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Phisics: A New Reactor Physics Analysis Toolkit

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*The main purpose of this paper is to introduce a newly developed reactor physics toolkit named PHISICS (**P**arallel and **H**ighly **I**nnovative **S**imulation for **I**NL **C**ode **S**ystem). This package is intended to provide a modern analysis tool for reactor physics investigation. It is designed with the mindset to maximize accuracy for a given availability of computational resources. This is obtained by implementing several different algorithms and meshing approaches among which the user will be able to choose in order to optimize his computational resources and accuracy needs.*

I. INTRODUCTION

In the last year INL has internally pursued the development of a new reactor analysis tool: PHISICS. The software is built in a modular approach in order to simplify the independent development of modules by different teams and future maintenance. Most of the modules at the time of this summary are still under development (time dependent transport driver, depletion, cross section I/O and interpolation, generalized perturbation theory, uncertainty and sensitivity analysis), while the transport solver INSTANT (**I**ntelligent **N**odal and **S**emi-structured **T**reatment for **A**dvanced **N**eutron **T**ransport) has already been widely used[1, 2, 3, 4]. For this reason we will focus mainly on the presentation of the transport solver INSTANT.

II. INSTANT

As already mentioned INSTANT is the neutron transport solver for PHISICS. The code is based on two different discretizations of the transport equation. The first one implemented is the Variational Nodal Method[5] and correspond, as shown in reference 1, to hybrid finite element in space and spherical harmonics in angle. The discretized equations are formulated in three different form and solved respectively using: iterative multi-color scheme, CG (Conjugate Gradient), or the GMRES (Generalized Minimum Residuals). The three different solution schemes provide the user with three different trade off options depending on high speed/high memory (multi-color) and low speed/low memory (GMRES) available machines. These three solution algorithm are implemented on Cartesian 2/3D, hexagonal, Z-hexagonal, 2D triangular (structured/unstructured) and Z-triangular. The Variational Nodal method, based on the P_N second order formulation is ill suited to deal with fine unstructured mesh while very effective for node size typical of one assembly[3]. However, the implementation of an unstructured mesh will be useful in conjunction of the soon available new discretization method based on the self adjoint form of the second order S_N equation[6]. This form of discretization should be well suited to deal with the flux discontinuities arising when using a detailed description of the core (e. g.. pin by pin). The variational nodal method has been implemented also in a parallel[2] computing environment with good results. We expect the implementation of self adjoint S_N equation to achieve a good level of scalability.

Table 1 shows the results for the Takeda 4 benchmark[7] that are well in agreement with the results previously obtained with this methodology. Figure 1 and 2 show respectively a detail of the triangular mesh for the C5G7 2D benchmark and its solution using the hybrid FEM approach[3].

TABLE I. Takeda Benchmark*: control rod in

Space polynomial order	Surface polynomial order	Angular order	K_{eff}
5	0	1	0.85866
6	1	3	0.87846
6	1	5	0.88176
7	2	7	0.87963
7	2	9	0.87983

*Reference value: 0.88001 ± 0.00038 (GVMP, Monte Carlo)

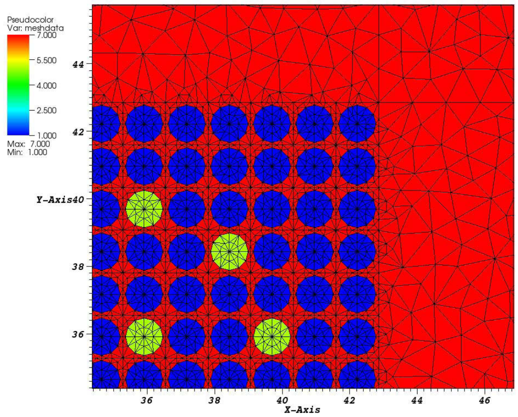

Fig. 1. C5G7 mesh detail (total 89426 elements).

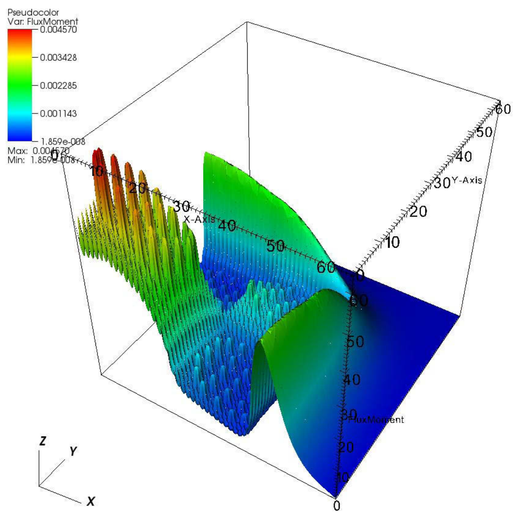

Fig. 2. Thermal flux C5G7 (P5 solution).

II. MODULES UNDER DEVELOPMENT

II. A. Time Dependent Driver

As part of the PHISICS toolkit a time dependent driver for INSTANT is ongoing. The practical realization of the driver follows closely the algorithm and the implementation shown in reference 8. This will allow a quick verification of results by comparison with already existing codes.

II. B. Depletion Module

In order to provide the depletion capability we are in the process to adapt the MRTAU code[9]. MRTAU is a depletion code that has been used insofar for fuel cycle analysis and developed at INL.

II. C. Perturbation Module

One of the major tasks that PHISIC should be capable to perform is the sensitivity and uncertainty quantification connected to the uncertainty in the input parameter. Fundamental step of this task is the implementation of the Generalized Perturbation Theory[10] (GPT). This effort is also already ongoing and the implementation of the adjoint solution is already present in INSTANT.

II. D. Medium and Long Term Future Developments

In the medium term a thermal hydraulics capability (at the beginning based on a subchannel approximation) will be added to PHISICS. This will allow coupled calculations with sensitivity/uncertainty capability. For the long term the addition of a cell code capable of treating all type of reactor spectra is foreseen.

III. CONCLUSION

PHISICS capabilities are quickly increasing; its modular approach allows parallel development and we foreseen this toolset to become soon available to the reactor physics community in order to provide a modern analysis tool. The embedded adjoint capability in conjunction with its scalability between different accuracy levels of the simulation will be the strength of this new toolset.

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