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Original Article

Evaluation of the Middle Part of the Nuclear Fuel Cycle

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ABSTRACT

This article describes a comprehensive methodology for the evaluation of the middle part of nuclear fuel cycles. Evaluation of fuel cycles is basically divided into two parts. The first comprises nuclear calculation, i.e., creation of the strategy for nuclear fuel reloading and core design calculations. The second part is the business–economic evaluation of the selected reloading strategy, which can be done either by financial analysis or economic analysis. The financial analysis incorporates the perspectives of a company while the economic analysis can be used primarily by national economists or politicians. This methodology was applied to a case study that is focused on impacts of switching from a 12-month to an 18-month fuel cycle strategy for Water-Water Energetic Reactor (VVER)-1000 reactors.

1. Introduction

Strategic management and decision making in respect of the middle part of nuclear fuel cycles is a very specific problem of power engineering. Although the strategy of nuclear fuel cycles directly influences key issues in nuclear power engineering, i.e., volume of produced electricity and spent nuclear fuel, it can be very inflexible. This can be explained by the fact that switching to a different nuclear fuel cycle strategy always means a substantial impact on the entire operation of a nuclear power plant (NPP).

Therefore we need to carry out a comprehensive analysis [1] of the proposed fuel cycle. Key variables, which influence the particular fuel cycle, are as follows:

- Fuel cycle length (e.g., 12-month fuel cycle or 18-month fuel cycle)
- Number of years the fuel spends in a core (maximum fuel burnup)
- Type of fuel loading pattern (low leakage fuel pattern or high leakage loading pattern)
- Type of fuel used [uranium fuel or mixed oxide (MOX) fuel]

This article focuses on the first variable, i.e., the evaluation of the fuel cycle length.

The major difference between a 12-month and an 18-month nuclear fuel strategy (herein referred to as 12M and 18M) can be seen mainly in the organization of the planned shutdowns for fuel reloading. The 18M cycle

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alternates 18-month-long production periods and shutdown periods (~ 45 days) for fuel reloading. The durations of shutdowns of both strategies are more or less the same. The prolongation of the fuel cycle results in a significant increase of availability of the power plant. 18M fuel cycles require only two refueling outages during a 3-year period instead of three, as is the case with the 12-month fuel cycles. It means that we can save one entire outage (i.e., 45 days) during the 3-year period. Nevertheless, such prolongation influences operation of the entire power plant. Therefore a detailed analysis has to be carried out.

2. Materials and methods

2.1. *Methodology for the evaluation of the middle part of a fuel cycle*

Generally speaking, it is very hard to construct a comprehensive methodology for evaluating the middle part of fuel cycles. However, there are many evaluation procedures that aim to solve separate parts of the problem, such as reload safety evaluation or calculation of costs of interim spent fuel storage Fig. 1.

The evaluation of fuel cycles is basically divided into two parts: the first comprises nuclear calculation, i.e., creation of a strategy for nuclear fuel reloading and core design calculations. Such calculations are crucial for the second part of the evaluation: the business–economic evaluation.

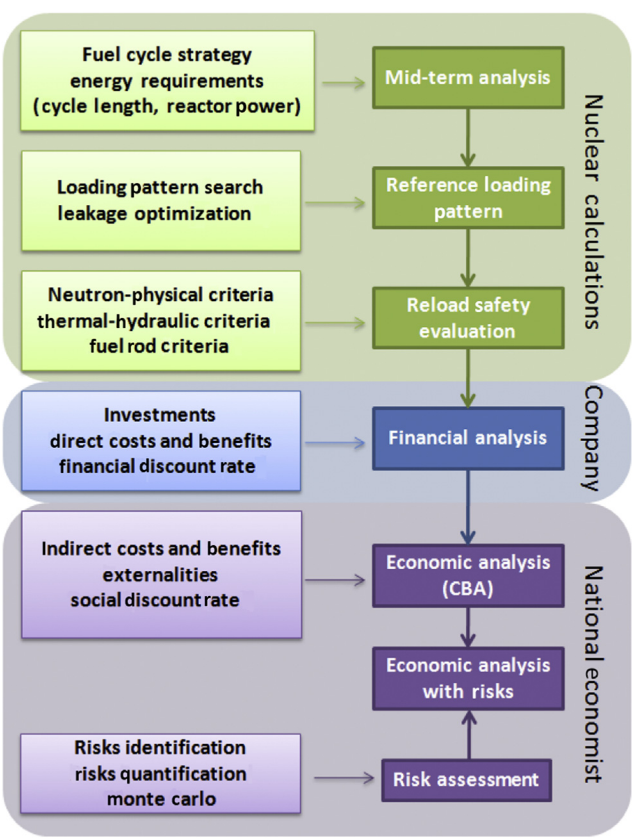

Fig. 1 – Methodology of fuel cycles assessment. CBA, cost-benefit analysis.

The business–economic evaluation must be based on specific nuclear calculations, which are essential as they determine a key input of the evaluation—the fuel costs of the proposed fuel strategy. The output of the nuclear calculations consists of proposed fuel reloads (loading patterns) for each fuel cycle, during which each loading pattern must meet energy requirements for the given power level and also all safety requirements that have to be fulfilled.

2.2. *Nuclear calculations of the fuel strategy*

Core design calculations are a challenging discipline in reactor engineering. Such calculations are reactor specific and therefore cannot be transferred from one power plant to another (especially if they have different reactor types). The fuel requirements also cannot be based on estimations because the core design has too many variables and too many restrictions. The nuclear calculations consist of the following aspects:

- Midterm analysis of reload strategy
- Proposal of a reference loading pattern
- Reload safety evaluation of proposed loading pattern

Midterm analysis of reload strategies comprises calculations of the fuel requirements for several reloads in a row using simple nuclear codes that are based on point kinetics and the linear reactivity model. This analysis aims to optimize the number of fresh fuel assemblies, their enrichment, and neutron leakage from the reactor core over several years (midterm analysis).

The proposal of a reference loading pattern or proposal of transition to a new fuel strategy is based on searching the loading patterns using 3D computational codes. Such outputs are crucial in respect of entire nuclear calculations. They provide detailed knowledge about the behavior of the reactor core during the fuel cycle. The output consists of the proposed fuel loading pattern which must meet energy (cycle length on full power), as well as all safety, requirements such as power distribution, peaking factors, and reactivity feedbacks. These calculations can be extended by cycle optimization, meaning, in particular, searching the low leakage loading patterns that have enhanced neutron and fuel economy.

Each change in the project or operation of an NPP requires safety assessment, especially for such a significant change as the switching of the fuel cycle strategy. The type of the particular safety assessment always depends on the nature of the change. Such calculations are then absolutely crucial for the entire middle part of the fuel cycle. In general, it must be proven that the new fuel strategy meets all safety criteria that come from the safety analysis report. These criteria are divided into three areas:

- Neutron–physical criteria
- Thermal–hydraulic criteria
- Fuel rod criteria