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# Fan Beam Tomography Technique for Scale Thickness Measurement in Geothermal Pipeline West Java Area

## *Teknik Tomografi Fan Beam untuk Pengukuran Tebal Kerak pada Jalur Pipa Pembangkit Listrik Panas Bumi di Wilayah Jawa Barat*

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## ABSTRACT

In the industrial field, tomography technique has been developed for inspection or maintenance by obtaining cross-sectional images of an object. Tomography application in geothermal power plant assist online inspection without interrupting operation process. Identification of scale materials in online condition is required to observe steam pipe productivity. A fan beam computed tomography system using gamma-ray transmission has been developed in laboratory experiment and field work. The aim of this study is to identify scale materials and its' parameters, for instance geometry, density, and concentration of elements. The system feature is an arc up to 100°, vertex distance of 413.5 mm, fan rotation increment of 2.813°, and fan sensor spacing of 0.781°. This auto control system is used to scan geothermal pipe with outer diameter (OD) of 220 mm and thickness of 8.18 mm. Gamma radiation source which used is Scandium-46 (Sc-46) with activity 15 mCi. In this paper, experiment data are compared with Monte Carlo simulation method to strengthen interpretation. The results showed that image reconstruction successfully identify geometry and distribution scale materials inside the pipe which is the thickest located in d position 62 mm. Element analysis tested using neutron activation analysis (NAA) method contain some elements, with confidence level 95%.

**Keywords:** fan beam, computed tomography, scale, geothermal

## ABSTRAK

Pada bidang industri, teknik tomografi telah banyak dikembangkan untuk pemeriksaan atau perawatan dengan memperoleh gambar penampang lintang suatu benda. Aplikasi tomografi pada pembangkit listrik tenaga panas bumi membantu pemeriksaan secara online tanpa mengganggu proses operasi. Identifikasi material kerak dalam kondisi online diperlukan untuk mengetahui produktivitas pipa uap. Sebuah sistem *fan beam computed tomography* menggunakan transmisi sinar gamma telah dikembangkan pada eksperimen laboratorium dan pekerjaan lapangan. Penelitian ini bertujuan untuk mengidentifikasi material kerak berdasarkan parameter tertentu seperti geometri, massa jenis, dan konsentrasi unsur/senyawa. Fitur sistem berbentuk busur 100°, jarak *vertex* 413,5 mm, *fan rotation increment* 2,813°, dan *fan sensor spacing* 0,781°. Sistem pengendali otomatis digunakan untuk memindai pipa panas bumi berdiameter luar 220 mm dan tebal 8,18 mm. Sumber radiasi gamma yang digunakan adalah Scandium-46 (Sc-46) dengan aktivitas 15 mCi. Dalam makalah ini, data eksperimen dibandingkan dengan metode simulasi Monte Carlo untuk memperkuat interpretasi. Hasil yang diperoleh menunjukkan bahwa rekonstruksi citra berhasil mengidentifikasi geometri dan distribusi material kerak di dalam pipa dimana ketebalan kerak tertinggi terdapat pada posisi d, setebal 62 mm. Analisis unsur yang diuji menggunakan metode analisis aktivasi neutron (NAA) menujukkan kandungan unsur, dengan tingkat kepercayaan 95%.

**Kata kunci:** fan beam, tomografi komputasi, kerak, panas bumi

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## INTRODUCTION

All geothermal power plants use thermal fluid or steam from underground reservoirs to turn large turbines of power electricity. Geothermal fluid chemistry is characterized by presence of many chemical element and compounds in various combinations [1],[2]. The chemistry of these fluids can contain significant challenges for the efficient operation of pipeline. Physical-chemical processes that occurred in two-phase flow can affect pipe corrosion, scaling, and aggressive components behavior through heat mass-transfer processes [3],[4]. Composite material sedimentation will form a scale surrounding wall pipe which in turn decrease production capacity in general. In this case, it is required to do early online inspection technique to study growth of scale thickness, providing necessary supporting data of regular maintenance.

The development of non-destructive technology has been advanced and applicable to industrial scale. The application of tomography techniques has expanded, not only in the medical, but also in industrial field which is nowadays get the advantages from it's application. Modalities of tomography use gamma radioactive materials, x-ray generator, or neutron source [5]. Fan beam tomography technique is a scanning method that has been developed from parallel beam generation to obtain cross-sectional images of an object [6]. The purpose of this work is to identify scale materials in geothermal pipe using fan beam tomography modality. In this study, Monte Carlo program aims to simulate gamma intensity on normal pipe without scale. The gamma tomography technique cannot distinguish composition of element or chemical compound, therefore data is complemented by neutron activation analysis (NAA) test to determine concentration of elements in pipe scale materials.

## PRINCIPLE

Gamma rays or commonly called photons are electromagnetic waves that have a wavelength $\lambda$ = 0.1 - 0.0001 Å [7]. Based on this frequency of 1017 Hz – 1025 Hz, gamma rays have high energy to penetrate metal materials or high atomic number elements. Before penetrating the object, photon is emitted by collimated radioisotope source, for example in this case is Sc-46. The transmitted photon beam intensity I is given by the following equation [8]:

$$I = I_0 \exp\left(-\int_{-\infty}^{\infty} \mu(x,y)\,dY\right) \quad (1)$$

Where $I_0$ is the incident intensity, $\mu(x,y)$ is the attenuation coefficient of element $(x,y)$ and $Y$ is the beam path length through the object. The main principle of the gamma-rays phenomenon for industrial applications is that the higher the density of absorbing material, the lower gamma rays intensity measured.

The design of mechanical scanning system is related to CT generation. There are four configuration of scanning system categorized according to the work principle. This principle refers to the geometrical arrangement of combination of detectors, the beam geometry from radiation source, and the method adopted for acquiring the data for the requisite number of projections. Table 1 summarize the development from the first to the newest [9],[10].

**Table 1**. The development of measurement geometry for gamma or x ray CT scanners [9],[10]

| Geometry system | Beam geometry | Data acquisition system |
|---|---|---|
| First generation (parallel beam) | Single pencil beam of radiation | Linear translation then rotate to next angular |
| Second generation | Multiple pencil beams | Translation rotation |
| Third generation (fan beam) | Arc concentric like a fan | Fix detector rotating source arrangement in a few numbers |
| Fourth generation | Arc beam in the ring of detectors | Fix detector rotating source arrangement in a large numbers |

The electronic system consist of scintillation system, data acquisition, and micro controller which integrated with computer system. Scintillation process occurs in photo multiplier tube (PMT) of radiation detector and give an output of current pulse. This pulse counted as radiation intensity data then transmitted from control modules to the computer [11]. After collecting data, cross-sectional image is reconstructed using filter back projection algorithm [12]. Positioning accuracy of the CT scanner is one factor in reducing artifacts of the reconstructed image.

The image reconstruction on equiangular fan beam geometry is carried out by calculating value C pixel, represented by L distance from radiation source S. C value is determined based on intensity and gamma ray path measured by the

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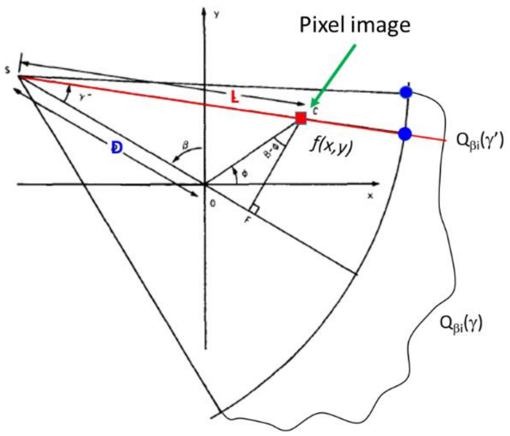
$Q_{\beta i}(\gamma)$ detector, with spacing detector ($\gamma$=0.781). When measure $Q_{\beta i}(\gamma)$, source (S) is at the projection angle ($\beta$) and vertex distance of D = 41.35 cm with i=1-128 and $\gamma$=0.781° while $\beta$ = n 2.813° where 0≤ n ≤127, as seen in Figure 1.




$$P(\beta,\gamma) = -ln\left(\frac{I_{\beta}(\gamma)}{I_0}\right) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mu_{\gamma,L}\, d_l d_{\gamma}$$

$$L\,(x,y,\beta) = \sqrt{[D + x.sin\beta - y.cos\beta]^2 + [x.cos\beta + y.sin\beta]^2}$$

$$\gamma = tan^{-1}\left[\frac{x.\cos\beta + y.\sin\beta}{D + x\sin\beta - y\cos\beta}\right]$$

**Figure 1.** Fan beam reconstruction algorithm

## MONTE CARLO SIMULATION

Monte Carlo simulation is commonly used for radiation transport such as computing neutron fluxes in reactor facility and for dosimeter calculation to measure how safe the conditions are [13]. This method is a computational algorithm that can provide approximate solution to a variety of nuclear and also other physical problems by the simulation of random quantities [14]. Monte Carlo N Particle eXtended (MCNPX) software were used in this study to generate expected data samples from arbitrary Sc-46 gamma source distributions. The interactions of nuclear particles such as photons with scale materials can be described through statistical mean and stochastic modelling [15].

Simulations were performed for the geometry of Fig. 1. To generate tomographic data, transmitted radiation from 128 different source points (red point) is calculated. The radiation source is simulated as a gamma sealed source, which is a Sc-46 in capsule of 40 mm diameter, 40 mm length and collimated in cone shape. Radiation source is placed in a source holder, in lead material. The source capsule is contained in tungsten collimator. The function of collimator is to confine the beam direction to face the detector. The source collimator has cylindrical tungsten shielding block with 1 cm window silt and beam angle of 50°.

Phantom object with diameter of 220 mm placed in the center system, with vertex distance 413.5 mm. The detector is capsulated with 40 x 40 mm detector holder and made of lead. Different with source holder, detector holder use panoramic collimator with an open window 10 mm width. The open window designed based on crystal NaI(Tl) position in scintillation sensor. Detector step is 0.781° to represent 128 measurement points along arc length, often called by fan sensor spacing. The fan beam rotate with 128 steps along the source track, so the fan rotation increment is 2.813° per projection.

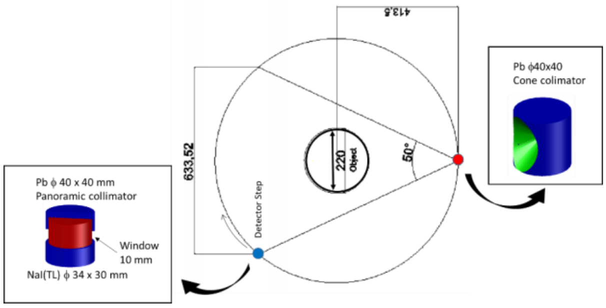



**Figure 2.** Design geometry of Monte Carlo simulation

This simulation generated 5 x $10^6$ radiation particles to measure the number of photon in crystal detector after penetrating through materials. The pulse height tally of F8 for each detector is used to simulate a single channel counting without variance reduction [16]. Since Sc-46 has two energies level, the energy bins are set at $10^{-6}$, 0.2, 0.5, 0.7, and 1.2 MeV. This range of energy simulate different threshold levels. The threshold energy for photo-peak range is determined from energy spectrum simulated by MCNPx [17]. Fig. 3(a) shows image reconstruction of the phantom. As seen in the graph (right side), the simulation results show data that matches the phantom geometry. The size of the number of photons plotted on a graph is in accordance with the concept of radiation attenuation. The resulting cross-sectional image of the pipe shows the absence of scale around the

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inner pipe wall. Based on the calculation of statistical data, the measurement error for each iteration of particles is observed that less than 1%.

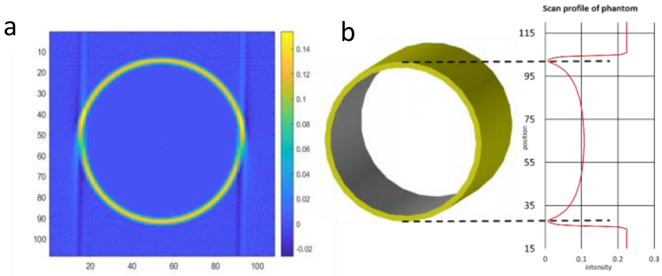


**Figure 3.** (a) Cross-section of image reconstruction
(b) Scan profile for 0° projection

## EXPERIMENTAL METHOD

Laboratory experiments were performed using fan beam tomography modality, using radioisotope Sc-46 with 15 mCi of activity. The sample was placed in the center of scan area, with 210 mm distance from pipe wall to the internal edge of ring system. The fan beam device as seen in Figure 4 (a) consists of two rings, both driven by two motors and integrated with a microcontroller system. Coverage area of detector in linear is 633.52 mm, seen in Figure 4 (b). Detector ring moves 0.781° of step detector, while the source ring located under detector ring moves 2.813° of step source. One projection or one view defined if condition of data acquisition has been performed for 128 step detectors (128 rays). Furthermore, source and detector had moved simultaneously and rotated 128 views in 360°. The radiation intensity was measured for 1 second using NaI(Tl) detector and Ludlum counter system. In accordance with basic theory, the measurement data carries information about object material in its path, so that the measurement system can identify scale materials inside the pipe.

## RESULT AND DISCUSSION

Radiation intensity is derived from the function of material density and material thickness. The value of radiation intensity values were stored in units of count per second (cps). The intensity data matrix consists of 64 x 128 data, where the number of rows explained fan projection, and the number of columns explained detector steps. After data matrix has been normalized, image processing was performed using the MATLAB© application. The pixel matrix size resulted was 88 x 88.

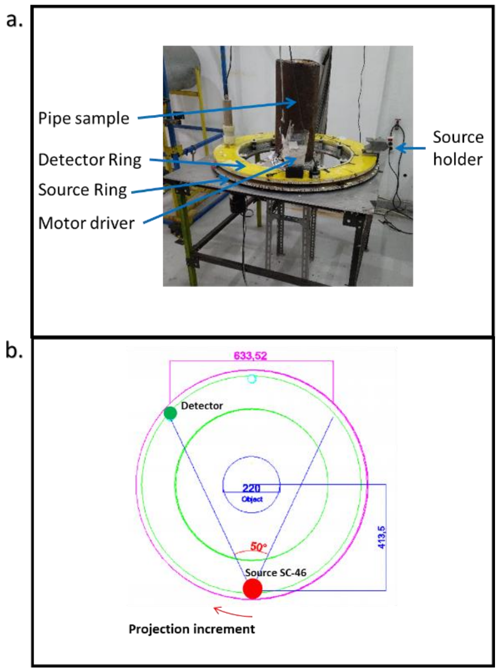


**Figure 4.** (a) Fan beam tomography system
(b) Schematic drawing of measurement system

The scanning result of geothermal pipe object was reconstructed using MATLAB© program. Figure 5 showed various colors which represented various density of material. Dark blue represented air material. It was clearly seen that the air outside the pipe was darker than inside pipe. The yellow color represented higher density, such as iron or stainless steel. The configuration of scale materials distribution in the pipe was not linear, and was not perfectly circular.

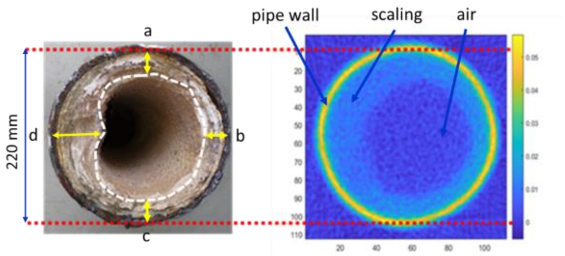


**Figure 5.** Image reconstruction of scale materials distribution

Table 2 explained scaling thickness at each location. Location of a, b, c, and d presented the form of materials on the wall pipe. The reconstruction image successfully revealed the real scaling distribution was appeared at “d” location which is the thickest part (62 mm) as shown in Figure 5.

**Table 2.** Scale materials distribution

| Location of scale | Pixel Value | Thickness of scale (mm) |
|---|---|---|
| a | 0.35 | 29 |
| b | 0.34 | 28 |
| c | 0.34 | 28 |
| d | 0.74 | 62 |
| Average | 0.44 | 36.75 |

Nuclear activation analysis testing was done in order to get information of chemical content, especially for types of element and concentration. Table 3 described major elements in scale materials, which consisted of aluminum, sodium, iron, europium, and ytterbium. Iron and aluminum were the two biggest concentration in materials of scale, 21185 mg/kg and 11563 mg/kg respectively. Uncertainties given with confidence level of 95 % and k = 2.

**Table 3**. Elements concentration in scale materials

| Sample | Element | Unit | Concentration |
|---|---|---|---|
| Scale of geothermal | Aluminum (Al) | mg/kg | 11563.94 ± 451.42 |
| | Sodium (Na) | mg/kg | 5563.46 ± 61.88 |
| | Iron (Fe) | mg/kg | 21185.00 ± 404.07 |
| | Europium (Eu) | mg/kg | 0.25 ± 0.2 |
| | Ytterbium (UYb) | mg/kg | 0.31 ± 0.02 |

## CONCLUSION

Fan beam gamma tomography technique was successfully implemented in industrial field for identification of scale materials distribution. According to the experimental laboratory, scale materials were distributed around the inner pipe wall with various thickness. Gamma tomography fan beam is an effective and efficient tool to identify geothermal pipe in online inspection. Iron (Fe) was the most abundant element with concentration 21185 kg/mg.

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