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Constraints on the Required Number of Debris for the Nuclear Fuel Debris Trapping Efficiency Test

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1. Introduction

Debris is one of main fuel failure mechanism in Korean plants, and is likely to become the leading PWR fuel failure mechanism within the EPRI(Electric Power Research Institute) membership in the future. Fuel rod cladding failures (leaking fuel rods) can be caused by debris trapped in a grid region which vibrates against the fuel rod cladding.

In the worldwide fuel failure causes occurring in PWRs from the year 2006 to 2010, the percentage of the grid-to-rod fretting wear-induced fuel failure is about 40% and that of the debris-induced fuel failure is about 13% [1]. In addition, it is reported that the percentage of the debris-induced fuel failure covers more than 35% for BWRs. Since debris is produced during nuclear power plant construction or overhaul period, types of debris may be dependent upon plant environment and systems. Debris that can generate the fuel failure is mostly metals having various shapes. Nuclear fuel vendors have their own test facilities for evaluating debris-filtering efficiency of nuclear fuels but every fuel vendor may seem to employ its own debris types for debris-filtering tests. In addition, its test method along with its test facility is different one another.

To protect fuels from debris, fuel vendors including KEPCO NF (KEPCO Nuclear Fuel) provide the fuel with debris filtering capacity [2]. During the fuel development process, debris filtering test is usually performed for filtering efficiency measurement.

This paper discusses the required number of debris specimens for confident test results considering the constraints such as geometry, significance level, and economy.

2. Overview of the Test

An actual reactor core is composed of hundreds of nuclear fuels and reactor internal structures. Especially, the lower core plate is the first barrier for debris entering to the core. Therefore the structure should be considered in the test. In addition, counting the debris caught in the fuel should be performed.

Considering the above requirements, the test facility consists of a transparent test housing, a debris insert valve, a pump, water tank, and flow velocity controller. Absolutely, the lower core plate simulator is also included in the housing. For debris observation in the housing, the tester records the number of debris caught in the fuel. That is, debris caught in the fuel should be observed with the naked eyes. The other kinds of instruments instead of the human vision can be used, but it seemed that nothing could be replaced with the human being. Strainers are attached before the pump inlet and after the flow housing to collect debris. The fuel assembly housing can load a full size grid, and the fuel usually consists of one bottom nozzle, one bottom grid including protective grid, and one mid grid. Since debris must be blocked below protective grid, the test mock-up is quite reasonably assembled to review the debris blocking and trapping ability. The details on the test facility and the procedure can be seen in the author’s another work [3].

3. Required Number of Debris Specimens

Although there exist many kind of debris in their shape and dimension, a typical debris will be considered for straightforward analysis and computational purpose. Metal wires are usually seen in the core, thus this work will use metal wires which are beneficial in preparing specimens.

The moderate number of debris inserted for the debris-filtering test is to be determined. The large number of debris inserted may generate interference between debris, while the small number of debris inserted may cause some difficulty in obtaining a reliable result since repetitive debris-filtering tests usually generate a wide range of debris-filtering efficiency. In the view of reliability of the test result, since one can reduce significance level with lots of information, it is desirable when lots of specimens are used in the test.

When the specific debris is used in the specified fuel, the fuel will have the filtering probability of p for the debris. Therefore, the filtering success for that debris will follow binomial probability distribution. Accuracy of the test data is dependent on the number of the injected debris. It is known that as the number of trials increases, the binomial distribution approaches normal distribution. Thus, considering relationship between the confidence interval and the expected filtering success, the precision of the test results can be derived as

$$\beta p \le \frac{t_{\alpha}\sqrt{p(1-p)}}{N} \qquad (1)$$

Where β denotes distance ratio between the true and estimated filtering efficiency. N is the simultaneously injected number of specimens, and t_α denotes t-value for α significance level. Therefore one can estimate the maximum required number of debris using the equation. For example, Fig. 1 shows the required number of debris as a function of the accuracy ratio and the filtering probability.

As mentioned earlier, the lower core plate is the first barrier and the debris will pass through the holes in the structure. The lower core plate is accompanied by 4 holes where coolant flow are provided to the fuel. It should be noted that there is no lower core plate in the OPR1000 plant and the geometry is also different. Coolant flow as well as debris can be provided through the holes, and a moderate number of debris should be used to minimize interference between themselves and counting efforts. When a characteristic length of the debris is l and the lower core plate hole diameter is D, the total debris occupation area should be less than the hole area. This idea can be supported by introducing the mean free length, λ. Then the required number can be written as

$$N = \frac{D^2 x}{l^2 \lambda} \tag{2}$$

Where, x denotes the length in a specified area. If the mean free path equal to x, the required number is D^2/l^2. On the other hand, assuming $\lambda = 2x$, the maximum number reduced to half. When, the wire debris with 2mm diameter and 10mm length, the required number is less than 100 based on Eq.(2). The case when the number of debris injected at the same time is different, the results are delineated in Fig. 2. It is found that the filtering efficiency rapidly converges as the number of simultaneously injected debris becomes larger.

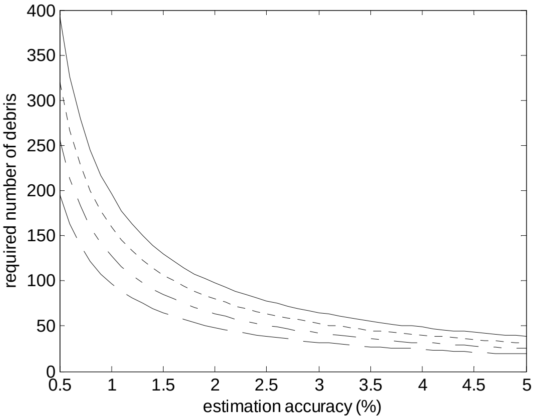

Fig. 1 Required number of debris specimens considering the accuracy and confidence interval(solid: p=0.5, dot: p=0.6, dash-dot: p=0.7, dash: p=0.8)

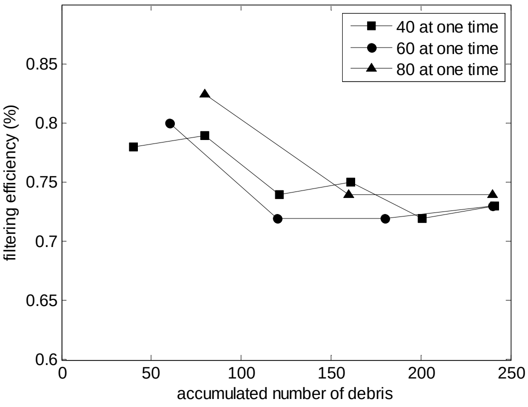

Fig. 2 Filtering probability as a function of the number of specimens

4. Conclusions

Debris induced fuel failure is one of major failure mechanism in the nuclear fuel. Therefore, the filtering capability should be implemented in the fuel. Debris filtering performance can be measured through a debris filtering test.

In this paper, the constraints on the number of debris specimens was discussed. To guarantee independent filtering event for a specific debris, one must minimize the interference between themselves during the test. In addition, to acquire confident evaluation result, one must use lots of specimens. Trade-off of the two concepts was the motivation of the work. Thus, the authors developed a guidance to determine moderate number of specimen. Some of their work is still being verified, and their final work will also be reported.

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