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Review of Annular Fuel Database for CIMBA Fuel Development

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1. Introduction

The CIMBA (Cylindrically Inserted & Mechanically Seperated Burnable Absorber), an innovative nuclear fuel that is expected to have many advantages as an iSMR fuel, is annular fuel pellet which has a coated Gd2O3 structure in its center region as shown in Figure 1.[1]

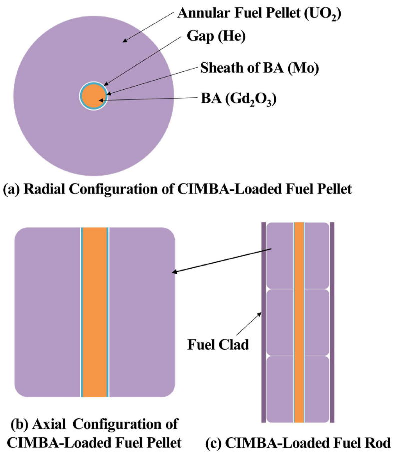

Fig. 1. Structure of CIMBA fuel

Despite of the many advantages, an experimental database is the most important thing for commercializing a new fuel, because database is a base of performance model which is inevitable to get design license.

Although, there is little experience for annular pellet study in Korea, some annular pellet databases have been collected, analyzed and used to support fuel performance modeling aspects.

Recently, the annular pellet database that KAERI has been used before are newly reviewed and examined to support the development of CIMBA. In this paper, densification, swelling, fission gas release behaviors of annular pellet were presented and the code application of the results was summarized.

2. Annular Pellet Database

2.1 Halden Reactor Project database

The Halden Reactor Project(HRP) is the oldest international joint study of nuclear fuel and materials organized by the OECD NEA since 1958. The project is operated by the Institute for Energy Technology (IFE) in Norway and is supported by dozens of research, regulation and industry organisations in 19 countries.[2]

In HRP, a performance test of various WWER fuel(annular pellet) have been conducted to gain a in-pile test database. In addition, recentrly, some LOCA(Loss Of Coolant Accident) test were performed to compare WWER fuel's safety with western type PWR fuel.

Representatively, IFA-503, 509, 519, 550, 676, 650, 720 tests have been performed since the mid-1990s.

2.2 IFPE Database

International Fuel Performance Experiments (IFPE) is the public domain database on nuclear fuel performance experiments for the purpose of code development and validation. The aim of the project is to provide a comprehensive and well-qualified database on Zr clad UO_2 fuel for model development and code validation in the public domain.[3]

The IFPE database contains test results performed under normal and transient conditions for hundreds of fuels and provides detailed PIE results.

Among the databases of IFPE, the Sofit, KOLA3 and Zaporoshye databases contain various performance tests of annular pellet fuel as summarized in Table 1.

Table 1. IFPE annular pellet database

Project	Test ID	No. of test
SOFIT	Test 1.1	12 rods
	Test 1.3	5 rods
KOLA3	FA 198	16 rods
	FA 222	16 rods
Zaporoshye	-	FGR 44 rods
		Gap 38 rods
HBEP	BK, BSH series	Some

2.3 Annular Fuel Performance Modelling and Codes

Nuclear fuel vendors such as WEC and Framathome have developed and applied annular pellets for various purposes, and developed codes such as TRANSURANUS(developed by JRC) and PAD that reflect the characteristics of annular pellets.

Database for annular pellet code development and verification mainly used public databases such as IFPE, and it was known that the difference in model with PWR UO2 pellet is not significant. The results of the annular pellet experiment conducted by WEC, etc. were also provided to international joint studies such as FUMEX-III through IFPE.

2.4 Annular Pellet In-reactor Behavior

- Densification & swelling

Figure 2 shows the measurement results of densification behavior of annular(WWER) and solid pellet(PWR) nuclear fuel.[4]

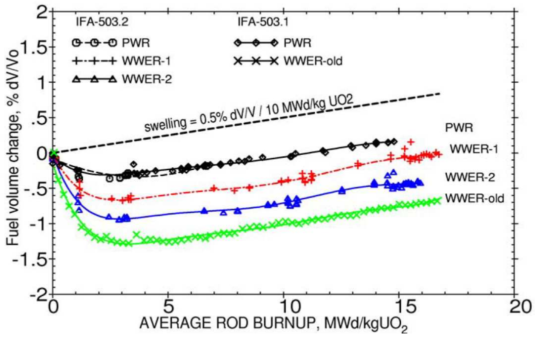

Fig. 2. Densification & swelling of annular fuel

The test results show that there is a difference in the densification behavior between two fuels, and this difference is known as the characteristics of the UO2 powders used in the pellet manufacturing process, as illustrated in Fig. 3.[4]

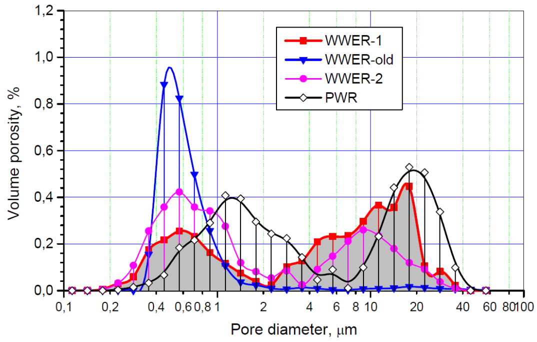

Fig. 3. Volume porosity distribution of fuels in IFA-503

There is no significant difference in the densification behavior between solid and annular pellets if using the same powder [5]

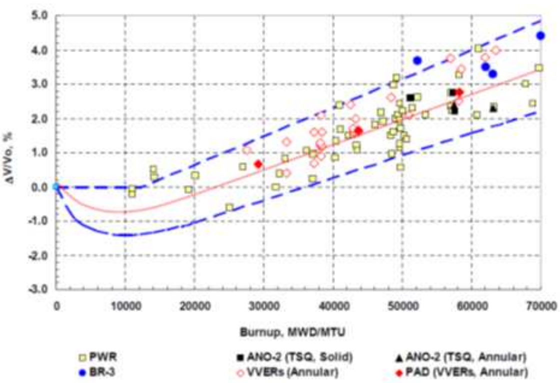

Fig. 4. Measured and PAD predicted fuel swelling

Figure 4 shows the small swelling difference between the annular and the solid pellet. Due to the similar neutron spectrum and fissile material, solid swellig is almost same regardless of pellet shape

- Fission gas release

Vitanza et al. determined an empirical FGR threshold curve, so called Vitanza threshold, by gathering a wide range of PWR and/or BWR FGR data. And, as shown in Fig. 5, the Vitanza threshold has also been shown to be applicable to WWER annular pellets.

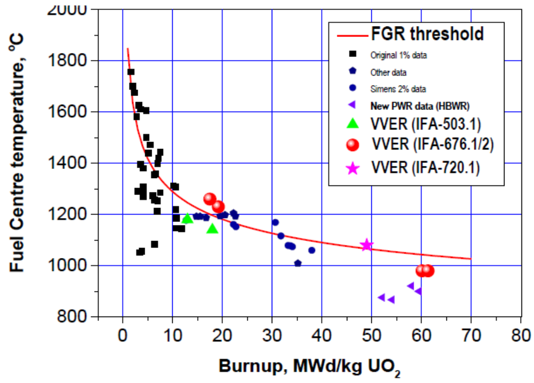

Fig. 5. FGR threshold [6]

Fig. 6 and 7 show FGR data measured from KWU/France PWR fuel and annular pellet respectively.

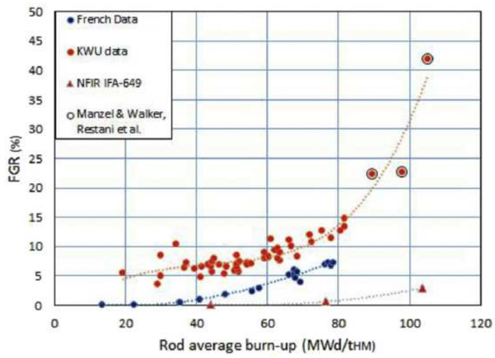

Fig. 6. KWU and France FGR data [7]

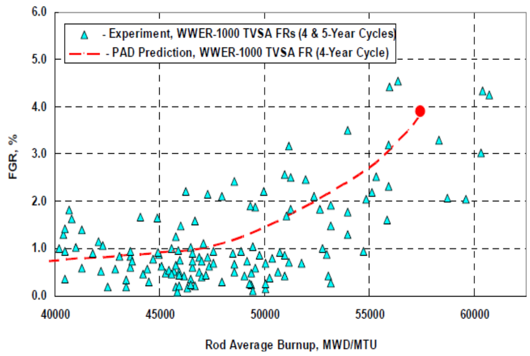

Fig. 7. Annular pellet FGR data [8]

From Fig 8, it can be confirmed that the FGR phenomena, which increase with the burnup accumulation, similary in the annular pellets. The reason why the amount of FGR in annular pellets is somewhat small is due to the lower fuel temperature characteristics of annular pellets.

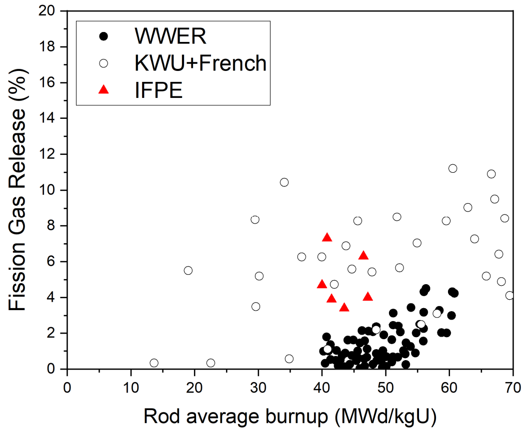

Fig. 8. FGR comparison (WWER(Annular) vs PWR)

- Performance modeling

Fig 9 summarizes reference model settings to analyze annular pellets in TRANSURANUS-WWER code. As we reviewed in previous chapter, it can be seen that the PWR solid pellet models are being applied as they are.[5]

MODFUEL (1÷4; 7÷20)	20	Standard LWR settings for UO_2 fuel properties.
MODFUEL (6)	21	Fuel thermal conductivity according to Harding and Martin correlation for UO_2.
POR000	0.03535*	Total fuel pellet fabrication porosity (average)
DENPOR	0.020**	Porosity at the end of sintering
DENBUP	5000**	Burn-up at which sintering has stopped

Fig.9. TRANSURANUS-fuel models reference setting

3. Conclusions

The review results of the currently available annular pellet database resulted in the following conclusion

- Since the burnable absorber in the center of the CIMBA fuel does not generate fission event, it will not affect the densification/swelling/FGR behavior of the annular fuel pellet
- The densification & swelling behavior of the annular pellet is almost the same as the PWR solid pellet. if there is no difference in powder conditions.
- The fission gas release behaivor of annular pellet is the same as that of the solid pellet.
- Since databases such as IFPE and HRP contain a number of data necessary for modeling an annular pellets, it is expected to be great help in developing and licensing CIMBA nuclear fuel.

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