Introduction to Nodal Method For Reactor Analysis

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Overview

Introduction

- Since it was proposed more than 40 years ago, nodal method has become a standard tool for many modern reactor simulators to perform routine reactor core calculations and safety analysis for commercial nuclear power plants.
- Nodal method reduces the number of unknowns by factor of hundreds or even thousands that allows reactor simulators to solve reactor problems rapidly compared to traditional Finite Difference Method (FDM).
- It also enables reactor spatial-kinetic calculations, instead of point kinetic, to be accomplished in today's computers with acceptable running time.

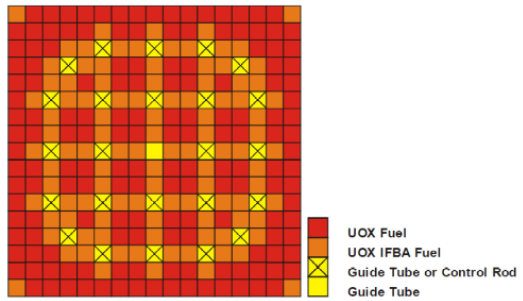
Introduction

Typical PWR Core

	1	2	3	4	5	6	7	8
A	U 4.2% (CR-D) 35.0	U 4.2% 0.15	U 4.2% (CR-A) 22.5	U 4.5% 0.15	U 4.5% (CR-SD) 37.5	M 4.3% 17.5	U 4.5% (CR-C) 0.15	U 4.2% 32.5
B	U 4.2% 0.15	U 4.2% 17.5	U 4.5% 32.5	M 4.0% 22.5	U 4.2% 0.15	U 4.2% (CR-SB) 32.5	M 4.0% 0.15	U 4.5% 17.5
C	U 4.2% (CR-A) 22.5	U 4.5% 32.5	U 4.2% (CR-C) 22.5	U 4.2% 0.15	U 4.2% 22.5	M 4.3% 17.5	U 4.5% (CR-B) 0.15	M 4.3% 35.0
D	U 4.5% 0.15	M 4.0% 22.5	U 4.2% 0.15	M 4.0% 37.5	U 4.2% 0.15	U 4.5% (CR-SC) 20.0	M 4.3% 0.15	U 4.5% 20.0
E	U 4.5% (CR-SD) 37.5	U 4.2% 0.15	U 4.2% 22.5	U 4.2% 0.15	U 4.2% (CR-D) 37.5	U 4.5% 0.15	U 4.2% (CR-SA) 17.5	
F	M 4.3% 17.5	U 4.2% (CR-SB) 32.5	M 4.3% 17.5	U 4.5% (CR-SC) 20.0	U 4.5% 0.15	M 4.3% 0.15	U 4.5% 32.5	
G	U 4.5% (CR-C) 0.15	M 4.0% 0.15	U 4.5% (CR-B) 0.15	M 4.3% 0.15	U 4.2% (CR-SA) 17.5	U 4.5% 32.5		
H	U 4.2% 32.5	U 4.5% 17.5	M 4.3% 35.0	U 4.5% 20.0				

Assembly Type
CR Position
Burnup [GWd/t]
Fresh
Once Burn
Twice Burn

CR-A	Control Rod Bank A
CR-B	Control Rod Bank B
CR-C	Control Rod Bank C
CR-D	Control Rod Bank D
CR-SA	Shutdown Rod Bank A
CR-SB	Shutdown Rod Bank B
CR-SC	Shutdown Rod Bank C
CR-SD	Shutdown Rod Bank D
O	Ejected Rod



Number of nodes for FDM

17x17x45x180x2 = 4,681,800

Number of nodes for Nodal Method

2x2x45x36x2 = 12,960

Images from [1]

Table: IAEA2D Problem

Code Methods	**Number of mesh or nodes**	**Running Time (second)**	**K-eff**
FDM	10,816	6.7	1.029541
Nodal	169	0.02	1.029600

Error on effective multiplication factor is 5.9 pcm

Table: IAEA3D Problem

Code Methods	**Number of mesh or nodes**	**Running Time (second)**	**K-eff**
FDM	2,055,040	1094	1.029013
Nodal	3,211	0.2	1.029082

Error on effective multiplication factor is 6.9 pcm

Introduction

IAEA3D Axially Averaged Power Distribution

					0.5910 0.6010 -1.66%		
				0.4740 0.4770 -0.63%	0.6980 0.7010 -0.43%	0.6040 0.6140 -1.63%	
			1.1800 1.1760 0.34%	0.9730 0.9710 0.21%	0.9210 0.9240 -0.32%	0.8600 0.8690 -1.04%	
		1.3720 1.3640 0.59%	1.3140 1.3080 0.46%	1.1820 1.1790 0.25%	1.0880 1.0890 -0.09%	0.9960 1.0010 -0.50%	0.7020 0.7150 -1.82%
	1.4020 1.3920 0.72%	1.4360 1.4260 0.70%	1.2940 1.2870 0.54%	1.0740 1.0690 0.47%	1.0550 1.0550 0.00%	0.9730 0.9770 -0.41%	0.7510 0.7600 -1.18%
0.7300 0.7270 0.41%	1.2870 1.2760 0.86%	1.4270 1.4170 0.71%	1.1980 1.1900 0.67%	0.6100 0.6100 0.00%	0.9540 0.9530 0.10%	0.9570 0.9610 -0.42%	0.7710 → FDM 0.7800 → NODAL -1.15% → Relative Error

Table: UO2-MOX PWR 3D Transient Problem

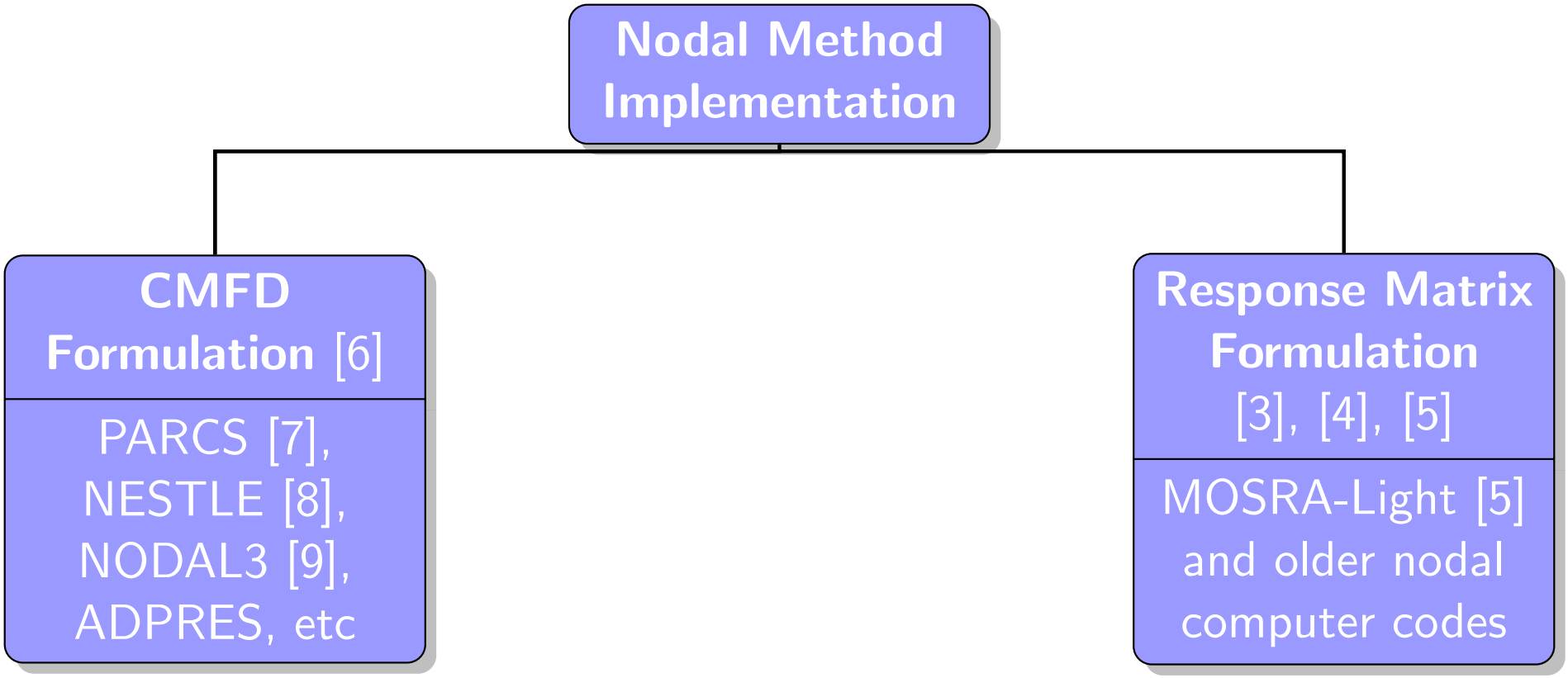
Codes	**Peak time (s)**	**Peak Power (%)**	**Reactivity Peak ($)**	**Integral Power (%.s)**
Serpent-SCF [2]	0.35	179±26	1.18±0.02	27.7
ADPRES $2G$	0.35	173	1.12	30.4
PARCS $2G$ [1]	0.34	142	1.12	27.2
PARCS $4G$ [1]	0.33	152	1.12	27.8
PARCS $8G$ [1]	0.32	172	1.14	29.1

CPU Time (mins)

Serpent-SCF: 9,600,00 (about 18 years). The simulation was done on a cluster with 1280 processors (@2.6GHz) and it took about 120 hours

ADPRES: 5

Nodal Method Implementation



Coarse Mesh Finite Difference

The Neutron Diffusion Equation

$$\frac{\partial}{\partial x}J_{gx}(x,y,z)+\frac{\partial}{\partial y}J_{gy}(x,y,z)+\frac{\partial}{\partial z}J_{gz}(x,y,z)+\Sigma_{r,g}(x,y,z)\phi_g(x,y,z)$$
$$=\frac{\chi_g}{k_{eff}}\sum_{g'=1}^{G}\nu\Sigma_{f,g'}(x,y,z)\phi_{g'}(x,y,z)+\sum_{\substack{g'=1\\g'\neq g}}^{G}\Sigma_{s,g'\rightarrow g}(x,y,z)\phi_{g'}(x,y,z) \tag{1}$$

Fick's Law

$$J_{gx}(x,y,z)=-D_g(x,y,z)\frac{\partial}{\partial x}\phi_g^k(x,y,z) \tag{2}$$

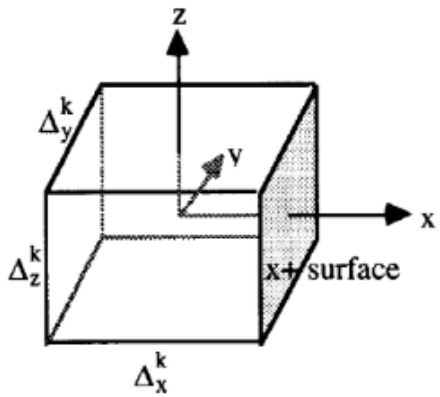
Coarse Mesh Finite Difference

Integrating over node k which is defined as

$$\left(-\frac{1}{2}\Delta_x^k \leq x \leq \frac{1}{2}\Delta_x^k\right),\left(-\frac{1}{2}\Delta_y^k \leq y \leq \frac{1}{2}\Delta_y^k\right),\left(-\frac{1}{2}\Delta_z^k \leq z \leq \frac{1}{2}\Delta_z^k\right) \tag{3}$$

We obtain discretized form of the neutron diffusion equation

$$\frac{1}{\Delta_x^k}\left(J_{gx+}^k - J_{gx-}^k\right) + \frac{1}{\Delta_y^k}\left(J_{gy+}^k - J_{gy-}^k\right) + \frac{1}{\Delta_z^k}\left(J_{gz+}^k - J_{gz-}^k\right) + \Sigma_{r,g}^k \overline{\phi}_g^k = \overline{Q}_g^k \tag{4}$$



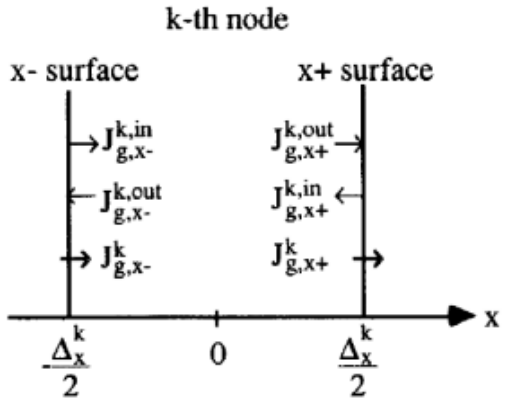


Image from [5]

Coarse Mesh Finite Difference

Where in Eq. (4)

$$\overline{\phi}_g^k = \frac{1}{V_k} \int_{-\Delta x/2}^{+\Delta x/2} dx \int_{-\Delta y/2}^{+\Delta y/2} dy \int_{-\Delta z/2}^{+\Delta z/2} dz \, \phi_g^k(x,y,z)$$

$$\overline{Q}_g^k = \frac{1}{V_k} \int_{-\Delta x/2}^{+\Delta x/2} dx \int_{-\Delta y/2}^{+\Delta y/2} dy \int_{-\Delta z/2}^{+\Delta z/2} dz \, Q_g^k(x,y,z)$$

$$J_{gx\pm}^k = \frac{1}{\Delta_y^k \Delta_z^k} \int_{-\Delta y/2}^{+\Delta y/2} dy \int_{-\Delta z/2}^{+\Delta z/2} dz \, J_{gx}^k \left(x = \frac{\pm \Delta_x^k}{2}, y, z \right)$$

$$V^k = \Delta_x^k \Delta_y^k \Delta_z^k$$

Coarse Mesh Finite Difference

Traditional Finite Difference Method (FDM)

$$J^k_{gx\pm} = \mp \widetilde{D}^k_{gx\pm} \left(\phi^{k\pm1}_g - \phi^k_g \right) \tag{5}$$

Coarse Mesh Finite Difference (CMFD)

$$J^k_{gx\pm} = \mp \widetilde{D}^k_{gx\pm} \left(\phi^{k\pm1}_g - \phi^k_g \right) - \widehat{D}^k_{gx\pm} \left(\phi^{k\pm1}_g - \phi^k_g \right) \tag{6}$$

$$\widetilde{D}^k_{gx\pm} = \frac{2 D^{k\pm1}_{gx} D^k_{gx}}{D^{k\pm1}_{gx} \Delta^k_x + D^k_{gx} \Delta^{k\pm1}_x} \tag{7}$$

Nodal Update

Transverse integrated diffusion equation can be obtained, for example, by integrating Eq. (1) over y and z

$$\frac{d}{dx}\overline{J}^k_{gx}(x) + \Sigma^k_{r,g}\overline{\phi}^k_{gx}(x) = \overline{Q}^k_{gx}(x) - \frac{1}{\Delta^k_y}L^k_{gy}(x) - \frac{1}{\Delta^k_z}L^k_{gz}(x) \tag{8}$$

where

$$\begin{aligned}
\overline{J}^k_{gx}(x) &= \frac{1}{\Delta^k_y\Delta^k_z}\int_{-\Delta y/2}^{+\Delta y/2} dy \int_{-\Delta z/2}^{+\Delta z/2} dz\, J^k_{gx}(x,y,z) \\
\overline{\phi}^k_{gx}(x) &= \frac{1}{\Delta^k_y\Delta^k_z}\int_{-\Delta y/2}^{+\Delta y/2} dy \int_{-\Delta z/2}^{+\Delta z/2} dz\, \phi^k_{g}(x,y,z) \\
L^k_{gy}(x) &= \frac{1}{\Delta^k_z}\int_{-\Delta z/2}^{+\Delta z/2} dz\, J^k_{gy}(x,y,z)\Big|_{y=-\frac{\Delta y}{2}}^{y=\frac{\Delta y}{2}} \\
L^k_{gz}(x) &= \frac{1}{\Delta^k_y}\int_{-\Delta y/2}^{+\Delta y/2} dy\, J^k_{gz}(x,y,z)\Big|_{z=-\frac{\Delta z}{2}}^{z=\frac{\Delta z}{2}}
\end{aligned} \tag{9}$$

Nodal Update

The one-dimensional flux is approximated by

$$\overline{\phi}^k_{gx}(x) \cong \overline{\phi}^k_{g,0} f_0(x) + \sum_{n=1}^{4} a^k_{gxn} f_n(x), \text{ in which } \left(-\frac{\Delta_x}{2} \leq x \leq \frac{\Delta_x}{2} \right) \quad (10)$$

The basis functions shall satisfy

$$\frac{1}{\Delta_x} \int_{-\Delta x/2}^{+\Delta x/2} dx f_n(x) = \begin{cases} 1, & \text{if } n = 0 \\ 0, & \text{otherwise} \end{cases} \quad (11)$$

- In Analytic Nodal Method (ANM), however, instead of approximating one-dimensional flux by polnomials, Eq. (8) is analytically solved
- This is possible because Eq. (8) material within the node is homogeneous
- However, this puts limit on ANM to solve reactor problems only with two-group energy

Nodal Method

- Substituting Eq. (10) to one-dimensional form of Eq. (2), one would obtain nodal solutions (not FDM solutions) for net currents (i.e $J^k_{gx\pm}$, $J^k_{gy\pm}$, and $J^k_{gz\pm}$)
- Using these corrected nodal net currents, now $\widehat{D}^k_{gx\pm}$, $\widehat{D}^k_{gx\pm}$, and $\widehat{D}^k_{gx\pm}$ in Eq. (6) can be updated
- To do so, we must determine nodal expansion coefficients a^k_{gxn}, a^k_{gyn} and a^k_{gzn} for $n = 1, 2, 3, 4$. This can be done by solving **Two Nodes Problem**, hence we need to determine $8G$ nodal expansion coefficients for both nodes (4 nodal expansion coefficients for each node and each group).
- Therefore, we need $8G$ equations to obtain the $8G$ nodal expansion coefficients.
- This process involves non-linear iteration

Nodal Method

- These $8G$ equations are
  - $2G$ neutron balance equations $\rightarrow$ substituting Eq. (10) to the first term on LHS of the Eq. (8), and integrating over x
  - $2G$ first moment equations $\rightarrow$ substituting Eq. (10) to Eq. (8), weighting by $f_1(x)$, and integrating over x
  - $2G$ second moment equations $\rightarrow$ substituting Eq. (10) to Eq. (8), weighting by $f_2(x)$, and integrating over x
  - G flux continuity equations $\rightarrow$ solve Eq. (10) for $x = -\frac{\Delta_x^k}{2}$ and $x = \frac{\Delta_x^k}{2}$
  - G net current continuity equations $\rightarrow$ substituting Eq. (10) to Eq. (2) and solve for $x = -\frac{\Delta_x^k}{2}$ and $x = \frac{\Delta_x^k}{2}$
- These proceedures are also carried out for y and z directions

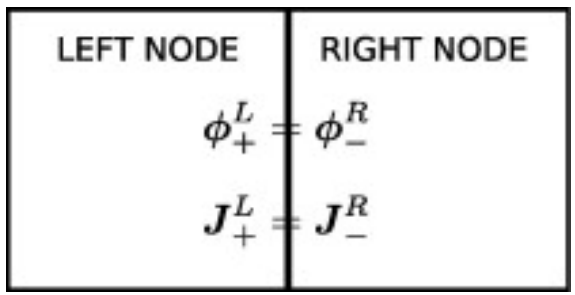


Image from [13]

Nodal Expansion Method (NEM)

NEM uses following basis functions [8]

$$f_0(x)=1$$

$$f_1(x)=\xi=\frac{x}{\Delta_x^k}$$

$$f_2(x)=3\xi^2-\frac{1}{4}$$

$$f_3(x)=\xi\left(\xi+\frac{1}{2}\right)\left(\xi-\frac{1}{2}\right)$$

$$f_4(x)=\left(\xi^2-\frac{1}{20}\right)\left(\xi+\frac{1}{2}\right)\left(\xi-\frac{1}{2}\right)$$

- This will results $8G \times 8G$ matrix to obtain $8G$ nodal expansion coefficients in the two-nodes problem
- This basis functions were initially used when nodal method was implemented using for matrix response formulation
- Not quite efficient because $8G \times 8G$ matrix must be solved for **each node and each direction**
- This method was implemented in NESTLE

Polynomial Nodal Method (PNM) [10]

In PNM, the Eq. (8) is mapped from $\left(-\frac{1}{2}\Delta_x^k \leq x \leq \frac{1}{2}\Delta_x^k\right)$ to $(-1 \leq u \leq 1)$

$$-\frac{d}{du^2}\phi_g^k(u) + \sum_{g'=1}^{G}\left(B_{gg'}^k\right)^2 \phi_{g'}^k(u) = -\frac{(\Delta x)^2}{4D_g^k} L_{gx}^k(u)$$

where:

$$u = \frac{2x}{\Delta_x^k} \text{ and } u \in [-1, 1]$$

$$\left(B_{gg'}^k\right)^2 = \frac{(\Delta x)^2}{4D_g^k}\left(\Sigma_{rg}^k \delta_{gg'} - \frac{\chi_g}{k_{eff}}\nu\Sigma_{f,g'}^k - \Sigma_{s,g'\to g}^k\right)$$

$$L_{gx}^k(u) = \frac{1}{\Delta_y^k} L_{gy}^k(u) + \frac{1}{\Delta_z^k} L_{gz}^k(u)$$

Polynomial Nodal Method (PNM)

PNM uses following basis functions

$$f_0(u)=1$$

$$f_1(u)=u$$

$$f_2(u)=\frac{1}{2}\left(3u^2-1\right)$$

$$f_3(u)=\frac{1}{2}\left(5u^3-3u\right)$$

$$f_4(u)=\frac{1}{8}\left(35u^4-30u^2+3\right)$$

- These basis functions are Legendre polynomials
- Legendre polynomials are orthogonal polynomials which enable the $8G$ matrix is decoupled into G and $2G$ matrices
- This makes the Polynomial Nodal Method (PNM) calculation is more efficient
- PNM has the same degree of accuracy as NEM

Semi-Analytic Nodal Method (SANM) [11]

SANM uses the same basis functions as PNM, except for

$$f_3(u)=\frac{\sinh\left(\alpha_{gx}^k u\right)-m_{gx1}^k(\sinh)f_1(u)}{\sinh\left(\alpha_{gx}^k\right)-m_{gx1}^k(\sinh)}$$

$$f_4(u)=\frac{\cosh\left(\alpha_{gx}^k u\right)-m_{gx0}^k(\cosh)f_0(u)-m_{gx2}^k(\cosh)f_2(u)}{\cosh\left(\alpha_{gx}^k\right)-m_{gx0}^k(\cosh)-m_{gx2}^k(\cosh)}$$

where

$$\alpha_{gx}^k=\sqrt{\frac{\sigma_{rg}^k}{D_k^g}}\frac{\Delta_x^k}{2}$$

$$m_{gx1}^k(\sinh)=\frac{1}{N_1}\int_{-1}^{1}\sinh\left(\alpha_{gx}^k u\right)f_1(u)du$$

$$m_{gxi}^k(\cosh)=\frac{1}{N_i}\int_{-1}^{1}\cosh\left(\alpha_{gx}^k u\right)f_i(u)du,\ \text{for } i=0,2$$

$$N_i=\frac{2}{2i+1},\ \text{for } i=0,1,2$$

Semi-Analytic Nodal Method (SANM) [11]

- These basis functions in SANM are also Legendre polynomials but in the trigonometric function forms for f_3 and f_4
- SANM accuracy is close to ANM
- SANM can be used to solve multi-group reactor problems

Table: Critical Boron Concentration in PPM for the NEACRP PWR Benchmark Problems

	Cases					
Methods	**A1**	**A2**	**B1**	**B2**	**C1**	**C2**
ANM	561.2	1156.6	1248.0	1183.8	1128.3	1156.6
SANM	560.5	1156.0	1247.4	1184.6	1127.7	1156.0
PNM	561.7	1159.6	1251.7	1188.1	1131.8	1159.6

Note: ANM results from PANTHER

ADPRES Features

- Input is straightforward, modular and in a free-format form
- Solves both static and transient core problems with or without TH feedback
- Performs forward, adjoint and fixed-source calculations
- Performs calculations using branched cross sections data.
- Critical boron concentration search
- Rod ejection simulation or Reactivity Initiated Accident (RIA)
- Solves multi-group of neutron energy
- Solves calculations with Assembly Discontinuity Factors (ADFs)
- Thermal-hydraulics solutions are obtained by solving mass and energy conservation equations in an enclosed channel
- Three nodal kernels are available:FDM, PNM, and SANM

General Rules

Some general rules for ADPRES inputs:

- Input deck is in free-format form with maximum 200 columns
- Comments are marked by !.

Example

```
! sigtr    siga    nu*sigf  sigf    chi    sigs_g1   sigs_g2
0.222222  0.010   0.000   0.000     1.0    0.1922    0.020
0.833333  0.080   0.135   0.135     0.0    0.000     0.7533    ! MAT1 : Outer Fuel
```

General Rules (continued)

- ADPRES input is modular, where it is broken into several cards. Cards' keywords shall be uppercase and marked by %.

Example

```
%MODE
FORWARD

%XSEC     ! Cross section card
2 4       ! Number of groups and number of materials

%GEOM     ! Geometry card
12 12 2   !nx, ny, nz
...
```

- Numbers can be repeated using * mark.

Example

```
10.0 5*20.0  !is equivalent to  10.0 20.0 20.0 20.0 20.0 20.0
```

ADPRES Input

%MODE and %XSEC cards

```
%MODE
FORWARD

%XSEC
2  5    ! Number of groups and number of materials
! sigtr   siga   nu*sigf sigf   chi   sigs_g1  sigs_g2
0.222222  0.010  0.000  0.000    1.0   0.1922   0.020
0.833333  0.080  0.135  0.135    0.0   0.000    0.7533   ! MAT1 : Outer Fuel
0.222222  0.010  0.000  0.000    1.0   0.1922   0.020
0.833333  0.085  0.135  0.135    0.0   0.000    0.7483   ! MAT2 : Inner Fuel
0.222222  0.0100 0.000  0.000    1.0   0.1922   0.020
0.833333  0.1300 0.135  0.135    0.0   0.000    0.7033   ! MAT3 : Inner Fuel + Control Rod
0.166667  0.000  0.000  0.000    0.0   0.1267   0.040
1.111111  0.010  0.000  0.000    0.0   0.000    1.1011   ! MAT4 : Reflector
0.166667  0.000  0.000  0.000    0.0   0.000    0.040
1.111111  0.055  0.000  0.000    0.0   0.000    0.000    ! MAT5 : Reflector + Control Rod
```

Two Group Cross Sections for Each Composition

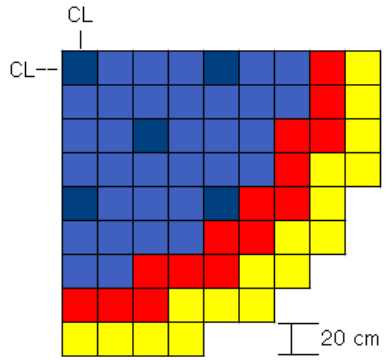
Material		D_g	Σ_{ag}	$\nu\Sigma_{fg}$	$\Sigma_{s2<-1}$
	Fuel1	1.500	0.010	0.000	0.020
		0.400	0.085	0.135	
	Fuel1+Rod	1.500	0.010	0.000	0.020
		0.400	0.130	0.135	
	Fuel2	1.500	0.010	0.000	0.020
		0.400	0.080	0.135	
	Reflector	2.000	0.000	0.000	0.040
		0.300	0.010	0.000	
	Reflector+Rod	2.000	0.000	0.000	0.040
		0.300	0.055	0.000	

Image from [12]

ADPRES Input

%GEOM cards

```
%GEOM
9 9 19          !nx, ny, nz
10.0 8*20.0     !x-direction assembly size in cm
1  8*2          !x-direction assembly divided into 2 (10 cm each)
8*20.0 10.0     !y-direction assembly size in cm
8*2  1          !y-direction assembly divided into 2 (10 cm each)
19*20.0         !z-direction assembly  in cm
19*1            !z-direction nodal is not divided
4               !np number of planar type
1  13*2  4*3  4      !planar assignment (from bottom to top)
! Planar_type_1 (Bottom Reflector)
....
....
! Planar_type_3 (Fuel+Partial Control Rods)
  3  2  2  2  3  2  2  1  4
  2  2  2  2  2  2  2  1  4
  2  2  3  2  2  2  1  1  4
  2  2  2  2  2  2  1  4  4
  3  2  2  2  3  1  1  4  0
  2  2  2  2  1  1  4  4  0
  2  2  1  1  1  4  4  0  0
  1  1  1  4  4  4  0  0  0
  4  4  4  4  0  0  0  0  0
...
! Boundary conditions (east), (west), (north), (south), (bottom), (top)
1 2 2 1 1 1
```



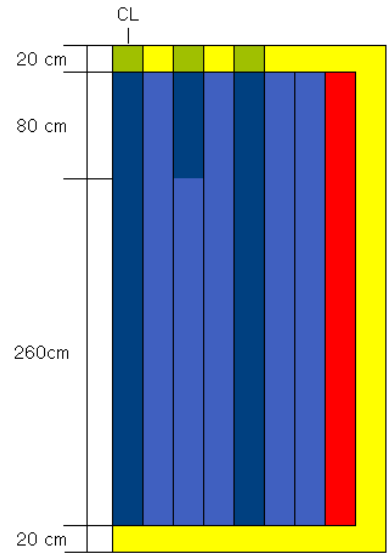
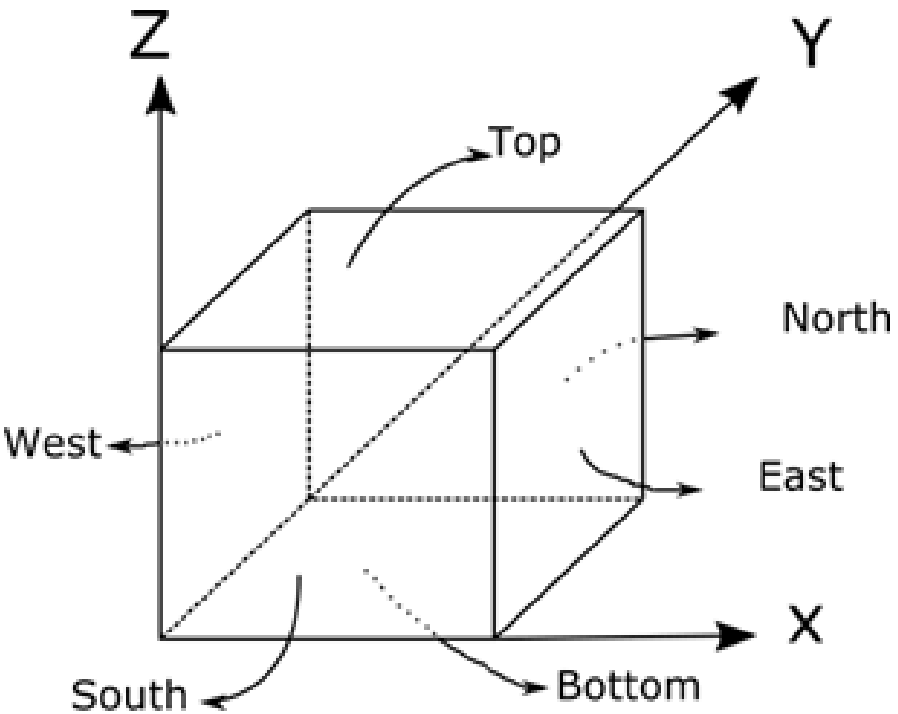
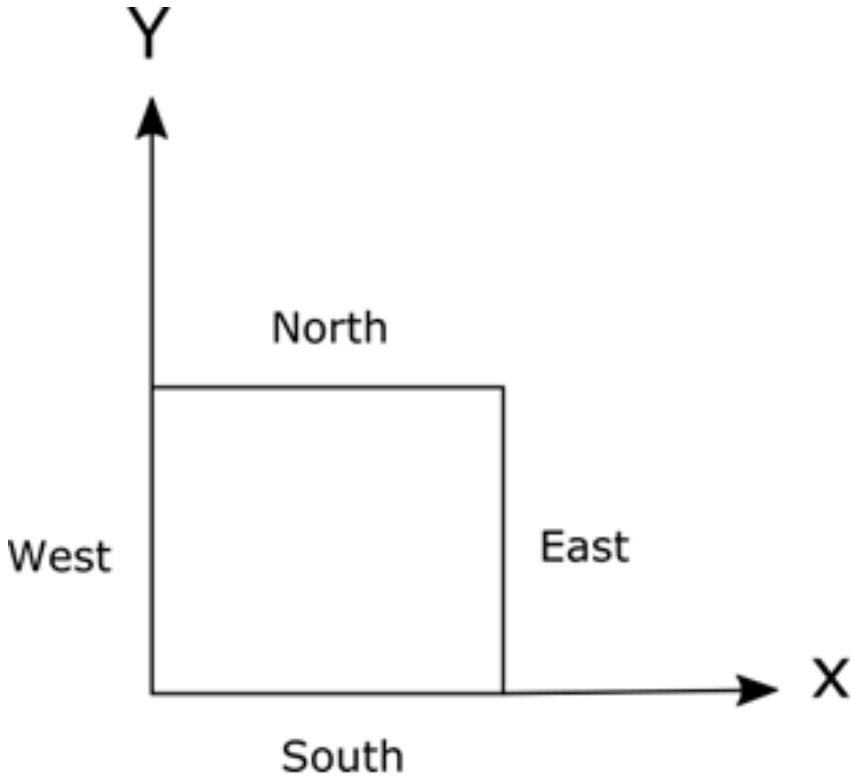


Image from [12]

ADPRES Input

Point of Origin for Geometry Modelling in ADPRES





ADPRES Output

Output

```
 ================================================================================
                          CALCULATION RESULTS
 ================================================================================

 Itr     k-eff      Fis.Src Error    Inner Error
-------------------------------------------------
   1     0.981424    5.47871E-01    8.55259E+03
   2     1.001319    2.41976E-01    8.56379E+00
   3     1.009804    1.67297E-01    6.27992E-01
   4     1.013500    1.33833E-01    1.44559E-01
    ...FISSION SOURCE EXTRAPOLATED...
   5     1.026980    2.65156E+00    1.31348E-01
   6     1.024050    2.69425E-01    1.90647E+00
   7     1.024688    9.31087E-02    4.43462E+01
   8     1.024358    3.99972E-02    1.10592E+00
   9     1.024191    3.47063E-02    1.96477E-01
    ...FISSION SOURCE EXTRAPOLATED...
  10     1.023838    1.12907E+00    5.87407E-02
  11     1.024188    1.12316E-01    9.62168E-01
  12     1.025744    1.03113E-01    4.24920E-01
  13     1.026299    8.09335E-02    1.86532E-01

   ...
   ...
   128     1.029082    9.48481E-06    2.04727E-05
   129     1.029082    7.46358E-06    9.66768E-06

   MULTIPLICATION EFFECTIVE (K-EFF) =  1.029082
```

ADPRES Output

Output

Radial Power Distribution

	1	2	3	4	5	6	7	8	9
9	0.727	1.276	1.417	1.190	0.610	0.953	0.961	0.780	
8	1.276	1.392	1.426	1.287	1.069	1.055	0.977	0.760	
7	1.417	1.426	1.364	1.308	1.179	1.089	1.001	0.715	
6	1.190	1.287	1.308	1.176	0.971	0.924	0.869		
5	0.610	1.069	1.179	0.971	0.477	0.701	0.614		
4	0.953	1.055	1.089	0.924	0.701	0.601			
3	0.961	0.977	1.001	0.869	0.614				
2	0.780	0.760	0.715						
1									

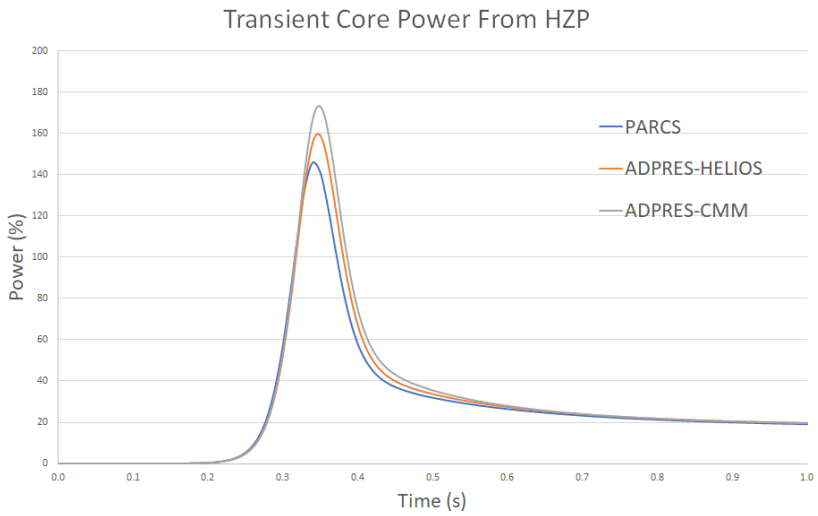
MAX POS.	Maximum Value
(7, 2)	1.426

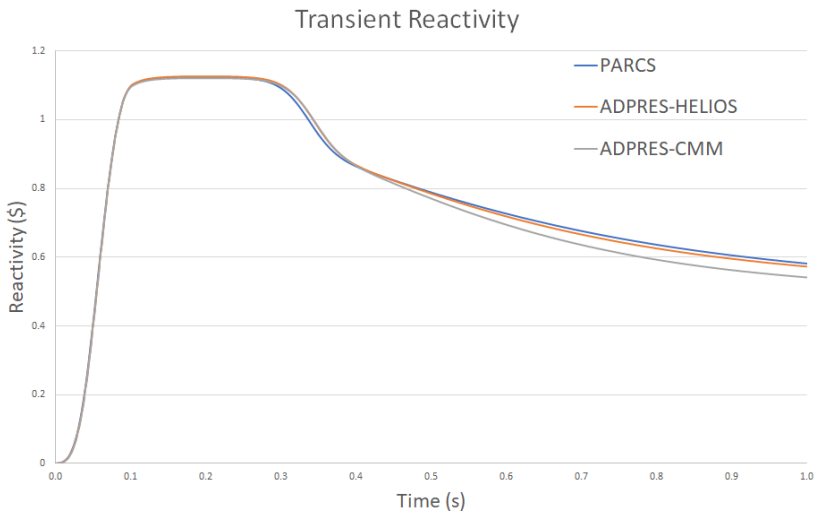
ADPRES Output

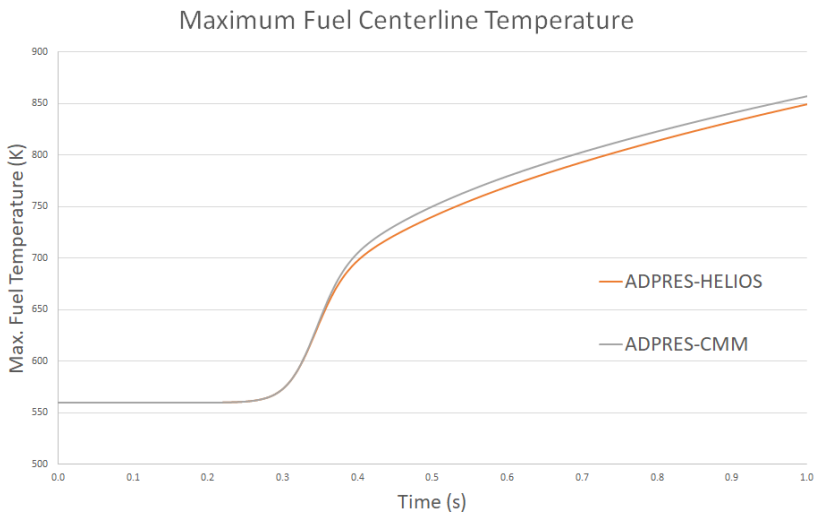
Output

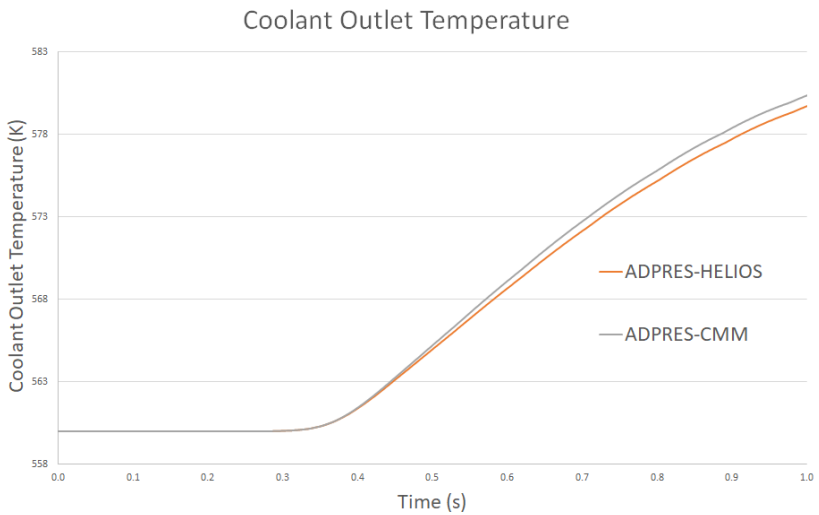
```
  Axial Power Density Distribution
==================================

  Plane Number         Power      Height
 ---------------------------------------
     19  (TOP)         0.000      380.00
     18                0.195      360.00
     17                0.353      340.00
     16                0.538      320.00
     15                0.743      300.00
     14                0.975      280.00
     13                1.182      260.00
     12                1.349      240.00
     11                1.470      220.00
     10                1.539      200.00
      9                1.554      180.00
      8                1.514      160.00
      7                1.420      140.00
      6                1.276      120.00
      5                1.087      100.00
      4                0.858       80.00
      3                0.599       60.00
      2                0.348       40.00
      1  (BOTTOM)      0.000       20.00

MAX POS.        Maximum Value
 (  9)              1.554
```

UO2-MOX PWR Transient Benchmark Results









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