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Optimization of MOX enrichment distributions in typical LWR assemblies using a simplex method-based algorithm

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Abstract

The enrichment distributions within light water reactor (LWR) fuel assemblies are optimized using a modified linear programming (SIMPLEX Method) technique initiated from a flat enrichment distribution until a target, maximum local power peaking factor is achieved. The optimum rod enrichment distribution when each rod is allowed to have its own individual enrichment (for this case the target, maximum local power peaking factor is 1.0) is obtained at an intermediate point of the optimization procedure. Later, the optimal locations and values for a reduced number of rod enrichments (groups) are obtained for an input target maximum local power peaking factor by applying sensitivity to change techniques. After an initial set of enrichment groups have been defined, interchanges of rods among neighboring groups are carried out to obtain the final assembly enrichment distribution. The optimization procedure is demonstrated by presenting results for both boiling water reactor (BWR) and pressurized water reactor (PWR) fuel assembly designs. Reactor-grade plutonium (with a fissile Pu fraction of 59.6%) and weapons-grade plutonium (with a fissile Pu fraction of 94.0%) were assumed to be the feed Pu material for the MOX fuel rods in the BWR and PWR examples, respectively. Hot-full-power-temperature and beginning-of-life conditions were also assumed in the example problems. © 2002 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The detailed design of a fuel assembly is not so large a problem that current computer resources limit the designer from obtaining relatively complete derivative information. With the use of an accurate nuclear model, the obtained derivative information can be employed not only to find the optimal rod enrichments (Hirano et al., 1997) for the case when the maximum local power peaking factor is 1.0 (each rod is allowed to have a different enrichment) but also to rank the rod positions according to their effect on the maximum local peaking factor. Then, the information can be used to determine optimal enrichment distributions for target maximum local power peaking factor values that are greater than 1.0. Given that the number of variables is modest, the feasibility and quality of candidate configurations can be evaluated accurately using state-of-the-art reactor physics programs that guide the search without requiring excessive computer resources. This study describes a SIMPLEX algorithm (Nash and Sofer, 1996) that has been applied along with the WIMS7b program to determine optimal assembly enrichment distributions for typical LWR assemblies containing either fresh low enriched uranium (LEU) and plutonium mixed oxide (MOX) fuels. MOX isotopics for both reactor-grade and weapons-grade plutonium were utilized to demonstrate the wide-range of applicability of the optimization technique.

This paper presents a method that makes more extensive use of derivative information than in many previous studies. Sensitivity information regarding the effects of enrichment at each rod position on the maximum local peaking factor inside the assembly are used to obtain the final enrichment distribution. The positions and numbers of fuel rods (using a minimum number of different MOX enrichments) are calculated so as to achieve a user-specified value for the maximum local power peaking factor in the assembly. The optimization methodology is flexible enough to allow the calculation of MOX enrichment distributions under a variety of "neutronic" heterogeneities such as the presence of gadolinium rods, internal moderator regions, or neighboring LEU fuel assemblies. In the example problems, layouts, materials and dimensions were used that resemble the configurations of modern assemblies utilized in commercial boiling water reactors (BWRs) and pressurized water reactors (PWRs). The use of fresh fuel was intentionally chosen in order to set limits on the problem and facilitate the discernment of the rod position-enrichment relationships. Also, the tendency to yield high local power peaking factors is expected when fresh fuel is present assuming ordinary fuel assembly designs and conditions. The final contribution of this study is to present a full deterministic technique capable of providing assembly enrichment distributions (using small numbers of enrichment groups) such that a maximum local power peaking factor criterion is met.

In the optimization examples presented here, the within assembly, rod power distributions and the rod position-enrichment sensitivities were obtained using WIMS7b (Anon, 1996). The WIMS7b model used a 69 energy group nuclear data library derived from the latest JEF 2.2 library and the CACTUS two-dimensional transport module.