
POLCA7/CROSS version    : 4.14.0
Fuel lattice data       : 429 4.02 4.40 SVEA96
cmpXLatt version        : 1.0.0
cmpXLatt execution time : Tue Nov 30 07:55:25 CET 2010
cmpXLatt user name      : Petri Forslund Guimaraes (forslupt)
-------------------- End of Quality Assurance Record --------------------


K-infinity comparisons [pcm]:
   Reference coolant density history case (DEPL)
         Tfuel  Tcool HDcool  Dcool Dnsbyp  Power  Boron Borbyp CRid SGid NrBup AveErr StdErr MinErr MaxErr
        ------ ------ ------ ------ ------ ------ ------ ------ ---- ---- ----- ------ ------ ------ ------
        473.00 286.00 0.4585 0.4585 0.7399 100.00    0.0    0.0    0    0    11    9.1    9.0   -9.6   17.3

K-infinity comparisons [pcm]:
   Coolant density branch case (DUMR)
         Tfuel  Tcool HDcool  Dcool Dnsbyp  Power  Boron Borbyp CRid SGid NrBup AveErr StdErr MinErr MaxErr
        ------ ------ ------ ------ ------ ------ ------ ------ ---- ---- ----- ------ ------ ------ ------
        473.00 286.00 0.4585 0.4585 0.7399 100.00    0.0    0.0    0    0    11    9.1    9.0   -9.6   17.3
        473.00 286.00 0.4585 0.7399 0.7399 100.00    0.0    0.0    0    0    11    8.4    9.2  -11.2   17.2
        473.00  20.00 0.4585 0.9982 0.9982 100.00    0.0    0.0    0    0    11    4.8    8.5  -15.1   14.0
        473.00 286.00 0.7399 0.4585 0.7399 100.00    0.0    0.0    0    0    11    9.9    8.3   -7.4   17.5
        473.00 286.00 0.7399 0.7399 0.7399 100.00    0.0    0.0    0    0    11    9.4    7.9   -7.7   16.5
        473.00  20.00 0.7399 0.9982 0.9982 100.00    0.0    0.0    0    0    11    8.8    8.5  -10.9   15.4

K-infinity comparisons [pcm]:
   Control rod insertion branch case (CROD)
         Tfuel  Tcool HDcool  Dcool Dnsbyp  Power  Boron Borbyp CRid SGid NrBup AveErr StdErr MinErr MaxErr
        ------ ------ ------ ------ ------ ------ ------ ------ ---- ---- ----- ------ ------ ------ ------
        473.00 286.00 0.4585 0.4585 0.7399 100.00    0.0    0.0    1    0    11    4.7    7.2   -9.4   12.4
        473.00 286.00 0.4585 0.7399 0.7399 100.00    0.0    0.0    1    0    11    5.7    7.9  -10.4   13.1
        473.00  20.00 0.4585 0.9982 0.9982 100.00    0.0    0.0    1    0    11    5.9    8.7  -13.8   13.3
        473.00 286.00 0.7399 0.4585 0.7399 100.00    0.0    0.0    1    0    11    5.4    6.8   -7.9   11.9
        473.00 286.00 0.7399 0.7399 0.7399 100.00    0.0    0.0    1    0    11    6.2    6.9   -7.6   12.6
        473.00  20.00 0.7399 0.9982 0.9982 100.00    0.0    0.0    1    0    11    7.7    8.2  -10.3   13.8

K-infinity comparisons [pcm]:
   Control rod insertion branch case (CROD)
         Tfuel  Tcool HDcool  Dcool Dnsbyp  Power  Boron Borbyp CRid SGid NrBup AveErr StdErr MinErr MaxErr
        ------ ------ ------ ------ ------ ------ ------ ------ ---- ---- ----- ------ ------ ------ ------
        473.00 286.00 0.4585 0.4585 0.7399 100.00    0.0    0.0    2    0    11    8.5    8.7   -9.2   16.4
        473.00 286.00 0.4585 0.7399 0.7399 100.00    0.0    0.0    2    0    11    8.4    9.0  -10.4   17.0
        473.00  20.00 0.4585 0.9982 0.9982 100.00    0.0    0.0    2    0    11    6.1    8.9  -14.2   13.9
        473.00 286.00 0.7399 0.4585 0.7399 100.00    0.0    0.0    2    0    11    9.4    8.0   -6.6   16.6
        473.00 286.00 0.7399 0.7399 0.7399 100.00    0.0    0.0    2    0    11    8.9    7.8   -7.8   15.8
        473.00  20.00 0.7399 0.9982 0.9982 100.00    0.0    0.0    2    0    11    9.1    8.3  -10.3   15.5

K-infinity comparisons [pcm]:
   Spacer grid insertion branch case (SPAC)
         Tfuel  Tcool HDcool  Dcool Dnsbyp  Power  Boron Borbyp CRid SGid NrBup AveErr StdErr MinErr MaxErr
        ------ ------ ------ ------ ------ ------ ------ ------ ---- ---- ----- ------ ------ ------ ------
        473.00 286.00 0.4585 0.4585 0.7399 100.00    0.0    0.0    0    1    11    8.7    9.0  -10.6   17.4
        473.00 286.00 0.4585 0.7399 0.7399 100.00    0.0    0.0    0    1    11    8.2    9.1  -10.8   16.9
        473.00  20.00 0.4585 0.9982 0.9982 100.00    0.0    0.0    0    1    11    6.2    9.1  -15.0   14.5
```

Figure 2. The contents of a typical cmpXLatt output file for a subset of branch case types.

In Table II the ranges (i.e. extreme values) of the average k-infinity error obtained for the verification cases are presented for the different cell data files used in the calculations. As may be observed, small errors are obtained for all cases as expected thereby verifying that the heterogeneity model was correctly implemented. The small errors still prevailing are mainly due to differences in the POLCA7 burn-up methodology compared to PHOENIX4 as well as due to some limitations in the POLCA7 cross section model (i.e. lack of higher order terms etc., see Ref. [2]) for a more detailed discussion).

Table II. Extreme values of the average k-infinity error for verification cases.

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
Cell data file with ΔC_{hom} = 1000 ppm and boron branches for the reference ρ_{his}											
33	460	150	0.740	0.917	0.917	0	0	29	-8.9	15.3	35.4
37	460	286	0.318	0.318	0.318	0	0	29	2.4	9.5	29.1
Cell data file with ΔC_{hom} = 1500 ppm and boron branches for the reference ρ_{his}											
33	460	150	0.740	0.917	0.917	0	0	29	-8.9	15.3	35.4
37	460	286	0.318	0.318	0.318	0	0	29	2.4	9.5	29.1
Cell data file with ΔC_{hom} = 3000 ppm and boron branches for the reference ρ_{his}											
33	460	150	0.740	0.917	0.917	0	0	29	-8.9	15.3	35.4
81	460	20	0.459	0.998	0.998	3000	3000	29	3.8	11.9	37.5
Cell data file with ΔC_{hom} = 1000 ppm and boron branches for all ρ_{his}											
33	460	150	0.740	0.917	0.917	0	0	29	-8.9	15.3	35.4
37	460	286	0.318	0.318	0.318	0	0	29	2.4	9.5	29.1
Cell data file with ΔC_{hom} = 1500 ppm and boron branches for all ρ_{his}											
33	460	150	0.740	0.917	0.917	0	0	29	-8.9	15.3	35.4
37	460	286	0.318	0.318	0.318	0	0	29	2.4	9.5	29.1
Cell data file with ΔC_{hom} = 3000 ppm and boron branches for all ρ_{his}											
33	460	150	0.740	0.917	0.917	0	0	29	-8.9	15.3	35.4
106	460	100	0.740	0.959	0.959	3000	3000	29	5.0	16.5	51.4

3.2. Validation of the heterogeneity cross section model

The real test of the heterogeneity model performance on a single node basis is accomplished by utilizing state points in the reference solution that are different from those used in the cell data tabulation. Based on engineering judgment, these state points were chosen manually to represent realistic states expected to be encountered during the considered simulated ATWS transient events. Consequently, the various state parameter combinations of heterogeneous water density (i.e. void fraction) and soluble boron concentration constituted a total of 94 different heterogeneity branch cases for each coolant density history using same depletion steps and coolant density histories as employed in standard cell data generation. In summary, a total of 10904 validation state points (burn-up included) were evaluated by cmpXLatt for each cell data file used in the study in order to quantify the accuracy of the heterogeneity model. It should also be noted that each of these validation state points is executed with the same computational efficiency as demonstrated for the verification analysis.

The large number of state points evaluated by cmpXLatt facilitates and supports the search for various patterns in observed k-infinity errors. In particular, as demonstrated in Tables III and IV, one easily recognizes that applying the heterogeneity model improves the simulation accuracy of the considered heterogeneity cases substantially (i.e. by about a factor 10) in terms of the average k-infinity error span (i.e. difference between the largest and smallest average k-infinity error considering all evaluated cases). In addition, employing soluble boron branch lattice calculations only for the reference coolant density history implies an accuracy that is similar to performing such branches for all coolant density histories. In other words, the heterogeneity model coefficients seem to have only a weak dependence on coolant density history thereby suggesting that the heterogeneity model formulation can be simplified with regard to coefficient data tabulation in the cell data file.

By studying the obtained numerical results in more detail, various other trends of interest can be observed as highlighted in Table V. Again the ease of generating a large sample space of reactivity point comparisons using cmpXLatt facilitates the analysis for finding any potential model weaknesses. For example, one may recognize that the heterogeneity model performs very well for pure water density heterogeneity cases with no soluble boron (i.e. $C_B^{act} = C_B^{byp} = 0$ ppm) or for pure soluble boron heterogeneity cases with no void in the bypass water region (ρ_{byp} = 0.7400 g/cm^3). In contrast, rather poor performance is obtained for heterogeneity cases with void in both the active coolant and bypass combined with soluble boron in these water regions. In this regard, the k-infinity errors seem to increase with both the void content and boron concentration in the bypass.

By further exploring these numerical results in a manner similar to what is described above, one may gain even deeper insight into the model performance and may also recognize areas of potential improvements to the model. In this regard, the availability of a test tool such as cmpXLatt is a great advantage as a systematic and comprehensive way of performing verification and validation of the model is provided by its application.

Table III. Extreme values of the average k-infinity error for validation cases with heterogeneity model switched on or off – cell data file with boron branches only for the reference history.

Cell data file with ΔC_{hom} = 1000 ppm and boron branches for the reference ρ_{his}

Model ON

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
308	460	286	0.740	0.318	0.318	400	800	29	-2995.5	321.4	3363.3
176	460	286	0.740	0.740	0.740	800	400	29	88.6	32.9	162.2
							AveErr span		3084.1		

Model OFF

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
211	460	286	0.599	0.740	0.740	3200	0	29	-12302.1	791.6	13340.7
88	460	286	0.740	0.740	0.740	0	3200	29	18142.2	1876.9	20313.5
							AveErr span		30444.3		

Cell data file with ΔC_{hom} = 1500 ppm and boron branches for the reference ρ_{his}

Model ON

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
308	460	286	0.740	0.318	0.318	400	800	29	-2946.4	318.0	3309.3
176	460	286	0.740	0.740	0.740	800	400	29	161.1	43.0	246.2
							AveErr span		3107.5		

Model OFF

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
211	460	286	0.599	0.740	0.740	3200	0	29	-12151.0	780.5	13172.7
88	460	286	0.740	0.740	0.740	0	3200	29	18142.2	1876.9	20313.5
							AveErr span		30293.2		

Cell data file with ΔC_{hom} = 3000 ppm and boron branches for the reference ρ_{his}

Model ON

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
308	460	286	0.740	0.318	0.318	400	800	29	-2806.3	306.2	3155.3
204	460	286	0.740	0.740	0.740	1600	800	29	474.5	87.9	602.9
							AveErr span		3280.8		

Model OFF

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
211	460	286	0.599	0.740	0.740	3200	0	29	-11698.4	739.6	12668.7
88	460	286	0.740	0.740	0.740	0	3200	29	18142.2	1876.9	20313.5
							AveErr span		29840.6		

Table IV. Extreme values of the average k-infinity error for validation cases with heterogeneity model switched on or off – cell data file with boron branches for all coolant density histories.

Cell data file with ΔC_{hom} = 1000 ppm and boron branches for all ρ_{his}

Model ON

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
308	460	286	0.740	0.318	0.318	400	800	29	-2979.2	310.3	3335.3
176	460	286	0.740	0.740	0.740	800	400	29	71.8	24.5	132.2
								AveErr span	3051.0		

Model OFF

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
212	460	286	0.740	0.740	0.740	3200	0	29	-12364.9	828.0	13454.4
88	460	286	0.740	0.740	0.740	0	3200	29	18142.2	1876.9	20313.5
								AveErr span	30507.1		

Cell data file with ΔC_{hom} = 1500 ppm and boron branches for all ρ_{his}

Model ON

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
308	460	286	0.740	0.318	0.318	400	800	29	-2930.0	306.3	3281.5
176	460	286	0.740	0.740	0.740	800	400	29	144.7	34.4	217.2
								AveErr span	3074.7		

Model OFF

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
212	460	286	0.740	0.740	0.740	3200	0	29	-12211.8	814.4	13283.4
88	460	286	0.740	0.740	0.740	0	3200	29	18142.2	1876.9	20313.5
								AveErr span	30354.0		

Cell data file with ΔC_{hom} = 3000 ppm and boron branches for all ρ_{his}

Model ON

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
308	460	286	0.740	0.318	0.318	400	800	29	-2790.8	295.4	3130.3
204	460	286	0.740	0.740	0.740	1600	800	29	443.1	71.0	551.9
								AveErr span	3233.9		

Model OFF

Case No.	T_{fuel}	T_{cool}	ρ_{his}	ρ_{act}	ρ_{byp}	C_{act}	C_{byp}	NrBup	AveErr	StdErr	|MaxErr|
212	460	286	0.740	0.740	0.740	3200	0	29	-11752.8	769.6	12770.4
88	460	286	0.740	0.740	0.740	0	3200	29	18142.2	1876.9	20313.5
								AveErr span	29895.0		

Table V. Average k-infinity error for a specific subset of evaluated assembly conditions – cell data file with ΔC_{hom} = 1500 ppm and boron branches for all ρ_{his}.

phis	0.4586

		Cbyp	0				200				400				800			
Cact	pact	pbyp	0.3179	0.4586	0.5993	0.7400	0.3179	0.4586	0.5993	0.7400	0.3179	0.4586	0.5993	0.7400	0.3179	0.4586	0.5993	0.7400
0	0.3179		4.3	27.9	13.8	-0.3	-784	-534.1	-264.1									
	0.4586			-1.3	-7.7	-1.9		-565	-281									
	0.5993				-19	-3.4			-289.5									
	0.7400					-4				37				48.9				1.4
200	0.3179		12.3	38.4	24.3		-765.7	-516	-249.6									
	0.4586			15.7	10.2			-536.5	-257									
	0.5993				8.3				-253.5									
	0.7400					32.3				75.2				90				50.4
400	0.3179														-2878.7	-2020.2	-1020.9	
	0.4586															-2021	-1006.6	
	0.5993																-981.8	
	0.7400					55.6				100.7				118.4				87.2
800	0.3179										-1442.4	-988.1	-478.7		-2799.2	-1957	-982	
	0.4586											-980.6	-461.5			-1929.1	-948.8	
	0.5993												-431.1				-902.8	
	0.7400					68				118				142.5				128.3

4. CONCLUSIONS

In this paper, the main features of the computer tool cmpXLatt were presented. A real life application of cmpXLatt was used to demonstrate the advantages of using cmpXLatt for verification and validation of nodal cross section representation models. Due to the large number of state points evaluated by cmpXLatt with high efficiency, a systematic and comprehensive test framework is obtained facilitating the search for various patterns in observed numerical results indicating areas of potential improvement.

In the real life application of cmpXLatt presented here, the evaluated state points were chosen based on engineering judgment to cover the fuel assembly and core conditions expected to be encountered during the specific event being studied. A future improvement in this regard would be to apply a stochastic generation of these validation state points to be evaluated by cmpXLatt. Furthermore, an extension from unit-assembly consideration to mini-core evaluations is desired in order to test various spectrum interaction and intranodal cross section models and related pin power reconstruction formulations.

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