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:

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\begin{align*}
\psi^{i+1} &= (A^i)^{-1}\left[\frac{1}{K^{i+1}} P^i[\psi^{i+1} + \text{Power}]\right] \\
P^{i+1}(\vec{r}) &= \alpha P^i[\psi^{i+1}] \int d\vec{r} d\vec{r}' \psi^{i+1} \\
Th^{i+1} &= f[P^{i+1}] \\
A^{i+1} &= Tab(Th^{i+1}) \\
F^{i+1} &= Tab(Th^{i+1})
\end{align*}
\]

Where
- \(\psi\) = Neutron flux
- \(A\) = Transport operator less fission operator
- \(K\) = \(K_{eff}\)
- \(F\) = Fission operator
- \(P\) = Spatial distribution of power
- \(\alpha\) = 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:

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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 $P^1(\bar{\rho}) = \alpha F^0[\psi^1] \frac{\text{Power}}{\int_V dV \alpha F^0[\psi^1]}$
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.