Unfolding Method of Inside Gamma Measurement base on First Layer Contribution

Yos Panagaman Sitompul, Hee-Sung Shin, Oh Jong Myeong, Ryu Hyeon Hee, Seo Hee, and Ho-Dong Kim
Korea Atomic Energy Research Institute, 989-111 Daedeokdaero, Yuseong-gu, Daejeon , Republic of Korea
yossitompul@kaeri.re.kr

1. Introduction

Burnup is an important parameter in the spent fuel reprocessing because it is used to derive the amount of interest nuclide in the spent fuel. The spent fuel burnup is determined by a measurement of a signature emission such as gamma emission. One method described here is the inside gamma measurement which is developed in Korea Atomic Energy Research Institute (KAERI). Gamma emitted from the spent fuel assembly is measured in each guide tube by using ion chamber, and the assembly is scanned axially. From the measurement, the gamma profile from each guide tube is obtained. The common procedure to determine burnup is to average the measured gamma for all measured points, and determine the burnup by using independent or self calibration 1). Herein, we develop a method to unfold the measured gamma to obtain the pin-wise source strength by using MCNPX simulation. In this method, the first layer contribution is used to calculate the pin-wise source strength.

2. Methods and Results

In this section, the unfolding method is described in detail and the result is shown.

2.1Background

Gamma emission from the spent fuel is widely used in the spent fuel burnup determination because their correlation is very linear. If the gamma emission is known, the burnup can be derived by using the correlation. However, during the transport of the gamma to the detector, many of gammas dissapear. One main reason is the shading effect by the fuel itself. The outside gamma measurement, such as fork detector *1)*, can only get the signature emission from the outer pins in the assembly. The measurement is improved in KAERI by measuring the inner pins also through the guide tube measurement. The information of the inner pins is obtained and the pin-wise source strength is derived by using unfolding method.

2.2Method

The unfolding method is the problem to invert the series of the detector contribution as shown in Equation 1 2).

$$\begin{bmatrix} \beta_{1,1} & \beta_{2,1} & \cdots & \beta_{I,1} \\ \beta_{1,1} & \beta_{2,2} & \cdots & \beta_{I,2} \\ \vdots & \vdots & \vdots & \vdots \\ \beta_{1,N} & \beta_{2,N} & \cdots & \beta_{I,N} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ \vdots \\ S_I \end{bmatrix} = \begin{bmatrix} D_1 \\ D_2 \\ \vdots \\ D_N \end{bmatrix} \quad \cdots\cdots\cdots\cdots \quad (1)$$

where,

$\beta = response$
$S = source$
$D = measured\ dose$
$I = source\ number$
$N = detector\ number$

The equation can be solved if the number of measurement is equal the number of pins. However, the number of measurement is only 16 at maximum (16 guide tubes) for 14×14 assembly so that the solution is infinite.

Since the exact solution cannot be obtained, we approximate the solution. To unfold the measured dose, Equation 2 is used.

$$S_i = \frac{D_n C_{i,n}}{\beta_{i,n}} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

where,

$C = detector\ contribution$
$i = source\ index$
$n = detector\ index$

First, the pin contribution is calculated by using a flat distribution. However, the pin contribution calculation is incorrect for an arbitrary distribution since the pin contribution itself is a function of source distribution. A good approximation is to calculate the contribution of the first layer surrounding the guide tube. The contribution of the layer depends weakly to source distribution. The response from each pin in the first layer is almost the same which make the total source calculation for the first layer accurate. This can be seen from Equation 3 and 4. There are 8 pins surrounding a guide tube.

$$S_1\beta_1 + S_2\beta_2 + \cdots + S_8\beta_8 = DC_{layer1} \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

if $\beta_1, \beta_2, \ldots, \beta_8 = \beta_{layer1}$

$$S_1 + S_2 + \cdots + S_8 = \frac{DC_{layer1}}{\beta_{layer1}} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4)$$

By doing this, the total source strength of the first layer is obtained accurately. To get all pin source strength, a fitting is used by using the source strength of the first layer of each guide tube. The source strength is averaged for each guide tube and the average value is determine to be at the detector position. A parabolic function is used in this case for simplicity, mostly the burnup distribution is a parabolic function as in the case the assembly studied here.

The pin-wise source strength can be obtained and the pin-wise burnup can be determined if the burnup correlation is provided. The source strength distribution can be used to correct the previous first layer contribution value and an iteration can be done to obtain more accurate result. The iteration can be stop by critera which are the first layer contribution value and pin-wise source strength convergence.

2.3 Result

The result of the calculation by using this method is shown here. The first layer contrbution for several condition is shown in Table 1.

Table 1. First layer contrbution (full pin case).

Guide Tube	Contribution		
	Flat Distribution	J14 Distribution*	C15 Distribution*
L03	58.88%	59.36%	60.05%
L06	56.09%	56.69%	58.22%
J05	54.35%	55.03%	57.11%

*Contribution by using design code distribution

The total first layer source calculate by this method is shown in Figure 1 for C15 assembly with a comparison with the reference from design code.

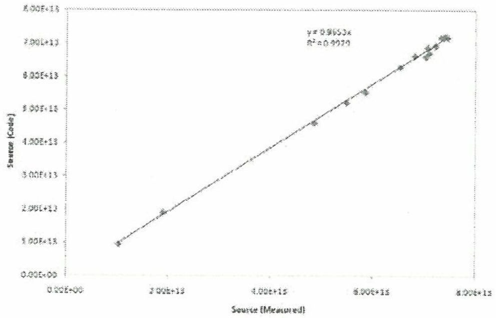


Fig. 1. First layer source from measurement and reference.

The source is averaged and the fitting coeficient is determined.

Table 2. Source fitting coefficient

f=y0+a*x+b*y+c*x^2+d*y^2	
y0	7.6303E+12
a	1.0362E+11
b	7.4436E+10
c	-1.7591E+09
d	-2.5859E+08

From the fitting the source distribution is determined as shown in Figure 2.

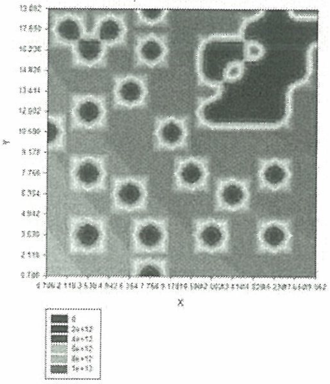
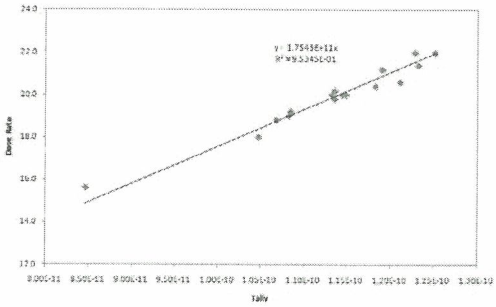


Fig. 2. Source distribution.

To validate the source distribution, the pin-wise distribution is inputed to MCNPX simulation, and the result is fitted with the measurement.



The result shows a good agreement between the source distribution determined by unfolding method and the measurement. The R2 is about 0.95. The result can be improved by iteration.

3. Conclusions

The unfolding method base on the first layer contribution was developed. The result from the unfolding method has good agreement with reference design code distribution and measurement. The source strength from unfolding can be used to determine the burnup, provided the burnup correlation.

4. REFERENCES

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