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The development and preliminary V&V of the MOC transport module in new lattice code LATC

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国家核电 SNPTC

CONTENT

Introduction of SNPSDC

- **Founded in May 2010, a subsidiary of SNPTC**
- **Take the leading role in the State Energy Key Lab of NPP software (proved by DOE of China in Sep, 2011)**
- **The sole state energy key lab specialized in self-reliance NPP**
- **>80 staff and 13 in reactor physics division**

Main Business

01

NPP design codes self-reliance R&D

02

Management, maintenance &technical support for the 3rd generation of NPP software

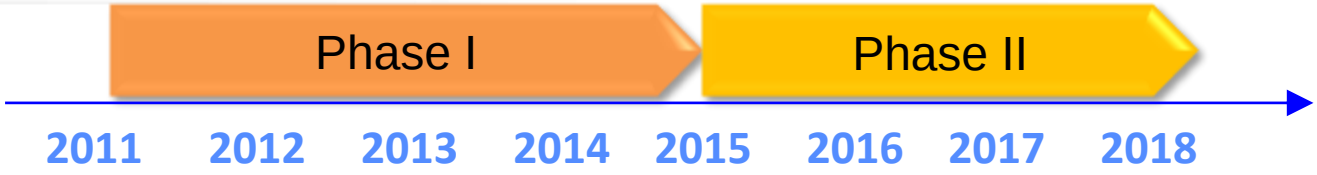
03

V&V technologies research for NPP software

04

The research on engineering application of advanced simulation technologies

R&D Phase



Core Melt Process Analysis Code
Source Term Analysis Code
Melt-Water Interaction Code
Hydrogen Analysis Code

Fuel Rod Safety Analysis Code
Fuel Rod Structure Analysis Code

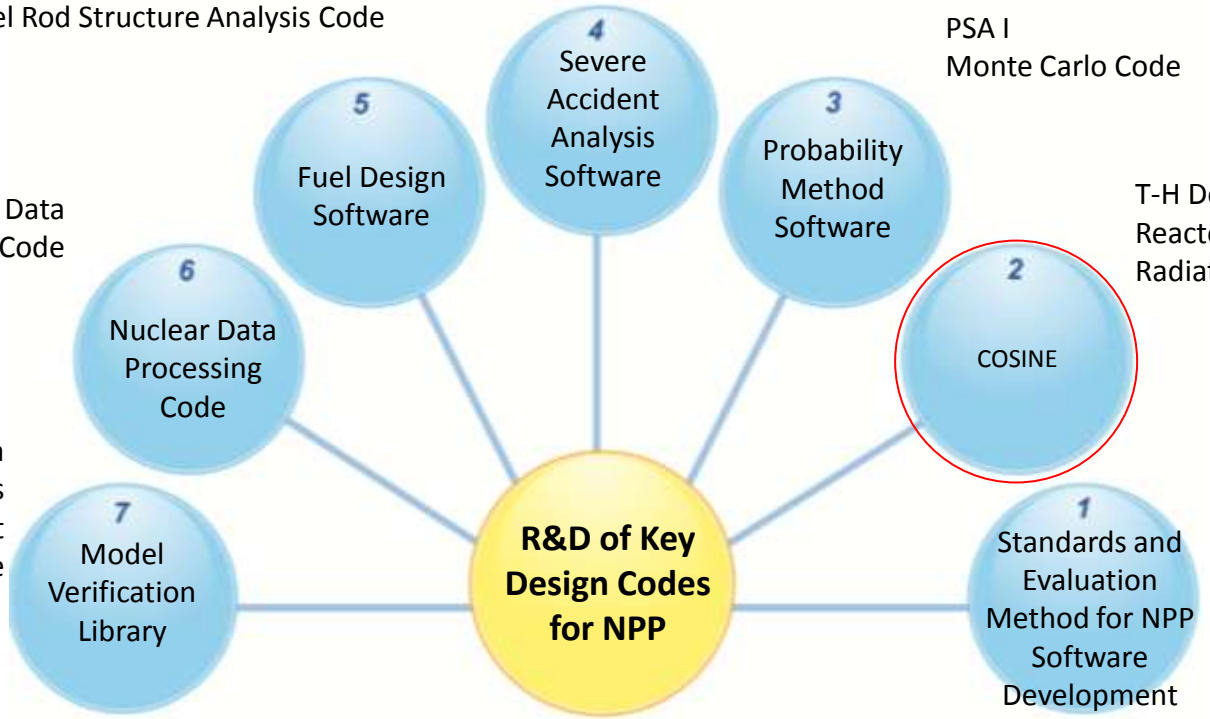
PSA I
Monte Carlo Code

Nuclear Data Processing Code

T-H Design/System Analysis Code
Reactor Physics Analysis Code
Radiation Shielding Design Code

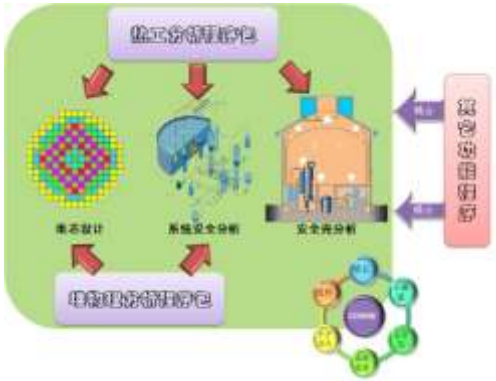
Collect Experiment Data
Carry on Experiments
Build the Experiment Data Base

Regulations & Standards Development Process
Model Evaluation Method
Uncertainty Analysis Method



COSINE

COre and System INtegrated Engine for design and analysis

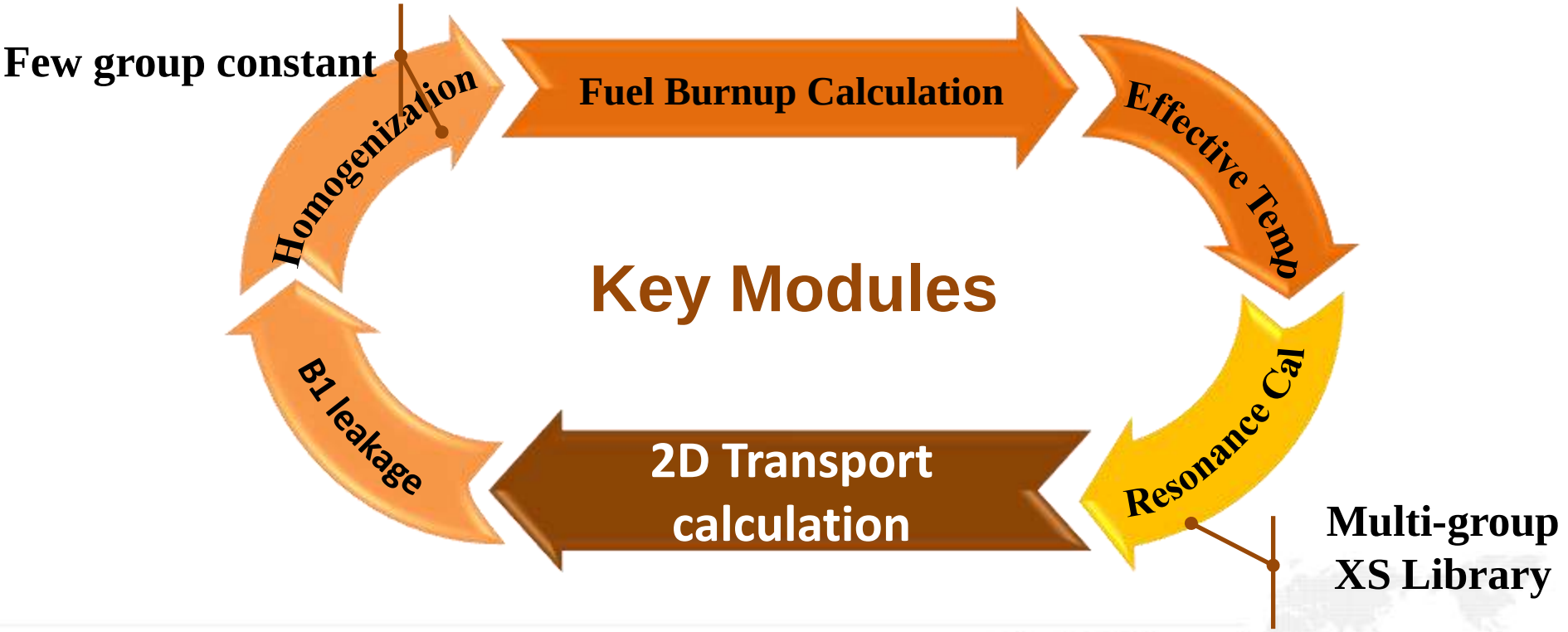


- ✓ An integrated platform
- ✓ Modular code system
- ✓ Multi-physics, multi-scale
- ✓ Sensitivity/Uncertainty analysis
- ✓ User friendly GUIs
- ✓ Parallel computations
- ✓ Software engineering QA
- ✓ ……

THERMAL CODE	PHYSICS CODE
■ Subchannel code(SUBC)	■ ***Lattice code(LATC)***
■ System code (SYST)	■ Core code (CORE)
■ Containment code(CONT)	■ Kinetics code(KIND)

LATC

- ✓A multi-group two-dimensional lattice transport code.
- ✓Mainly used on PWR assemblies or pin cells.
- ✓Capable of satisfying most of the needs for PWR lattice analysis.



Multi-group XS Library of LATC

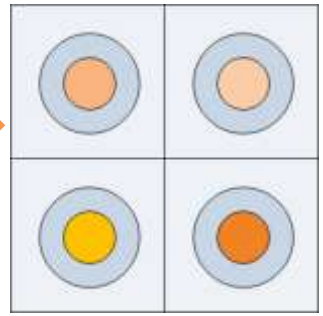
- Present
  - WIMSD-IAEA 69/172
  - Published by IAEA in WLUP
  - Adding the burn-up data of Wolfram isotope

- Future
  - A more accuracy library on develop
  - Energy Structure: SHEM281

Total Group No.	Total Nuclide No.	Fission Product No.	Resonance Nuclide No.
281	176	85	20

Effective Temperature Calculation in LATC

Temperature Distribution



IN

- Linear heating rate
- moderator temperature
- flow rate
- material conductance

Steady State Heat Equation

OUT

- Clad, fuel effective temperature interpolation table
- Depend on the burn up

Resonance Calculation in LATC

Intermediate Resonance Method

Spatially Dependent Dancoff Method

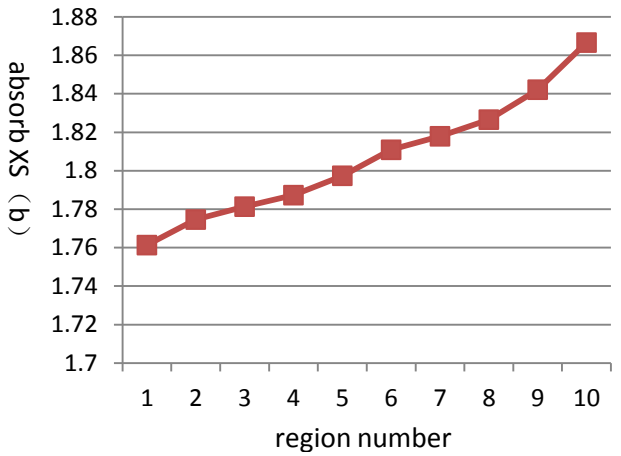
- fuel pin radial distribution
  - effective XS
  - power
  - nuclide density
  - burnup
  - …

IRM

- 2-term rational approximation
- only one resonance region

SDDM

- Stoker/Weiss Technique
- fuel can be subdivided



Equivalence theory

Burn-up Calculation Method of LATC

Predictor-Corrector Method

Burn-up Equation Solving:

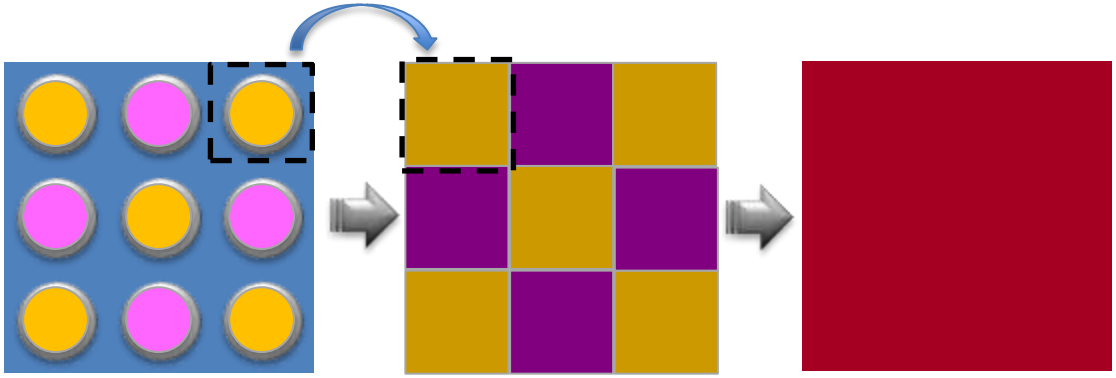
- The matrix exponential method
- Effective for stiff equation
- Bigger burn-up Step

Gadolinium Depletion

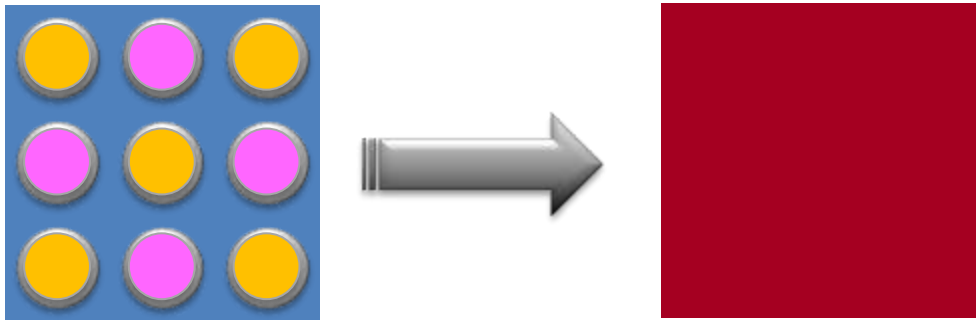
- Projected PC method
- Log Linear Rate Method

Transport Method of LATC

◆ Traditional two-step scheme: CP + SN



◆ One-step scheme : MOC



MOC General Theory

The transport equation can be written in the following discretised form:

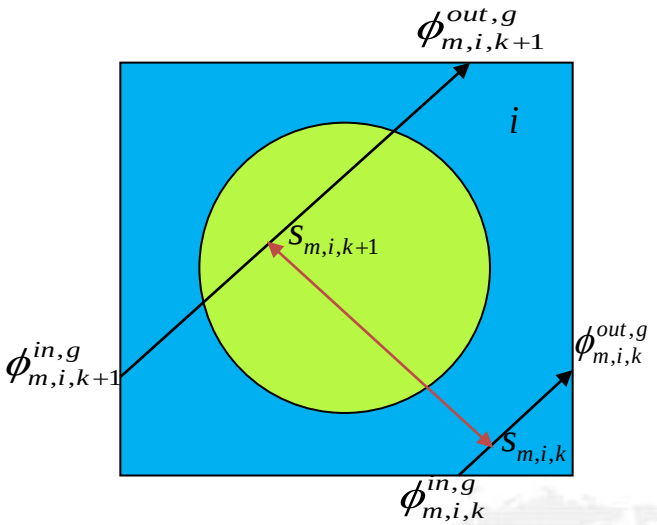
$$\frac{d\phi_{m,i}^{g}}{ds_m} + \Sigma_{tr,i}^{g}\phi_{m,i}^{g} = Q_{m,i}^{g} \qquad \text{Eq (1)}$$

The outgoing angular flux along the path k in i mesh can be given by:

$$\phi_{m,i,k}^{out,g} = \phi_{m,i,k}^{in,g}\exp(-\Sigma_{tr,i}^{g}s_{m,i,k}/\sin\theta_m) + \frac{Q_{m,i}^{g}}{\Sigma_{tr,i}^{g}}\left[1-\exp(-\Sigma_{tr,i}^{g}s_{m,i,k}/\sin\theta_m)\right] \qquad \text{Eq (2)}$$

The average angular flux can be obtained by integrating the Eq (2) along the path k:

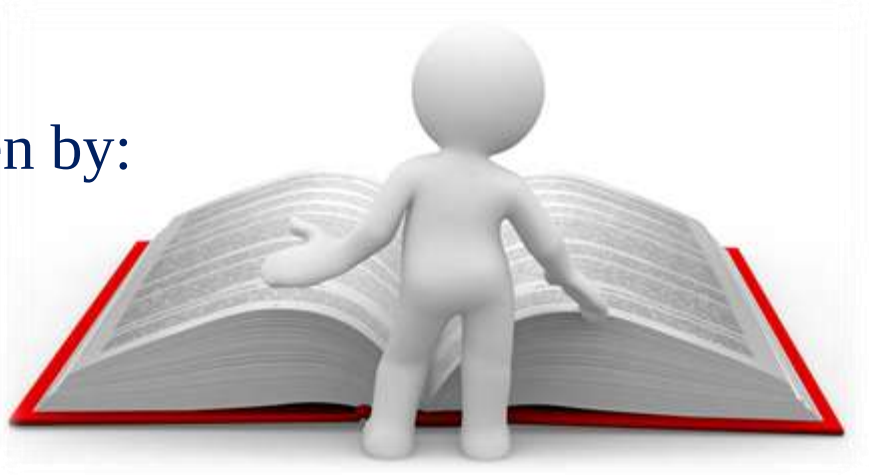
$$\bar{\phi}_{m,i,k}^{g} = \frac{Q_{m,i}^{g}}{\Sigma_{tr,i}^{g}} + \frac{\phi_{m,i,k}^{in,g} - \phi_{m,i,k}^{out,g}}{\Sigma_{tr,i}^{g}s_{m,i,k}} \qquad \text{Eq (3)}$$



MOC General Theory

The average mesh angular flux is given by:

$$\bar{\phi}_{m,i}^{g} = \frac{\sum_{k} \bar{\phi}_{m,i,k}^{g} s_{m,i,k} \delta A_{m}}{\sum_{k} s_{m,i,k} \delta A_{m}} \qquad \text{Eq (4)}$$



By summing up all the average angular fluxes within region i, the region average scalar flux is obtained as follows:

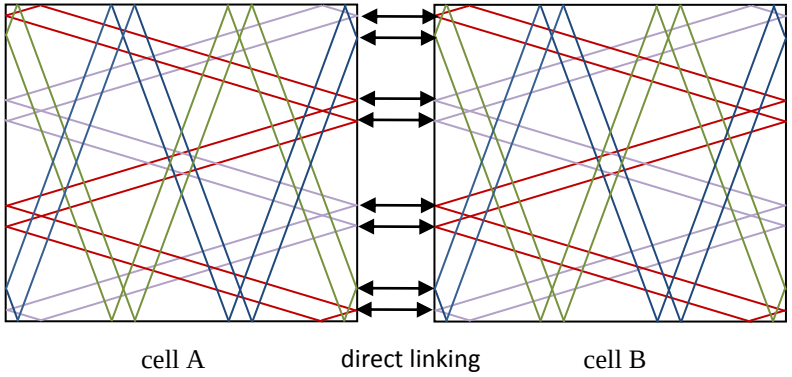
$$\bar{\phi}_{i}^{g} = \sum_{m} \bar{\phi}_{i,m}^{g} w_{m} \qquad \text{Eq (5)}$$

Modular Ray Tracing

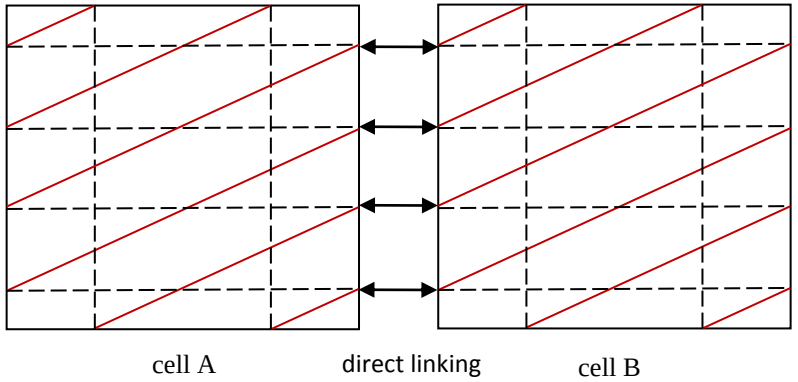
- MOC ray tracing process often takes large memory storage to save the neutron path information.
- Fortunately, in PWR core, many assembly have the same types and the number of types is not very large.
- In order to make the ray tracing be modular, each type of cell has its own neutron path information , and the path of every cell is associated with other's path

Two modular ray tracing in LATC

DNPL technique
(Direct Neutron Path Linking)



CMRT technique
(Cell Modular Ray Tracing)

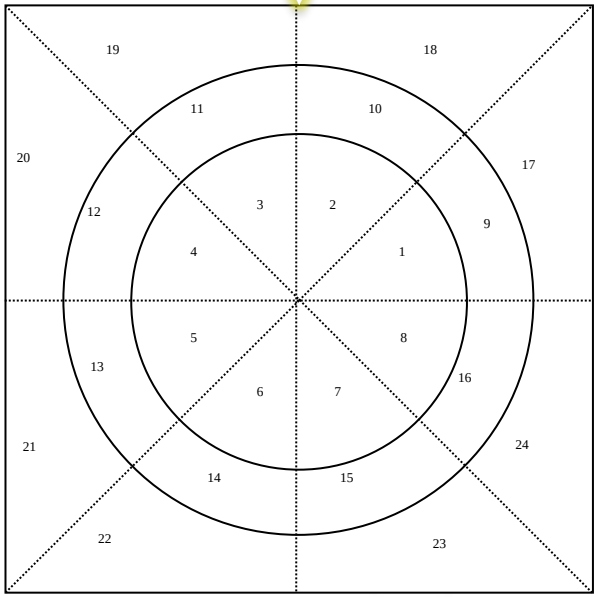


Both of the two schemes can make sure that each neutron flight path of a cell is linked to a corresponding path of the neighboring cell in order to perform a continuous characteristics calculation along the path through the cell interface.

Meshing

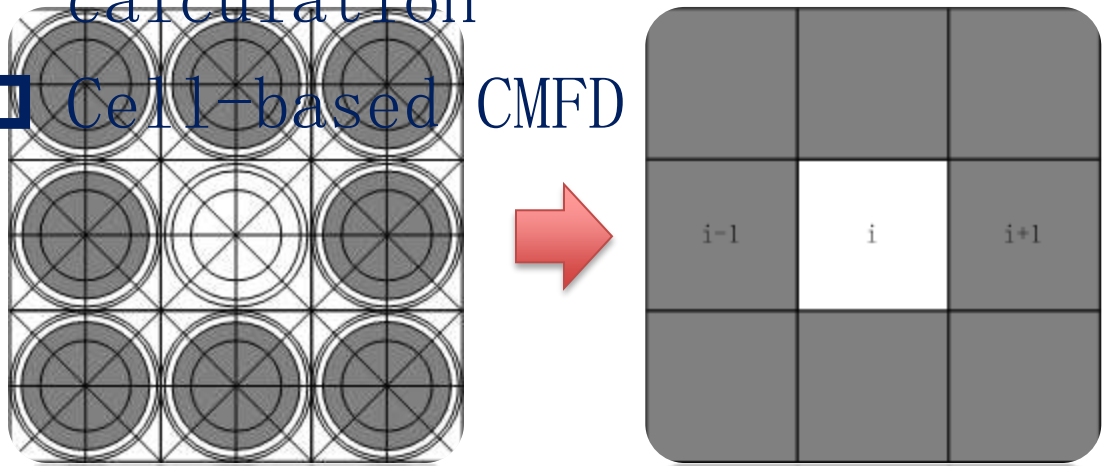
- Each cell in the problem needs to be broken into numbers of sub-regions.
- In the every sub-region, the source and flux are existed and flat.
- In this way ,it lends itself to an easy calculation of true areas for each mesh.

subdivided into octants areas.

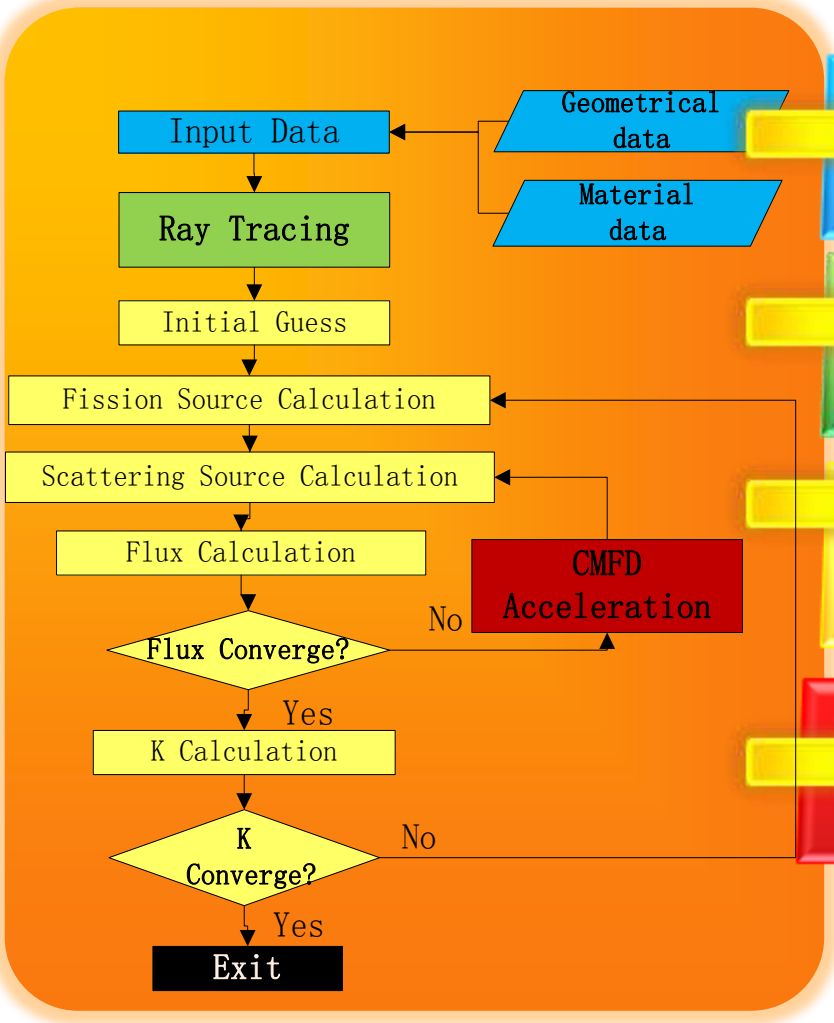


Acceleration Method CMFD

- The Coarse Mesh Finite Difference acceleration solver is implemented in LATC.
- It has been successful in reducing the computational burden for MOC transport calculation
- Cell-based CMFD



Transport Calculation Flow



the cross section comes from resonance calculation

generates all the necessary data related to neutron flight paths.

inner and outer iteration to calculate the flux and the eigenvalue.

the CMFD accelerate the inner iteration.

Validation and Verification

- V&V are part of the development process and with the quality assurance (QA) process.
- V&V are means by which the LATC is checked, and by which its performance is demonstrated and assured to be a correct interpretation of the requirements.

Critical Experimental Benchmark

LATC Versus WIMSD code

UME-LW-AECL–aecl_um
A uranium metal critical experimental benchmark of AECL Laboratory.

Pitch (cm)	5.359
Lattice geometry	Square
Water/fuel volume ratio	2.305
Moderator	H2O
Fuel material	U-met (0.714 wt% U-235)
Fuel Density (g/cm3)	18.95
Radius of fuel rods (cm)	1.6255
Clad material	Al
Clad Density (g/cm3)	2.6999
Outer radius of clad (cm)	1.7475
Thickness of clad (cm)	0.102
Temperature (all components) (K)	293.0
Experimental buckling B2 (cm-2)	-0.00193 ± 0.00008

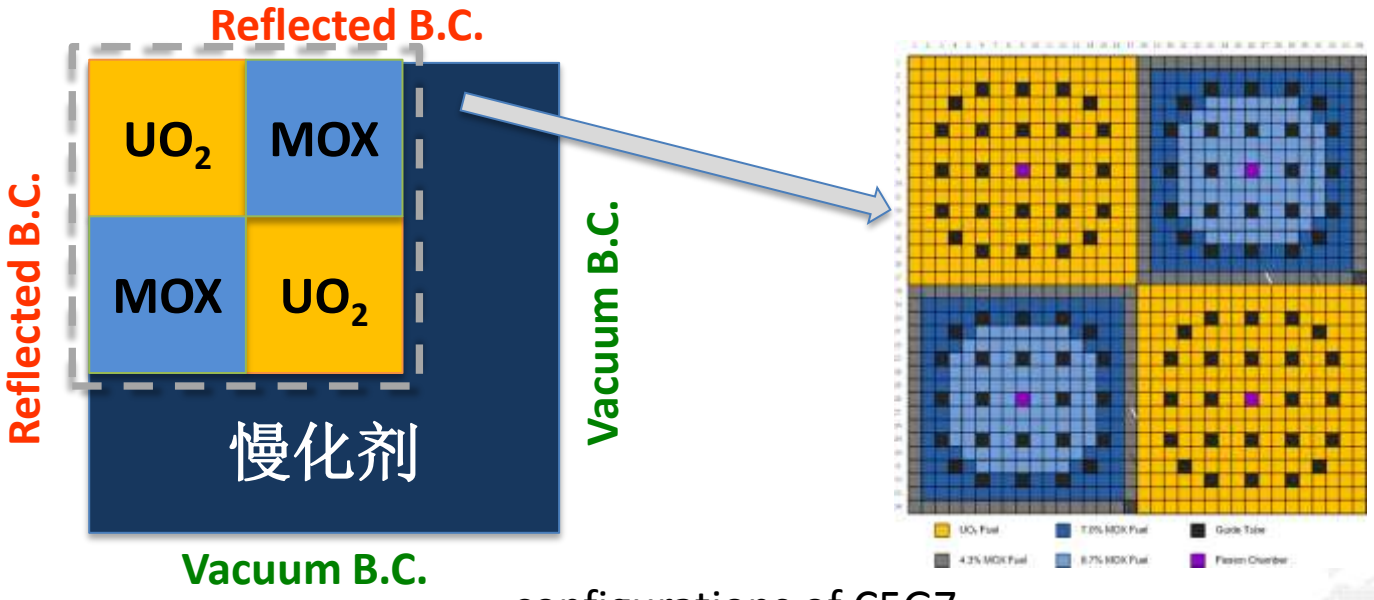
eigenvalue result

- **Under the condition of using the same iaea library.**

Code	eigenvale	Error
WIMSD-5B	1.00259	----
LATC	1.00323	64pcm

Comparison against C5G7 Benchmark

- The C5G7 benchmark is proposed by OECD/NEA for deterministic Transport calculation without spatial homogenization.
- The benchmark geometry is the sixteen assembly(quarter core symmetry) C5 MOX fuel assembly problem.
- Each fuel assembly is made up of a17×17 lattice of square pin cells.



configurations of C5G7

LATC Versus MCNP

The result of C5G7 benchmark

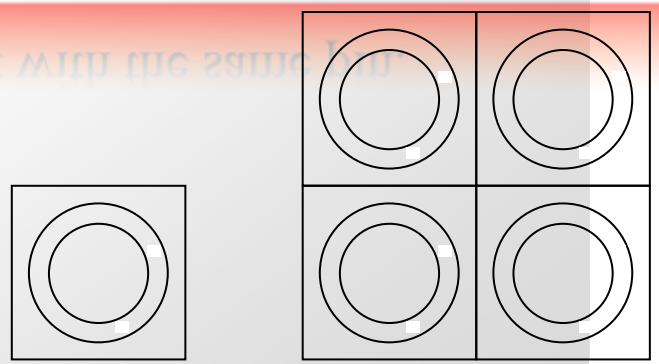
	Reference MCNP	LATC	error
Eigenvalue	1.18655	1.18744	89 pcm
Max pin power	2.498	2.502	0.16%
Min pin power	0.232	0.233	0.42%
inner UO_2	492.8	493.4	0.12%
MOX assembly	211.7	211.5	0.09%
outer UO_2	139.8	139.5	0.21%

CMFD acceleration effect：

	LATC(CMFD)	LATC(no CMFD)	error	Accelerate rate
Eigenvalue	1.18744	1.18741	3 pcm	——
Calculation time	693 s	22665 s	——	32.7

Validation of Ray Tracing Technique

The ray tracing routine can be validated by comparing the results of different kinds of layout with the same pin.



single pin　　2X2 pin by pin

- The pin by pin calculation results are fully coincided with the single pin calculation result.
- It proves that the angular fluxes at the pins interfaces are correctly transferred between pins.

Summary & outlook

01 **LATC**, the characteristics transport theory code, has been developing by **SNPSDC**.

02 Two ray tracing cyclical technique
- **DNPL** technique
- **CMRT** technique.

03 **Effective CMFD acceleration** technique is used in LATC.

04 Comparison against some codes. Much more V&V work need to do in the next phase.

Thank you for your attention!