RELAP5-3D with PHISICS Neutronics, Part 1 – Steady State

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The new INL-developed neutronics package, PHISICS, has been incorporated into RELAP5-3D as an alternative to its point, 1D, and NESTLE kinetics packages. In this multi-part newsletter series, the method of operation is discussed from a theoretical and flowchart perspective. The first part focuses on steady-state.

Computer Environment

The RELAP5-3D and PHISICS codes are connected by a shared FORTRAN 95 module. The module has shared memory and subroutines that move and translate data from RELAP5-3D to PHISICS and vice-versa. Computationally, PHISICS is multi-processor for exploitation of a massively parallel computer, such as the INL enclave cluster supercomputers. On the other hand, RELAP5-3D is suited to shared memory and only a few threads (four or less) on typical applications. It can run well on a single thread of a cluster while PHISICS makes use of many.

Subsystems of PHISICS

INSTANT is the name given to the portion of the PHISICS package that solves for the neutron flux and fission power spatial distribution from, respectively, the transport (diffusion as a special case) equation and fission power normalization. MIXER is the portion that performs table look-ups, based on the TH field (and possible others like burn up or xenon concentration), to generate the discrete Fission and transport operators.

Steady State

Steady state is achieved via Picard iteration applied to the MIXER, INSTANT and RELAP5-3D called in succession until convergence is reached. To take a single, steady-state advancement, RELAP5-3D does its usual heat and thermal hydraulics calculation to get an initial thermal hydraulic field, denoted Th^0. From this, the MIXER portion of PHISICS generates the discrete Fission and transport operators, and these are used by INSTANT to calculate the neutron flux and fission power spatial distribution.

Steady State Calculation

First we write the relevant equation set in a compact form thusly:

$$\begin{cases} \psi^{i+1} = \left(A^i\right)^{-1}\left[\frac{1}{K^{i+1}}F^i\left[\psi^{i+1}\right]\right] \\ P^{i+1}(\vec{r}) = \alpha F^i\left[\psi^{i+1}\right]\frac{Power}{\int_V d\vec{r}\alpha F^i\left[\psi^{i+1}\right]} \\ Th^{i+1} = f\left[P^{i+1}\right] \\ A^{i+1} = Tab\left(Th^{i+1}\right) \\ F^{i+1} = Tab\left(Th^{i+1}\right) \end{cases}$$

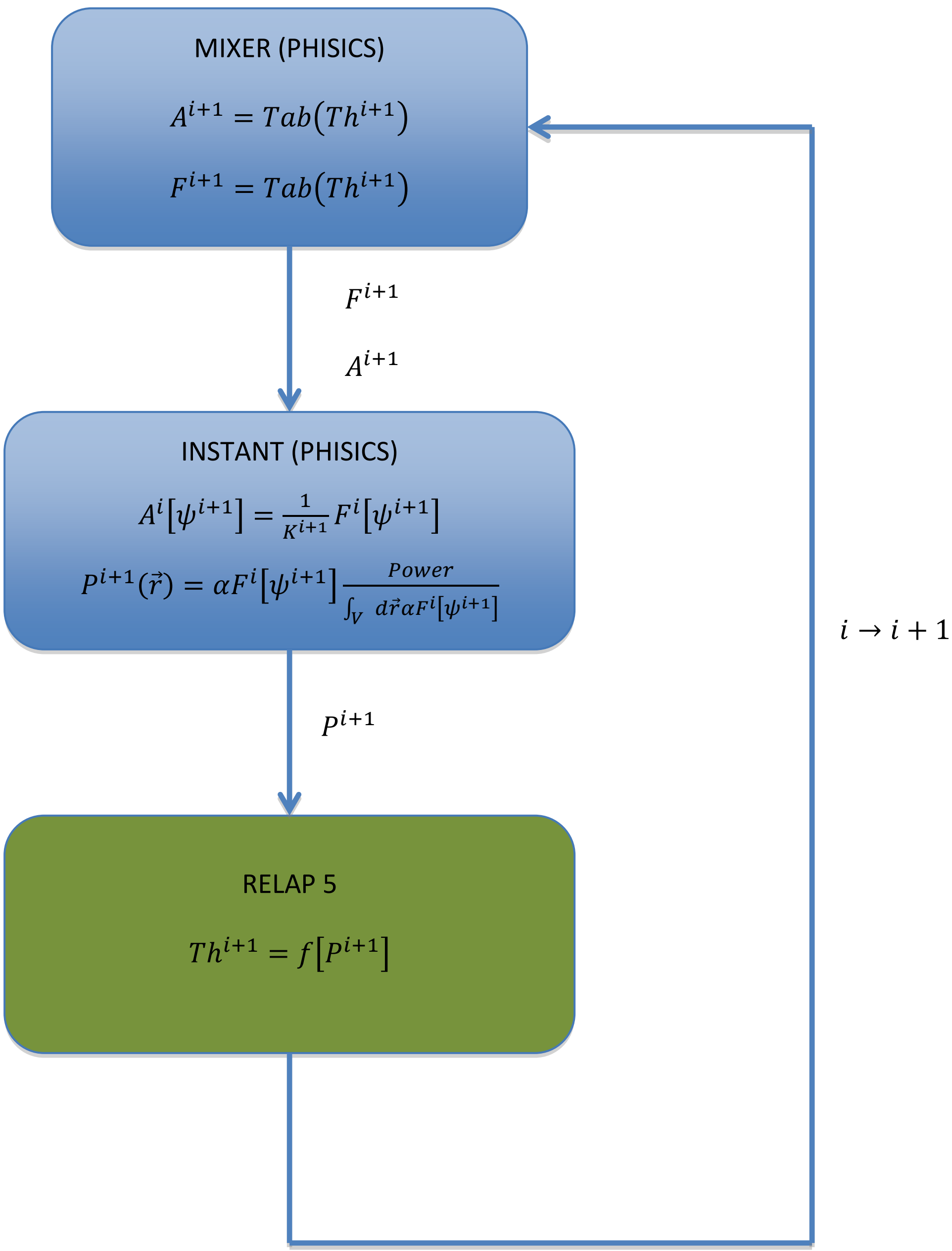
Where
ψ = Neutron flux
A = Transport operator less fission operator
K = K_{eff}
F = Fission operator
P = Spatial distribution of power
α = Energy by fission
Th = Thermo-hydraulic field
Tab = Interpolation function on cross section tables
f = Plant Thermo-Hydraulic response function (RELAP5)
i = iteration index

As explained above, the iteration scheme in algorithmic form is:

Steady State Iteration scheme:

1. A start value for Th^0 is chosen
2. $A^0 = Tab(Th^0)$ and $F^0 = Tab(Th^0)$ are solved by the MIXER (PHISICS)
3. $A^0[\psi^1] = \frac{1}{K^1} F^0[\psi^1]$ is solved by INSTANT (PHISICS)
4. The fission power spatial distribution is computed and normalized to the total power by INSTANT (PHISICS) solving $P^1(\vec{r}) = \alpha F^0[\psi^1] \frac{Power}{\int_V d\vec{r} \alpha F^0[\psi^1]}$
5. RELAP5-3D uses the power distribution to create the Thermo-hydraulic field solving $Th^1 = f[P^1]$
6. Repeat from step 2 until convergence

Steady State Coupling Software Scheme



Final Remarks:

While this scheme is rather commonly used for neutronics and thermo-hydraulic coupling, there are several relevant features that contribute to advance the current capabilities of RELAP5-3D.

- The limit on the number of energy groups is removed.
- The number of tabulation points for the cross sections with respect the parameters is unlimited. This removes the limit of assumed linear/quadratic behavior of the cross section for all the range of values of the TH field.
- The parallel implementation of neutronics allows us to simulate much larger cases in full 3D.
- Capability to run in transport becomes available.

For example the analysis of the OECD MHTGR Benchmark would not have been possible, since the following capabilities were needed:

- 26 energy groups.
- Four tabulation points for some of the parameters of the cross section tabulation.
- ~4000 neutronics nodes.
- ~230 (neutronics) composition.

The cost for all this added capability is:

- Slower running time than NESTLE
- The requirement to use a multi-processor.

However, when these items are unavailable with other means, this is no cost at all.