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Zirconium Alloys in Nuclear Power Plants

A. T. Motta(1)*

(1) Department of Mechanical and Nuclear Engineering, 227 Reber Bldg., The Pennsylvania State University, University Park, Pa, 16802-1408, USA, (814) 865-0036, atm2@psu.edu.
* Corresponding author.

Abstract – The use of zirconium alloys for nuclear fuel and reactor internals in nuclear reactors is reviewed, with special attention to the mechanisms that can limit fuel burnup extensions in light water reactors, such as corrosion and hydriding and irradiation growth and creep. Recent techniques for studying these processes open the possibility that they can be understood mechanistically such that alloys with superior performance can be designed. In particular the use of techniques such as synchrotron radiation diffraction and fluorescence has allowed the detailed study of corrosion and hydriding processes with a combination of spatial, elemental and angular resolution not previously available.

Zirconium alloys have been used for over fifty years, as the constituent materials of nuclear fuel cladding, fuel assemblies and of reactor internal components. The performance of these alloys has been very good, in spite of the harsh conditions encountered in the reactor core environment, including a high temperature corrosive coolant and high irradiation fields. Both during normal operation and during postulated accident scenarios, these alloys have shown good behavior, and much experience has been accumulated over exposures of 30-40 GWd/ton (corresponding to 10-20 dpa)[1, 2].

More recently, however, utilities and fuel vendors have been pushing towards higher burnups, and longer fuel cycles[3]. These higher burnups entail longer exposures, with concomitant increases in irradiation doses and in corrosion levels, if the corrosion rate remains the same. Moreover, changes in coolant chemistry (some mandated by the increased burnup) and increased incidence of boiling in PWRs, have also the potential of increasing corrosion rates and associated levels of hydriding. This entails in effect more severe fuel duty, even as performance requirements are made more stringent. Because such changes in fuel duty can cause enhanced in service degradation of these alloys, it is essential to understand mechanistically the degradation and failure processes, so that safe and economic operation of these alloys can be ensured. It is important to note that many of these processes are interlinked. Thus radiation damage to the cladding and associated microstructure changes can influence corrosion rates, or dimensional instability. The greater incidence of hydriding has also been proposed as potentially causing greater rates of dimensional change and accelerating the oxide transition.

Some of these issues will be reviewed in this talk, which will emphasize that in spite of the basic nature of some of the fundamental questions and intense study over the last fifty years, mechanistic understanding is still lacking, for example in what makes an alloy better than another with respect to processes such as corrosion, hydriding and irradiation growth. The use of advanced characterization techniques such as synchrotron radiation diffraction and fluorescence, transmission electron microscopy has been used to attempt to address some these fundamental questions, and allow the development of even better alloys capable of superior performance [4, 5].

References

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