International efforts are underway to develop a fuel with a higher uranium density in order to convert the highly enriched U fuel, currently used in research and test reactors, into a fuel of lower U enrichment. U-Mo alloy embedded in an Al matrix (UMo/Al) is considered as the most promising high-density fuel for the fuel conversion [1]. However, in-pile irradiation reveals a growth of an amorphous interdiffusion layer (IDL) at the UMo/Al interfaces which strongly degenerates the irradiation performance, e.g. fuel swelling, a decrease of thermal conductivity [2]. Therefore, it is essential to investigate the interdiffusion reactions of UMo/Al fuel and suppress the severe interdiffusion by fuel modifications. Mg is considered as alternative matrix material because it is thermally immiscible with both U and Mo, so that the interaction induced during the hot fabrication process can be limited. Furthermore, its low thermal neutron cross-section is comparable to that of Al [3]. The stability of UMo/Mg fuel was tested by swift heavy ion (127I at 80 MeV) irradiating on an UMo/Mg bilayer. Post-irradiation examination µ-XRD was executed at the beamline P06 of the synchrotron source PETRA III. Data sets were acquired in transmission mode using a 21 keV monochromatic X-ray beam. The beam size was 0.4 \times 0.5 \mu m^2 with an exposure time of 20 seconds per scan. The obtained diffraction patterns were analysed with Rietveld refinement. XRD patterns of the UMo/Mg bilayer irradiated at 200°C are presented in Figure 1. The XRD pattern of Figure 1A taken at the UMo region shows three phases: UMo (space group symmetry: Im-3m) with a = 0.3413(3) nm, UO₂ (Fm-3m), and Cu. As shown in Figure 1B, the broadening of Debye-Scherrer rings points out its poor crystalline state after irradiation. The XRD pattern at the interface of the UMo/Mg bilayer consists of a new phase \( \text{U}_{0.9}\text{Mg}_{0.1} \) alloy in BCC structure with a = 0.3131(1) nm and Cu from the grid. Indexing of μ-XRD pattern allowed a body-centered cubic (BCC) structure and the subsequent Rietveld analysis confirmed the stoichiometry \( \text{U}_{0.9}\text{Mg}_{0.1} \). This result demonstrates that UMo-Mg thermally interaction has been minimized due to the immiscibility but this immiscible system can be alloyed by swift heavy ion irradiation.

Figure 1: observed (open circles) and calculated (solid line) μ-XRD patterns of (A) the UMo region and (B) the interfacial region of UMo/Mg bilayer irradiated at 140°C. The flat discrepancy profiles given at the bottom in (A) and (B) demonstrate well-performed Rietveld calculations with all identified phases (bars) at the UMo layer and at the interface.
On the other hand, during the manufacturing process of the fuel elements, a decomposition of the γ-phase into the thermal equilibrium or α-phase takes place and this might lead to a degeneration of fuel performance. Therefore, a study on the isothermal transformation kinetics of an U8wt%Mo alloy at temperatures between 400°C and 525°C has been performed. The annealed samples were characterized at room temperature by high-energy X-Ray diffraction (HE-XRD at the beamline P07 of the synchrotron source PETRA III). Data sets were acquired in transmission mode using a 100 keV monochromatic X-ray beam. The beam size was $2 \times 2 \, \mu m^2$ with an exposure time of 20 seconds per scan. Figure 2 shows two exemplary Rietveld refined diffraction patterns obtained with HE-XRD. The diffraction patterns show the decomposition of the γ-UMo into its thermal equilibrium microstructure, α-U and U$_2$Mo. Figure 2A demonstrates that the decomposition began after 3 h of annealing compared to a fresh sample. After annealing 16 h at a temperature of 475°C, the decomposition reached an advanced stage (Figure 2B). Quantitative information on the crystallographic composition of heat-treated samples is listed in Table 1. This result points out that the γ-UMo decomposition might happen during the fabrication process of UMo fuel plate, which takes place at temperatures between 425 – 475 °C.

![Figure 1](image-url)  
Figure 1: (A) γ-UMo decomposition after annealing at 475°C for 3 h; (B) γ-UMo decomposition after annealing at 475°C for 16 h

<table>
<thead>
<tr>
<th>annealing duration</th>
<th>γ-UMo-a</th>
<th>γ-UMo-b</th>
<th>U$_2$Mo</th>
<th>α-U</th>
<th>UC</th>
</tr>
</thead>
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<tr>
<td>3 h</td>
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<td>20.32</td>
<td>5.56</td>
<td>18.38</td>
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<tr>
<td>16 h</td>
<td>16.30</td>
<td>22.02</td>
<td>22.27</td>
<td>38.35</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Table 1: Crystallographic composition of U8wt%Mo at 475 °C (γ-UMo-a denotes the initial γ-phase and γ-UMo-b represents a molybdenum enriched γ-phase)

References