ECONOMIC ASSESSMENT OF THE MULTI-RECYCLING OF URANIUM AND PLUTONIUM STRATEGY IN THE FRENCH NUCLEAR FLEET

Baptiste Métivier, IMT Atlantique / Subatech Laboratory Nantes, France. +33 2 51 85 81 00, baptiste.metivier@imt-atlantique.net
Nicolas Thiollière, IMT Atlantique / Subatech Laboratory Nantes, France. +33 2 51 85 86 42, nicolas.thiolliere@subatech.in2p3.fr
Fanny Courtin, IMT Atlantique / Subatech Laboratory Nantes, France. +33 2 51 85 86 49, fanny.courtin@subatech.in2p3.fr
Lionel Lemiale, IAE Nantes Université, France +33 2 40 14 17 72, lionel.lemiale@univ-nantes.fr
Xavier Doligez, LPSC Grenoble, France. +33 4 76 28 40 00, xavier.doligez@lpsc.in2p3.fr
Baptiste Durox, IJCLab Orsay, France. +33 1 69 15 51 96, baptiste.durox@ijclab.in2p3.fr
Marc Ernoult, IJCLab Orsay, France +33 1 69 15 81 08, marc.ernoult@ijclab.in2p3.fr

Overview

In France, the energy transition policy strategy is guided by the Multiannual Energy Program (PPE) which promote the complementarity between nuclear energy and the development of renewable energies. The progressive obsolescence of the nuclear fleet raises critical questions regarding the economic implications of facilities refurbishment and extension, particularly concerning their impact on electricity generation future costs.

The current French nuclear fleet, developed since the late 1970s, is based on Pressurized Water Reactor (PWR) technology and uses both UOX fuel and MOX fuel. UOX fuel is manufactured using natural uranium, enriched at the George Besse 2 facility. UOX spent fuel is reprocessed at the La Hague plant and the plutonium streams are used to produce MOX fuel at the Orano Melox recycling facility. MOX fuel undergoes a single irradiation cycle in PWRs, and the resulting spent MOX is currently stored awaiting reprocessing.

The replacement of the historic PWR fleet, as well as the associated reprocessing and recycling facilities, is a central focus in the formulation of France's nuclear strategy, discussed notably within the Nuclear Policy Council (Conseil de Politique Nucléaire, CPN). The reactor fleet is expected to be gradually replaced by third-generation PWRs (EPRs) starting in 2035. Reprocessing and recycling plants refurbishment and potential extension, targeted for 2040, depends on the chosen strategy for managing nuclear materials within the nuclear fleet. The latest Multiannual Energy Plan (PPE) has established the deployment of a multi-recycling strategy for uranium and plutonium in EPRs (MRREP program) by 2050 as a reference framework, while postponing the deployment of a fast neutron reactors to 2100.

Traditionally, assessment of future nuclear strategies, are based on technical simulations which describe the evolution of material flows throughout each facility in the fleet. However, as far as recycling strategies are concerned, only a few studies conduct economic assessment [1]. This type of study typically involves the use of distinct tools: on one side, physical analysis for modeling material flows, and on the other, economic calculations to assess associated costs. A direct coupling of these approaches would enable a more targeted economic analysis and provide a more accurate estimate of the impact of facilities costs based on the chosen strategy. This integrated approach would offer a better understanding of the interactions between technical and economic aspects, thereby facilitating the assessment of nuclear future strategies in the framework of the French energy transition.

Methods

Our team developed the CLASS tool [2], funded by CNRS/IN2P3[1] and IRSN[2] for over 10 years, to model precisely the evolution of radioactive mass flows within an electro-nuclear fleet at the century scale. Recent developments integrate an economic framework within the CLASS tool to evaluate the levelized cost of nuclear electricity at each step of power generation process. This work then provides an overview of CLASS current capabilities, focusing on its economic calculations and comparing cost options within the French nuclear fleet. A comparison with the standard approach based on Levelized Cost of Electricity will also be presented.

The CLASS code integrates both fixed and variable costs of installations (fuel fabrication, reactors and reprocessing) to provide a comprehensive economic analysis of nuclear installations throughout their lifecycle. Fixed costs include facilities capital expenditures (CAPEX) for construction, operation and maintenance (O&M) cost, and dismantling expenses for decommissioning. Variable costs encompass operational expenditures (OPEX),

[1] National Centre for Scientific Research / French National Institute of Nuclear and Particle Physics
[2] French Institute for Radiation Protection and Nuclear Safety

fuel costs, particularly recycled fuel, and waste management expenses. The model incorporates a temporal distribution of costs, capturing the time-dependent nature of expenditures across operational phases with a specific focus on fuel costs which are computed from material flows and reprocessing facility capacity requirements.

The methodology is applied on three distinct scenarios to assess the economic performance of the French nuclear fleet under different configurations. The first scenario considers a PWR UOX with one enrichment plant (also called open cycle). The second scenario adds a PWR MOX alongside the PWR UOX, combined with a separation plant and a MOX fabrication plant. Finally, the third scenario introduces a more complex configuration, with uranium and plutonium multirecycling in PWR. These scenarios are modeled using specific input data reflecting the operational and economic parameters of each plant type, enabling a comprehensive comparison of their economic viability.

Results

This study demonstrates that the cost of the single MOX fuel strategy is comparable to that of fully UOX fuel. This result is consistent with common findings among nuclear operators and in academic literature [3]. The analysis is based on a detailed cost comparison of fuel fabrication, irradiation, and recycling, taking into account both capital and operational expenditures. Despite the additional costs associated with MOX, such as plutonium management and recycling plant operations, the results show that the MOX cycle remains competitive with the traditional UOX cycle.

This study also demonstrates that the expansion of the Orano Melox facility, which would require adaptation for plutonium multi-recycling, is not a significant determinant of the nuclear fuel cycle cost in terms of capital expenditure. Indeed, while the investments in recycling and irradiation infrastructure for MOX are significant, they do not seem to exert substantial pressure on long-term costs when compared to the initial expenditures associated with reactor construction and the maintenance of treatment facilities. Similarly, the expansion of the La Hague plant, while essential for managing multi-recycled spent fuel, does not appear to significantly influence cycle costs in terms of initial investment.

In a scenario where plutonium and uranium are multi-recycled, key parameters are the separation and reprocessing variable costs of spent MOX fuel. These costs play a critical role in determining the overall cycle cost and significantly influence the system's economics. The separation and reprocessing of spent MOX fuel involve complex chemical processes and technical challenges, leading to non-negligible costs, which are, however, highly uncertain. Accurately quantifying these costs is essential, and we show that sensitivity analyses can offer valuable insights into their impact and can guide economic optimization.

Conclusions

The methodology outlined in this work integrates material flows with corresponding cashflows into the CLASS code, offering an innovative approach to evaluating nuclear energy strategies. By linking nuclear fleet management operations, such as fuel production, recycling, and waste treatment, with their economic implications, this framework provides a comprehensive perspective on the feasibility and cost-effectiveness of various nuclear strategies. The focus on the economic aspects of the fuel cycle, particularly UOX/MOX optimized fuels, advances the discussion on nuclear power's role in the energy transition.

This study makes a significant academic contribution to understanding the cost structure of future nuclear energy systems. The transparent and reproducible calculations presented here lay a strong foundation for future research aimed at optimizing nuclear fuel cycles and assessing the long-term economic sustainability of nuclear energy. This approach enables more accurate estimations of long-term economic outcomes, supporting informed decision-making in response to evolving energy markets and regulatory frameworks.

References

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