Theoretical Study of Transmission Tomographic Gamma Scanning On Simulated Radwaste Samples

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1. Introduction

At different nuclear facilities, radioactive wastes are generated that packed into waste drums. The safe and economic disposition of these drums requires NDA to assay the amount of waste in each drum. Tomographic gamma scanning (TGS) method [1] which includes transmission and emission computed tomography is one of the most advanced NDA methods. It locates, identifies and qualifies gamma-ray emitting isotopes and others, in nuclear waste drums. The TGS method uses a HPGe detector to record the spectra of gamma-rays emitted from within a drum and to measure the transmission of gamma rays through the drum from an external source. TGS method has been developed in several countries for use in safeguards and waste characterization [1,2]. It has been successfully employed for field operation. However, Due to proprietary constrains, there is no detailed information of software developed is available.

In this paper, we develop an image reconstruction algorithm for transmission image in TGS differs from previous algorithms [1,2]. Our iterative algorithm [3] base on general ART and combine Monte Carlo (MC) modification. Simulated transmission tomographic databases are generated by MC method for different transmission images, or linear attenuation coefficients, distributions. Comparison between reconstructed images by our present algorithm and known images are made, it is shown that reconstructed values fitted the known data very well with the relative errors less than 5%.

2. Reconstruction algorithm for transmission TGS

The TGS uses simple voxel model as a basis for image reconstruction. The simulated radwaste sample can be divided into many voxels by three dimensional scanning, it is assumed that linear attenuation coefficient of each voxel distributed uniformly. To obtain linear attenuation coefficients, considering the special situation in TGS transmission characteristics that large volume HPGe detector and diverging cone solid angle were used, we deduced the TGS transmission rate equation according to particle transport theory and MC method:

$$P_i = \frac{1}{N}\sum_{k=1}^{N}[\exp(\sum_{j=1}^{n}(-x_{ijk}\mu_j))] \qquad (1)$$

where

N is sampling gamma-rays numbers from external transmission source

P_i is transmission rate in the i'th measurement

μ_j is linear attenuation coefficient of j'th voxel

x_{ijk} is the linear thickness of the k'th gamma ray passing through j'th voxel in the i'th measurement

meanwhile, with the equivalent attenuation idea [3], the mathematical expression of equivalent attenuation track length of all the gamma-ray through one voxel can be written as follows:

$$T_{ij} = -\frac{1}{\mu_j}\ln[\frac{1}{N}\sum_{n=1}^{N}\exp(-\mu_j x_{ijn})] \qquad (2)$$

combine conventional transmission equation [1] and equation (2), the iterative transmission image reconstruction algorithm are presented [4]:

$$\begin{cases} \sum_{j=1}^{J} T_{ij}\mu_j = V_i \\ T_{ij} = -\frac{1}{\mu_j}\ln[\frac{1}{N}\sum_{n=1}^{N}\exp(-\mu_j x_{ijn})] \end{cases} \qquad (3)$$

3. Simulation

To insure the theoretical investigation is valid, we have carried out simulation on computer to examine the feasibility and reliability of the new algorithm in the previous section. In our simulation, a mathematical model of object is created, an external transmission source is generated, and corresponding measurement date of a detector is calculated by established simulation platform using MATLAB language.

3.1 Simulated Samples

We have proposed two types of simulation sample models under considering some certain real states of radwaste drums. One is 9 voxels (3 by 3), each voxel of 5cm×5cm ×5cm, external source is located left side of sample, detector is in the opposite of external source. It is 26.2cm from external source to the center of sample, the distance of detector to the center of sample is 43.9cm. The other is 36 voxels (6 by 6) numbered from 1 to 36 (see Fig.1).

3.2 Simulation Results

The linear attenuation coefficients μ of five medium (iron, aluminum, plastic, air, and lead) for one certain gamma-ray energy are pre-set randomly in the model sample voxels. TGS transmission measurement data was performed to obtain one group transmission rate which corresponded to one group μ distribution by MC simulation in established simulation platform. For former model, scanning pattern is 3 translation positions with four rotation angles, 0^0, 45^0, 90^0, 135^0, in each position. For latter model, scanning pattern is 6 translation positions with nine rotation angles, 0^0, 20^0, 40^0, 60^0, 80^0, 100^0, 120^0, 140^0, 160, in each position. Then, the algorithm present in this paper is used to reconstruct the μ of the medium in the voxels, comparisons are listed in Fig.2 and Fig.3 respectively. The relative errors are found to be less than 5%.

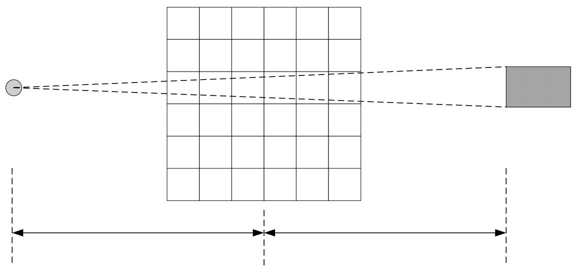

Figure 1. Schematic illustration of transmission TGS system.

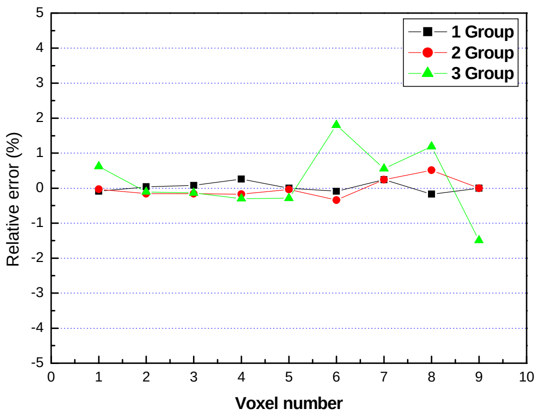

Figure 2. The relative error of linear attenuation coefficient between "true" value and reconstructed value in each voxel for simulated sample 1 (3 by 3) with different three groups.

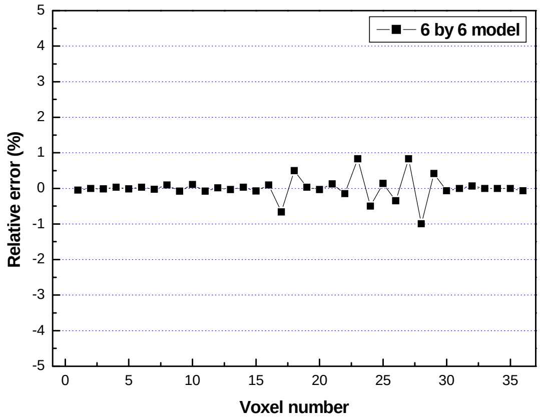

Figure 3. The relative error of linear attenuation coefficient between "true" value and reconstructed value in each voxel for simulated sample 2 (6 by 6).

4. Conclusion

A new linear attenuation coefficient image reconstruction algorithm has been created for transmission TGS based on MC method, considering the characteristics of actual conditions of transmission TGS system. Simulation research was performed, the simulation results demonstrate the superior accuracy of the algorithm for very heterogeneous matrices included some extreme cases, for example, lead. It can meet the necessary requirements of prototype TGS device completely.

REFERENCES

[1] R. J. Estep, T. H. Prettyman, and G. A. Sheppard, Tomographic Gamma Scanning to Assay Heterogeneous Radioactive Waste, Nuclear Science and Engineering, 118, 145-152 (1994).

[2] D. C. Camp, H. E. Martz, G. P. Roberson, D. J. Decman, R. T. Bernardi, Nondestructive waste-drum assay for transuranic content by gamma-ray active and passive computed tomography, Nuclear Instruments and Methods in Physics Research A 495 (2002) 69-83.

[3] Zhang Quanhu, Research on The Reconstruction Techniques for Tomographic Gamma Scanning, Doctoral Dissertation, China Institute of Atomic Energy, 2003.

[4] Zhang Quanhu, Sui Hong Zhi, Lu Feng, Li Zeng, Monte Carlo Statistical Iteration Image Reconstruction Algorithm, Atomic Energy Science and Technology (in Chinese), Vol. 37, No. 6, 555-557, 2003.