Modelling fuel behaviour in a reactor park using fuel cycle kinetics

J.A.B. van Rhijn, S.A. Christie, D. Lathouwers, J.L. Kloosterman

Delft University of Technology, Department of Radiation, Radionuclides and Reactors, Physics of Nuclear Reactors, Mekelweg 15, 2629 JB Delft, The Netherlands

ARTICLE INFO
Article history:
Received 20 December 2011
Received in revised form 10 May 2012
Accepted 25 June 2012
Available online 2 October 2012

Keywords:
Reactor park
Fuel cycle kinetics
LWR
FBR
MOX

ABSTRACT
The theory of fuel cycle kinetics is re-examined. This theory is a powerful tool to describe the time-dependent fuel behaviour of large populations of nuclear reactors. The aim of this paper is to verify the fuel cycle kinetics theory and use it to find a pre-determined asymptotic growth of nuclear reactors based on an expected growth of energy demand. The theory is based on the principles of a reactor park and an analogy to point kinetics. A reactor park is the description of the interconnections between a population of nuclear reactors with various designs. In the fuel cycle kinetics theory, point kinetics is used as a model to simplify space-, energy-, and time-dependent burn-up equations of the reactors in a park to a set of only time-dependent equations, called the fuel cycle kinetics equations. Reducing the problem to being only time-dependent makes it possible to research complex reactor systems in a short time and at low computational cost. The theory is also used for a new application, adjusting reactor parks to match given growth rates.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Predictions show the world electricity demand growing the most strongly of all final forms of energy (IEA, 2010) in the coming years. Combined with the goal of reduced global CO2 emissions, countries have to change their energy policies. Due to this a global shift to nuclear power, renewables and low-carbon technologies is expected. The energy strategy that a country chooses is of great influence on the growth of nuclear power. The World Nuclear Association show in their World Nuclear Outlook (WNA, 2008) the number of nuclear reactors now in operation and give upper and lower predictions for the upcoming century. New innovations are needed to research such large and complex reactor scenarios.

One candidate for use in this kind of research is fuel cycle kinetics. The theory of fuel cycle kinetics was first developed in the 1970s (Maudlin, 1979; Maudlin and Ott, 1979). The theory projects the behaviour of a population of reactors due to their designs and fuel cycles without the use of detailed calculations. This article re-examines this theory and tests its use in predicting reactor park behaviour. The scenarios studied are a single deployment of FBRs and symbiotic deployments of PWRs and FBRs. The solutions of the fuel cycle kinetics equations found are compared to TRITON (DeHart, 2009) calculations on the same systems. The theory is then used to adjust the growth rates of reactor parks to required levels.

2. Reactors designs and fuel

Throughout this paper two types of reactor will be used for describing a reactor park, the light water reactor, LWR, and the fast breeder reactor, FBR. The LWR that is used is a pressurised water reactor, PWR. The design of the FBR that is used is similar to the one used in (Ott and Borg, 1980). The PWR is described with a three zone block model, loosely based on the European Pressurised Water Reactor (EPR).

Both types of reactor will use mixed oxide fuel, MOX. Only the growth of plutonium is considered here, so the fuel used is composed of Pu and 238U oxides only. The composition of the fuel changes over time, but eventually reaches an equilibrium. An illustration of this behaviour in the core of an FBR is shown in Fig. 1.

3. Reactor park

A reactor park consists of multiple reactors of different designs which are interconnected by an external fuel cycle, see Fig. 2. The single quotation mark, double quotation marks, etc., indicate that a reactor is at a different time in its life and therefore has a different fuel composition. The charge $\xi$ and discharge $\kappa$ terms are explained in detail below. The reactors do not have to be in the same geographical location to be part of a reactor park, they only have to be linked by their external fuel cycles. The fuel behaviour of a reactor park can be described by considering the burn-up equations of single reactors of every type.