Applied Radiation and Isotopes 135 (2018) 232–238

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Novel edge treatment method for improving the transmission reconstruction quality in Tomographic Gamma Scanning

Miaomiao Han[a,*], Zhirong Guo[a,b], Haifeng Liu[b], Qinghua Li[b]

[a] Department of Nuclear Science and Technology, Harbin Engineering University, Harbin 150001, China
[b] Wuhan Second Ship Design and Research Institute, Wuhan 430205, China

HIGHLIGHTS

- Novel edge voxel treatment method proposed and compared with the traditional method.
- Novel edge voxel treatment method significantly improved the performance of TGS.
- MLEM worked better than ART as the transmission reconstruction algorithm.

ARTICLE INFO

Keywords:
Algebraic reconstruction technique
Edge treatment method
Maximum likelihood expectation maximization
Monte Carlo simulations
Quality of transmission reconstruction
Tomographic Gamma Scanning

ABSTRACT

Tomographic Gamma Scanning (TGS) is a method used for the nondestructive assay of radioactive wastes. In TGS, the actual irregular edge voxels are regarded as regular cubic voxels in the traditional treatment method. In this study, in order to improve the performance of TGS, a novel edge treatment method is proposed that considers the actual shapes of these voxels. The two different edge voxel treatment methods were compared by computing the pixel-level relative errors and normalized mean square errors (NMSEs) between the reconstructed transmission images and the ideal images. Both methods were coupled with two different interative algorithms comprising Algebraic Reconstruction Technique (ART) with a non-negativity constraint and Maximum Likelihood Expectation Maximization (MLEM). The results demonstrated that the traditional method for edge voxel treatment can introduce significant error and that the real irregular edge voxel treatment method can improve the performance of TGS by obtaining better transmission reconstruction images. With the real irregular edge voxel treatment method, MLEM algorithm and ART algorithm can be comparable when assaying homogenous matrices, but MLEM algorithm is superior to ART algorithm when assaying heterogeneous matrices.

1. Introduction

Non-destructive assays (NDAs) are gradually becoming the mainstream methods for characterizing low level and intermediate level radioactive wastes. These wastes are routinely packed in economical large waste containers, e.g., waste drums, according to national legal restrictions. Tomographic Gamma Scanning (TGS) (Estep, 1994) and Segmented Gamma Scanning (SGS) (Jack, 1984) are the two main NDA methods. TGS was developed based on SGS and it obtains results with higher accuracy. TGS divides one waste drum into multiple layers and each layer is subdivided into a certain number of voxels, which are assumed to comprise a homogeneous matrix that is fully filled with a uniform distribution of radionuclides. There are two stages in TGS. In the transmission reconstruction stage, a transmission source is used to reconstruct the linear attenuation coefficients (LACs) of voxels in each layer, whereas the emission reconstruction stage does not use a transmission source to display the distribution of radionuclidic activity in the whole drum. The LACs acquired in the transmission reconstruction stage are used for attenuation compensation with respect to the activity of radionuclides in the emission reconstruction stage, so the accuracy of the LACs acquired is of great importance.

An issue that affects TGS is how to deal with the voxels at the periphery of the waste drum, where they have been frequently treated as cubic voxels (Kane et al., 2007; Croft et al., 2004), but they may be considered as real irregular voxels. No previous studies have addressed this problem in detail. The γ-rays that pass through these edge voxels may have different absorption properties due to the different path lengths in regular cubic voxels and irregular edge voxels (Krings et al., 2013). The traditional method for treating these edge voxels regards them as regular cubic voxels in order to compute their path lengths

* Corresponding author.
E-mail address: miaomiaohan321@163.com (M. Han).

https://doi.org/10.1016/j.apradiso.2018.02.006
Received 6 March 2017; Received in revised form 23 January 2018; Accepted 4 February 2018
Available online 06 February 2018

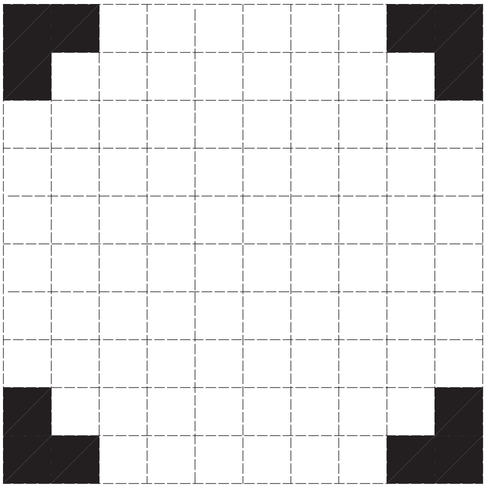

Fig. 1. Traditional method for dealing with voxels in the whole waste drum layer.

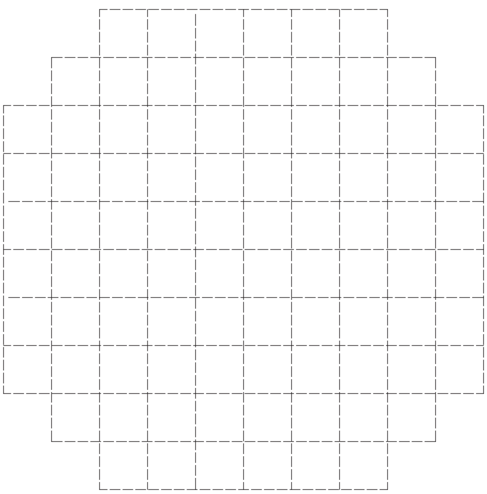

Fig. 2. Traditional voxel arrangement in the whole waste drum layer.

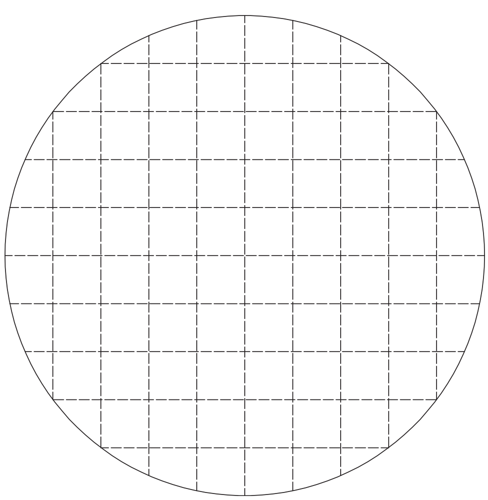

Fig. 3. Accurate voxel arrangement in the whole waste drum layer.

easily, but a novel method for treating the real edge voxels is proposed in the present study. These two different methods for treating edge voxels were compared according to specific criteria for comparing the quality of transmission reconstruction. Two transmission reconstruction algorithms - comprising the Algebraic Reconstruction Technique (ART) (Gordon et al., 1970; Estep et al., 1994; Thierry and Pettier, 1999; Bruyant, 2002; Hansen, 2004; Chen, 2006) with a non-negativity constraint and Maximum Likelihood Expectation Maximization (MLEM) (Shepp and Vardi, 1982; Lange and Carson et al., 1984; Prettyman et al., 1995; Goodman, 1997; Burr et al., 1998; Krings and Mauerhofer, 2012; Wang et al., 2014) were tested separately to explore the effects of different edge voxel treatment methods on the quality of transmission reconstruction.

2. Theory

2.1. Edge voxel treatment methods in TGS

The TGS technique divides every layer of the waste drum into numerous voxels. In the present study, we consider the national standard waste drum of 200 liters, with an interior height of 85.0 cm, interior diameter of 56.0 cm, and iron wall thickness of 0.15 cm. The drum is subdivided into 16 vertical layers and two perpendicular diameters of the drum are subdivided equally into 10 intervals to obtain 100 voxels with a side length equal to 5.6 cm.

2.1.1. Traditional edge voxel treatment method

The traditional TGS technique usually regards irregular edge voxels as regular cubic voxels (Kane et al., 2007; Croft et al., 2004). The traditional edge voxel treatment method is shown in Figs. 1 and 2, where three voxels in each of the four corners are excluded from the cylindrical drum layer to obtain only 88 voxels used.

2.1.2. Accurate edge voxel treatment method

In this study, we propose an exact division method for voxels to obtain the voxel arrangement shown in Fig. 3.

2.2. Path lengths of voxels using two different edge voxel treatment methods

The layout of the TGS simulation model is shown in Fig. 4. The transmission source used generally had multiple γ-ray energy lines. In this study, these energy lines were detected by a high resolution and coaxial High Purity Germanium (HPGe) detector, which had a relative efficiency equal to 30% and a resolution (Full Width of Half Maximization, FWHM) of 1.85 keV for the 1.33 MeV ^{60}Co photopeak, where it was collimated by a lead collimator with a truncated diamond-shaped window (Estep, 1994; Estep et al., 1994; Gu et al., 2013), as shown in Fig. 4. The size was larger than the diameter of the Ge crystal in the HPGe detector in order to obtain a nearly uniform vertical efficiency distribution in the drum. In general, the fission products ^{137}Cs, ^{60}Co are the key gamma emitting nuclides in low level and intermediate level radioactive waste drums, so Monte Carlo simulations were mainly conducted based on three kinds of γ ray energies as the transmission source: 0.66167 MeV (^{137}Cs), 1.1732 MeV (^{60}Co) and 1.3325 MeV (^{60}Co).

The TGS scanning mode was stepwise with five translation positions comprising 1/10, 3/10, 5/10, 7/10, and 9/10 for the waste drum radius shown in Fig. 4, which are marked as P1, P2, P3, P4, and P5, respectively, and with 24 successive rotation positions uniformly over 360°. Thus, we found that the path lengths of the edge voxels and their nearby voxels using the two different edge voxel treatment methods varied for all of the different translation and rotation positions shown in Fig. 5. As shown in Fig. 5, at the five translation positions comprising P1, P2, P3, P4, and P5, the path lengths through the whole real layer were A1B1, A2B2, A3B3, A4B4, and A5B5 respectively, and they differed significantly from those obtained by the regular cubic edge voxel treatment method.

3. Simulation set-up

The Monte Carlo Neutral Particle (MCNP) transport code was employed as a tool of Monte Carlo simulations to perform the numerical