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Pressure Drop Performances of 3D Printed Debris Filtering Bottom Grid

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1. Introduction

- Debris filtering bottom grid (DFBG)

DFBG is located at the lower most of the nuclear fuel and performs various roles.

- Mechanical function to support fuel rods
  . To prevent excessive behavior due to abnormal fuel rod vibration
  . To maintain the fuel rod supporting stably through end of life
- Protect function to filter debris during operation

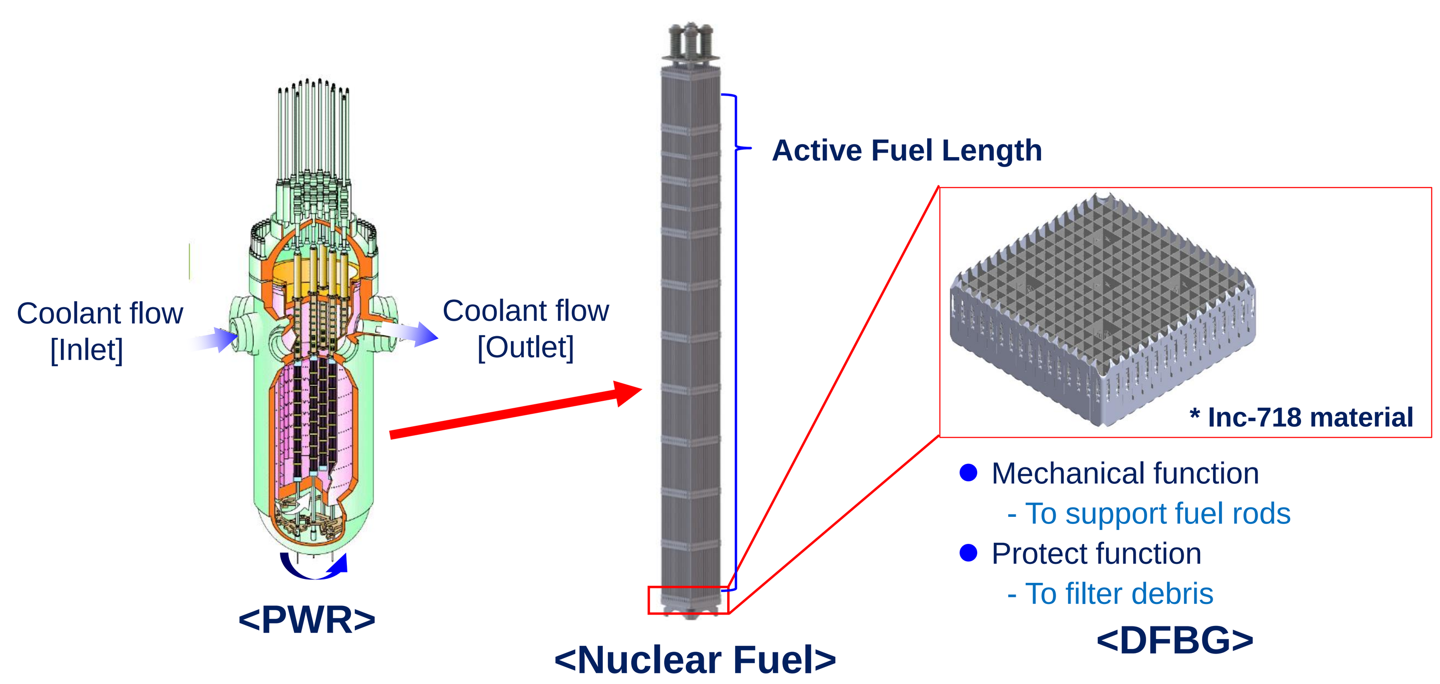
- Difficulties to meet functional requirements

To perform above functions, DFBG design with complicated structure and longer grid height is desirable.

- These can lead to an unfavorable design to the nuclear fuel.
  . Longer fuel rod length, higher pressure drop

To overcome these difficulties, KEPCO Nuclear Fuel (KNF) is considering to adopt (3D printing) additive manufacturing technology.

- It allows to make desired shape with complex geometries.
- KNF has chosen powder bed fusion (PBF) process.



<PWR> <Nuclear Fuel> <DFBG>

2. Design Feature and Manufacturing

2.1 DFBG candidates

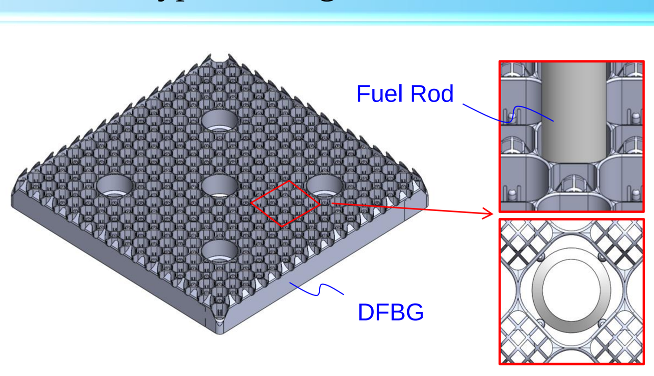
- DFBG candidates with full size (16x16) of grid array

Various debris filtering configurations has been created and performance verification tests were carried out.
To validate design effectiveness, some evaluations were carried out as following items;

- Prototype quality (dimension, shape, roughness)
- Mechanical test (load-deflection, dynamic crush)
- Hydraulic test (pressure drop, debris filtering)

2.2 Prototype DFBG-1

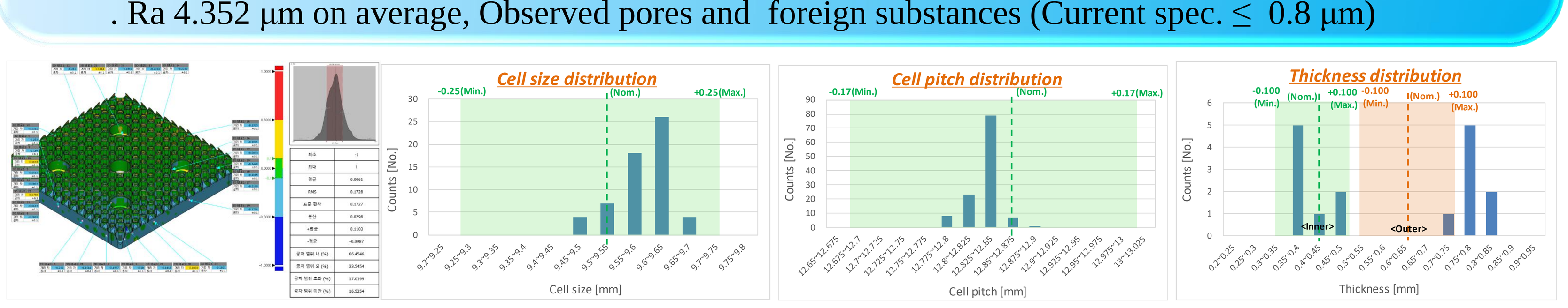
- DFBG-1 design and manufacture
  - Design feature and manufacture of DFBG-1
    . Cell shapes as rhombus, large and small cells optimally combined to reduce pressure drop
    . Grid wall to be spring-like so that it can make entirely grid elastic and flexible.
    . Conical mesh-type filtering structure installed at the top of each small cell to trap foreign materials



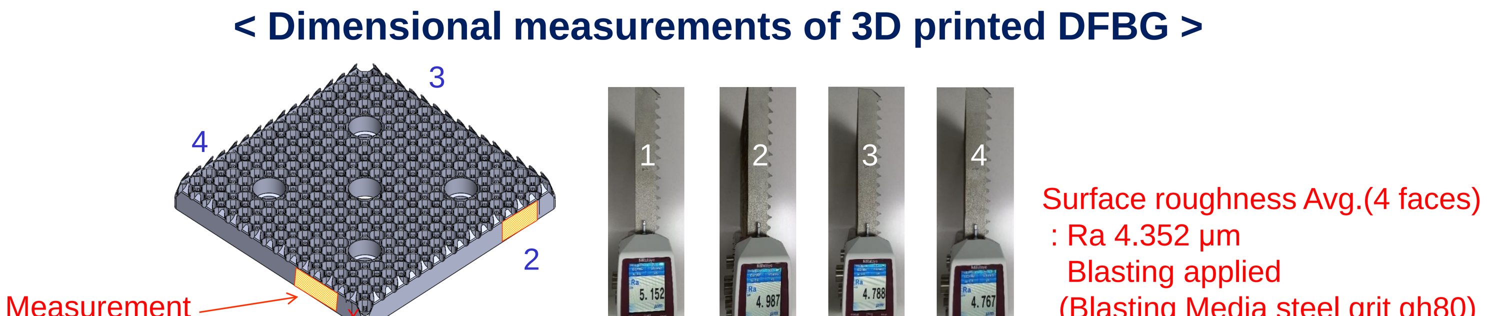
<Design feature>

<Prototype of 3D printed DFBG>

- Qualities of DFBG-1
  - Dimensional measurements
    . Envelop: satisfied, Surface/Wall: need to be improved
    . Thickness / cell size & pitch / height: overally satisfied, but need to be accurate in some parts
  - Surface roughness
    . Ra 4.352 μm on average, Observed pores and foreign substances (Current spec. ≤ 0.8 μm)



< Dimensional measurements of 3D printed DFBG >



< Roughness of 3D printed DFBG outer surface >

3. Pressure Drop

3.1 Prediction

- Pressure drop characteristics

Minimizing pressure drop is one of the main goals on designing nuclear fuel assembly.

- Factors: cross-sectional area of the flow, wetted perimeter, the height of the grid, surface roughness
- Derived equation from Bernoulli and Darcy-Weissbach's formula (in case of a non-circular shape)
- Two designs were compared; 3D printed DFBG, Commercial DFBG

Equation of predicted pressure drop

$$\Delta P = \gamma \cdot \lambda \cdot \frac{L}{4R_h} \cdot \frac{V^2}{2g}$$

where, P = pressure drop,
γ = specific gravity
λ = coefficient of friction
L = vertical height of grid
R_h = hydraulic radius
V = velocity of fluid
g = acceleration of gravity

Comparison of the predicted pressure drop

Items	Commercial DFBG	3DP DFBG
Flow sectional area (in^2)	0.210	0.209
Height of the grid (in)	1.922	0.600
Hydraulic radius R_h (in)	0.106	0.103
Pressure drop*	λ·4.533	λ·1.456

* λ × geometric characteristics

<Comparison of predicted pressure drop>

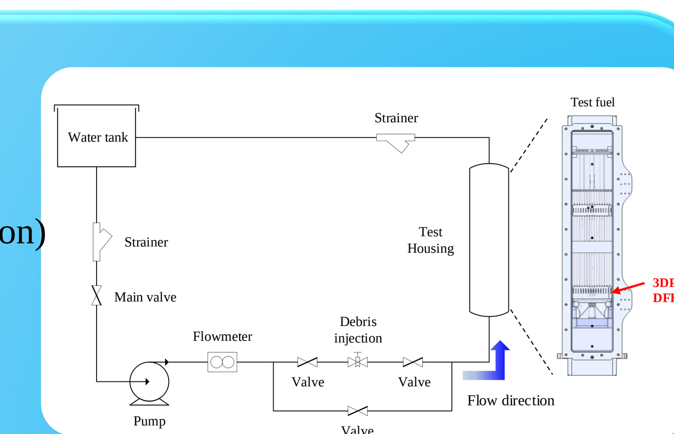
- Comparison
  - Assuming that the operation conditions are the same, the converted pressure drop characteristics for one cell can simply calculated.
  - Surface roughness is dominated to the pressure drop. If the value of roughness is same, reduction of pressure drop of 3D printed DFBG is better by mitigation of loss head.

3.2 Pressure Drop Test

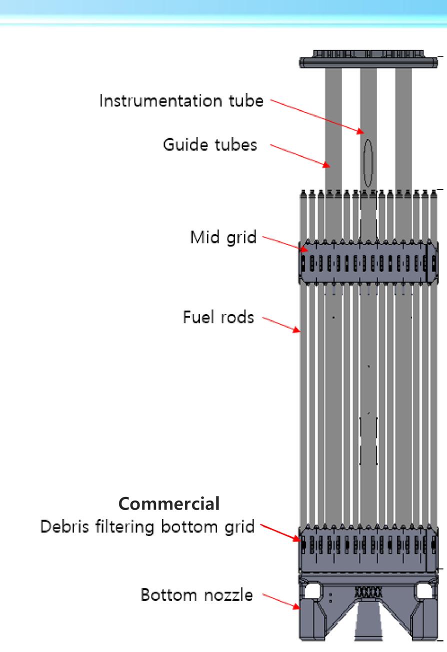
- Test for Pressure drop

For verification of the pressure drop characteristics, tests were performed in KNF test loop.

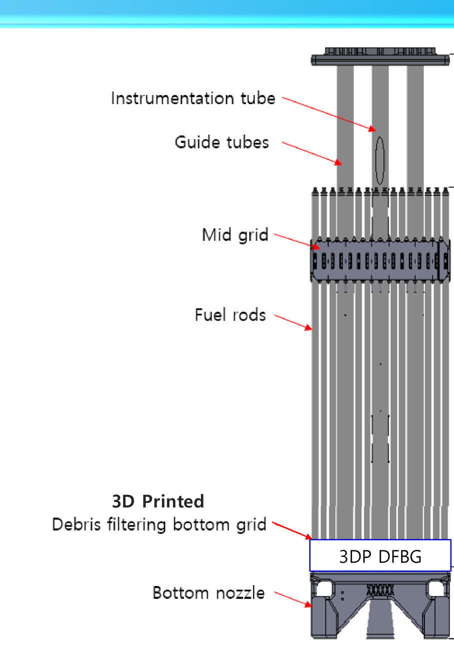
- Test loop: INFINIT(Investigation flow-induced vibration)
- Two specimens were prepared.
- Nominal in-core velocity of coolant: approx. 5 m/s
- Range of flow velocity: 4~6 m/s
  (85 % to 115 % of the nominal flow velocity)



Schematic of the test facility



<Test Fuel Ass'y with Commercial DFBG>



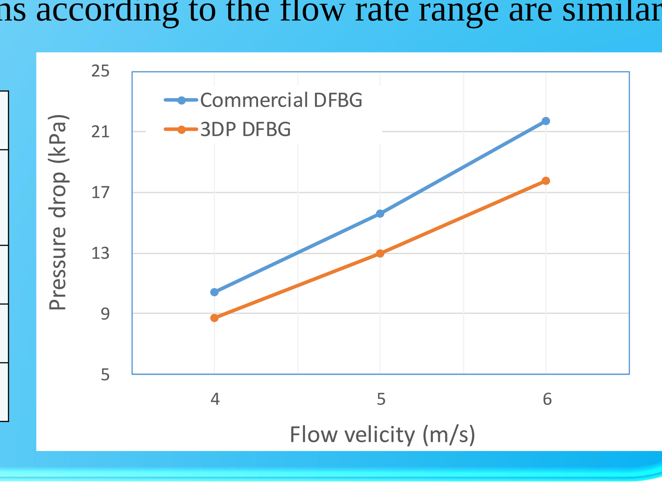
<Test Fuel Ass'y with 3D printed DFBG>

Pressure drop characteristics of 3D printed DFBG is reduced at about 16~18% in the test flow rate compared to that of commercial one.

- It can be understood that main reason is affected to mitigate loss head by lower grid height.
- The results of pressure drop test of the two specimens according to the flow rate range are similar.

Summary of the pressure drop test results

Flow velocity (m/s)	Commercial DFBG	3DP DFBG	Reduction rate (B/A-1) (%)
4	10.44	8.73	16.3
5	15.57	12.98	16.6
6	21.71	17.75	18.2



4. Conclusions

KNF has created several DFBG candidates that are full size (16x16) of grid array and performed out-of-pile tests for verification. DFBG-1's design feature and manufactured qualities that is one of the candidates are introduced. Also, results of pressure drop test with two specimens were compared.

- Based on the prediction from the equation, surface roughness is dominated to the pressure drop.
- For accurate prediction, it is required to be measured of the friction coefficient from the research, which is planned to be carried out in the future. In addition, surface roughness improving methods are being studied at the same time.
- Based on the test of pressure drop, 3D printed DFBG has more advantages.
- 3D printing technique can make complex geometries while the height and flow blockage area are improved compared to that of commercial one.