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Hydride reorientation in fuel cladding under interim storage conditions with low hoop stress

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Abstract. The restart of the search for a final repository for high-level nuclear waste in Germany and the resulting so-called white map lead to a reassessment of the safety of interim storage as well. Due to the resulting increase in interim storage periods with a prospected timescale until 2068, among other things, renewed consideration of cladding tube integrity is required for the handling of the fuel assemblies during repackaging into the final storage containers. Besides oxide formation during operation, hydrides can have a negative influence on stability during interim storage and handling later on. The hydrides, which are initially precipitated tangentially in the tube material during operation, can reorient during interim storage as a result of the temperature and load history and precipitate again in a radial direction during cooling under load. In recent years, a number of investigations have already been carried out with respect to this topic, with cladding conditions that are present in high burn-up fuel assemblies with corresponding high hydrogen contents. In these cases, reorientation effects did occur with stresses that can be encountered in interim storage, but the proportions of radial hydrides were very low and were classified as not being harmful. In addition to the tests with cladding tubes containing high hydrogen contents, sporadic tests with low hydrogen contents were also carried out, for example, by Hardie and Shanahan (1975) and later by Chu et al. (2008). These indicated that strong reorientation effects could occur because of the complete dissolution of hydrogen under high temperature and tensile stress. In recent years, Kaufholz et al. (2018) also formulated a hypothesis that describes this effect as being the consequence of free nucleation without the presence of precipitates. This results in the possible formation of extremely pronounced radial hydrides, which can even extend through the tube wall. This is possible because residual hydrides that can hinder free precipitation or represent preferential points for nucleation are absent. The results of the present investigations confirm this behaviour. They show that massive reorientations can already occur at stresses at the lower end of the literature values and that, until now, these reorientations were interpreted as being uncritical. Considering the hysteresis in solubility between terminal solid solubility for dissolution (TSSD) and precipitation (TSSP), it becomes apparent that precipitation at hydrogen contents of 100 ppmw (parts per million by weight) already starts at approx. 538 K and that the hydrides precipitate radially under a stress of 52 MPa and form extremely pronounced hydrides. This results in a need for further research, since the thermal and mechanical loads under which the tests were carried out are well below the permissible limit loads in interim storage and below the values expected so far. This applies in particular to materials and cladding tubes that either absorb less hydrogen during operation or have only low burn-ups. The study provides an overview of the status quo, presents part of the investigations carried out during the project MUDZ (Modellierung und Untersuchung der Degradation von Hüllrohrmaterialien aus Zr-Legierungen durch Hydridbildungs- und Hydridverteilungsprozesse im Hinblick auf die Langzeitzwischenlagerung) in the KEK (Kompetenzerhalt in der Kerntechnik) initiative and the results obtained, and discusses the ramifications of the results.

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