Journal of Basic and Applied Engineering Research
Print ISSN: 2350-0077; Online ISSN: 2350-0255; Volume 1, Number 9; October, 2014 pp. 76-79

http://www.krishisanskriti.org/jbaer.html

Neutron Imagining – a Versatile Technique to Investigate Internal Structure of Objects

R.C. Sharma

Department of Applied Sciences & Humanities,
Dronacharya College of Engineering Gurgaon – 122001, Haryana, India

Abstract: **Two dimensional Neutron Imaging techniques have been established as invaluable nondestructive inspection methods and quantitative measurement tools. They have been used in a wide variety of applications ranging from inspection of aircraft engine, turbine blades to study of two phase fluid flow in operating proton exchange membrane fuel cells. Neutron imaging produces an attenuation map of neutron radiation that has penetrated the object being examined. With the emergence of digital cameras and the rapid development of digital detectors with better spatial and temporal resolution, neutron imaging has developed into a valuable, reliable technique whose importance for materials research is finally being recognized. The present paper critically analyses, the historical development of neutron source, recent advances in neutron imaging technology and an overview of possible applications.**

Keywords: **Neutron Imaging, Non destructive, Internal structure, Neutron source.**

1. INTRODUCTION

Neutron radiography is a powerful nondestructive imaging technique that produces a two dimensional attenuation map of neutrons that have penetrated an object being examined. The neutrons interact with objects nucleus and strongly tied to its elemental composition. Because the technique is based on attenuation from a well collimated beam, either scattering or absorption will results in intensity variations to create an image. Materials of low atomic number such as hydrogen are easily imaged due to scattering, while boron and cadmium are readily imaged due to their strong absorption.

The outcome from the application of the neutron imaging depends strongly on the neutron source properties and the detection system used. This has, in turn, generated much demand for research and development in these areas. Detection systems have taken a big jump from conventional photographic film to digital real-time imaging. The use of fast and epithermal neutrons [1] as sources and the exploitation of more specialized neutron interactions, like resonance absorption and phase shifts, has further opened up the field of neutron imaging for research and development.

Historical Development of Neutron Source

In 1920, Rutherford [2] postulated that there were neutral, massive particles in the nucleus of atoms. James Chadwick, [3,4] a colleague of Rutherford, discovered the neutron in 1932. He bombarded a beryllium target with alpha particles producing neutrons that recoiled into a block of paraffin. Chadwick's apparatus, the first neutron generator is described in Fig. 1

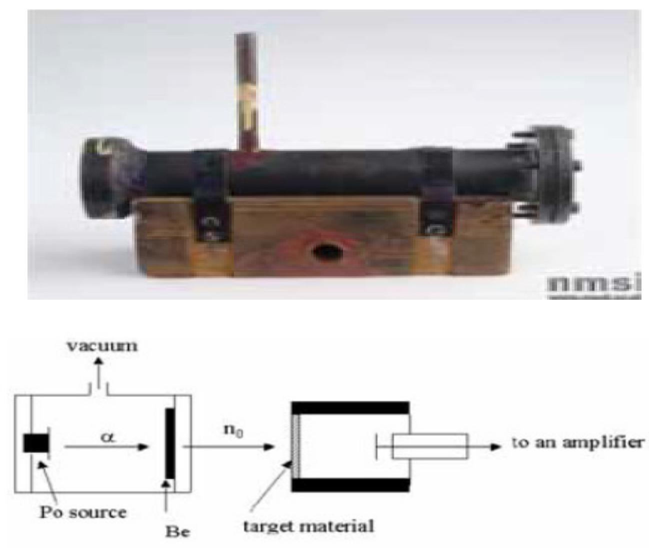

Fig. 1 Detector used by James Chadwick to discover the neutron

Inside the detector, particles from a radioactive source hit a beryllium target. The reaction $9Be+ \longrightarrow 12C \ +n$ produced neutrons that were detected when they knocked protons of paraffin wax. By measuring protons emerging from the paraffin with a Geiger counter, Chadwick inferred that the neutron had a mass comparable to that of the proton. Soon Enrico Fermi recognized that neutrons could be used to produce radioactive nuclides. George de Hevesy helped Fermi obtain samples of rare earths, and he too became interested in activating these materials. His assistant Hilde Levi irradiated dysprosium with neutrons producing a large amount of radioactivity that decayed with time. This episode triggered the realization that the half-lives and magnitudes of induced activities could be used to identify and quantify trace elements and led to the invention of Neutron Activation Analysis. Neutrons produced by charged particle induced reactions is much lower, but neutron generators are more widely available and produce a wide variety of neutron energies. They are much easier to operate and can be shut down completely when not in use. Some reactions for producing neutrons, their respective incident particle energy, Q value and threshold neutron energy are given in Table 1

TABLE 1. REACTIONS FOR PRODUCING NEUTRONS

Reaction	Threshold Incident Particle Energy (MeV)	Q Value (MeV)	Threshold Neutron Energy (MeV)
$^{3}H(d,n)^{3}He$	0	+3.266	2.448
$^{3}H(p,n)^{3}He$	1.019	−0.764	0.0639
$^{3}H(d,n)^{4}He$	0	+17.586	14.064
$^{9}Be(\alpha,n)^{12}C$	0	+5.708	5.266
$^{12}C(d,n)^{13}N$	0.328	−0.281	0.0034
$^{13}C(\alpha,n)^{16}O$	0	+2.201	2.07
$^{7}Li(p,n)^{7}Be$	1.882	−1.646	0.0299

The discovery of Uranium nuclear reactor by Lise Meitner, Fritz Strassmann and Otto Hahn in 1938 provide an excellent source of neutrons. Large fluxes of neutrons are produced by the fission of 235U at nuclear reactors. These can be thermalised for use in various applications.

2. NEUTRON IMAGING

The outcome from the application of the neutron imaging depends strongly on the neutron source properties and the detection system used. This has, in turn, generated much demand for research and development in these areas. Detection systems have taken a big jump from conventional photographic film to digital real-time imaging. The use of fast and epithermal neutrons as sources and the exploitation of more specialized neutron interactions, like resonance absorption and phase shifts, has further opened up the field of neutron imaging for research and development

The history of neutron imaging begin in 1935 when first experiment generating images using neutrons was performed in Germany by Kalmann and Kuhn [5] and subsequently by Peter [6] with more intance neutron source. In 1956 Thewlis and Derbyshire [7] used the 6MM BEPO graphite reactor at Harwell in England for their neutron source producing radiographs of better quality. This work helps to illustrate a number of possible applications specifically the inspection of neutron shielding materials and the studies of organic specimens. With the emergence of digital cameras and the rapid development of digital detectors with better spatial and temporal resolution, neutron imaging has developed into a valuable, reliable technique whose importance for materials research is finally being recognized [8]. In this direction, a Coordinated Research Project by ten countries (India, Bangladesh, Malaysia, Romania, Russian Federation, Brazil, Germany, Switzerland and United States of America) on "Development of Improved Sources and Imaging Systems for Neutron Radiography" was launched by in 2003. The development of detection systems for fast neutron radiography, software for correction to radiographs and microtron [9] based neutron source are some of the outputs of the Coordinated Research Project, which was completed in 2006.

3. APPLICATIONS AND RESULTS

The outcome from the application of the neutron imaging depends strongly on the neutron source properties and the detection system used. This has, in turn, generated much demand for research and development in these areas. Detection systems have taken a big jump from conventional photographic film to digital real-time imaging. The use of fast and epithermal neutrons as sources and the exploitation of more specialized neutron interactions, like resonance absorption and phase shifts, has further opened up the field of neutron imaging for research and development. The selected fields of application on neutrons source[10] are summarized in Table 2.

Field	Category	Energy Required	Energy Required
Security	Explosives detection	14 MeV	luggage inspection, Suspicious objects,C,O,N
Safeguards	Nuclear material detection	2.5 MeV	Fission product nuclides
Industrial	on-line analyzers	2.5 MeV, 14 MeV	Cement process Monitoring, Coal and mining Industries, Ca, Si, Fe, Al
Industrial	metal cleanliness	14 MeV	Oxygen in Mg, Al, Steel
Industrial	Energy production	thermalized	H in fuel cell technology
Medical	body screening	pulsed 14 MeV	pulsed 14 MeV C, O, N, Ca, Na, Cl,P
Nutrition	protein content of food	14 MeV	N

Environmental	Recycled material & waste materials	2.5 MeV thermalized	Cd, Hg, Br, Cl
Environment	Radiography	2.5 MeV	Water content of plants (in vivo)
Environment	Pesticides	2.5 MeV 14 MeV Halogens (F)	Halogens (Br, Cl) Halogens (F)

Table: 2 Selected fields of Application on Neutrons Source.

The use of neutrons in geosciences has high relevance due to the ability to detect water migration in porous media [11]. Both volumetric and temporal information can be obtained from the moisture transport process. Water in a rock sample of about 8 cm diameter, where a voxel size of 0.1 mm can be obtained is shown in Fig.1

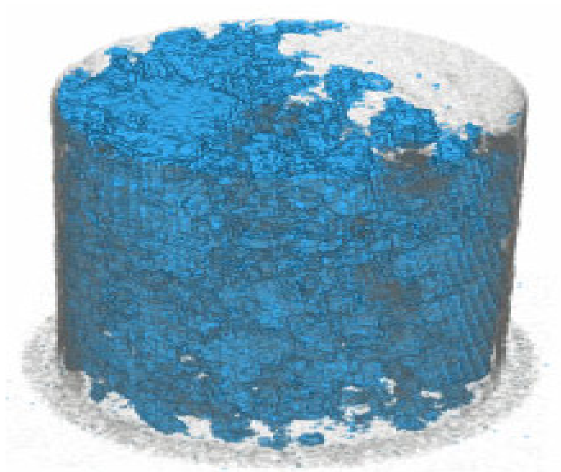

Fig.1 . Water in a rock sample of about 8 cm diameter, where a voxel size of 0.1 mm can be obtained.

The application of neutron imaging in inspection of the injection nozzle for diesel engines is shown in Fig. 2. It may be seen that the metallic parts become very transparent, whereas small amount of hydrogenous diesel fuel can be detected, visualized and quantified with very high precision.

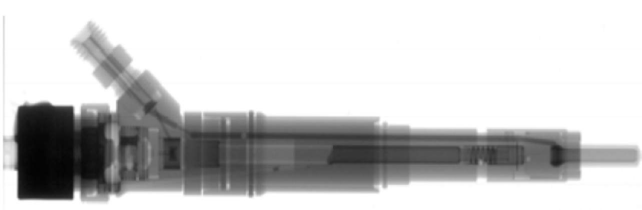

Fig.2 . This neutron image of the injection nozzle for diesel engines. This image was taken at the ICON station.

There are many interesting aspects in Biology to be investigated with the help of neutrons: root growing, moisture distribution in soil and plants, the detection of pollutions and poisons. Organic materials deliver very high contrasts for neutrons in the transmission mode. This dried fish (Piranha) can be studied in very detail because a high resolution was obtained in the image (50 µm are possible nowadays). The neutron image of a dried fish is shown in Fig.3.

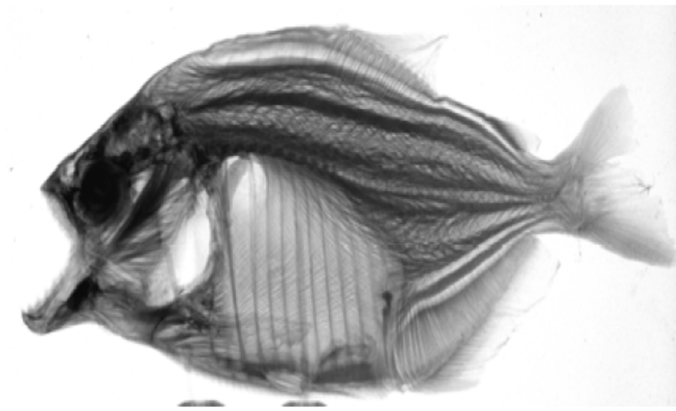

Fig. 3. The neutron image of a dried fish (Piranha)

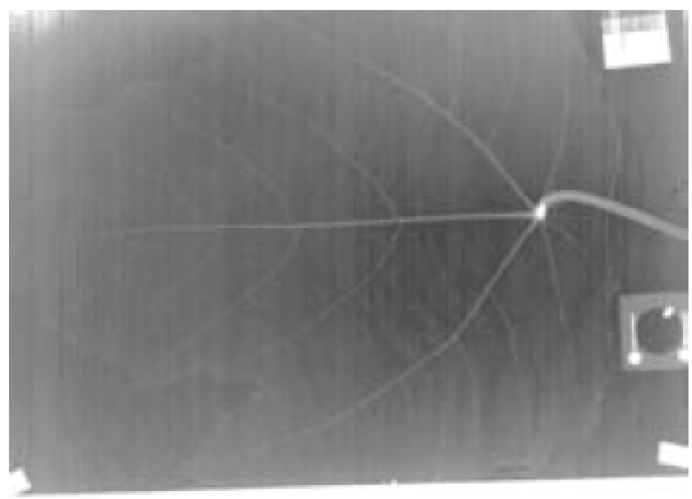

Fig.4. NR image of biological sample.

The neutron radiographic image represents the attenuating behavior of thermal neutron beam due to constituents within the jute reinforced polymer composites. The attenuation of thermal neutron beam is mainly due to scattering and absorption of neutrons. The optical density of the neutron radiographic images of the samples changed with the increase of water absorbed by the samples. Optical density is related with the transmitted neutron through the samples. So, density is also related with the thickness of the absorbed water by the samples. A plot of optical density versus immersion time is shown in Fig. 5.

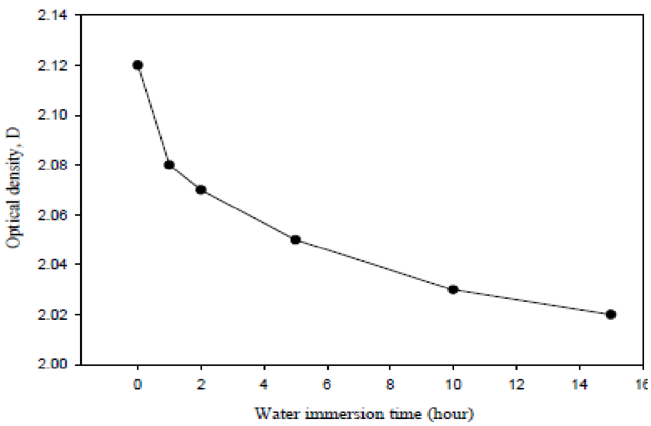

Fig. 5. Densitometric measurement of jute reinforced polymer composite.

4. CONCLUSION

Neutron imaging has been established as a non-destructive versatile technique to investigate the internal structure of objects. The improvement in resolution and contrast with technological advancement is promising. The volumetric and temporal information obtained by this technique make it more application oriented.

ACKNOWLEDGEMENT

Author is grateful to management and administration, Dronacharya College of Engineering Gurgaon for providing R & D atmosphere and encouragement during the work.

REFERENCES

[1] Z.B. Alfassi, N.Lavi, (1983) Epithermal neutron activation analysis using (n, n′) reaction, J. Radioanal. Chem. **76** pp 257.

[2] E.Rutherford (1920) Proc. Roy.Soc. A 97 pp374-400.

[3] J. Chadwick (1932) Possible Existence of a neutron, Nature 129 pp312.

[4] J. Chadwick (1932) Existence of a neutron, Proc. Roy. A 136 pp 692-708.

[5] H.Kallmann, E.Kuhn (1940). Photographic Detection of Slowly Moving Neutrons. United States Patent 2,186,757, January 9, 1940.

[6] O. Peter Neutronen-Durchleuchtung (1946) Zeitschrift Naturforschung Teil A, 1, pp. 557–559

[7] J. Thewlis Neutron, Radiography (1956) British Journal of Applied Physics, 7, pp. 345–350

[8] Neutron Imaging: A Non-Destructive Tool for Materials Testing, IAEA, September, 2008.

[9] A.Sinha,.et al, Design of a microtron based photo-neutron source and its applications for radiography and elemental characterization of bulk samples, Proceedings of the International scientific and technical conference on Portable Neutron Generators and technologies on their basis Oct 18–22, 2004 All Russia Research Institute of Automatics, Moscow, Russia (ed. T.G. Novikova).

[10] Neutron Generation for Analytical Purposes, IAEA, Vienna 2012.

[11] Azali Muhammadd, et.al.(2004), Application of Neutron radiography in investigation of Moisture Distribution in Malaysia Wood, Proceeding MINT R&D 2004 Seminar,MINT Bangi, pp 12–127.