# Development of Hydration Resistant Gadolinium-based Burnable Absorber

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## 1. Introduction

In pressurized water reactors (PWRs), reactivity is mainly controlled by control rods, soluble boron, and burnable absorbers [1]. Burnable absorbers such as $B_4C$, $ZrB_2$, erbia, and gadolinia are neutron-absorbing materials consumed during the fuel cycle, reducing excess reactivity at the beginning of operation [2]. When boron is used in the form of soluble boric acid, increasing boron content can cause a positive moderator temperature coefficient (MTC), which threatens the inherent safety of the reactor. In addition, boron dissolution requires time, making load-following operation difficult. Therefore, low-boron or boron-free concepts have been proposed to enhance both safety and load-following capability.

Due to the high neutron absorption cross-section of gadolinium, gadolinia-based materials have been considered for achieving low-boron or boron-free operation in power plants and small modular reactors (SMRs). However, gadolinia reacts with water under the high-temperature and high-pressure conditions of PWR, leads to swelling and cracking, limiting the applicability of $UO_2$-gadolinia composite fuels [3]. Previous studies attempted to mitigate hydration or dissolution issues by introducing Gd-based compounds such as $GdAlO_3$ [4]. Mixing more than 50 mol% $Al_2O_3$ with gadolinia, a stable perovskite phase can be formed, which suppresses phase transformations and hydration under high-temperature and irradiation conditions. However, the formation of such intermediate phases reduces the Gd content by at least 50% compared to pure gadolinia, thereby lowering the neutron absorption cross-section and reactivity control capability.

This study aims to control the dissolution behavior of gadolinia-based burnable absorbers by doping small amounts of additive elements. Through such minor doping, we aimed to control hydration resistance while minimizing the loss of neutron absorption performance. Gadolinia samples with different dopant types and concentrations were synthesized, and their crystal structures and hydration resistance were systematically evaluated.

## 2. Methods and Results

### *2.1 Fabrication of doped gadolinia burnable absorber*

To investigate the dissolution behavior of gadolinia with varying dopant elements and compositions, doped $Gd_2O_3$ pellets were fabricated. Candidate dopants were selected based on phase diagram considerations and previous reports [4-6] of stable Gd-based compounds, including $Al_2O_3$, $ZrO_2$, Nb2O5, and $TiO_2$. In addition, rare-earth oxides such as $CeO_2$, $Y_2O_3$, $Dy_2O_3$, $Eu_2O_3$, and $Er_2O_3$ were chosen by applying the Hume–Rothery criteria, considering factors such as ionic radius, valence, and crystal structure, as well as their relative basicity. The specimens with different dopant types and concentrations were then synthesized using a conventional sintering process at 1600°C for 10 hours.

### *2.2 Phase analysis*

crystal structure, as well as their relative basicity.

X-ray diffraction (XRD) analysis was performed on the fabricated burnable absorbers to examine their phase composition. Pure gadolinia is known to undergo an irreversible transformation from the cubic to the monoclinic phase at approximately 1250°C. As a result, under the typical nuclear fuel sintering temperature, which generally exceeds 1700°C, gadolinia tends to form a monoclinic structure. In contrast, when doped with certain oxide elements, the formation of solid solutions was observed, which contributed to the stabilization of the cubic phase.

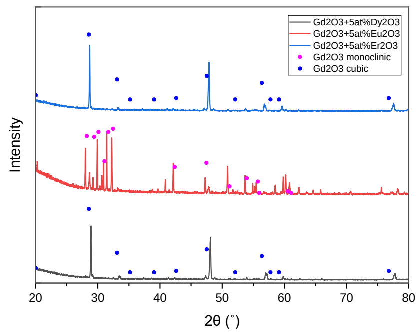


Fig. 1. XRD results for REO doped gadolinia burnable absorber

*2.3 Dissolution analysis*

To evaluate the dissolution behavior of the fabricated burnable absorbers, high-temperature and high-pressure autoclave tests were carried out. The specimens were exposed to water at temperatures up to 350ºC and pressures up to 15MPa. Hydration resistance was examined by observing phase changes and identifying hydrated phases, while the concentration of dissolved Gd ions in the solution was measured using inductively coupled plasma mass spectrometry (ICP-MS). Based on the XRD data and dissolution data, the hydration resistance was assessed as a function of dopant type and composition.

Fig. 2. Autoclave test results on pure $Gd_2O_3$ and 15at.% $CeO_2$ doped $Gd_2O_3$

## 3. Conclusions

This study focused on preventing the hydration and subsequent dissolution of gadolinia burnable absorbers through minor oxide doping. Phase and dissolution analyses were carried out on the fabricated samples. XRD results showed that stable cubic phases could be obtained with the addition of specific oxide elements. Autoclave tests further demonstrated that small amounts of oxide doping effectively suppressed hydration. In particular, Ce and Zr stabilized the gadolinia crystal structure from monoclinic to cubic, while their smaller cation radii and tetravalent state reduced basicity, thereby inhibiting hydration.

This work contributes to enhanced fuel safety and supports the development of advanced nuclear fuels.

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