Energy Deposition Model in STREAM with Photon Transport

Nhan Nguyen Trong Mai[a], Kyeongwon Kim[a], Woonghee Lee[a], Sooyoung Choi[b], Kiho Kim[c], Deokjung Lee[a*]
[a] *Department of Nuclear Engineering, Ulsan National Institute of Science and Technology, 50 UNIST-gil, Ulsan 44919, Republic of Korea*
[b] *University of Michigan, 2355 Bonisteel Blvd., Ann Arbor, MI, USA, 48109*
[c] *Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon 34142, Republic of Korea*
E-mail: deokjung@unist.ac.kr

1. Introduction

STREAM developed by the Computational Reactor Physics and Experiment Laboratory (CORE) at the Ulsan National Institute of Science and Technology (UNIST) is a deterministic neutron-transport code specialized for the analysis of two-dimensional or three-dimensional reactor cores [1]. Recently, effort has been taken to implement a photon transport module in STREAM to extend the code's calculation capabilities.

Conventionally, the photon energy is assumed to deposit locally. However, the photon can transverse to other regions from its birth places and thus changing the calculated power distribution. The photon transport module, therefor, can improve the power distribution calculation in reactor core calculations. The STREAM photon transport module was implemented based on the adaptation of the MOC solver already present for the neutron calculation. The implementation of this module was detailed in references [2,3] and the impacts of explicit photon transport on pin power distributions in STREAM with the use of this photon module are presented in this paper.

2. Method and Results

2.1. On-The-Fly Energy Release per Fission Model

The energy release per fission, Kappa, is applied to obtain the pin power. The current Kappa in STREAM [4] is based on the On-The-Fly Energy Release per Fission Model (OTF Kappa), which has been implemented in CASMO-5 [5]. The OTF Kappa value in STREAM for isotope *i* is computed via the following Equation:

$$\kappa_i \approx ER_i(0) + 1.157\overline{E}_i - 8.07[\overline{\nu}_i - \nu_i(0)] + \overline{Q}_c \qquad (1)$$

where, $ER_i(0)$ is the total energy released per fission less the neutrino energy from Evaluated Nuclear Data File (ENDF) [6]

$1.157\overline{E}_i - 8.07[\overline{\nu}_i - \nu_i(0)]$ is a correction term for contribution of delayed photon, delayed beta and prompt neutron emission induced by incident neutron energy $\overline{E}_i$.[6]

$\overline{Q}_c$ is the average energy release per neutron fission, obtained by diving the total energy of photon from neutron capture, Q_c in a system by the number of fissions in that system.

$$\overline{Q}_c = \frac{\sum_i q_i n_i \sum_n \sigma_{c,n,i}\phi_n}{\sum_i n_i \sum_n \sigma_{f,n,i}\phi_n} \quad (2)$$

Recoverable energy per capture and fission for each isotope *i*, namely q_i and $ER_i(0)$, are tabulated in a separated ***data file*** and will be called for OTF Kappa calculation. For each fissionable isotope, a new kappa value is updated at the beginning of every depletion step.

The energy release per fission is obtained with this model as $\phi_n \Sigma_f \kappa$, where ϕ_n is the flux of neutron and $\Sigma_f \kappa$ is fission cross section times OTF Kappa.

2.2. Modified OTF Kappa with photon transport

When photon transport is turned on in STREAM, OTF Kappa value is modified by changing the Q_c and $ER_i(0)$ values. If the photon cross section is available for isotope *i*, the contribution of photon energy q_i, from neutron capture of isotope *i* to Q_c is set to zero. The contribution of prompt and delayed photon in the $ER_i(0)$ is also removed if total photon transport mode is selected in the input file or just prompt photon component is removed in the $ER_i(0)$ if only prompt photon mode is considered (delayed photon energies deposited locally). If photon cross section of isotope *i* is not available, then contribution q_i of isotope *i* to Q_c and the $ER_i(0)$ are unchanged as in the ***tabulated data file,*** meaning the photon from such nuclide deposits their energies locally. The correction term in Eq. (1) is adjusted to $1.232\overline{E}_i - 8.07[\overline{\nu}_i - \nu_i(0)]$ if the delayed photon is considered. The total power when photon transport turned on is:

$$\phi_n \Sigma_f \kappa^* + \phi_p \Sigma_{heat} \qquad (3)$$

Where: ϕ is the flux of neutron (n) or photon (p)

$\Sigma_f \kappa^*$ is fission cross section times modified Kappa.

Σ_{heat} is photon heating cross section (computed by NJOY [2,7])

2.3. Results for pin power distribution with modified OTF Kappa

Problem VERA-2B, VERA-2N and VERA-2P [8] are run. Layouts of a quarter of an assembly are shown in Fig.1.

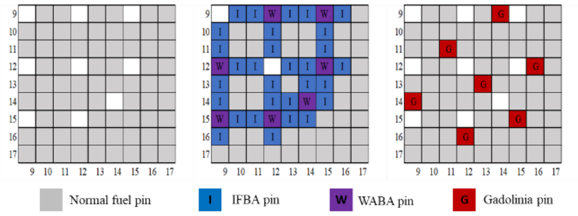

Figure 1. Layout of VERA 2B, VERA 2N and VERA 2P (quarter of assembly)

The first run employed conventional OTF Kappa values where no photon transport involved while the second run includes photon transport (both prompt and delayed photon) and modified Kappa values. The depletion mode, input power density is 40 W/gHM the relative difference in total pin power between the two runs is calculated where results with the normal Kappa (no photon transport) serve as references. The pin powers and the differences are shown in Fig.2-4 for BOC, MOC (30MWd/kgHM) and EOC (60MWd/kgHM).

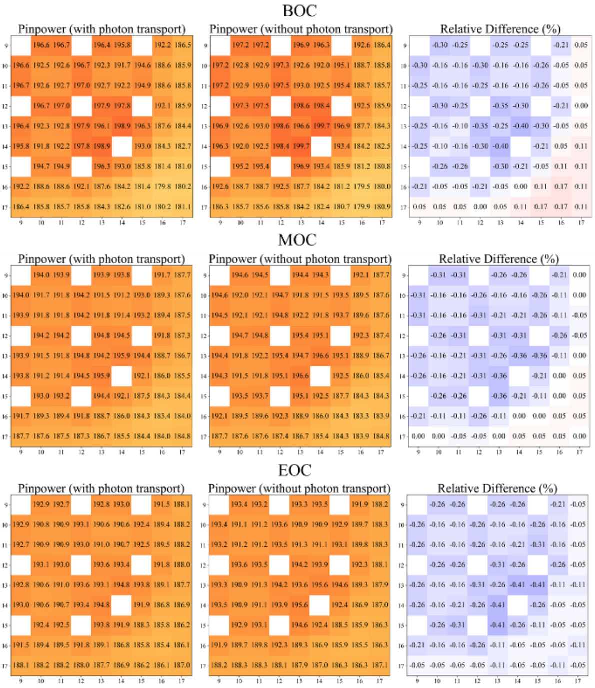

Figure 2. Pin power (Watt) for VERA-2B (quarter of assembly)

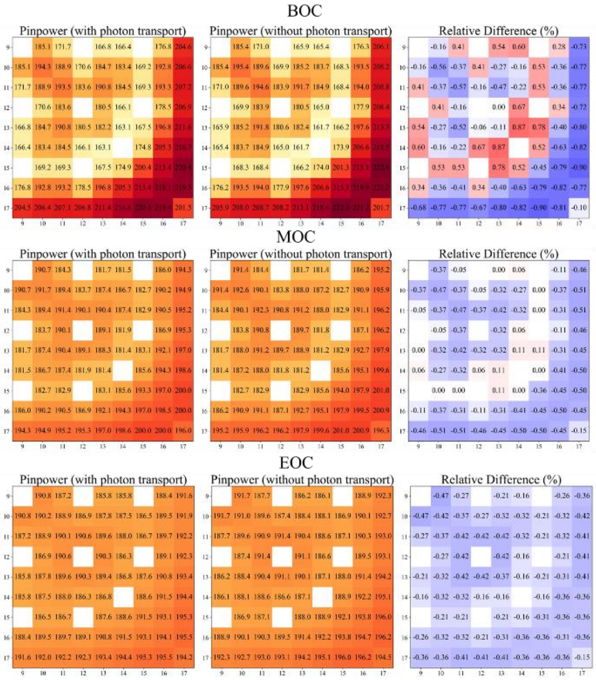

Figure 3. Pin power (Watt) for VERA-2N (quarter of assembly)

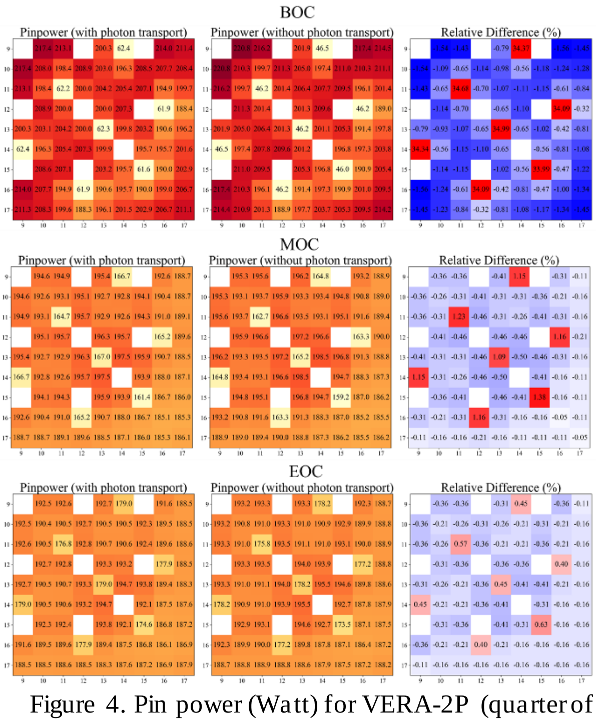

Figure 4. Pin power (Watt) for VERA-2P (quarter of assembly)

The approximation of photon energy from neutron captures $\overline{Q}_c$ in Eq. (1) is more valid if there is no poison (strong gamma emitters) in the problem. Normally, photons exhibit rather flat distribution and the photon energy can be averaged throughout the problem by using average value $\overline{Q}_c$. However, in the presence of strong gamma emitters, the contribution of photon energy in such pins can be underestimated with the normal OTF Kappa since the photon energy from neutron capture in that pin is already dissipated into the system via the definition of $\overline{Q}_c$. On the other hand, power of pins without poisons will be overestimated since they receive additional contributions from the dissipation of pins having strong gamma sources. These effects can be observed in Fig. 3 and more significant in Fig.4. Once the poison burned out, the difference between the two runs started to diminish. Differences in the k_{eff} are shown in Fig.5.

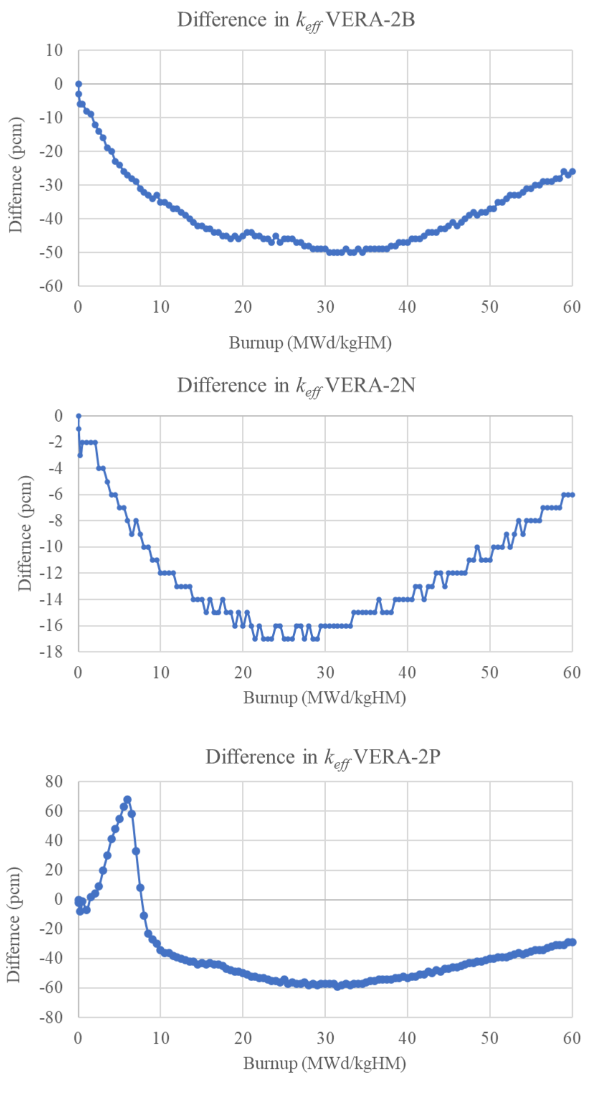

Figure 5. Difference in k_{eff} between two runs (with and without photon transport).

With explicit photon transport, the differences in pin powers are noticeable when strong gamma emitters are presenting in the core. The change in k_{eff} is not so significant, 50 to 70 pcm difference is observed during the depletion of VERA 2B and VERA 2P.

8. Conclusion

A photon transport module based on the present MOC neutron solver has been implemented in STREAM code. The explicit photon transport offers a more accurate power distribution calculation compared to the conventional approach that assuming photon deposit its energy locally. The power distribution is affected mostly when strong gamma emitters are introduced. Calculation of three-dimensional cores with photon transport and thermal hydraulics feedback will be conducted to further determine the impact of the modified energy deposition model in STREAM.

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