The Continuous Fuel Cycle Model and the Gas Cooled Fast Reactor

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ABSTRACT: The gas cooled fast reactor (GFR) is one of the generation IV designs currently being evaluated for future use. It is intended to behave as an isobreeder, producing the same amount of fuel as it consumes during operation. The actinides in the fuel will be recycled repeatedly in order to minimise the waste output to fission products only. Striking the balance of the fissioning of various actinides against transmutation and decay to achieve these goals is a complex problem. This is compounded by the time required for burn-up modelling, which can be considerable for a single cycle, and even longer for studies of fuel evolution over many cycles.

The continuous fuel cycle model [1] approximates the discrete steps of loading, operating and unloading a reactor as continuous processes. This simplifies the calculations involved in simulating the behaviour of the fuel, reducing the time needed to model the changes to the fuel composition over many cycles. This method is used to study the behaviour of GFR fuel over many cycles and compared to results obtained from direct calculations. The effects of varying fuel cycle properties such as feed material, recycling of additional actinides and reprocessing losses are also investigated.

KEYWORDS: Gas cooled fast reactor, fuel cycle, continuous fuel cycle model

I. INTRODUCTION

Sustainability is a key issue for modern nuclear power. It is generally held that to improve sustainability, all available uranium isotopes should be used for power production, rather than only U-235. Achieving this requires transmuting U-238 to Pu-239 via neutron capture and two β-decays. Traditionally this has been done using breeder reactors, whose neutron surplus allows them to produce more fuel than they consume. This process raises the question of proliferation issues, particularly as the plutonium bred in such a system can be of very high quality for weapons production.

The solution proposed for this problem is the creation of isobreeders, reactors that convert fertile isotopes to fissile ones at the same rate they consume them. This improves the sustainability of such a system, without running the risk of the spread of nuclear weapons. Designing a system that behaves in this manner requires careful study of the fuel cycle over a significant period of time, to ensure that the rates of production and loss of fuel remain equal even as the fuel composition develops.

The gas cooled fast reactor is intended to operate in this fashion, with spent fuel being reprocessed and returned to the reactor until all actinides are fissioned. The design of the reactor has not yet been fixed, and changes to the reactor itself or the associated fuel cycle may well affect the long term behaviour of the system. Given the amount of computational effort needed to study the long term behaviour of the fuel cycle, it is impractical to propagate the effects of every single design change through a full set of burn-up calculations. A less computationally intensive method of determining the effects of changes would allow their individual impacts to be studied.

The continuous fuel cycle model is designed to simplify the process of modelling fuel composition behaviour over many burn-up cycles. This is achieved by treating the various processes involved as continuous instead of discrete. This allows the evolution of the fuel composition to be modelled as an eigenvalue problem, which requires significantly less time and fewer resources to solve than a full burn-up model. The model was originally developed for breeder systems, and gives the system growth rate as the fundamental eigenvalue of the problem solved. Applying this model to an isobreeder such as the GFR may allow the behaviour of the fuel to be studied more quickly and easily.

II. THE CONTINUOUS MODEL

The continuous model was described by Ott and co-workers, and is summarised in [1]. A brief description of the model will be given here.

The model is centred on the production and loss matrix \( C \) and the composition vector \( N \). These can be used to form an eigenvalue problem that describes the system once it has reached asymptotic operation (denoted with a superscript \( \infty \)). This is the stage at which the fuel has reached a fixed composition and only the amount varies as time passes. This behaviour is seen in systems with multiple recycling of their own fuel, such as the GFR. The asymptotic