Concept of Evaluation Method of Fuel Rod Wear by Debris

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1. Introduction

Debris is one of the most common causes of the nuclear fuel rod failure. Debris is suspected to cause fretting wear by interact with grid structures. Most debris related failure occurs in the bottom area of the nuclear fuel, which is composed of bottom nozzle, protective grid, bottom grid and mid grid. Because of these various structures, the flow is extremely complex, and can lead to fluid induced vibration, such as vortex induced vibration or galloping. In 1994 ~ 2006, around 11% of the total fuel failure is conjectured by debris [1]. In 2006 ~ 2010, the portion of debris rises to over 13% [2]. Debris concerned failure has a much higher ratio in domestic reactors. Therefore, the research on debris related failure is required to enhance the fuel reliability. One of the main concerns in the field is the possibility of fuel failure caused by specific known debris. This can be achieved by evaluating fuel durability on the specific debris existence environment. The concept of methodology to evaluate specific debris induced fuel rod wear is presented.

2. Evaluation Method of Fuel Rod Wear by Debris

2.1 Concept of the methodology

To damage the nuclear fuel, debris needs to satisfy the following steps.

- Debris should be captured by fuel structure.
- Relative motion between debris and fuel rod should occur.
- Wear rate should be high enough to cause fuel failure.

These steps can be organized as Fig. 1 to produce quantified probability. Two of main mechanisms of this methodology are debris captivate rate and debris-fuel rod wear rate. Each factor is obtained by 'debris filtering effectiveness test', 'debris-fuel rod wear test' and 'debris movement observation test'. Debris captivate rate and debris wear rate are integrated using system reliability analysis. The system reliability can be described as a simply connected parallel system and be derived as follows.

$$R_s(t) = 1 - \left(1 - R_{captivate}\right)\left(1 - R_{wear\ rate}(t)\right)$$

Where R_s is fuel reliability, which is survival possibility until time t. $R_{captivate}$ is debris captivate reliability and $R_{wear\ rate}$ is debris-fuel rod wear rate reliability. Debris captivate reliability is the debris ratio which do not contact with the fuel rod. Wear rate reliability is a fuel survival possibility defined by wear distribution of certain debris within a reactor operation cycle.

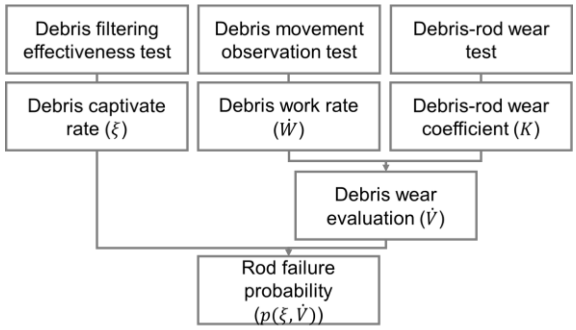

Fig. 1. Debris related rod failure probability evaluation methodology diagram.

2.2 Wear Model

The work rate wear model is commonly used in steam generator wear evaluation [3]. Since the nuclear fuel has similar geometry with steam generator, work rate wear model could be acceptable to evaluate fuel rod wear caused by debris. The work rate model is described as follow.

$$\dot{V} = K\dot{W}$$

Wear rate ($\dot{V}$) consists of work rate($\dot{W}$) and wear coefficient(K). The term, work rate is defined by contact force and sliding distance between debris and fuel rod. Wear coefficient is relation between wear rate and work rate.

2.3 Test Equipments

The debris captivate rate can be derived from the standard debris filtering test which is developed by KEPCO NF [4]. Fig. 2 shows the P&ID of the debris filtering test facility. The test is conducted with full array nuclear fuel under room temperature, atmospheric pressure and in-core flow velocity condition. The test is repeated to acquire statistically relevant result with the concerned debris specimen.

Debris-fuel rod wear test equipment (Fig. 3) is designed to quantify debris-fuel rod wear coefficient. The test equipment simulates fretting wear between fuel rod and debris by rotating an eccentric rod under water with room temperature condition. The rod follows a certain orbit in order to provide constant contact force and sliding distance. Since contact force and sliding distance are measured, debris-fuel rod wear coefficient can be calculated by measuring wear volume. The room temperature wear coefficient is known to be similar with in-core temperature wear coefficient [5].

Debris work rate is measured from debris movement observation test equipment (Fig. 4) which is a hydraulic loop with high speed camera. All outside walls of test section are transparent and 2×6 size nuclear fuel is used to secure a visual inspection by camera. The test condition is room temperature, atmospheric pressure and in-core flow velocity. The debris specimen floats by hydraulic forces and interacts with fuel geometry freely. Once the movement is observed, sliding distance between fuel rod and debris is measured using image analysis tool. The debris-rod contact force is calculated from the numerical analysis.

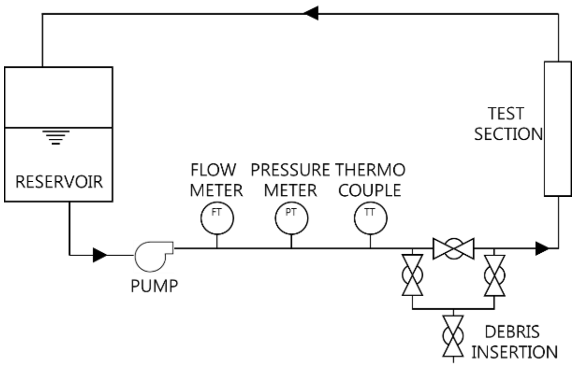

Fig. 2. Debris filtering effectiveness test facility

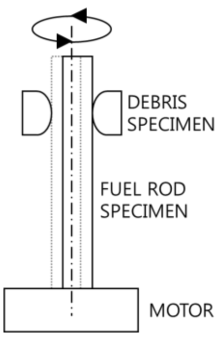

Fig. 3. Debris – Fuel rod wear test equipment

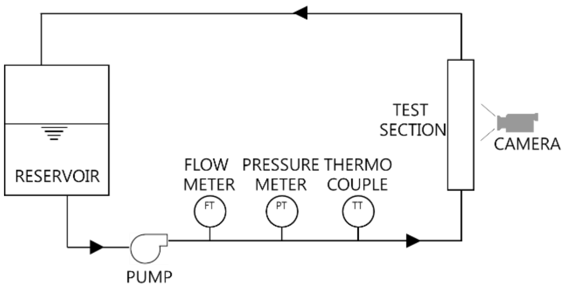

Fig. 4. Debris movement observation test equipment

3. Conclusions

Debris caused wear evaluation methodology is currently developing. The main concept of the methodology is to integrate the debris captivate rate and debris-fuel rod wear rate using reliability analysis. Each factor is obtained from test equipment designed for each purpose. The possibility of debris wear failure can be determined based on the shape and size of debris which is found in the reactor. The accuracy of this methodology is expected to be proportional to the size of the test data. The methodology can help to enhance reactor safety by evaluating the fuel reliability to the end of cycle.

REFERENCES

[1] Review of Fuel Failures in Water Cooled Reactors, IAEA NF-T-2.1, Vienna, 2010

[2] V. Onufriev, Results of the IAEA Study of Fuel Failures in Water Cooled Reactors in 2006-2010, 2012 IAEA TWGFPT Annual Meeting, Vienna, 2012

[3] T. M. Frick, T. E. Sobek, J. R. Reavis, Overview on the Development and Implementation of Methodologies to Compute Vibration and Wear of Steam Generator Tubes, Symposium on Flow-Induced Vibrations: Volume 3 Vibration in Heat Exchangers, ASME Special Publication, pp.149-161, 1984

[4] EPRI Technical Report, Technique Development for Debris Filter Testing Standards, 3002005520, 2015

[5] N. J. Fisher, M. K. Weckwerth, D. A. E. Grandison, B. M. Cotnam, Fretting-wear of zirconium alloys. Nuclear Engineering and Design, Vol.213, pp. 79-90, 2002