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Practical Applications of Neutron Radiography and Gaging Springer Science & Business Media

This paper will describe ongoing efforts at Oak Ridge National Laboratory to develop a unique experimental capability for investigating flow through porous and fractured geological media using neutron imaging techniques. This capability is expected to support numerous areas of investigation associated with flow processes relevant to EGS including, but not limited to: experimental visualization and measurement of velocity profiles and other flow characteristics to better inform reduced-order modeling of flow through fractures; laboratory scale validation of flow models and simulators; and a 'real-time' tool for studying geochemical rock/fluid interactions by noninvasively measuring material effects such as precipitation and dissolution in EGS representative conditions. Neutron scattering and attenuation based techniques have many distinctive advantages over other radiographic imaging methods for studying certain types of physical processes because cold and thermal neutrons are more highly attenuated by materials with large Hydrogen compositions while they more easily penetrate higher Z materials, such as those used in structural applications. Experiments exploiting this behavior may therefore be devised to study flow behaviors in samples even when thick pressure vessel walls and large sample masses are present. The objective of this project is to develop an experimental setup and methodology for taking EGS representative core samples with engineered fractures and fracture features, subjecting them to a triaxial stress state at EGS representative temperatures (up to 300 degrees C), and pumping high pressure fluid through the sample while imaging and measuring fluid flow characteristics using high flux neutron beams. This effort will take advantage of signature Oak Ridge National Laboratory facilities, including the Spallation Neutron Source and High Flux Isotope Reactor, as well as its core expertise in Neutron Science. Towards this end, a geothermal pressure test cell and flow system has been developed that can accommodate 1.5 diameter, 6 long core samples and apply a radial confining pressure up to 10,000 psi with fluid flow pressures up to 5,000 psi. This cell has been specially designed to optimize the transmission of neutrons and permit improved imaging of the interior of the sample of interest. Proof of principle measurements of the system have been performed and will be discussed in this paper. Techniques for injecting fluid contrast agents to permit visualization and quantification of flow profiles are also being developed and will be described along with future development plans.

Neutron Radiography Handbook CRC Press

This book provides an extensive overview of the application of neutron characterization techniques in cultural heritage to a broad audience and will be of interest to both scientists and non-scientists in the field. Archaeologists, paleontologists, restaurateurs and conservators, historians and collectors will be fascinated by the wealth of information that can be obtained using neutron techniques, while material scientists and engineers will find details of the experimental techniques and materials properties that can be determined. Neutrons, due to their weak interactions with materials, provide a penetrating, but non-invasive probe of bulk properties. They allow the characterization of the composition and mechanical properties of materials, helping to answer questions related to the dating, the manufacturing process or the state of degradation of artefacts. They allow detailed interrogation of the internal structures of objects that may be otherwise hidden from view. The first section of the book is dedicated to stories describing spectacular discoveries brought about by the use of neutron techniques in a range of applications. The second section covers the experimental techniques in appropriate detail: basic principles, limitations and fields of application.

Neutron Detection and Imaging Springer Science & Business Media

Proceedings of the Second World Conference, Paris, France, June 16-20, 1986

Automating X-ray and Neutron Imaging Applications with Flexible Automation Springer

Neutron Imaging and Applications offers an introduction to the basics of neutron beam production in addition to the wide scope of techniques that enhance imaging application capabilities. An instructional overview of neutron sources, detectors, optics and spin-filters allows readers to delve more deeply into the discussions of radiography, tomography and prospective applications available in neutron holography techniques. A section devoted to current applications describes imaging single grains in polycrystalline materials, neutron imaging of geological materials and other materials science and engineering areas. Coverage of thermal neutron imaging of biological tissues, plant physiology, Homeland Security and contraband detection explore the future prospects of this cutting-edge research. Written by key experts in the field, researchers and engineers involved with imaging technologies will find Neutron Imaging and Applications a valuable reference.

Neutron Applications in Earth, Energy and Environmental Sciences Springer

We are proceeding with the development of a high-energy (10 MeV) neutron imaging system for use as an inspection tool in nuclear stockpile stewardship applications. Our goal is to develop and deploy an imaging system capable of detecting cubic-mm-scale voids, cracks or other significant structural defects in heavily-shielded low-Z materials within nuclear device components. The final production-line system will be relatively compact (suitable for use in existing or proposed facilities within the DOE complex) and capable of acquiring both radiographic and tomographic (CT) images. In this report, we will review our programmatic accomplishments to date, highlighting recent (FY06) progress on engineering and technology development issues related to the proposed imaging system. We will also discuss our preliminary project plan for FY07, including engineering initiatives, proposed radiation damage experiments (neutrons and x rays) and potential options for conducting classified neutron imaging experiments at LLNL.

Neutron Radiography John Wiley & Sons

Neutron radiography represents a powerful non-destructive testing technique that is still very much in development. The book reveals the amazing diversity of scientific and industrial applications of this technique, the advancements of the state-of-art neutron facilities, the latest method developments, and the expected future of neutron imaging.

Neutron Imaging and Applications Springer Science & Business Media

Thermal neutrons (with mean energy of 25 meV) have a scattering mean free path of about 20 m in air. Therefore it is feasible to find localized thermal neutron sources up to ~30 m standoff distance using thermal neutron imaging. Coded aperture thermal neutron imaging was developed in our laboratory in the nineties, using He-3 filled wire chambers. Recently a new generation of coded-aperture neutron imagers has been developed. In the new design the ionization chamber has anode and cathode planes, where the anode is composed of an array of individual pads. The charge is collected on each of the individual 5x5 mm2 anode pads, (48x48 in total, corresponding to 24x24 cm2 sensitive area) and read out by application specific integrated circuits (ASICs). The high sensitivity of the ASICs allows unity gain operation mode. The new design has several advantages for field deployable imaging applications, compared to the previous generation of wire-grid based neutron detectors. Among these are the rugged design, lighter weight and use of non-flammable stopping gas. For standoff localization of thermalized neutron sources a low resolution (11x11 pixel) coded aperture mask has been fabricated. Using the new larger area detector and the coarse resolution mask we performed several standoff experiments using moderated californium and plutonium sources at Idaho National Laboratory. In this paper we will report on the development and performance of the new pad-based neutron camera, and present long range coded-aperture images of various thermalized neutron sources.

The Characterization and Monte Carlo Simulation of the Neutron Radiography Facility at Sandia National Laboratories Springer Science & Business Media

Radiography with neutrons can yield important information not obtainable by more traditional methods. In contrast to X-rays as the major tool of visual non-destructive testing, neutrons can be attenuated by light materials like water, hydrocarbons, boron, penetrate through heavy materials like steel, lead, uranium, distinguish between different isotopes of certain elements, supply high quality radiographs of highly radioactive components. These advantages have led to multiple applications of neutron radiography since 1955, both for non-nuclear and nuclear problems of quality assurance. The required neutron beams originate from radioisotopic sources, accelerator targets, or research reactors. Energy "tailoring" which strongly influences the interaction with certain materials adds to the versatility of the method. Since about 1970 norms and standards have been introduced and reviewed both in Europe (Birmingham, September 1973) and the United States (Gaithersburg, February 1975). The first world conference on neutron radiography will take place in December 1981, in San Diego, U.S.A. . In Europe the interested laboratories inside the European Community have entered into systematic collaboration through the Neutron Radiography Working Group (NRWGl. since May 1979. This Handbook has been compiled as one of the common tasks undertaken by the Group. Its principal authors are J.C. Domanus (Ris0 National Laboratory). and R.S. Matfield (Joint Research Centre, Ispra) Major contributions have been received from R. Liesenborgs (SCK/CEN Mol) R. Barbalat (CEN Saclayl.

Imaging and Radioanalytical Techniques in Interdisciplinary Research CRC Press

Rapid advances in tomography and imaging techniques and their successful application in soil and plant science are changing our sciences today. Many more articles using imaging and tomography are being published currently compared to 20 years ago. Soil – Water – Root Processes: Advances in Tomography and Imaging is a unique assemblage of contributions exploring applications of imaging and tomography systems in soil science—it provides an updated collection of X-ray computed tomography, synchrotron microtomography, neutron imaging, magnetic resonance imaging, geophysical imaging tools, and other tomography techniques for evaluating soils and roots. Exciting new procedures and applications have been developed, with the promise to propel forward our understanding of soil and plant properties and processes.

Neutron Imaging Springer

This book comprehensively presents the concepts of neutron physics and imaging including neutron properties, neutron matter interaction, neutron imaging, comparison with X-ray and physics and design of neutron sources. It discusses how neutron imaging has gained importance as a powerful non-destructive technique to understand the internal structures of materials/engineered components in wide range of industries by increasing their applicability and efficiency. The book also covers the topics of neutron optics and detectors, basic principles of neutron radiography and tomography, related standards, safety, metrology and regulations in neutron imaging. The book presents applications of neutron imaging in the areas of aerospace industry, nuclear power and manufacturing industry, materials science and engineering, geomechanics, national security, biological, and medical domain. Given its scope, the book will be highly beneficial for postgraduate students, researchers and industry professionals working in the area of engineering and physics, especially non-destructive testing and non-destructive evaluation through neutron imaging.

Neutrons in Soft Matter ASTM International

Neutron and synchrotron facilities, which are beyond the scale of the laboratory, and supported on a national level in countries throughout the world. These tools for probing micro- and nano-structure research and on fast dynamics research of atomic location in materials have been key in the development of new polymer-based materials. Different from several existing professional books on neutron science, this book focuses on theory, instrumentation, an applications. The book is divided into five parts: Part 1 describes the underlying theory of neutron scattering. Part 2 describes the various instruments that exist and the various techniques used to achieve neutron scattering or bombardment. Part 3 discusses data treatment and simulation methods as well as how to assess the environment of the sample (temperature, pressure, shear, and external fields). Part 4 addresses the myriad applications of small and large molecules, biomolecules, and gels. Part 5 describes the various global neutron sources that exist and provides an overview of the different reactors.

Neutron Imaging for Applications in Industry and Science Springer Verlag

This work demonstrates the neutron sensitivity of single crystal lithium indium diselenide (LiInSe2 or LISe [lithium indium diselenide]). The study aimed to design and characterize a neutron imaging system capable of achieving spatial resolution less than 50 [mu]m [micrometer], operating as a first of its kind direct conversion semiconductor neutron detector. Early detection experiments utilized lithium-6 indium diselenide, enriched to 95% in 6Li [lithium-6], following the experimental investigation of enriched chalcopyrites for semiconductor detection. In this work, lithium indium diselenide (LISe) interchangeably refers to its isotopically enriched complement (6LiInSe2 or 6LISe [lithium-6 indium diselenide]). The primary detection mechanism follows the 6Li(n, [alpha])3H [lithium-6, neutron, alpha, hydrogen-3] reaction, with a Q-value of 4.78MeV. The proof-of-concept detector consisted of a single LISe crystal patterned with thin film gold contacts on opposite surfaces. After showing a semiconductor response to both alpha particles ([alpha]'s) and mixed neutron spectrum, the technology was extended to a 4×4 pixel detector using square pixels of 50 [mu]m size and 550 [mu]m pitch. Using the super-sampling technique, this system successfully resolved features of 300 [mu]m, roughly half the pixel pitch, in a cold neutron beam. Concurrently in the study, higher optical quality LISe sensors demonstrated a scintillation response to neutron exposure. An array of scintillating LISe sensors achieved a resolution of 34 [mu]m, calculated via modulation transfer function (MTF), and were used to reconstruct a neutron computed tomography (nCT) of a small biological sample. Bolstering these results, a semiconducting LISe sensor was patterned with the 55 [mu]m pitch pattern, derived from the 256×256 channel Timepix. The Timepix coupled LISe imager (LISePix) completed the groundwork for the detector as a high-resolution neutron imager, surpassing the design goal with a published spatial resolution limit of 34 [mu]m (full width at half maximum (FWHM) of 111 [mu]m) for LISe. This project has demonstrated the first application of direct conversion semiconductors for neutron detection and imaging, while qualifying a viable neutron detection material for solid-state devices. The LISePix imaging technology offers a low-cost, low-power, compact neutron detection platform comparable to state-of-the-art neutron imaging technologies.

Advanced Neutron Imaging for Nuclear Engineering Applications John Wiley & Sons

Small accelerator neutron sources offer considerable potential for applied neutron radiography applications. Among the desirable features are relatively low costs, limited operating hazards, opportunities for tailoring primary neutron spectra, compactness and portability, and modest licensing requirements (compared to fission reactors). However, exploitation of this potential has been somewhat limited, in part, by incomplete knowledge of the primary-neutron yields and energy spectra from the favorable source reactions. This work describes an extensive experimental determination of zero-degree neutron yields and energy spectra from the 9Be(d, n) 1 ° B source reaction, for incident deuterons of 2.6 to 7.0 MeV on a thick beryllium metal target. This information was acquired by means of time-of-flight measurements that were conducted with a calibrated uranium fission detector. Tables and plots of neutron-producing reaction data are presented. This information provides input which will be essential for applications involving the primary spectrum as well as for the design of neutron moderators and for calculation of thermal-neutron yield factors. Such analyses will be prerequisites in assessing the suitability of this source for various possible neutron radiography applications and, also, for assisting in the design of appropriate detectors to be used in neutron imaging devices.

Neutron Radiography Springer

The field of x-ray radiography is well established for doing non-destructive evaluation of a vast array of components, assemblies, and objects. While x-rays excel in many radiography applications, their effectiveness diminishes rapidly if the objects of interest are surrounded by thick, high-density materials that strongly attenuate photons. Due to the differences in interaction mechanisms, neutron radiography is highly effective in imaging details inside such objects. To obtain a high intensity neutron source suitable for neutron imaging a 9-MeV linear accelerator is being evaluated for putting a deuteron beam into a high-pressure deuterium gas cell. As a windowless aperture is needed to transport the beam into the gas cell, a low-emittance is needed to minimize losses along the high-energy beam transport (HEBT) and the end station. A description of the HEBT, the transport optics into the gas cell, and the requirements for the linac will be presented.

Springer Science & Business Media

Neutron imaging is a powerful tool in the field of non-destructive testing as well as for many applications in fundamental research. This publication contains examples of how neutron imaging has been used in applications requiring the identification of (light) materials inside solid samples. It provides detailed information on how the technique has become a standard method for various applications, from the examination of nuclear fuels, explosives, electronic components and engine turbine blades to the characterization of fuel cells and geological samples.

Accelerator System for Neutron Radiography John Wiley & Sons

Neutron radiography has in recent years emerged as a useful and complementary technology for radiation diagnosis. It is now routinely used in industrial quality assurance and in support of selected research and developmental activities. Conferences are held on the subject, pertinent handbooks exist, and technical papers appear regularly reporting on new developments. While neutron radiography has indeed passed through the transition from a scientific curiosity to technological relevance, it is a sign of its continuing dynamic evolution that little material has appeared which provides an integrated mathematical and physical analysis of the subject possessing both an instructional as well as reference function. It is our hope that this monograph will fill this need. The distinctiveness of neutron radiography rests on the unique interactions between neutrons and nuclei. This leads to some special relationships between the material and geometrical properties of an object and the neutron radiographic image. The evolution of a technical discipline demands that specific conceptual constructs be developed and their mathematical representations examined and compared with controlled experiments. Experience has convinced us that a particular and substantial body of knowledge has accumulated endowing neutron radiography with the essential foundations of a unique mathematical and physical science. Our scientific and professional involvement in neutron radiography began some 15 years ago when the senior author (A.A.H.) found himself with convenient access to the McMaster

University Nuclear Reactor and research support from the Government of Canada.

Abstracts of the 3rd International Meeting on Neutron Radiography Materials Research Forum LLC

This book comprehensively presents the concepts of neutron physics and imaging including neutron properties, neutron matter interaction, neutron imaging, comparison with X-ray and physics and design of neutron sources. It discusses how neutron imaging has gained importance as a powerful non-destructive technique to understand the internal structures of materials/engineered components in wide range of industries, including defense, aerospace, and healthcare. The book also covers the topics of neutron optics and detectors, basic principles of neutron radiography and tomography, and standards, safety and regulations in neutron imaging. In the last section of the book, it covers wide range of applications of neuro imaging in the areas of aerospace industry, nuclear power and manufacturing industry, 3D printing, materials science and engineering, geomechanics, archeology and palaeontology, national security, biological, and medical industries. Given its scope, the book will be highly useful for postgraduate students, researchers and industry professionals working in the area of engineering and physics, especially non-destructive testing and non-destructive evaluation of neutron imaging.

Application of Neutron Imaging to InvestigateFlow Through Fractures for EGS. Springer Nature

This publication contains examples of how neutron imaging has been used in applications requiring the identification of (light) materials inside solid samples. It provides detailed information on how the technique has become a standard method for various applications, from the examination of nuclear fuels, explosives, electronic components and engine turbine blades to the characterization of fuel cells and geological samples.--Publisher's description.

High-Energy Neutron Imaging Development at LLNL. Neutron Imaging and Applications

In evaluating the feasibility of neutron radiography and tomography in the 10-14 MeV region, it is important to estimate the radiation backgrounds that could potentially interfere with the measurements. In this context, backgrounds refer to all counts in the detector other than those due to neutrons transmitted through the sample without scattering. There are two principal sources of backgrounds: (1) neutrons and gammas resulting from incident neutrons interacting in the sample, and (2) events in the detector arising from neutrons scattering in the accelerator vault and collimation system, together with natural and induced activation. Counts due to these backgrounds are spread fairly uniformly across the detector, and therefore do not compromise the ability to identify small features in the sample on the millimeter scale in a tomographic reconstruction; however, they do increase the neutron dose required to achieve sufficient statistical accuracy to reveal features of interest. Backgrounds are generally considered to be tolerable if their count rates are less than or comparable to the rates from the transmitted (uncollided) beam. If they are significantly above this level, they are a potentially serious problem. Understanding radiation backgrounds is thus critically important in determining the required source strength and running time. The backgrounds must be characterized by their energy, radiation type (neutron or gamma), and their timing relative to emission time at the source. These properties may have a profound effect on the design of the source and detector (e.g., whether a pulsing-and-timing technique is necessary to reduce backgrounds, and whether a simple plastic-scintillator based integrating detector will suffice). In the geometry that we have chosen to study, the sample is located approximately two meters from the neutron source, and the detector (a plastic-scintillator neutron-imaging camera; Ref. 1) is located another two meters downstream. A thick shielding wall with a collimating channel approximately 30 cm in diameter is located between the sample and detector to reduce room-scattered backgrounds. We have studied the first source of background ("internal" or "sample" scattering) in this geometry using the COG Monte Carlo radiation transport code, and have found that these backgrounds should be tolerable (the effect of internal scattering should, in fact, be minimized in a system geometry with 2:1 magnification). The second type of background ("external" or "room" scattering and activation) is more difficult to study with a simulation code because these backgrounds are dependent on specific details of a facility that are difficult to know a priori. We have therefore carried out a measurement of these backgrounds in an existing facility, the Ohio University Accelerator Laboratory (OUAL), whose layout closely resembles the system geometry we envisage using for neutron radiography. These measurements were carried out in February, 1996. The results of this experiment indicate that room-scattering and residual activation backgrounds are low enough to allow the use of an integrating plastic-scintillator-based detector in radiographic applications. It appears that neither time gating nor neutron/gamma discrimination will be necessary to obtain satisfactory images. This results in a significant simplification of the requirements for both the neutron source and the detector; however, it is clear that the detector must be placed in a sufficiently well isolated detector cave, and attention must be paid to optimizing the shielding in the neighborhood of the detector. While these measurements were carried out with 10 MeV neutrons from the D+D reaction, it is likely that the results would be similar for 14 MeV neutrons from a D+T source. We currently favor a D+D source for a practical facility, largely because there is no need for handling tritium with this source.

Thermal Neutron Imaging Using A New Pad-Based Position Sensitive Neutron Detector Springer Science & Business Media

The growing demand for electrical power presents one of the major challenges for the well-being of future generations. For the foreseeable future, it seems highly unlikely that the projected energy needs can be met by fossil and/or alternative energy sources alone; therefore, nuclear power will continue to play a significant role in power generation.

Neutrons can be used to study a wide range of problems related to these efforts, providing a unique probe ranging from crystal chemistry of nuclear fuels to engineering diffraction of structural materials used in nuclear reactors. Traditionally, most experimental investigations with neutrons invoke diffraction techniques. However, recent advances in neutron detection resulted in new capabilities of material characterization using neutron imaging, which provides unparalleled opportunities particularly for nuclear materials, where heavy elements (e.g., uranium) need to be imaged together with light elements (e.g., hydrogen, oxygen). The inherent energy sorting of the neutrons at pulsed sources permits performing isotope-specific studies through selected settings of the contrast to a particular isotope (via neutron resonances). Moreover, the application of state-of-the-art tomographic reconstruction algorithms allows reconstructing, in 3D, the spatial distribution in cm-sized samples of quantities derived from these effects, in particular element or isotope distributions. None of this is currently possible with X-ray or reactor neutron radiography, and at present this technique is only possible at pulsed neutron sources at Los Alamos Neutron Science Center (LANSCE), Spallation Neutron Source at Oak-Ridge National Laboratory, ISIS in the United Kingdom, and at the Japan Proton Accelerator Research Complex (J-PARC) in Japan, of which only the J-PARC facility has a dedicated beam line for this technique. In this dissertation, I present the results of spatially-resolved neutron imaging and diffraction experiments (including texture measurements) on non-irradiated nuclear fuels. Furthermore, I present absolute isotopic areal density measurements with a two-dimensional detector and a pixel size of 55[mu]m using the time-structured LANSCE neutron beam applied to some nuclear-engineering application for the first time. More specifically, I introduce a novel, energy-resolved neutron imaging technique that utilizes the physical properties of neutron cross sections by analyzing nuclear resonances with the SAMMY code, which was developed by Oak Ridge National Laboratory for the analysis of cross section data in the resolved and unresolved resonance regions. To the best of my knowledge, this work presents the first applications beyond demonstration experiments of absorption based energy-resolved neutron imaging by applying this technique to characterize the isotope distributions in nuclear fuel and study the diffusion of ions dissolved in aquaeous solution into cement. My dissertation emphasizes the benefits of neutron radiography as a non-destructive characterization method to guide future experiments on post-irradiated nuclear fuels, enabling the quantification of isotope concentrations for a variety of imaging problems.