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# Metallic Fuel Slug prepared by a Modified Injection Casting Method for Reducing Volatilization

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Metallic fuels, such as the U-Pu-Zr alloys, have been considered as a nuclear fuel for a sodium-cooled fast reactor (SFR) related to the closed fuel cycle for managing minor actinides and reducing the amount of highly radioactive spent nuclear fuels since the 1980s. Management of minor actinides (MA) became an important issue because direct disposal of the long-lived MA can be a long-term burden for a tentative repository up to several hundreds of thousand years. In order to prevent evaporation of volatile elements such as Am, one of the main MAs, and improve the quality of fuel slugs, U-Zr alloy fuel slugs were fabricated through a modified injection casting method instead of a vacuum injection casting method, which is a method of fabricating a metallic fuel slug conventionally by modifying the casting process conditions.

***Keywords:*** *Metallic fuel, sodium-cooled fast reactor, injection casting, U-Zr alloys.*

## 1. Introduction

The fabrication technology of metal fuel for an SFR has been under development in Korea as a national nuclear R&D program since 2007 [1]. Although injection casting has been a well-established fabrication method for metal fuel for decades, Am addition to the metal fuel hampers conventional fuel fabrication processes because of the high vapor pressure of Am at the melting temperature of the uranium alloys. In this study, a fuel slug fabrication method has been introduced to develop an innovative fabrication process of metal fuel of an SFR for preventing the evaporation of volatile elements such as Am. Metal fuel slugs were fabricated using an improved injection casting method in KAERI. Volatile species can be retained through the use of a cover gas with over pressure, covered crucibles, and short cycle times under this fuel fabrication method, and melted under an inert atmosphere [2].

## 2. Experimental procedure

The feasibility of an improved injection casting method including melting under an inert atmosphere was evaluated in a small-size induction-melting furnace. For a preliminary test, pure copper was selected as a surrogate material, which has a melting temperature similar to uranium. After a surrogate fuel slug was generally soundly cast by the improved injection casting method under an inert atmosphere, fuel slugs in U-Zr alloy by improved casting method have been successfully fabricated in KAERI for the prevention of evaporation of volatile elements such as Am.

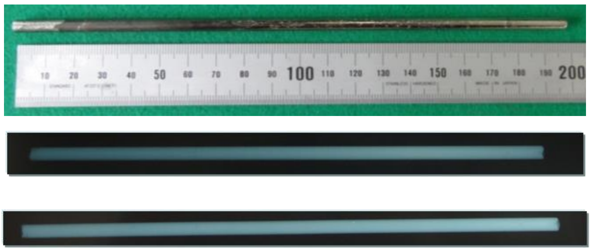

Fig. 1 Typical U-10Zr-5Mn fuel slug (upper), gamma-ray radiography at 0 degrees (middle) and gamma-ray radiography at 90 degrees (bottom) (#S13-06).

## 3. Experimental results and discussion

Through the experience of the surrogate fuel slug, U-10wt.%Zr-5wt.%Mn fuel slugs containing a volatile surrogate element, Mn, shown in Fig. 1, were soundly cast by improved injection casting for the prevention of evaporation of volatile elements such as Am under various atmospheres such as a vacuum state, reduced atmosphere, and an inert atmosphere. The gamma-ray radiography of the as-cast surrogate slug was performed to detect internal defects such as cracks and pores. The general appearance of the slug was smooth, and the diameter and length were 5.4 mm and about 200-250 mm, respectively. The density variations according to the location of the fuel slugs are shown in Fig. 2.

The melting and casting parameters of the fuel slug casting process such as the melting batch size, coating method, melting and casting temperature, and mold pre-heating temperature were investigated to obtain the sound fuel slugs.

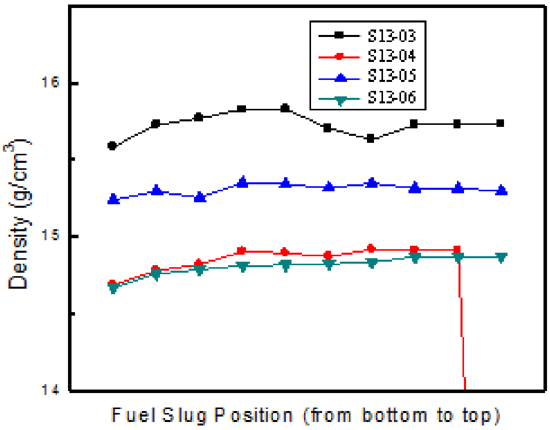


Fig. 2 Alloy density of U-10Zr fuel pins prepared by injection casting method.

The density of the fuel pins prepared using an injection casting method shows a different way in accordance with the casting process conditions. The U-10Zr (#S13-03) fuel pins in which the surrogate Mn for volatile radioactive constituents was not added showed the highest density because of the lighter density of Mn elements, but the others such as U-10Zr-Mn (#S13-04, #S13-05, #S13-06) by adding an equal amount of Mn elements such as 5wt,% showed a difference owing to the conditions of the casting process. The density of the fuel pins in an inert atmosphere (#S13-06) showed the lowest value, which means the lowest evaporation because of the consumption of light elements. However, the U-10Zr-Mn fuel pins (#S13-04) for a reduced atmosphere in which a vacuum was applied for a short time showed a higher density even when the volatile amount of Mn was small compared to the other casting method. The U-10Zr-Mn fuel pins (#S13-05) in a vacuum state showed the highest density because of a high evaporation.

The alloy compositions of U-10 wt.%Zr-5 wt.%Mn fuel slugs are shown representatively in Table 1. From the variations of Mn compositions, the same trend was observed as the density results. Based on these results there is a high level of confidence that Am losses will also be effectively controlled by application of a modest amount of overpressure.

These limited experiment results show that the Mn was not volatilized and conserved in the inert gas conditions compared to the vacuum condition. The volatility of Mn can be controlled by changing the casting process, and minimal Mn (and Am) loss is possible. An improved casting method under an inert atmosphere is more effective in the prevention of vaporization than casting under a vacuum and reduced atmosphere. In addition, improved casting under a reduced atmosphere shows a considerable effect on the prevention of vaporization.

Table 1 Alloy compositions of U-10Zr fuel slugs (#S13-06).

| | | U (wt.%) | Zr (wt.%) | Mn (wt.%) | C (ppm) | O (ppm) | N (ppm) |
|---|---|---|---|---|---|---|---|
| Upper | 1 | 85.2 | 10.7 | 5.10 | 70 | 480 | 10 |
| | 2 | 84.9 | 10.7 | 4.99 | 70 | 500 | 10 |
| (g/cm$^3$) | 3 | 84.7 | 10.6 | 5.11 | 60 | 510 | 10 |
| Middle | 1 | 86.0 | 10.5 | 4.96 | 50 | 610 | 10 |
| (g/cm$^3$) | 2 | 84.0 | 11.0 | 5.08 | 70 | 340 | 10 |
| | 3 | 85.5 | 10.5 | 5.02 | 60 | 770 | 10 |
| Bottom | 1 | 84.4 | 10.5 | 5.04 | 60 | 1190 | 10 |
| (g/cm$^3$) | 2 | 84.1 | 10.8 | 5.02 | 90 | 820 | 10 |

## 4. Conclusion

In order to prevent the evaporation of volatile elements such as Am, a fabrication method of metal fuel slugs was examined using an improved injection casting method. U-10wt.%Zr and U-10wt.%Zr-5wt.%Mn fuel slugs were soundly fabricated for the retention of the volatile surrogate element. Based on these results, there is a high level of confidence that Am losses will also be effectively controlled by the application of a modest amount of overpressure. The Mn element was almost recovered with the prevention of evaporation. It was seen that the losses of these volatile elements such as Am can be effectively controlled to below the detectable levels using modest argon pressure.

## References

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