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Development Status of Nodal Diffusion Code RAST-K v2.2

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1. Introduction

The dynamic reactor nodal computational code is used as the second part of a conventional two-step approach in a traditional procedure for nuclear reactor core analysis. The conventional two-step approach code systems such as CASMO/SIMULATE, DeCART/MASTER, and KARMA/ASTRA have been developed for the light water reactor core design [1-4].

RAST-K v2.2 [5] is the second part of a conventional two-step approach code system, which have been developed by Ulsan National Institute of Science and Technology and sponsored by Korea Hydraulic & Nuclear Power Co. Ltd. RAST-K adopts the state-of-the-art solvers to obtain high accuracy and computational performance for pressurized water reactor core analysis and design. Engineering features are implemented to support convenient core design and analysis. Besides, multi-physics coupling work have been performed based on RAST-K pin power reconstruction capability coupled with CTF, FRAPCON, FRAPTRAN, VIPRE, or BOA for the purpose of high-fidelity reactor core analyses such as axial offset anomaly and reactivity-initiated accident situation [6, 7].

2. Features

The state-of-the-art solvers are adopted in RAST-K to achieve high accuracy of reactor core analysis. There are many engineering features in RAST-K for supporting user to perform conveniently core design and analysis. The solvers of several engineering features of RAST-K are introduced in this section.

2.1 Solvers

The lattice physics code STREAM [8] generates two- or multi- group constants for fuel and reflector region in a STN file. Next, the STN files are processed to cross section files by a linkage code STORA. In the cross-section file, residual macroscopic XS, microscopic XS, assembly discontinuity factor, form function, corner discontinuity factor, fresh and burned number densities, decay constant, fission yield, and kinetics parameter information are printed. Because the XS is edited in terms of RAST-K nodalization, many types of control rod and burnable absorber, and the asymmetric fuel assembly can be modelled. Fig. 1 shows the two-step code structure of RAST-K v2.2.

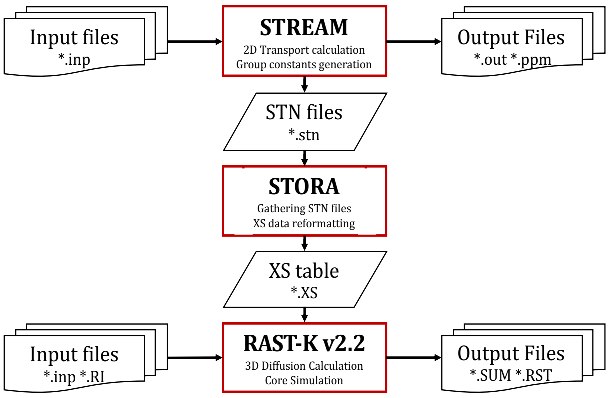

Fig. 1. Two-step code structure of RAST-K v2.2.

RAST-K utilizes the non-linear scheme based on multi-group coarse mesh finite difference acceleration with three-dimensional multi-group unified nodal method to solve steady state and transient problems with assembly-wise nodes.

For the TH feedback on cross section correction in terms of temperature, the simplified 1-dimensional single channel TH solver, which was developed in PARCS, is implemented in RAST-K. The equivalent pin, which is the representative of TH model of fuel assembly, is used to perform radial heat conduction and axial heat convection calculations. Various thermal conductivity model can be selected in RAST-K. Basically, the fuel and cladding thermal conductivity and gap conductance are obtained from the fitting function of conventional PWR. In order to simulate the thermal conductivity degradation effect, the burnup-dependent thermal conductivity model from FRAPCON-4.0 [7] are implemented to RAST-K thermal hydraulic calculation. Besides, the thermal conductivity fitting function for accident tolerance fuel (ATF) are also implemented.

The micro depletion method is adopted in the fuel cycle calculation of RAST-K in order to track the amount of each main heavy nuclide one by one to consider the history effect. RAST-K depletion solver can consider 22 actinides, 10 fission products, and 7 gadolinium isotopes. The neutron transmutation equation can be expressed as matrix form Bateman equation, and it is solved by Chebyshev Rational Approximation Method (CRAM). The predictor-corrector methodology is implemented to obtain accurate solution of the depletion calculation. Table I represents the characteristics of solvers of RAST-K.

Table I: Characteristics of RAST-K solver

	Characteristics
Nodal diffusion	Every diffusion analysis method can be selected with basis function by UNM.
XS model	Many types of control rod and burnable absorber can be simulated. Asymmetric fuel assembly model can be analyzed.
TH	Several thermal conductivity models and steam table can be selected for TH feedback.
Depletion	Number density of major isotopes can be tracked by micro depletion. Depletion solvers is converged well with long burnup step with CRAM.

2.2 Tools

For the multi-cycle calculation, the restart calculation and fuel assembly shuffling and rotation capability should be required. The restart file contains the burnup and number density from the depletion calculation, and it is generated for each burnup point. The shuffling and rotation capability can support that user easily make input for multi cycle fuel batch. During the core design with quarter core calculation, user need full core calculation to calculate control rod worth or transient calculation and it is easily performed by restart folding/unfolding capability. Several search options are possible during nodal calculation. There are critical search options based on the boron concentration and control rod position. Also, the mass flow rate can be searched for target average moderator temperature and burnup can be searched for target boron concentration. Next, the design parameter such as peaking factor, temperature coefficient, and xenon/samarium/gadolinium worth are automatically generated by performing the stacked branch cases.

During the nodal calculation, the pin power distribution is required to check peaking factors or pin burnup. Those pin power distribution can be calculated from pin power reconstruction method by using the form function and corner discontinuity factor from STREAM. Because the B-10 in coolant are depleted during the core depletion in real condition, the adjusted critical boron concentration can be calculated for considering B-10 depleted condition. The in-core detector signal can be obtained by solving the detector material depletion chain. The actual flux in detector region is calculated from pin power reconstruction or pin-to-box factor from STREAM. To obtain the ex-core detector signal, the conventional detector response functions are implemented for several reactor type, so that it is multiplied with node power to calculate ex-core detector signal. Table II represents the characteristics of engineering features of RAST-K.

Table II: Characteristics of RAST-K engineering features

	Engineering features
Core Design	Restart calculation - Folding & Unfolding - Shuffling & Rotation - Jump-in Search option - CBC & critical rod position search - Mass flow for target inlet temperature. - Burnup for target CBC Print option - Mini-RSAC parameter - NDR parameter
Core Analysis	Pin power reconstruction B-10 depletion in coolant and control rod In/Ex-core detector signal Simple CRUD modeling

3. Applications

RAST-K v2.2 can be applied for various area. The practical reactor core in Korea have been analyzed by RAST-K for V&V purpose. Besides, the multi-physics coupling work is carried based on nodal diffusion calculation. The multi cycle core depletion calculation is performed by RAST-K standalone and multi-physics calculation based on RAST-K.

3.1 Practical Reactor Core Analysis

The multi cycle whole core depletion calculation of practical reactor cores are performed by RAST-K v2.2. Table III shows the practical reactor core analysis result of RAST-K. The reactor types are divided into four; OPR-1000, APR-1400, Westinghouse 3-loop (WH-3L) and 2-loop type reactor (WH-2L).

Table III: Practical Reactor Core Analysis Result

Compare w/ NDR	No. Cycles	CBC Diff. (ppm)	Power Diff. (%)
OPR-1000	29	15.687	2.085
ARP-1400	1	2.640	1.100
WH-3L	10	9.972	0.890
WH-2L	31	19.817	1.731
Compare w/ Measurement	No. Cycles	CBC Diff. (ppm)	Power Diff. (%)
OPR-1000	9	6.023	1.337
ARP-1400	1	5.940	1.170
WH-3L	10	12.636	1.100

RAST-K core following calculation results are compared with the NDR and measurement for the critical boron concentration (CBC) and the assembly power. The difference of CBC is calculated by average of absolute difference and the difference of power is calculated by average of relative difference. The PWR core analysis results of RAST-K are agree with NDR and measurement within 20 pcm difference of CBC and around 2% difference of power. It is noted that RAST-K can provide reasonably accurate results without any tuning or correction of physics models.

3.2 Multi-Physics Coupling

To perform high-fidelity core depletion through multi-physics coupling calculation, RAST-K is coupled with subchannel analysis code CTF [6] and fuel performance code FRAPCON [7]. In order to make consistency during coupling, the channel centered model of CTF is changed to pin centered model. The pin power distribution of RAST-K is transferred to CTF and FRAPCON as an input variable. To perform FRAPCON calculation, the coolant temperature and pressure information from CTF is transferred to FRAPCON as an input. After performing pin-wise CTF and FRAPCON calculation, the moderator temperature from CTF and the fuel temperature from FRAPCON are transferred to RAST-K for cross-section feedback. For the multi-cycle calculation, the restart capability of FRAPCON is newly implemented. From this coupling calculation, more detailed condition can be considered such as multi-channel model with cross flow, fuel deformation, fission gas release, dynamic gap conductance, and etc. Fig. 2 shows the flowchart of RAST-K / CTF / FRAPCON multi-physics coupling simulation.

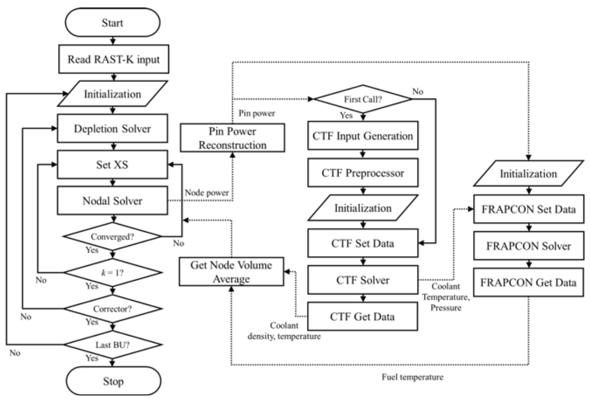

Fig. 2. Algorithm of RAST-K / CTF / FRAPCON multi-physics coupling simulation.

The multi-physics simulation based on RAST-K was performed for four cycles of OPR-1000 type reactor. The multi-physics simulation results are compared with that of RAST-K standalone calculation. In order to analyze the coupled effect of each code, the RAST-K is coupled with CTF and FRAPCON separately. Table IV shows the difference of coupled result with respect to that of RAST-K standalone. The average absolute difference of CBC and average relative difference of assembly power are investigated for four cycles of OPR-1000 reactor. The coupled results only with CTF are very similar with RAST-K standalone results. Otherwise, the results of other cases show around 11 ppm difference of CBC and 1.3% difference of assembly power at BOC. It means that the main difference of coupled simulation is caused by FRAPCON rather than CTF.

The simple CRUD modeling function is implemented to RAST-K to model the phenomenon of CRUD deposition during cycle depletion. The thickness of CRUD is calculated by the shape function based on the burnup and the axial height of fuel assembly. The number density of boron in CRUD is calculated by using the CRUD thickness. Next, the number density of boron and the time increment terms by CRUD is used for cross section and TH feedback. Also, it is possible to search the boron density for target ASI (fuel assembly-wise or core-wise).

Table IV: Comparison of multi-physics coupling results and RAST-K standalone result

		CTF	FRAPCON	CTF+ FRAPCON
CBC Diff. (ppm)		1.565	11.110	11.126
Power Diff. (%)	BOC	0.096	1.334	1.333
	MOC	0.075	0.750	0.749
	EOC	0.054	0.358	0.359

By coupling the RAST-K with VIPRE and BOA, it is possible to track the deposition of CRUD. The input file of VIPRE can be generated based on the power distribution from RAST-K. After the VIPRE / BOA simulation, the output of BOA containing the boron distribution can be read by RAST-K, and it is used for XS feedback.

RAST-K standalone and coupled calculation for CRUD modeling are performed for OPR-1000 cycle depletion, which has AOA situation. Fig. 3 shows the results of CRUD modeling by RAST-K standalone and RAST-K / VIPRE / BOA coupling calculation. The ASI from normal depletion calculation (ST/R2) is similar with that from NDR and both results cannot follow the measurement correctly. Otherwise, it is possible to track the ASI by using the CRUD modeling simulation of RAST-K standalone and coupled calculation.

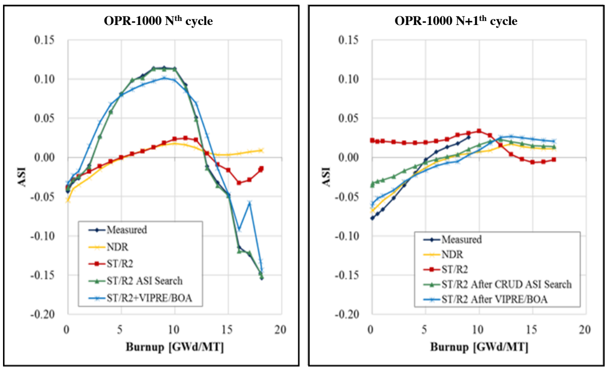

Fig. 3. Results of CRUD modeling by RAST-K standalone and RAST-K / VIPRE / BOA coupling calculation.

4. Conclusions

This paper presents the development status of RAST-K v2.2 in terms of features and applications. The state-of-the-art neutronics, thermal hydraulic, depletion solvers are adopted. For the reactor core analyses and design applications, user-friendly engineering features are implemented. The practical reactor core analysis has been performed by RAST-K. RAST-K can provide reasonably accurate PWR core analysis results. Recently, high-fidelity core depletion capability is possible by multi-physics coupled capability based on RAST-K. The preliminary result of RAST-K / CTF / FRAPCON multi-physics coupling calculation is performed for cycle depletion. Next, the CRUD deposition can be modelled by RAST-K / VIPRE / BOA coupling simulation.

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