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# Development of doped-$UO_2$ pellets for a PCI remedy

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## 1. Introduction

Extending the fuel discharged burn-up, while enhancing the safety features is one of the major challenges to nuclear energy industries because it can reduce the maintenance and fuel cycle costs [1]. The uranium enrichment, industrial fuel cycle length and fuel discharged burn-up have been increased about 50% during the last 15 years. Increasing the burn up may lead to a faster and higher power variation such as a higher maximum power or normal operating transient (load follow). In such operating conditions, the risk of a fuel failure is related to a pellet-clad-interaction (PCI).

From a fuel pellet¡s aspect, PCI improvement can be achieved by enlarging the pellet grain size and enhancing the fuel deformation at an elevated temperature. Large grain pellet can reduce the corrosive fission gas release at high burn up. Soft pellets can lower the pressure to a cladding caused by a thermal expansion of a pellet at an elevated temperature during transient operations. So, the recent development of advanced fuel pellet materials is mainly focused on the soft pellet having large grains [2].

In this paper, we briefly review the development activities of major nuclear fuel vendors for an advanced $UO_2$ fuel pellets for the PCI remedy. The required fuel pellet properties are discussed. Some research activities in KAERI are also introduced.

## 2. $UO_2$ pellets for a PCI remedy

PCI was the major failure mechanism in BWR in the past. Introduction of liner materials resulted in a drastic reduction of such failures. However, PCI is still the important failure mechanism in BWRs. In the case of PWRs, PCI is not a major problem yet. There was no noticeable PCI failure in the US PWRs until the 90ies. However, the EPRI reported recently that fuel failure due to the PCI started to be observed in the 2000ies. Therefore, PCI resistance needs to be satisfactorily addressed in the case that it needs to operate under load follow condition or high duty in the PWRs.

In order to mitigate the PCI, nuclear fuel pellets might have following properties,

- Large grain size to reduce the fission gas release.
- High plasticity
- Resistance to the pellet chipping

The rate control process of fission gas release is the diffusion of fission gas from the grain matrix to the grain boundary. A large grain sized $UO_2$ pellet can effectively retain a corrosive fission gas such as iodine so that it enhances the mechanical property of clad materials at a high burn-up.

A faster and a higher variation of reactor power causes a rapid thermal expansion of fuel pellets and this thermal expansion loads an excessive hoop stress to the clad, thereby leading to fuel failure. Enhanced pellet deformation property of fuel pellets can mitigate the PCI and the risk of fuel failures.

Another important property is the chipping resistance of fuel pellet. The pellet chipping inside the cladding should be avoided because it provides an abnormal stress distribution on the cladding tube.

## 3. International development activities

The major nuclear fuel vendors of AREVA, Westinghouse, and GNF have been developing their own additive-doped large grain $UO_2$ pellets technology in order to improve the PCI behavior since the early 90ies.

Table 1 briefs the characteristics of developed advanced nuclear fuel pellets. The common feature between the developed pellets is using the small amounts of additives in the $UO_2$ pellet to increase the grain sizes and enhance the deformation behavior.

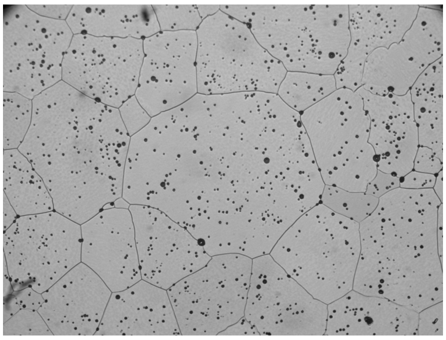
The developed pellets are planned to become a new standard for BWR fuel and is being considered for advanced PWR fuels.

Tabel. 1. Developed large grain $UO_2$ pellets

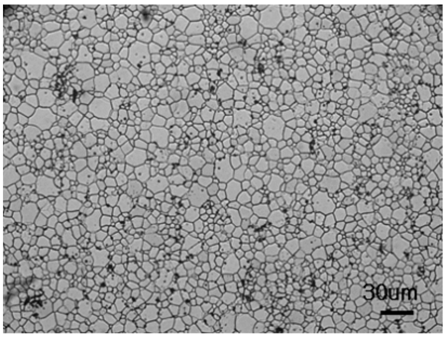
| | **Cr-doped $UO_2$** | **ADOPT** | **Additive fuel** |
|---|---|---|---|
| Vendor | AREVA | Westinghouse | GNF |
| Additives | $Cr_2O_3$ | $Cr_2O_3+Al_2O_3$ | Alumino-silicate |
| Contents | 1600ppm | 700ppm | ~2500ppm |
| Grain size | 40~50 ㎛ (1500ppm) | ~35 ㎛ | above ~20 ㎛ |

## 4. Our activity

At 2007, KAERI launched a new project of 'High Performance Fuel Technology Development'. As a part of this project, we started to develop large grain pellets by adapting an additives technology. We selected several new Mn-base binary or ternary mixed oxides as additives. Those additives were mixed with $UO_2$ powders and made to $UO_2$ pellets.



(a)




(b)

Fig. 1. Grain structure of a developed $UO_2$ pellet (a), and a pure $UO_2$ pellet (b).

Fig. 1 shows the typical grain structure of a developed fuel pellet. The grain size of the developed pellet was measured to be about 50μm. This grain size is about 6 times larger than that of un-doped $UO_2$ pellets.

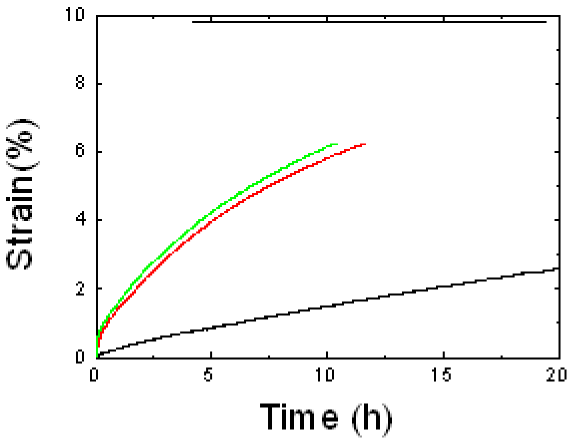



Fig. 2. Creep deformation curves for developed pellets (green, red line) and a pure $UO_2$ pellet (black line).

Fig. 2 shows the typical compressive creep deformation curves of the developed fuel pellet. The graph reveals that the creep deformation is considerably increased in the developed large grain $UO_2$ pellet.

The grain size and creep deformation behavior of our newly developed pellets are similar to or better than those of other developed pellets. Two distinct advantages of our technology are the lowest additives amount and the good compatibility with the commercial fuel pellet manufacturing process. The additive amount of our pellet is in the lowest level among the developed doped large grain pellets. Because the additives lower the U contents and enhance the fission product diffusion, it prefers to minimize the additive amount as possible. The sintering atmosphere of our pellet is the $CO_2$ contained $H_2$ mixed gas. It was found that the pellet property does not noticeably depend on the volume ratio of $CO_2/H_2$ when the $CO_2/H_2$ is in the 0.003~0.01.

**Acknowledgements**

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