# Lower Length Scale Characterization and Validation of Formation and Stability of Helium Bubbles in Nano-structured Ferritic Alloys under Irradiation

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**ABSTRACT:**

**Background** Safety and durability of the advanced structural materials are the two major issues during the design and development of the cladding material in the light water reactor (LWR) nuclear energy applications. As a promising advanced oxide dispersion strengthen iron alloy, 14YWT [1] with oxygen enriched nanoclusters has exhibited excellent strength and hardness at both room and elevated temperatures [2], low creep rate at 650˚C-900˚C (reduced by six order of magnitude [3]) and a high resistance to irradiation [4-7]. The helium bubbles induced by irradiation remain the ultrafine size (~1nm in diameter), mitigating the swelling degradation of the material. Accordingly, it becomes a potential candidate to serve as cladding material of LWRs, extending the burn-up limits with the tolerant temperature up to 800˚C. Moreover, compared with the current cladding material Zircaloys, 14YWT can reduce the impacts of hydrogen generation to avoid possible hydrogen explosions during accidents (such as the hydrogen explosion during the Fukushima accident). Thus the application of 14YWT can improve both economical and safety sides of LWR operations. However, the formation and stability mechanism of these ultra-fine helium bubbles is not clearly understood due to the atomic structure complexity of the nano-clusters within 14YWT and the computational/experimental limitations.

**Objectives** This research will provide a fundamental knowledge about the formation and stability of ultra-fine helium bubbles within 14YWT after neutron/ion irradiation. The specific scientific goals are: (1) propose a theoretical model to elucidate the formation mechanism of helium bubbles within the iron matrix through the energetic study by first principles theory calculations; (2) investigate the formation and stability criteria of helium bubbles under various temperature and strain conditions by energetic study of first principles theory calculations; and (3) validate the theoretical model by characterizing the size and distribution of helium bubbles through STEM and EESL techniques. With this study, we will provide a fundamental understanding about the formation and stability of helium bubbles within 14YWT as well as a full data matrix that can be used to expend the current material library of BISON.

**Merit and Impact** The study of 14YWT can provide a novel and fundamental knowledge for further design of new advanced structural materials with a characteristic high density nanoparticles feature which can increase the mechanical strength, hardness, irradiation resistance, and the operational temperature range of materials. With the data matrix generated in this research, BISON can be easily extended to include this material as one of the cladding materials for design and optimization of current LWRs and future fusion energy. Finally, the high temperature strength, stability and irradiation resistance make 14YWT a potential cladding material for current LWRs. Even though the working temperature of LWR is around 300oC, the high temperature strength and stability of 14YWT as a cladding material can bring us more time and opportunity during the accident situation to minimize the damage and prevent the severe disaster from happening. In the long term, to optimize 14YWT for in-core use will allow utilities to operate their reactors with greater efficiency and lower maintenance, inspection and repair costs.

**Reference** [1] D.T. Hoelzer, *et al., Journal of Nuclear Materials*, **367-370**, 166-172. [2] M.K. Miller, *et al.*, Intermetallics **13**:387 (2005). [3] R. L Klueh, *et al*., J. Nucl. Mat. **307-311**:773 (2002). [4] M. K. Miller, *et al*. J. Nucl. Mat. **418**:307 (2011). [5] M.K. Miller *et al*., Mater. Sci. Eng. A **353**:140 (2003). [6] S. Yamashita, *et al*. J. Nucl. Mat. **329-333**:377-381 (2004). [7] G.R. Odette, *et al*. J. Nucl. Mat. **417**:1001-1004 (2011).