Statistical Analysis of Pellet Fabrication Data for Design Application

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1. Introduction

A conservative analysis is required to ensure the fuel integrity in the nuclear power reactor. To improve margins against design limits for CANDU6 fuel rods evaluation, design data are revised based on the as-built data. A statistical analysis of pellet grain size and density was performed by analyzing the recent 5-year as-built data manufactured with strict quality control procedures.

2. Methods and Results

The U.S. NRC's Regulatory Guide 1.126 Rev.2 [1] describes general statistical methods for achieving 95/95(probability/reliability) conditions. The normality statistical tests presented in Regulatory Guide 1.126 is divided into W and D′ statistical tests according to the number of samples. This paper describes the methods and results of D′ statistical tests of Reference 2. The methods for obtaining the mean and standard deviation for the measurements are as follows.

(1) Average of Measurement Target

$$\frac{\sum_{i=1}^{n}(x_i)}{n} = \bar{x_t} \quad (1)$$

(2) Standard Deviation of Measurement Target

$$\frac{\sum_{i=1}^{n}(x_i-\bar{x}_t)^2}{n-1} = \sigma_t^2 \quad (2)$$

x_i = Value of Measurement Target
n = Number of Specimens
$\bar{x}_t$ = Average of Measurement Target
σ_t = Standard Deviation of Measurement Target

2.1 Factors Affecting of the Pellet Grain Size

Two dominant factors for the pellet grain size are the powder conversion process and the sintering temperature during manufacturing process. Generally, Grain sizes are depending on the amount of additives injected into the UO_2 powder and sintering temperatures. Since this cannot be verified by visual inspection, it is decided by applying the quality control criteria after checking it through a grain size measuring instrument.

2.2 Quality Control Criteria of the Pellet Grain Size

The quality control criteria for the pellet grain size should be ranged from 5 μm to 25 μm. These criteria are stipulated in the Pellet Product Specification and controlled by the Quality Control Procedure.

2.3 Sampling and Statistical Analysis Results

820 pellet grain size measurements were used for statistical analysis. In the case of measurement errors for the pellet grain size, measurement error of each value were not considered. The measurement value will be almost the same as the true value of actual specimen. Therefore it is reasonable to use these measures. The average and standard deviation of the sample values for the pellet grain size were calculated and the normality verification was performed according to the method described in Regulatory Guide 1.126. Individual values were extracted by deriving individual upper and lower bound values from nonnormal distribution according to the results of the normality verification.

Using formula 1 and 2, the average measurement of the pellet grain size 7.69 μm and the standard deviation is 0.75 μm. The next step is to arrange the sample measurements in ascending order and calculate the linear combination coefficient T value for normality verification. Using the linear combination coefficient T and the standard deviation of the sample, the D′ value is 217,113.9. The calculated D′ value must exist within the probability distribution values described below to determine that it follows a normal distribution. The values corresponding to 820 measurement samples are 6,640 and 6,748, based on the 95% probability. The measured sample values follow a nonnormal distribution as the results of the D′ test do not fall within the range of $6{,}640 < D' < 6{,}748$. Reference 1 was applied to estimate individual bound. As a result, the individual upper and lower bound values that satisfy 95/95 are the 31th values. Table I shows summarized statistical analysis results for the pellet fabrication data (Grain Size).

Table I. The Result of Statistical Analysis for Pellet Fabrication Data (Grain Size)

	Grain Size
Number of Targets	820
Average	7.69 μm
Standard Deviation	0.75 μm
95/95 Upper Bound	31th upper value
95/95 Lower Bound	31th lower value

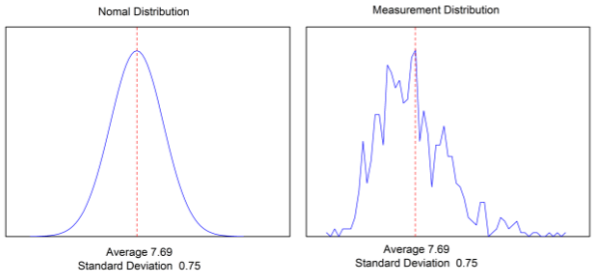

Fig. 1. Comparison of Normal and Measurement Distributions (Pellet Grain Size)

2.4 Factors Affecting of the Pellet Density

The processes that have the greatest impact on the pellet density are the sintering conditions, the pelletizing process and the amount of U_3O_8 addition.

2.5 Quality Control Criteria of the Pellet Density

The quality control criteria for the pellet density should be ranged from 10.50 to 10.80 Mg/m^3. These criteria is stipulated in the Pellet Product Specification and controlled by the Quality Control Procedure.

2.6 Sampling and Statistical Analysis Results

7,958 pellet density measurements were used for statistical analysis. In the case of measurement errors for the pellet density, measurement error of each value were not considered. The measurement value will be almost the same as the true value of actual specimen. Therefore it is reasonable to use these measures. The average and standard deviation of the sample values for the pellet density were calculated and the normality verification was performed according to the method described in Regulatory Guide 1.126. Individual values were extracted by deriving individual upper and lower bound values from nonnormal distribution according to the results of the normality verification.

Using formula 1 and 2, the average measurement of the pellet density 10.65 Mg/m^3 and the standard deviation is 0.01 Mg/m^3. Using the same method as in section 2.3, the D′ value is 21,820,697. The measured sample values follow a nonnormal distribution as the results of the D′ test do not fall within the range of 351,502 < D′ < 352,681. Reference 1 was applied to estimate individual limit bound. As a result, the individual upper and lower bound values that satisfy 95/95 are the 366th values. Table II shows summarized statistical analysis results of the pellet fabrication data (Density).

Table II. The Result of Statistical Analysis for Pellet Fabrication Data (Density)

	Density
Number of Targets	7,958
Average	10.65 Mg/m^3
Standard Deviation	0.01 Mg/ m^3
95/95 Upper Bound	366th upper value
95/95 Lower Bound	366th lower value

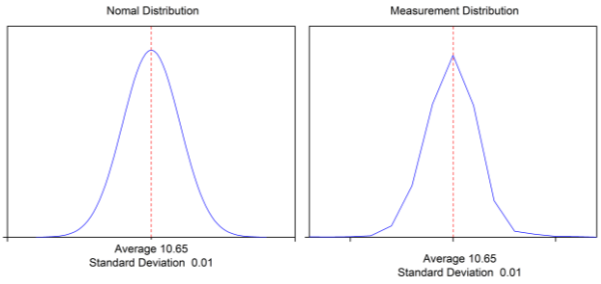

Fig. 2. Comparison of Normal and Measurement Distributions (Pellet Density)

3. Conclusions

The statistical analysis of recent CANDU6 fuel pellet as-built data for grain size and density was performed. This is to apply as-built real data to enhance more margins to the CANDU6 fuel rods design. Statistical analysis results are valid unless the process and internal management criteria for determining the grain size and density of the pellet are changed. The CANDU6 fuel design of the Wolsong Power Plant can be applied with the statistical analysis results given in Table I and Table II.

Further study will be performed for the statistical analysis of other manufacturing data affecting CANDU6 fuel rod performance. In addition, performance evaluation of the CANDU6 fuel rods will be performed using the statistical approach described in Reference 3.

REFERENCES

[1] USNRC Regulatory Guide 1.126, Rev.2, “An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification,” 2010.03.
[2] ANSI N15.15, “American National Standard Assessment of the Assumption of Normality,” 1974.10.
[3] Kang-Moon Lee, “KNF Techniques for Establishing and Confirming Uncertainties for CANDU Fuel Performance Analyses,” KNS, 2018.05.