RADIATION DAMAGE FROM DIFFERENT PARTICLE TYPES

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1. INTRODUCTION

In the 1960s and 70s, heavy ion irradiation was being developed for the purpose of simulating neutron damage in support of the fast breeder reactor program. [1-3] Ion irradiation and simultaneous He injection have also been used to simulate the effects of 14 MeV neutron damage in conjunction with the fusion reactor engineering program. Lately, the application of ion irradiation (defined here as any charged particle, including electrons) to the study of neutron irradiation damage is being revisited by the light water reactor community in an effort to solve the irradiation assisted stress corrosion cracking (IASCC) problem. [4-6], as additionally, ion irradiation is being used to understand performance in reactor pressure vessel steels, Zircaloy fuel cladding, materials for advanced reactor concepts in the GenIV program and materials for the advanced fuel cycle initiative, AFCI. While the environment plays a role in IASCC, the appearance of a “threshold” fluence demonstrates that the observed behavior is strongly related to irradiation-induced changes in the alloy that may involve microstructural changes, microchemical changes, transmutation, or some synergistic combination of these effects.

Clearly there is significant incentive to use ion irradiation to study neutron damage as this technique has the potential for yielding answers on basic process in addition to the potential for enormous savings in time and money. The nature of performing neutron irradiation experiments is not amenable to studies involving a wide range of conditions, which is precisely what is required for investigations of the basic damage processes. Simulation by ions allows easy variation of the irradiation conditions.
Regarding cost and time, typical neutron irradiation experiments in test reactors require 1-2 years of exposure in core. However, this is accompanied by at least another year of capsule design and preparation as well as disassembly and cooling. Analysis of microchemical changes by Auger electron spectroscopy (AES) or microstructural changes by energy dispersive spectroscopy via scanning transmission electron microscopy (STEM) and mechanical property or stress corrosion cracking (SCC) evaluation can take several additional years because of the precautions and special facilities and instrumentation required for handling radioactive samples. The result is that a single cycle from irradiation through microanalysis and mechanical property/SCC testing may take between 4 and 6 years. Such a long cycle length does not permit for iteration on irradiation or material conditions that is a critical element in any experimental research program. It also requires the stability of financial support for periods of at least 5 years, which is often difficult to guarantee. Because of the long cycle time, the requirement of special facilities and special sample handling, the costs for neutron irradiation experiments are very high.

In contrast to neutron irradiation, ion (heavy ions, light ions or electrons) irradiation enjoys considerable advantages in both cycle length and cost. Ion irradiations of any type rarely require more than a few tens of hours to reach 1-5 dpa levels. Irradiation produces little or no residual radioactivity allowing handling of samples without the need for special precautions. These features translate into significantly reduced cycle length. For instance, samples of 304 SS have been irradiated with protons to 1 dpa, the grain boundary composition was characterized via AES, the microstructure was characterized via STEM-EDS and constant extension rate tensile (CERT) experiments were conducted in 288°C water to determine IASCC susceptibility, all in a time period of 3-4 months! Analysis of results indicated the need for another experiment in which the alloy composition was slightly modified in order to isolate the effect of impurities, which could not have been foreseen. This next experiment (iteration) was conducted over the course of the next 3-4 months. The rapidity of the technique allows for several such iterations in the course of a year! In terms of cost, on a per sample basis, ion irradiation is about 1/100 the cost of neutron irradiation and requires less than 1/10 the time. If one considers the cost of obtaining the same amount of information over a common time period, then the cost per data point by ion irradiation is approximately 1/100 x 1/10 or 1/1000 of that for neutron irradiation. The magnitude of the savings is something that can’t be ignored. The challenge is then to verify the equivalency of the results of neutron and ion irradiation.