Advancements in the Behavioral Modeling of Fuel Elements and Related Structures

M. C. Billone
Argonne National Laboratory, Argonne, IL USA
R. O. Montgomery, Y. R. Rashid
ANATECH Research Corporation, San Diego, CA USA
J. L. Head
Royal Naval College, London, England, UK

ABSTRACT

An important aspect of the design and analysis of nuclear reactors is the ability to predict the behavior of fuel elements in the adverse environment of a reactor system. By understanding the thermomechanical behavior of the different materials which constitute a nuclear fuel element, analysis and predictions can be made regarding the integrity and reliability of fuel element designs. The SMiRT conference series, through the division on fuel elements and the post-conference seminars on fuel element modeling, provided technical forums for the international participation in the exchange of knowledge concerning the thermomechanical modeling of fuel elements. This paper discusses the technical advances in the behavioral modeling of fuel elements presented at the SMiRT conference series since its inception in 1971. Progress in the areas of material properties and constitutive relationships, modeling methodologies, and integral modeling approaches was reviewed and is summarized in light of their impact on the thermomechanical modeling of nuclear fuel elements.

INTRODUCTION

The SMiRT Conference series began at a time when nuclear power was perceived to have come of age. No major industry-wide problems existed, and the system performed as expected. The first generation thermal reactor technology was almost relegated to a text-book status, clearing the way for intensified development in the fast breeder technology as a natural extension and a necessary second generation system. However, at the start of the seventies decade, this orderly progression was not to continue uninterrupted as public opposition to nuclear power began to develop, encouraged by unfavorable trends in nuclear power economics. This coincided with the emergence of performance problems in light water reactor (LWR) fuel when increased incidents of pellet-clad interaction (PCI) failures forced industry to re-evaluate their fuel design methods and to develop fuel research programs to better understand fuel behavior.

Prior to that time, LWR fuel design was governed by physical and chemical considerations which placed significant constraints on the fuel's thermal performance. For example, the initial thickness of the fuel-cladding gap had to be increased, thereby penalizing the gap heat transfer, in order to accommodate end-of-life fuel swelling. The mechanical design was far less important, almost a loose end that needed to be addressed only to satisfy conventional design requirements which, in some cases, were irrelevant. For example, the cladding thickness was initially selected to satisfy such benign condition as the contact stresses caused by the spacer grid spring forces. Because of this elementary nature with which the mechanical behavior of fuel elements was viewed, structural mechanics aspects of fuel elements were not considered to be proper topics for technical forums. It was not until the first SMiRT conference that a major international conference provided a