# AN OVERVIEW OF X-RAY MICRO COMPUTED TOMOGRAPHY (MICRO-CT) APPLICATION AT THE MALAYSIAN NUCLEAR AGENCY

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## ABSTRACT

*This technical paper provides an overview of the applications of X-ray Micro Computed Tomography (Micro-CT), with a specific focus on Skyscan 1172 Micro-CT, at the Malaysian Nuclear Agency. Micro-CT is a non-destructive imaging technique that has gained widespread use in scientific and industrial fields. The paper examines the fundamental principles and techniques of Skyscan 1172 Micro-CT and explores its applications in the Malaysian Nuclear Agency for material characterization and defect detection. Additionally, the paper discusses the advantages and limitations of Micro-CT and outlines the challenges and opportunities for its use in Malaysia. Overall, this review aims to provide insights into the potential applications of Micro-CT in Malaysia and to encourage further research and development in this field.*

## ABSTRAK

*Kertas teknikal ini memberikan gambaran keseluruhan aplikasi X-ray Micro Computed Tomography (Micro-CT), dengan fokus khusus pada Skyscan 1172 Micro-CT, di Agensi Nuklear Malaysia. Micro-CT adalah teknik pengimejan yang tidak merosakkan yang telah mendapat penggunaan meluas dalam bidang saintifik dan perindustrian. Kertas kerja ini mengkaji prinsip dan teknik asas Skyscan 1172 Micro-CT dan meneroka aplikasinya dalam Agensi Nuklear Malaysia untuk pencirian material dan kecacatan Selain itu, kertas kerja ini membincangkan kelebihan dan batasan Micro-CT dan menggariskan cabaran dan peluang untuk kegunaannya di Malaysia. Secara keseluruhan, ulasan ini bertujuan untuk memberikan pandangan tentang potensi aplikasi Micro-CT di Malaysia dan untuk menggalakkan penyelidikan dan pembangunan selanjutnya dalam bidang ini.*

**Keywords:** X-ray micro computed tomography, non-destructive imaging technique, defect detection

## INTRODUCTION

Tomography technology underwent significant developments around the 1970s and began to be used in the field of medicine as an essential tool for producing internal images of the human body. In its early stages, the use of tomography was limited to scanning the human body using X-rays in clinics and hospitals. This technology provided detailed images of patients' conditions and assisted doctors in carrying out appropriate treatments.

In parallel with the advancement of computer technology and increasing data processing capabilities, innovations leading to the development of X-ray Micro Computed Tomography (Micro-CT) emerged. Micro-CT is a tomography system specifically designed for scanning and producing high-resolution cross-sectional images of objects on a microscopic scale. Compared to conventional tomography systems, Micro-CT can generate more detailed and precise images of the internal structure of objects.

In the 1980s, Micro-CT was first introduced and has since gained popularity among researchers, scientists, and industry professionals. The main advantage of Micro-CT lies in its ability to scan small-sized samples with high resolution. By using Micro-CT, users can visually observe and analyse the internal structure of objects on a microscopic scale without the need for physical cutting of the object. This enables more precise research into the structure of materials such as biological tissues, morphology, and the distribution of small components within a product.

## MICRO-CT PRINCIPLES

The principle behind Micro-CT imaging is based on a similar principle as medical CT. A Micro-CT scanner uses a source of cone beam X-rays that is directed towards the object being imaged. The X-rays pass through the object, and some of the X-rays are absorbed by the object's internal structures depending on its density. The remaining X-rays which reach the planar detector will record the intensity of the X-rays. During scanning, the object on the turn table is rotated thus taking multiple X-ray projections from different angles, Figure 1. These projections are then processed by a computer to reconstruct a two-dimensional cross section image of the object's internal structure.

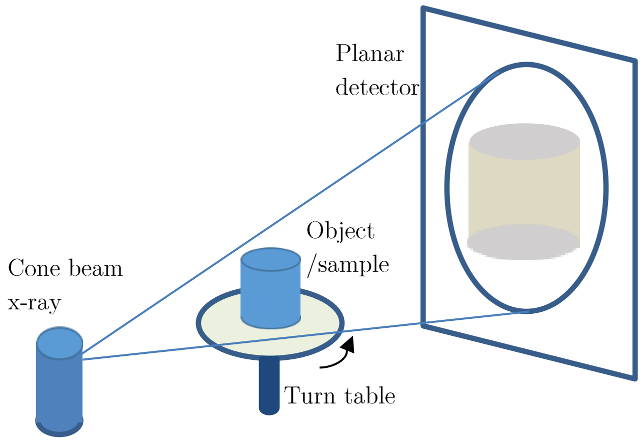


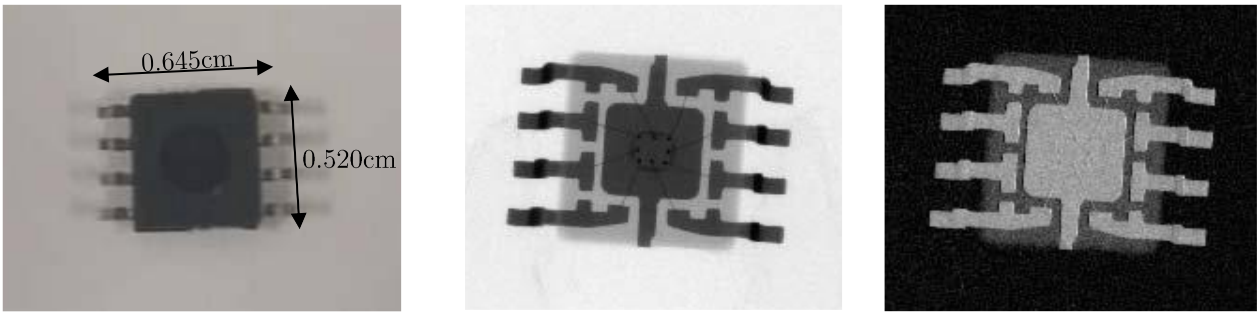

**Figure 1.** Micro-CT scanning configuration

The resolution of Micro-CT is determined by several factors, including the X-ray source focal point, detail detectability of the planar detector and sample size. In general, Micro-CT can achieve resolutions in the range of a few micrometers depending on the model of Micro-CT system.

Sample preparation is also an important consideration in Micro-CT imaging. The sample must be fixed and stabilized to prevent movement during imaging and may need to be stained or contrasted to highlight specific structures of interest especially for very low-density object. Additionally, the sample size and density can affect the quality of the image, as thicker or denser samples may require higher X-ray energies and filtration.

## APPLICATIONS OF MICRO-CT AT NUCLEAR MALAYSIA

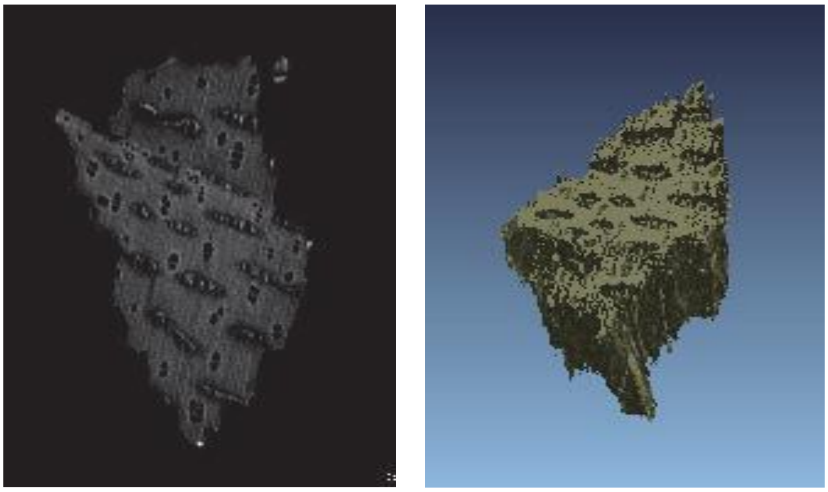
The application is remarkably versatile, as it can be applied to a wide range of fields and industries, offering adaptability and utility in various research. Whether in scientific research, industry, medical diagnostics, or other sectors, it effectively addresses diverse needs and challenges, providing valuable insights and solutions. One of the applications involves the investigation of whether the dual-energy imaging technique could serve as a viable alternative to the conventional method and enhance the quality of output images. For this research, an electronic microcontroller was selected as the specimen, primarily due to its intricate internal composition. The microcontroller underwent scanning using Micro-CT scanner, utilizing two different energy levels: 60kVp and 100kVp. Subsequently, the acquired images underwent dual-energy image processing, and the resulting outcomes were compared with those of single-energy images in terms of contrast and overall image quality. The integrated data obtained from the dual-energy scans at 60kVp and 100kVp effectively revealed the internal structure of the sample, including any raised surfaces.




(a) (b) (c)

**Figure 2.** Image of microcontroller (a) Actual picture of microcontroller with dimension, (b) Projection image using dual-energy weighted average method, (c) Projection image using dual energy subtraction method

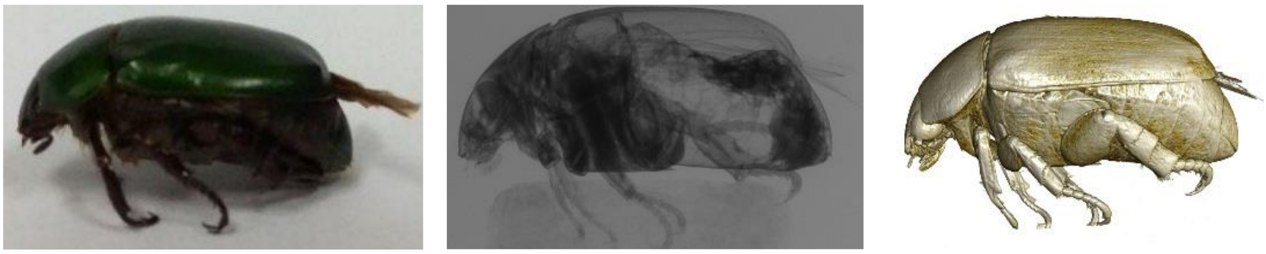
Another research explores the potential utility of Micro-CT, in conjunction with scanning electron microscope as imaging tools for the purpose of visualizing the micro-structure of resin within agarwood. These methods were applied to compare two sets of agarwood chips, one of high quality and the other of lower quality. The results led to the conclusion that wood cells containing resin deposits exhibit greater levels of attenuation. The combination of scanning electron microscopy and Micro-CT effectively provides high-resolution images, revealing both the localization and structure of resin within agarwood. Scanning electron microscopy offers detailed 2D morphological information, while Micro-CT enables a comprehensive 3D examination of the internal structure of agar wood, Figure 3. These advanced imaging techniques hold potential for standardization, particularly in the context of grading agarwood for commercial purposes.



(a) (b)

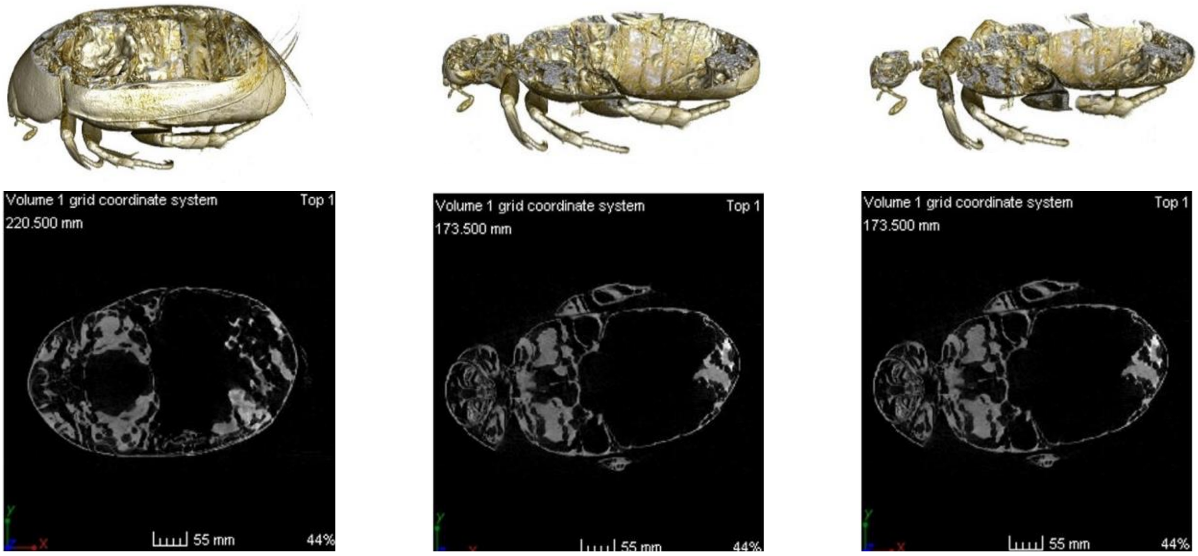
**Figure 3.** Reconstruction image of low oleoresin sample (a) Cross section view, (b) 3D view

Yet another intriguing study aims to showcase the potential of x-ray microtomography in the field of entomology, particularly for investigating small insects, such as the flower beetle, Figure 4. In this research, Micro-CT has been effectively utilized to perform scans, resulting in the creation of high-quality images that reveal the external and internal morphological features of the flower beetle, Figure 5. This advancement in imaging technology holds promise for enhancing our understanding of these tiny creatures and their intricate structures, providing valuable insights for entomologists and researchers in related fields. It has significant potential for entomology research and education, providing interactive images that highlight the complexity of insect morphology. In the future, it may contribute to the development of virtual reality teaching methods in entomology.



(a) (b) (c)

**Figure 4.** Flower beetle image (a) in actual photo, (b) x-ray radiographic, (c) 3D view




(a) (b) (c)

**Figure 5.** 3D view of Flower Beetle (Top) and 2D cross section image (bottom) (a) Cross-section at upper segment, (b) Cross-section at middle segment and (c) Cross-section at bottom segment

In addition to the samples analysed in these studies, a wide range of other specimens have been subjected to Micro-CT scanning. These include diverse items such as rat femurs (bones), rat teeth, human teeth, fly larvae, dried fruits, materials used in additive manufacturing, composites, sandstone, and numerous others. The reason these samples were suitable for Micro-CT scanning is because of their manageable size, lack of high-density materials, and solid composition, all of which make them amenable to this imaging technique.

## ADVANTAGES OF MICRO-CT

Micro-CT boasts numerous advantages compared to alternative imaging methods. One of its key benefits includes its non-destructive nature, making it perfect for visualizing and studying the internal structures of objects without causing harm, especially for delicate or rare specimens. Additionally, it can produce high-resolution 3D images of small objects with micron precision, enabling in-depth analysis of structures and features beyond the reach of other imaging methods. Versatility of Micro-CT allows it to image various objects, including biological specimens, materials, and even small living organisms, in different orientations and with varied contrasts. Moreover, it offers relatively rapid imaging, depending on object size and required resolution, making it valuable for examining numerous samples within a brief time frame. Furthermore, Micro-CT furnishes quantitative data about object properties such as density, volume, surface area, and porosity. Therefore, this data enables the analysis of material properties, fluid dynamics, biological structures, and their functions. Finally, Micro-CT can produce three-dimensional images of objects, allowing for rotation and observation from various angles, thus facilitating a comprehensive examination of their internal structures. In brief, Micro-CT stands as a powerful imaging technique and has become an indispensable tool in various research and development fields, from materials science and biology to engineering.

## LIMITATION OF MICRO-CT

Although it has numerous advantages, Micro-CT does have several notable limitations. Clearly, its limitations are influenced by the size of the sample, typically accommodating specimens ranging from a few millimeters to a few centimeters. To accommodate a larger sample, it requires higher X-ray energies especially for high density material. Large samples could also potentially impact the resolution issue because of the constraint to accommodate the whole radiographic image on the planar detector. Additionally, the use of X-rays although commonly at slightly lower energies in medical CT, it can still induce radiation damage especially for imaging small living organisms over extended periods. Another challenge lies in contrast limitations, as some samples lack inherent contrast, necessitating the use of contrast agents that may alter the properties of sample. Furthermore, Micro-CT images may exhibit artifacts, such as streaking due to beam hardening effect on high density sample. Introducing filters will reduce this effect. However, due to the need of use higher energy X-ray, there is a possibility of losing some details on the less dense side of the sample. Last but not least, even though Micro-CT offers exceptional spatial resolution, its temporal resolution is restricted by the time required for acquiring multiple projections, thus limiting its utility in capturing fast-paced dynamic processes.

## BASIC SPECIFICATIONS OF MICRO-CT

Malaysian Nuclear Agency houses the Skyscan 1172 Micro-CT system as part of its equipment, Figure 6. This Micro-CT system has the capability to produce high-resolution images down to 5μm, depending on the size of the object. It utilizes X-ray sources ranging from 20 to 100 kV, and its radiation detector consists of a CCD (charge-coupled device) with a resolution of 1.3Mp. The system can scan samples with a maximum size of up to 20mm in diameter and 20mm in length.

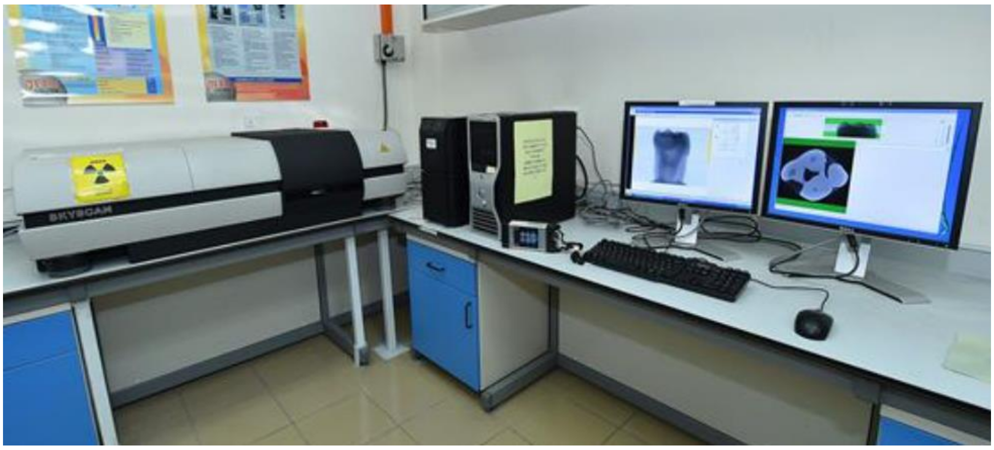


**Figure 6.** Micro-CT system at Malaysian Nuclear Agency

The scanning time for any given object depends on the resolution and sample size but typically ranges between 15 minutes to nearly 1 hour. Image reconstruction is performed using Nrecon software, enabling data processing and the generation of cross-sectional images from the radiographic images obtained after the scanning process. Images resulting from the scanning process can be saved in TIFF format, which is suitable for analysis and visualization. Additionally, the system supports various other 2D/3D image formats for analysis and data presentation purposes. With its specifications and features, the Skyscan 1172 Micro-CT is a suitable system for scientific research, product development, and material testing, especially for studying the microscopic-scale structure and characteristics of objects.

## CONCLUSION

Micro computed tomography (Micro-CT) is a valuable non-destructive imaging technique capable of visualizing and analysing the internal structure of small objects in three dimensions. It shares the fundamental principles of X-ray-based imaging with medical CT but excels in offering higher resolution images. The process involves directing X-rays toward the object and recording their intensity after passing through it, creating 3D images through computer processing. Micro-CT has a wide range of applications in materials science, biology, and engineering, such as in examining materials and biological specimens. This imaging technique offers several advantages, including non-destructiveness, high resolution, versatility, speed, quantitative analysis, and the ability to provide 3D images. However, it also presents certain limitations, encompassing restrictions on sample size, the potential for radiation-induced damage, contrast challenges, the presence of artifacts, and temporal resolution constraints. Overall, Micro-CT stands as a powerful and indispensable tool in various research and development domains.

## ACKNOWLEDGMENT

The authors would like to thank the Malaysian Nuclear Agency for acquiring the X-ray Micro-CT systems, made possible through the assistance of the International Atomic Energy Agency (IAEA). Very special thanks go to the Manager of the Plant Assessment Technology (PAT) group, as well as the Plant Assessment Technology (PAT) group research team and researchers from other divisions, for their generous support and collaboration.

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