ON ISOTOPIC ALLOYING TO TAILOR HELIUM PRODUCTION RATES
IN MIXED-SPECTRUM REACTORS*

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The insoluble inert gas helium has been found to produce significant changes in the irradiation response of structural materials when introduced at levels in the appm range and above. In the structural materials for future fusion reactors, (n, α) transmutation reactions induced at a high rate by the 14 MeV component of the neutron spectrum will lead to helium production rates of the order of 10 appm/dpa. However, until a fusion reactor is available, materials scientists must study radiation effects, including the interactions with helium, by means of accelerator and fission reactor irradiations.

Displacement dose rates comparable to those of fusion reactors can be achieved in high flux fission reactors like the fast spectrum Fast Flux Test Facility (FFTF) and mixed-spectrum reactors like the High Flux Isotope Reactor (HFIR). However, the helium transmutation rates per dpa in fast reactors are always too low compared to those of fusion reactors. This is also usually the case for irradiations in mixed-spectrum reactors. However, there are exceptional cases in mixed spectrum reactors. For example, in alloys containing nickel, the slow component of the neutron spectrum leads to a two-step reaction that produces helium at high rates,

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In stainless steels containing about 15% nickel irradiated to high doses in HFIR, this reaction leads to helium contents about an order of magnitude higher than is expected in a fusion reactor.

Recently, we described an approach that allows helium generation to be varied very widely, spanning the fusion reactor levels of interest, in nickel bearing alloys of identical chemical composition, during side by side irradiations in mixed spectrum reactors [1]. Here we briefly summarize this paper. We term the method isotopic alloying. The idea is to systematically deplete or enrich ^{58}Ni during alloy fabrication in favor of ^{60}Ni or other stable isotopes of nickel that do not have high cross-sections for helium production, while maintaining the overall nickel chemical composition constant. A general analysis for helium production by isotopic alloying was presented, followed by specific calculations covering the case of nickel. Several planned experiments for irradiation in HFIR were analyzed. Related approaches to isotopic tailoring have been described recently by several authors [2-4].

Figure 1 shows an example of the results calculated. The alloy is a 300 series stainless steel labeled PCA. The three curves (top to bottom) correspond to cases where the contained nickel is, respectively, fully enriched in ^{58}Ni , unchanged from the naturally occurring level of 68% and depleted in favor of ^{60}Ni to a level of 17% ^{58}Ni .

More generally, three types of experiments can be identified where isotopic alloying would be useful in radiation effects research. These relate to studies of mechanisms, to applied research for fusion reactor applications, and to novel experiments to encompass alloys that do not normally contain nickel. The first type of experiment addresses the

physical bases of helium effects and may be formulated based on the theory of radiation effects. The second type aims to characterize helium effects in parameter regimes and materials of direct interest for fusion reactor applications. The novel experiments involve introducing nickel to produce helium in materials that do not normally contain nickel. Both isotopic controls containing the same fraction of nickel but depleted in ^{58}Ni , and compositional controls containing no nickel are to be irradiated simultaneously. In this way, the effects of helium on the material should be separable from the effects of nickel on the physical metallurgy of the alloy systems.

We are also examining a helium injection method that again employs isotopic dilution of ^{58}Ni with ^{60}Ni but does not involve any direct manipulation of the isotopic or chemical composition of the specimens of interest. Nickel (or nickel-bearing) injector materials that are isotopically tailored to suit the study at hand are interposed between specimens of the material where helium effects are to be investigated. During mixed spectrum irradiations, some of the 4.7 MeV helium generated by the $^{59}\text{Ni}(n,\alpha)^{56}\text{Fe}$ reaction in the injectors will be implanted into the neighboring specimen to a typical range on the order of 10 μm depth in structural materials of interest. This technique offers control material within the same specimen beyond the range of the α -particles, where conditions should be otherwise identical. There is thus no need to alloy the materials of interest with nickel, where this might alter the physical metallurgy of the alloy. The injectors are also innocuous

prior to irradiation and can be made compatible at high temperatures with a wide variety of materials. Other advantages and disadvantages are discussed more fully elsewhere [5]. Electron microscopy and other techniques can then be used to examine the effects of microstructural and microcompositional evolution produced by irradiation both within and outside the region of helium deposition. Such a technique may prove to be a significant application of the isotopic alloying method that is described in detail in Ref. [1].

REFERENCES

1. L. K. Mansur, A. F. Rowcliffe, M. L. Grossbeck, and R. E. Stoller, "Isotopic Alloying to Tailor Helium Production Rates in Mixed-Spectrum Reactors," J. Nucl. Mater. 139 (1986) in press.
2. Ch. De Raltdt, Proc. Conf. on Fast, Thermal and Fusion Reactor Experiments, April 1982, Salt Lake City, Utah (American Nuclear Society, 1982) p. 2-336.
3. R. L. Simons, U. S. Department of Energy Damage Analysis and Fundamental Studies Quarterly Progress Report (February 1983) DOE/ER-0046/12.
4. G. R. Odette, "Isotopic and Spectral Tailoring Techniques to Simulate Fusion Environments in Fission Reactors," this conference.
5. L. K. Mansur, to be published.

FIGURE CAPTION

Calculated helium accumulation in the 300 series stainless steel PCA which contains 16% nickel. From top to bottom the curves show results for 100%, 68% (natural nickel) and 17% enrichment of ^{58}Ni .

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Fig 1, Mansur et al.