# Preliminary Steady State and Transient Analyses of SMART Reactor Core Using the COREDAX Code

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## 1. Introduction

The 3-D neutronics code COREDAX [1] has been developed based on AFEN (Analytic Function Expansion Nodal) method [2] for x-y-z geometry [3] and for hex-z geometry [4]. In this study, the COREDAX code, as a regulatory review tool independent of the designer's, was applied to the SMART reactor core which is a small sized integral type pressurized water cooled reactor with 330MWth power. For nuclear cross section generation, the HELIOS lattice code [5] is used in this study.

The steady state calculation of SMART core was performed in [6] by the COREDAX code. Additionally, transient calculation and steady state calculation under other conditions are performed and repeated in this paper.

## 2. Methods and Results

### *2.1 AFEN Methodology*

The AFEN formulation in the x-y-z system starts from the following multi-group diffusion equations in a homogenized node:

$$-\nabla^2 \vec{\phi}(x,y,z) + [\Lambda]\vec{\phi}(x,y,z) = 0, \qquad (1)$$

where

$$[\Lambda] = [D]^{-1}\left([\Sigma] - \frac{1}{k_{eff}}[\chi][\nu\Sigma_f]\right),$$

and all the notations are standard.

A general solution to Eq. (1) can be represented in terms of analytic basis functions that can be obtained using the method of separation of variables. For practical implementation, we choose the solution of a node expressed in a finite number of terms [3]:

$$\begin{aligned}\overrightarrow{\phi^n}(x,y,z) = \overrightarrow{E^n} + \overrightarrow{\varphi^n}(x,y,z) + \overrightarrow{\varphi^n}(y,x,z) \\ + \overrightarrow{\varphi^n}(z,x,y),\end{aligned} \qquad (2)$$

where

$$\begin{aligned}\overrightarrow{\varphi^n}(x,y,z) = \sinh(\sqrt{\Lambda^n}x)(\overrightarrow{A^n_{0x}}) + \cosh(\sqrt{\Lambda^n}x)(\overrightarrow{B^n_{0x}}) \\ \sinh(\frac{\sqrt{2\Lambda^n}}{2}(x+y))\overrightarrow{C^n_{00x}} + \cosh(\frac{\sqrt{2\Lambda^n}}{2}(x+y))\overrightarrow{C^n_{01x}} \\ \sinh(\frac{\sqrt{2\Lambda^n}}{2}(x-y))\overrightarrow{C^n_{10x}} + \cosh(\frac{\sqrt{2\Lambda^n}}{2}(x-y))\overrightarrow{C^n_{11x}}\end{aligned} \qquad (3)$$

Note that each term in Eq. (2) is an analytic solution of Eq. (1). The 19 coefficients in Eq. (2) are made to correspond to the 19 nodal unknowns for a node: i) one node average flux, and ii) six interface fluxes, and iii) twelve edge fluxes.

To determine nodal unknowns, we build as many solvable nodal equations as the number of these nodal unknowns. These equations consist of a nodal balance equation and associated coupling equations. The coupling equations are obtained from six interface current continuity equations and twelve edge balance equations.

### *2.2 Steady State Results*

A nuclear reactor operates in various conditions (e.g., fuel/coolant temperature, boron concentration, etc…). Therefore, in this paper, several different cases were tested for the SMART reactor core based on the reference design [7]. The HELIOS lattice code generates assembly-level two group cross sections for various conditions, and then the COREDAX code performs steady state whole-core analysis. Table 1 shows the $k_{eff}$ and reactivity results for given conditions.

Table 1: $k_{eff}$ and reactivity for each calculation conditions

| Condition* | $k_{eff}$ | Reactivity |
|---|---|---|
| 20℃/ 0MWd/ 0ppm | 1.276 | 0.216 |
| 20℃/ 0MWd/ 3100ppm | 0.875 | -0.142 |
| 200℃/ 0MWd/ 0ppm | 1.259 | 0.205 |

* Core temperature / Burnup / Boron concentration

Additionally, from the COREDAX steady state analysis, assembly-level power distribution and power peaking factor are obtained. Table 2 shows radial peaking factor for i) all rod out case, and ii) R3 group rod insertion case at BOC and EOC.

Table 2: Radial peaking factor

| Rod Position | BOC | EOC |
|---|---|---|
| All rod out | 1.30 | 1.36 |
| R3 insertion | 1.28 | 1.35 |

### *2.3 Control Rod Assembly Ejection Accident*

One of the most important accidents in nuclear reactor accident analysis is control rod assembly ejection accident. In this section, control rod assembly ejection accident is analyzed by the COREDAX code.

The power change on time is described in Fig. 1 when R3 group rod is fully initially inserted in the SMART core.

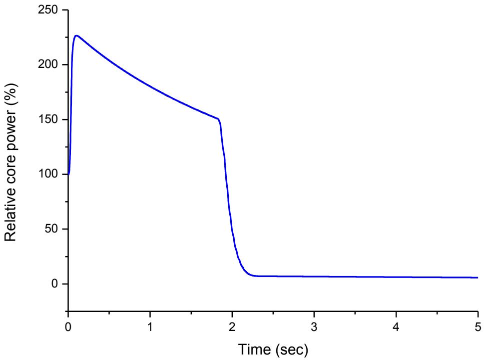

Fig.1 Power change curve in time

*2.4 Xenon/Samarium Oscillation Analysis*

The treatment of xenon/samarium has been implemented in the COREDAX code to treat global and local power shifts resulting from xenon/samarium imbalances during reactor operation.

The time-dependent depletion of xenon/samarium which affects the absorption cross sections is expressed as follows:

$$\frac{d}{dt}N_I(t) = \gamma_I \sum_{g=1}^{G} \Sigma_{fg}(t)\phi_g(t) - \lambda_I N_I(t), \tag{4a}$$

$$\frac{d}{dt}N_{Xe}(t) = \lambda_I N_I(t) + \gamma_{Xe} \sum_{g=1}^{G} \Sigma_{fg}(t)\phi_g(t) - \lambda_{Xe} N_{Xe}(t) - \sum_{g=1}^{G} \sigma_{Xe,ag}(t)\phi_g(t) N_{Xe}(t), \tag{4b}$$

$$\frac{d}{dt}N_{Pm}(t) = \gamma_{Pm} \sum_{g=1}^{G} \Sigma_{fg}(t)\phi_g(t) - \lambda_{Pm} N_{Pm}(t), \tag{4c}$$

$$\frac{d}{dt}N_{Sm}(t) = \lambda_{Pm} N_{Pm}(t) - \sum_{g=1}^{G} \sigma_{Sm,ag}(t)\phi_g(t) N_{Sm}(t), \tag{4d}$$

where

$N_i(t)$ = nuclei number density of isotope *i*,

$\sigma_{i,ag}(t)$ = group-wise microscopic absorption cross section of isotope *i*,

$\gamma_i$ = effective yield (atom/fission) of isotope *i*,

$\lambda_i$ = decay constant of isotope *i*.

To update the number density of xenon/samarium, the COREDAX code uses a general solution of Eq.(4).

Fig.2 shows the axial shape index (ASI) of xenon/samarium oscillation, in which ASI is defined as:

$$ASI = \frac{power_{top} - power_{bottom}}{total\ power}. \tag{5}$$

Generally, for a large pressurized water reactor, ASI oscillates unstably. However, for a small reactor such as SMART core, this is stable when time goes on as shown in Fig.2.

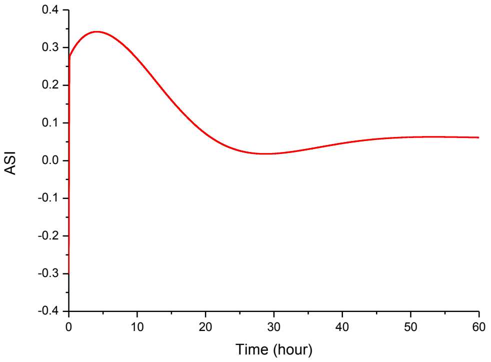

Fig.2 ASI by xenon/samarium oscillation

## 3. Conclusions

The COREDAX code based on the AFEN method was used to analyze, independently of the designer's tool, the SMART reactor core in various conditions. From these results, it is shown that whole-core (especially on parallelepiped reactor) steady state analysis and transient calculation can be done by the COREDAX code. For transient calculations, control rod assembly ejection accident and xenon/samarium oscillation were analyzed in this study.

## References

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