A Very High Uranium Density Fission Mo Target Suitable for LEU Using atomization Technology

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1. Introduction

Currently HEU minimization efforts in fission Mo production are underway in connection with the global threat reduction policy [1]. In order to convert HEU to LEU for the fission Mo target, higher uranium density material could be applied [2]. The uranium aluminide targets used world widely for commercial ^{99}Mo production are limited to 3.0 g-U/cc in uranium density of the target meat [3]. A consideration of high uranium density using the uranium metal particles dispersion plate target is taken into account. The irradiation burnup of the fission Mo target are as low as 8 at.% and the irradiation period is shorter than 7 days [2]. Pure uranium material has higher thermal conductivity than uranium compounds or alloys. It is considered that the degradation by irradiation would be almost negligible.

In this study, using the computer code of the PLATE developed by ANL the irradiation behavior was estimated. Some considerations were taken into account to improve the irradiation performance further. It has been known that some alloying elements of Si, Cr, Fe, and Mo are beneficial for reducing the swelling by grain refinement. In the RERTR program recently the interaction problem could be solved by adding a small amount of Si to the aluminum matrix phase. The fabrication process and the separation process for the proposed atomized uranium particles dispersion target were reviewed.

2. Suggestion of A Very High Uranium Density Plate Target

In connection with converting HEU to LEU a higher uranium density material has been requested as a candidate of fission Mo target to secure the fissionable material of ^{235}U. From the density point of view pure uranium is best for LEU fission target material. The uranium density of pure uranium metal is 19.05 g/cm^3, which is 4.2 times higher than uranium density of UAlx. It was reported that the uranium density of the fission Mo target in South Africa is about 3.0 g-U/cm^3 [3].

In KAERI, the atomization technology for producing uranium silicide as well as U-Mo powders had been developed in 1990s. In the mean time some pure uranium metal powder has been produced many times to provide for advanced nuclear fuel development. So it is considered that the pure uranium metal powder can be supplied without any difficulties.

The fabrication process of the UAl plate target was reported as in Fig. 1 [5]. If fission Mo target meat is supposed to be atomized uranium particles dispersion, atomized U metal powder is mixed with aluminum powder and pressed to a compact using a forming die. The compact is loaded in the space between the frame and cover plates of the upper and bottom sides as in the dispersion plate fuel fabrication process for research reactor. The other steps are almost the same as the fabrication process of the UAl plate target. It is considered that the process of the atomized particles dispersion plate target could be established with some modification.

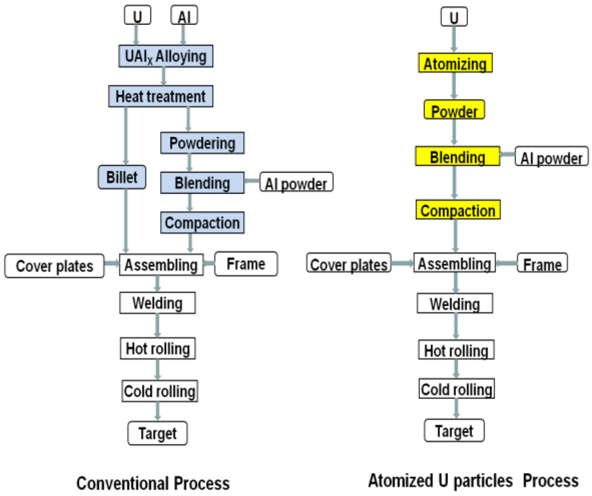

Fig. 1. Comparison for the fabrication processes of UAlx plate target and atomized particles dispersion plate target

Atomized uranium particles tend to have a spherical shape. In general the spherical particles powder has better plasticity in rolling work than irregular particles powder due to a smooth surface. The average fabrication porosity in fuel meat dispersed with atomized particles appeared to be as small as less than 3 Vol.% from the better plasticity [5]. The average volume of U_3Si_2 dispersion fuel by rolling work was about 45 Vol.%. The maximum volume fraction of dispersion fuel was reported to be about 50 Vol.%[6]. If the volume fraction is supposed to be 50 Vol.% in case of atomized spherical particles powder, the highest available uranium density would be 9.2 g-U/cm^3. When the HEU fission Mo target of 1.5 g-U/cm^3 is converted to LEU, a LEU uranium density of more than 7.5 g-U/cm^3 is required. It is considered that the atomized U metal particles dispersion plate target of more than 9.0 g-U/cm^3 would be applicable.

3. Estimation on target temperatures during irradiation

The major degradation of the target is swelling. Uranium metal especially is very weak in temperature. Accordingly the target center temperature was calculated by using the PLATE computer code developed by ANL by supposing that the heat flux and cooling water speed are 250 W/cm^2.and 6 m/sec, respectively. The average thermal conductivity of atomized particles dispersion was calculated to be 85 W/m-K. The temperature increases for the uranium particles dispersion target with a thickness of 1.0 mm and cladding with a thickness of 0.3 mm were calculated to be 4.5 ℃ and 1.5 ℃. The temperature increase at the interface between the cladding and the coolant water was about 25 ℃. When the coolant temperature at the outlet is supposed to be 40 ℃, the peak temperature at the target center is estimated to be 71 ℃. It is considered that these values are negligible from the aspect of affecting the thermal inducing swelling. It is considered that these values have enough safe margins from the aspect of affecting the thermal inducing swelling. The center temperature of about 71 ℃ is presumed to be too low to induce an interaction at the interface between the uranium particles and the aluminium matrix.

4. Application of Other Fuel R&D Experiences to improve Dispersion Target Performance

In uranium metal fuel the irradiation behaviour could be improved by alloying some elements of Fe, si, Al, Cr, and Mo [6]. The irradiation test could be extended to greater than 10,000 MWd/t at temperature up to 400 ℃. The fission Mo target is irradiated less than 8 at% burnup, which is approximately equivalent to 15,000 MWd/t. As shown above, the fission target temperature is much lower than the metal fuel temperature due to very thin thickness. The irradiation period of the fission target in the reactor is much shorter than that of research reactor fuel. It is considered that the integrity of the atomized uranium particles dispersion target could be maintained up to the aiming irradiation.

The uranium particles containing those kinds of alloying elements can be easily made by adding the alloying elements into the atomization crucible. The atomization process has an advantage of a very rapidly solidification in forming particles. So the grains inside the particles are very fine. The grain sizes for atomized U particles were measured to be a few microns while the grain sizes of the uranium common cast ingot were measured several hundred microns. It would be possible not to add the grain refining alloying elements.

In developing U-Mo dispersion fuel for high performance research reactors an interaction problem between dispersed U-Mo particles and Al matrix occurs. A silicon addition to an aluminium matrix was found to give a good effect on retarding the interaction rate.

5. Advantages

In the aspect of the fabrication process, the existing fabricators can adapt this atomized particles dispersion process if atomized U powder is supplied effectively. The additional steps such as the mixing of u powder and Al powder and compacting are very common and proven technology in research reactor fuel fabrication. Presumably the cost could not increase much for adapting the additional steps.

In dissolving the steps for separating 99Mo from the solution, the fission target can be put into the dissolving vessel. Because the target is not opened, any leakage radioactive gas would not take place. If the aluminium matrix and cladding is dissolved by NaOH and the solution containing aluminium is decanted, aluminium material can be separated as a low level- waste. Then the remaining particles can be dissolved by HNO_3. The following steps are the same as the CITICHEM process. Most of fission products are contained in the uranium particles. The high radioactive waste would be produced as a small quantity.

6. Conclusion

Taking advantage of the atomization technology developed at KAERI, a very high uranium fission target with atomized uranium particles dispersion in aluminium matrix is taken into a consideration. The available uranium density would be more than 9.0 g-U/cm^3. The temperature increases for the uranium particles dispersion target with a thickness 1.0 mm and cladding with thickness 0.3 mm were calculated to be 4.5 ℃ and 1.5 ℃. The temperature increase at the interface between the cladding and the coolant water was about 25 ℃. It is considered that these values have enough safe margins from the aspect of affecting the thermal inducing swelling. The atomization process has an advantage of very rapidly solidifying in forming particles. So the grains inside the particles are very fine. The dispersed uranium particles containing alloying elements of Fe, Si, Al, Cr, and Mo can easily be made by adding the alloying elements in atomization process. Because the target is not opened, any leaking radioactive gas would not take place. If the aluminium matrix and cladding is dissolved by NaOH and the solution containing the aluminium is decanted, aluminium material can be separated as a low level- waste.

7. Reference

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