Analysis Of Fuel Loading Management in Fuel Cycle Simulation Tools In The Framework Of The FIT Project

X. Doligez[a], B. Feng[b], M. Halasz[c], A. Hernandez[d], I. Merino[e], B. Mouginot[f], A.V. Skarbeli[l], N. Thiollière[g,*], F. Alvarez-Velarde[l], E. E. Davidson[h], H. Druenne[i], M. Ernoult[a], R. Hays[j], K. Huff[k], M. Szieberth[c], B. Vermeeren[i], A. Villacorta[l], P. Wilson[f]

[a]*Institut de Physique Nuclaire dOrsay, CNRS-IN2P3/Univ, Paris-Sud, France*
[b]*Argonne National Laboratory, 9700 Cass Ave., Lemont, IL 60439, USA*
[c]*Budapest University of Technology and Economics (BME), Institute of Nuclear Techniques, 1111 Budapest, Megyetem rkp. 3-9, Hungary*
[d]*Studiecentrum voor kernenergie - Centre d'tude de l'nergie nuclaire (SCK-CEN), Boeretang 200, Mol, Belgium*
[e]*Catholic University of the Maule, Av. San Miguel 3605, Talca, Chile*
[f]*Univ. of Wisconsin Madison, Department of Nuclear Engineering and Engineering Physics, Madison, WI, United States*
[g]*Subatech, IMTA-IN2P3/CNRS-Université, Nantes, F-44307, France*
[h]*Oak Ridge National Laboratory, Building 5700, Mail Stop 6172, Oak Ridge, TN 37831, United States*
[i]*Tractebel Engie, Boulevard Simn Bolvar 34-36, 1000 Brussels, Belgium*
[j]*Idaho National Laboratory, 2525 Fremont Ave., Idaho Falls, ID 83402, USA*
[k]*University of Illinois, Department of Nuclear, Plasma, and Radiological Engineering, United States*
[l]*CIEMAT, Avda. Complutense, 40, 28040 Madrid, Spain*

Abstract

Abstract beginning...

In this paper, the first tested functionality is presented. The impact of the fuel composition dependency with stock versus a fixed fraction approach is tested. Results from different methodologies are compared.

Keywords: Nuclear Fuel Cycle, Simulation, Functionality, Benchmark

---

*Corresponding author
Email address: `nicolas.thiolliere@subatech.in2p3.fr` (N. Thiollière)

Since the 1990's, many different fuel cycle dynamic simulator code have been developed by several institutions for different purposes.

Fuel cycle tools are used to study current nuclear fleet for industrial operation optimization. The future of nuclear energy could also be assesed by those simulators and provide informations for political decision process. Finally, those tools are used for Research and Development training. As they model an entire nuclear fleet with nuclear reactors, fuel fabrication plants, reprocessing plants, cooling pool and waste disposal among others, they help identify drivers and interactions between parameters in fuel cycle physic. For that, they often implement physic models for different key points of the cycle like fuel fabrication or burn up depletion calculations for instance.

The different institutions that use fuel cycle simulations pursue different goals. Consequently, their computational tools vary in term of complexity, from a spreadsheet to a complex simulation code framework. The level of complexity of each software has to be coherent in regards to the different studies it is used for. To improve confidence in the results, institutions are tempted to increase the complexity of their software even if this complexity might not be necessary.

As an example, the neutron and gamma doses calculation requires the precise knowledge of each material isotopic composition in each facilities whereas uranium consumption calculation does not require this degree of detail. As a consequence, some software features may not be necessary regarding the technical question the code assesses. Yet, developing a new feature is time consuming. Actually, to solve a given technical question associated to a targeted precision, some features are needed and others are not. Knowing the importance of each ones helps to choose an appropriate software or to engage code developments to solve the question. On the other side, some technical issues are assessed by numerous studies performed with different software and it is often difficult to compare them. Knowing the impact of features on different simulation outputs helps to estimate the confidence level of studies.

The FIT project (for Functionality Isolation Test) has been conceived for this purpose. According to the type of study and the wanted confidence level, what should be the level of details in fuel cycle simulations that has to be taken into account? Among different features of interest, this first work focuses on the ability of fuel cycle software to adapt the fresh fuel composition regarding to the available material for fuel fabrication.

The first part of the paper describes the FIT project, its philosophy and the participant with their own software. It explains how each code is used with and without the feature to test in order to quantify its impact on fuel cycle observables and why this is not a traditional benchmark. This part ends by the description of the particular feature tested in this work which is the fuel loading management. The second part presents the design of experiment used to test this particular feature: input simulation descriptions, technical specificities and finally output metrics used to quantify the impact of the use of fuel loading management in fuel cycle studies are detailed. Finally, the third part is dedicated to the different results of each software involved in this first exercise and some conclusion are withdrawn.

1. Presentation Of The FIT Project

The FIT (Functionality Isolation Test) Project is an international effort devoted to improve the fuel cycle tools confidence. This section aims to precisely describe the project.

1.1. Goals of the projet

A nuclear fuel cycle is a very complex system in which isotopes evolution can be impacted by various parameters such as reactor technology deployment, fuel reprocessing strategies, etc. A fuel cycle code calculates radio-nuclides evolution in nuclear facilities from the description of a nuclear fleet. The material evolution is estimated during the irradiation process in reactors and during cooling phases is other facilities. Taking into account all the physics phenomena and industrial practices requires a huge effort in code development. For this reason, fuel cycle tools integrates many simulation simplifications. A lot of fuel cycle tools are developed and used worldwide [1, 2, 3] with large level of complexity or range of applications. The FIT Project was initiated in 2017 and aims to improve the quality of data produced by fuel cycle tools.

Increasing the ability to reproduce an operated nuclear fleet involves increasing the complexity if the simulation tool by developing new functionalities. We call fuel cycle code functionality a computer translation of a physical or a technical process observed in a nuclear fleet. The Table1.1 lists some examples of functionalities that could be developed in replacement of a reference treatment, which is the fuel cycle code current state.

The FIT project goals is to determine which functionalities are required according to the question that needs to be answered and the precision level to reach. Indeed, the starting point of a fuel cycle study is a technical question such as "In a PWR fleet in which plutonium from spent UOX fuel is reprocessed in MOX fuel, what is the PWR-MOX fraction that perfectly balances the plutonium produced by PWR-UOX?". The user identify then the set of output data needed to answer the technical question. In the example above,

Reference	Functionality to develop
At each reactor loading, the reactor fresh fuel composition is constant	At each reactor loading, the reactor fresh fuel composition depends on available material isotopic composition
The reactor load factor is constant over the reactor lifetime	The reactor load factor takes into account precise industrial constraints, such as partial refueling
The mean cross sections used to perform the fuel evolution in reactor are calculated at BOC and kept constant during the cycle	The mean cross sections used to perform the fuel evolution in reactor are updated according to fuel composition
The reactor first cycles composition is not taken into account and is assumed to be the steady states composition	The exact reactor first cycles composition is used

Table 1: Examples of simplified and more complex functionalities.

the user needs to assess the plutonium inventory contained in facilities between the UOX spent fuel and the PWR MOX fuel. For illustrating, we use the first functionality of the Table 1.1. The FIT project would provide in this case the impact of using a model to calculate the reactor fresh fuel composition versus using a constant fresh fuel composition. According to this impact, the user can decide if a new functionality devoted to the fresh fuel composition assessment is needed or not. The user can also decide to use another tool that already include this functionality. In addition, FIT project results could also be used to evaluate if a functionality not present in a study could have an impact on the observable that is used to solve the question.

The FIT project approach is very different from fuel cycle code benchmarks, as for example the NEA benchmark [4], since there is no code to code comparison. The specificity here is to take advantage of the multiple tools developed since many years with different approaches. A functionality effect is isolated from a simple basic exercise designed for this purpose. Comparisons are done between the exercise resolution obtained from the reference case and from the functionality enabled. The impact of the functionality is calculated for each participant code. This methodology provide various quantification of a functionality impact on the fuel cycle. Some practical conclusions can be built if there is an agreement between results.

1.2. Fuel cycle tools and institutions

The originality and the efficiency of the FIT project lies in the large number of fuel cycle tools. The Table 1.2 presents participating institution with used fuel cycle code.

Fuel cycle code	Institution
CLASS[]	CNRS / IN2P3 (FRA)
CYCLUS[]	Univ. of Wisconsin Madison (USA) Univ. of Illinois (USA)
DYMOND[]	Argonne National Lab (USA)
ORION[]	Oak Ridge National Lab (USA)
VISION[]	Idaho National Lab (USA)
Tr_Evol[]	CIEMAT (ESP)
ANICCA[]	TRACTEBEL (BEL) Univ. Catlica del Maule (CHL)
JOSSETTE[]	BME (HUN)

Table 2: List of institutions and fuel cycle codes involved in FIT project.

FIT project aims to be built on exercises related to test a specific functionality. Some tools can be used to test a functionality if they are designed for. The participation to an exercise also depends on the availability of participants. For this reasons, not all the codes and institutions are involved in an exercise.

1.3. Description of the tested feature

In the present work, we focus on the impact of using a Fuel Loading Model (FLM) or a Fixed Fraction (FF) approach.

A FLM approach consists to adapt the fresh fuel composition according to the reactor requirements and the available isotopes. A FLM means there is a process that connects the fresh fuel composition to the available materials, whatever the complexity of the model. For instance, the fissile fraction is calculated from the fissile stock quality in order to reach the required burn-up of the reactor. A FLM could be based on neural network, Plutonium equivalence model, analytic functions, built-in depletion, etc. A FLM is usually built from physics constraints and reactor physics calculations.

A Fixed Fraction (FF) approach consists in using the same constant fissile fraction at each fresh fuel loading whatever the isotopic vector of the available fissile material is. Using a PWR MOX which is always loaded with a fresh fuel that contains 7% of plutonium regardless the ^{239}Pu content is a FF approach.

The present work aims to quantify the impact of using a FLM versus a FF approach considering this last one as the reference. In a fuel cycle code, the FF approach is the easiest method to handle fresh fuel loading in a reactor. The user simply define explicitly the fuel composition that is used in all the simulation. Developing a FLM may be an important development process that may require time and effort. Testing the impact of using a FLM rather than a FF approach aims to show applications that need FLM and study that can be solved with FF approach.

2. Exercice definition

2.1. Specification

2.2. Methodology

2.3. Output observables

coucou

References

References

[1] C. Coquelet-PAscal, M. Tiphine, G. Krivtchik, D. Freynet, C. Cany, R. Eschbach, C. Chabert, Cosi6: a tool for nuclear transition scenario studies and application to sfr deployment scenarios with minor actinides transmutation, Nuclear Technology 192 (2) (2015) 91–110.

[2] L. Van Den Durpel, Dynamic Analysis of Nuclear Energy System Strategies: Daness v7, Global2015, September (2015) 20–24.

[3] K. D. Huff, M. J. Gidden, R. W. Carlsen, R. R. Flanagan, M. B. McGarry, A. C. Opotowsky, E. A. Schneider, A. M. Scopatz, P. P. Wilson, Fundamental concepts in the Cyclus nuclear fuel cycle simulation framework, Advances in Engineering Software 94 (2016) 46 – 59.

[4] K. A. McCarthy, B. Dixon, Y.-J. Choi, L. Boucher, K. Ono, F. Alvarez-Velarde, E. M. Gonzalez, B. Hyland, Benchmark study on nuclear fuel cycle transition scenarios - analysis codes, Tech. rep., N.E.A., Nuclear Energy Agency of the OECD (NEA) (2012).
URL http://inis.iaea.org/search/search.aspx?orig_q=RN:44089401