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Application of Statistical Evaluation Method for Debris Filtering Effectiveness

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1. Introduction

Fuel failure due to debris is one of the largest failure causes in PWR fuel assembly. Pieces of debris involuntarily enter the fuel assembly, which may be trapped between fuel rods. If these are trapped for a long enough time, it can wear the fuel rod by fretting [1]. PWR fuel vendors have developed the anti-debris features, but there is difficulty in judging the effectiveness of the features that need to be monitored for a long time. Since reactor conditions cannot be exactly simulated in test facilities, it needs to evaluate the debris filtering effectiveness based on the test results. Especially, it is necessary to standardize the type of debris for the relative evaluation, because test results depend on the debris types, such as wires and metal chip etc. and test duration time. The relative evaluation method is discussed through simulation test and statistical analysis of sample test results.

2. Debris Filtering Test

2.1. Test Configuration

The configuration of debris filtering test is shown in Figure 1. The test components consisted of PVC(polyvinyl chloride) flow loop with transparent test housing, pump and tank. The test housing has a 84mm square test section which can test 6×6 array partial assembly. Debris is inserted between two ball valves in a bypass line for entering the main flow path. The flow velocity is measured by ultrasonic flowmeter for simulating the reactor condition.

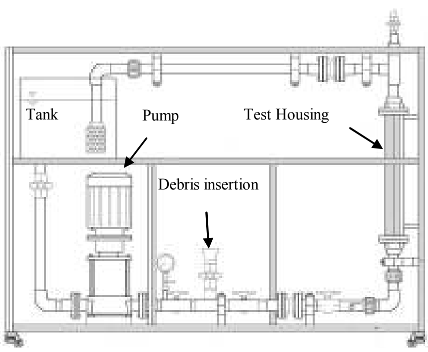


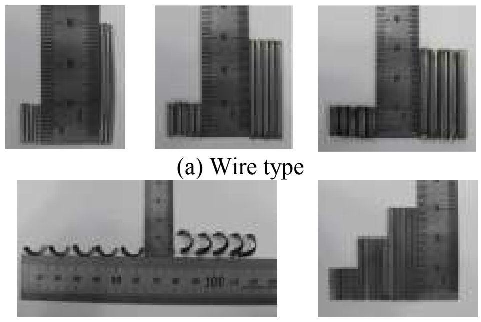
Figure 1. Configuration of Debris Filtering Effectiveness Test

2.2. The Debris specimens for test

Since the effectiveness is affected by the type of debris and size, it is necessary to standardize the type of debris and size for an objective and conservative evaluation. The backgrounds of selecting debris for standardization are as follows:

- Three types of debris, such as wire, metal chip and flat shape are used.
- Wire types are 1.0mm~3.5mm in diameter and with 10mm~30mm long, since Fine wire segments are capable of causing severe fuel rod damage.
- Metal chips are approximately 2.0mm~3.5mm in width that could be from the plant maintenance operations
- Flat shapes are 0.267mm~0.889mm in thickness to simulate the torn spacer straps.
- Most debris size is small enough to pass the flow hole of bottom nozzles.

The three types of some debris shapes are shown in Figure 2. All debris specimens consisted of 22 groups according to the type and size. These consisted of 12 groups of wire, 4 groups of metal chip and 6 groups of flat shape.



(a) Wire type

(b) Metal chip (c) Flat shape

Figure 2. Some debris shapes of each type

2.3. Test Performance

Debris is inserted into the test loop step by step after dividing into each group according to debris type and size. The number of debris for each group is limited to five pieces of debris to prevent from being caught by other debris and find them easily within the partial assembly. Flow is maintained until the debris is trapped in the partial assembly or for a minimum of 5 minutes.

3. Analysis of Test Results

Test results can be expressed as the percentage of debris trapped at debris filter grid. However, not having adequate time and data to test, we are concerned in finding difference in the averages of filter percentage between different debris filtering grids.

Analysis of variance, ANOVA is a method of testing the equality of three or more population means by analyzing sample variances. Therefore, ANOVA is an effective method to detect difference in effectiveness of various debris mitigation features.

What follows is an example of the ANOVA using the popular statistical software package, Minitab [2]. Table 1 gives summarized results from debris filtering example test. The test is performed twice for each group using 22 groups consisted of 3 types of debris as described above. The effectiveness is directly computed for each type based on the amount of debris trapped at debris filtering grids.

Table 1. Example of Sample Test Results

	Type of debris filter grid		
Debris type	"A"	"B"	"C"
Wire (12 groups)	73%	68%	45%
Metal chip (4 groups)	100%	100%	93%
Flat (6 groups)	87%	65%	58%
Total	82%	73%	57%

Table 1 shows "A" type of debris filter grid has the highest effectiveness. But we could obtain different results through ANOVA method. Figure 3 shows the ANOVA table using Minitab. In this example, P-value of grid type is less than 0.05 which indicates that all averages are not equal. The results from Tukey's simultaneous tests indicate that the percentage for type "A" is significantly higher than type "C" ; the confidence interval(-35.08,-14.01) does not include zero and the corresponding P-value for type "C" is less than 0.05. However, types "A" and "B" are not significantly different from each other ; the confidence interval(-19.17,1.90) includes zero and the corresponding P-value for type "B" is greater than 0.05. This indicates that types "A" and "B" have similar effectiveness. For the above reasons, types "A" and "B" have better effectiveness than type "C". Furthermore, the sample test results from ANOVA must be checked for the validity, because ANOVA is based on a normal distribution and homogeneity of variance. It, however, works well unless one or more of the distributions are highly skewed or if the variances are quite different, while these assumptions are violated.

General Linear Model: Effectiveness(%) versus Grid Type, Debris Type

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Factor     Type Levels Values
Grid Typ  fixed      3 A B C
Debris T  fixed     22 F1-1 F1-2 F1-3 F2-1 F2-2 F2-3 M1-1 M1-2 M2-1 M2-2 W1-1
                       W1-2 W2-1 W2-2 W3-1 W3-2 W4-1 W4-2 W5-1 W5-2 W6-1 W6-2

Analysis of Variance for Effectiv, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS      F      P
Grid Typ    2    13642.4    13642.4     6821.2  15.78  0.000
Debris T   21    68790.9    68790.9     3275.8   7.58  0.000
Error     108    46690.9    46690.9      432.3
Total     131   129124.2

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Effectiv
All Pairwise Comparisons among Levels of Grid Typ

Grid Typ = A subtracted from:

Grid Typ     Lower    Center     Upper  ------+---------+---------+---------+
B           -19.17     -8.64      1.90                 (---------*----------)
C           -35.08    -24.55    -14.01   (---------*----------)
                                        ------+---------+---------+---------+
                                            -30       -20       -10         0


Grid Typ = B subtracted from:

Grid Typ     Lower    Center     Upper  ------+---------+---------+---------+
C           -26.44    -15.91    -5.377            (---------*----------)
                                        ------+---------+---------+---------+
                                            -30       -20       -10         0

Tukey Simultaneous Tests
Response Variable Effectiv
All Pairwise Comparisons among Levels of Grid Typ

Grid Typ = A subtracted from:

Level        Difference       SE of              Adjusted
Grid Typ       of Means  Difference   T-Value     P-Value
B                 -8.64       4.433    -1.948      0.1303
C                -24.55       4.433    -5.537      0.0000

Grid Typ = B subtracted from:

Level        Difference       SE of              Adjusted
Grid Typ       of Means  Difference   T-Value     P-Value
C                -15.91       4.433    -3.589      0.0015
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Figure 3. ANOVA Table for Sample Test

4. Conclusion

This study discussed the relative evaluation method for debris filtering effectiveness. To estimate the performance of debris mitigation feature, the debris filtering test is accomplished. Since the test can not be exactly simulated reactor conditions, it needs to standardize the type of debris for relative evaluation and statistically analyze the test results. Debris types were selected as wire, metal chip and flat shape for an objective and conservative evaluation. ANOVA is a statistical method to detect difference in debris filtering effectiveness. In conclusion, the debris filtering feature can be objectively determined by using sampling test and ANOVA method.

ACKNOWLEDGEMENT

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[2] Keith M. Bower, "Analysis of Variance (ANOVA) Using Minitab", Scientific Computing and Instrumentation, Scientific Computing, 2000.