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Thermal Expansion and Density Data of UO_2 and Simulated Fuel for Standard Reference

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1. Introduction

Standard Reference Data (SRD) is the scientific, technical data whose reliability and accuracy are evaluated by scientist group[1]. Since SRD has a great impact on the improvement of national competitiveness by stirring up technological innovation in every sector of industries, many countries are making great efforts on establishing SRD in various areas. Data center for nuclear fuel material in Korea Atomic Energy Research Institute plays a role to providing property data of nuclear fuel material at high temperature, pressure, and radiation which are essential for the safety evaluation of nuclear power. In this study, standardization of data on thermal expansion and density of UO_2 were carried out in the temperature range from 300 K to 3100 K via uncertainty evaluation of indirectly produced data. Besides, standardization of data on thermal expansion and density of simulated fuel were also done in the temperature range from 350 K to 1750 K via uncertainty evaluation of directly produced data.

2. Methods and Results

In this section two kinds of methods used in evaluating data of UO_2 and simulated fuel are described. The UO_2 data to be dealt with were indirectly produced, which means that data are collected from scientific documents. Simulated fuel data were produced by direct experiments.

2.1 Evaluation of Indirectly Produced Data

In order to present representative values and uncertainty of thermal expansion of UO_2 from 300 K to 3100 K, data of thermal expansion were collected from many papers and reports. The data were displayed every 50 K using model equations given in each document. Fig. 1 shows the thermal expansion data of UO_2 by many authors from 300 K to 3100 K. Initial representative value and A type uncertainty of thermal expansion at each temperature were presented by arithmetic average and standard deviation of average. Since it is reasonable that data with large uncertainty contribute little to the model equation, the model equation of thermal expansion was obtained using weighted least square method. To consider B type uncertainty (systematic uncertainty), the differences of initial representative value and the value obtained by model equation were calculated and the maximum value was selected. Then the combined standard uncertainty was assessed by the square-root of the summation of the square of A and B type uncertainties. Ultimately, extended uncertainty was given by multiplying coverage factor 2, which guarantees 95% confidence level. Fig. 2 displays the final representative values and uncertainties of UO_2 from 300 K to 3100 K.

2.2 Evaluation of Directly Produced Data

Thermal expansion data of simulated fuel have been obtained by the experiment using dilatometer. Simulated fuel has several components which simulate fission products contained in spent PWR fuel[2]. The process of uncertainty evaluation is based on the guideline in GUM[1]. The first step required to evaluate uncertainty is establishing model equation of thermal expansion.

$$Y(T) = \frac{l(T) - l_0}{l_0} f_{cal} \tag{1}$$

where $Y(T)$, $l(T)$, l_0, and f_{cal} are thermal expansion, length at temperature T, length at room temperature(298 K), and calibration factor, respectively. From the above equation, we can find out that $l(T)$, l_0, and f_{cal} constitute the elements of uncertainty. First, uncertainty related with $l(T)$ is A type uncertainty which originates from repetitive observation. In the above section, we already mentioned that it was standard deviation of average. Next, uncertainty related with l_0 which is B type uncertainty comes from the resolution and the calibration reports of equipment. Finally, uncertainty related with f_{cal} originates from the uncertainty of standard material and the uncertainty generated from the repetitive experiment using standard material. Because each uncertainty has different sensitivity to the total uncertainty, sensitivity coefficients, which can be acquired by differentiate model equation partially, are needed. Fig. 3 shows representative values and uncertainties of simulated fuel from 300 K to 3100 K.

2.3 Density of UO_2 and Simulated Fuel

Density of UO_2 and simulated fuel can be calculated using thermal expansion data. The model equation of density is given by

$$\rho(T) = \frac{m}{V(T)} \tag{2}$$

where $\rho(T)$, m, and $V(T)$ are density, mass, and volume, respectively. Since we are dealing with disk-type specimens, volume is calculated using length and diameter. From the equation (1), length and diameter at temperature T is given by

$$l(T) = l_0\left(1 + \frac{Y(T)}{f_{cal}}\right), d(T) = d\left(1 + \frac{Y(T)}{f_{cal}}\right) \qquad (3)$$

where $d(T)$ is diameter at temperature T. Using the equations (2) and (3), density of UO_2 and simulated fuel is given by

$$\rho(T) = \rho_0\left(1 + \frac{Y(T)}{f_{cal}}\right)^{-2} \qquad (4)$$

Combined uncertainty of density consists of uncertainty of initial density, thermal expansion, and calibration factor. Fig. 4 and Fig. 5 show density and its uncertainty of UO_2 and simulated fuel from 300 K to 3100 K, respectively.

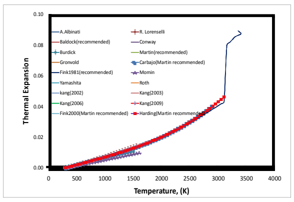

Fig. 1. Thermal expansion data of UO_2 from 300 K to 3100 K by many authors.

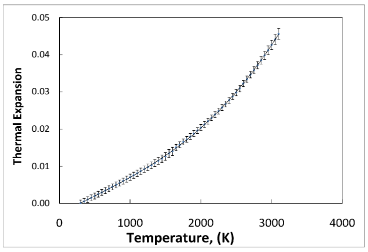

Fig. 2. Representative values of thermal expansion and uncertainty of UO_2 from 300 K to 3100 K.

3. Conclusions

In order to establish standard reference of nuclear fuel material, data evaluation of thermal expansion of UO_2 and simulated fuel has been carried out using the evaluation method of indirectly produced data and that of directly produced data. From this result, we also calculated density of UO_2 and simulated fuel. This work is expected to contribute to the development of the high burn-up and quality fuel and future nuclear system.

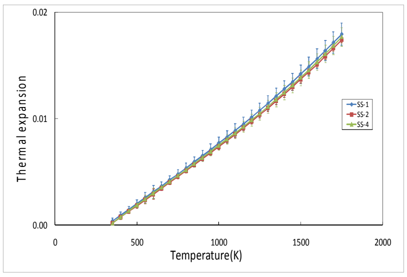

Fig. 3. Representative values of thermal expansion and uncertainty of simulated fuels from 350 K to 1750 K.

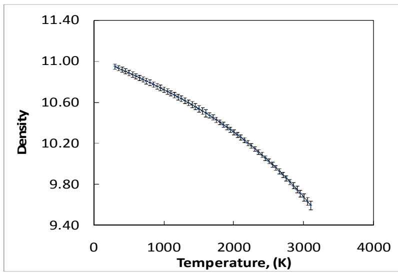

Fig. 4. Representative values of density and uncertainty of UO_2 from 300 K to 3100 K.

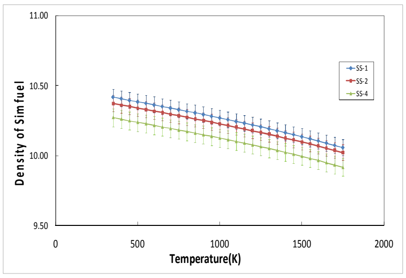

Fig. 5. Representative values of density and uncertainty of simulated fuels from 350 K to 1750 K.

REFERENCES

[1] ISO, Guide to the Expression of Uncertainty in Measurements, ISO, Geneva, 1995.
[2] Kweon Ho Kang, H. J. Ryu, K. C. Song, and M. S. Yang, Thermal Expansion of UO2 and Simulated DUPIC Fuel, Journal of Nuclear Materials, Vol.301, pp.242-244, 2002.