# Neutron Imaging Study Of the Water Transport Mechanism in a Working Fuel Cell

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## Objectives

- Quantify water content in fuel cell.
- Quantify water dynamics in fuel cell.
- Optimize neutron imaging spatial and temporal resolutions.
- Demonstrate neutron imaging as a tool for analyzing water management and performance of operational fuel cells.

## Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- R. Thermal and Water Management
- P. Durability

## Approach

- Stage 1. Based on previously established design parameters and goals, the facility was designed and the components manufactured. Careful radiation safety analysis was performed to ensure the effectiveness of radiation protection at the facility.
- Stage 2. Parallel discussions were held with fuel cell developers to evaluate a realistic fuel cell system in-situ. This included the use of a fuel cell and a fuel cell controller to monitor the operation of a fuel cell during operation on the neutron beam line.
- Stage 3. Assembled facility is extensively tested for radiation protection.
- Stage 4. Fuel cell experiments are run to observe the flow field dynamics and water build-up and clogging in the gas diffusion layer (GDL).

## Accomplishments

- Designed and built a neutron imaging facility.
- Demonstrated real time neutron imaging method.
- Examined operational fuel cells for fuel cell component developers.

## Future Directions

- Evaluate coded source imaging as a method for high-resolution real time imaging.
- Provide license-free distributable software for fuel cell developers to independently analyze fuel cell operation data.

- Upgrade detector systems to allow both:
  - oreal time frame rate (30 fps) and
  - ohigh spatial resolution.
- Conduct both non-proprietary and proprietary imaging experiments to improve knowledge of how water management systems function in fuel cells.
- Develop neutron imaging methods to accurately measure water gradients across a fuel cell proton exchange membrane (PEM).
- Determine diffusion coefficient and hydrophobic characteristics of the GDL.
- Characterize the two-phase flow mechanism in the fuel cell flow field.
- Conduct a time-dependent study of the membrane-catalyst-GDL interface integrity.

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## Introduction

In a fuel cell, water is formed as a byproduct of the reaction between hydrogen and oxygen. If the water does not drain quickly and efficiently, then fuel cells will not work properly. Water formation is also a signature of activity in a fuel cell, so the lack of water formation demonstrates a defective area of the fuel cell.

Since fuel cells are not transparent to visible light, other forms of penetrating radiation (example: x-rays, neutrons) must be used to analyze the operation of the fuel cell. X-ray imaging is unsuitable because hydrogen is nearly invisible to the high-energy x-rays required to penetrate the metallic encasement of the fuel cell. Neutrons, which are massive, neutrally charged particles, can easily penetrate metals and still be extremely sensitive to water in quantities less than a microgram. The reason for this is best illustrated by a comparison of the relative cross sections shown in Figure 1. The large x-ray cross section of Al compares to a small neutron cross section. Conversely, the x-ray cross section for hydrogen is small compared to the neutron cross section. This makes neutrons ideal for sensing microgram quantities of water.

## Approach

A new Neutron Imaging Facility (NIF) has been constructed at the BT6 high intensity thermal beam line at the NIST Center for Neutron Research (NCNR) nuclear reactor (Figure 2) to non-destructively characterize water transport mechanism in single or multi-stack PEM fuel cells. The facility features a very high uniform neutron flux and high spatial resolution over area (Figure 3). The high neutron flux will allow attaining a time resolution of less than 1 second and a spatial resolution as low as 10-30 mm with an appropriate neutron detector.

Experimental tests of the facility have been performed in collaboration with various fuel cell

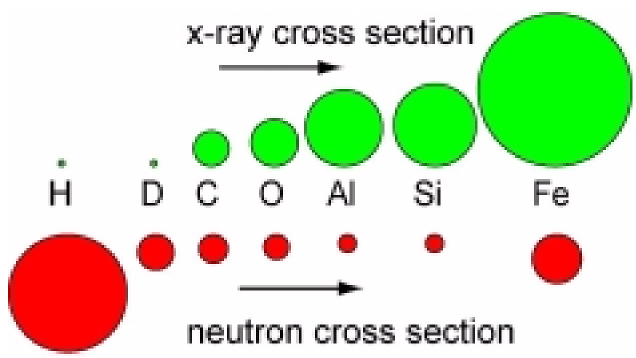


**Figure 1.** Comparison of X-Ray Cross Sections to Neutron Cross Sections (The neutron cross section for hydrogen is much larger than the higher Z elements. The converse is true for x-ray cross sections.)

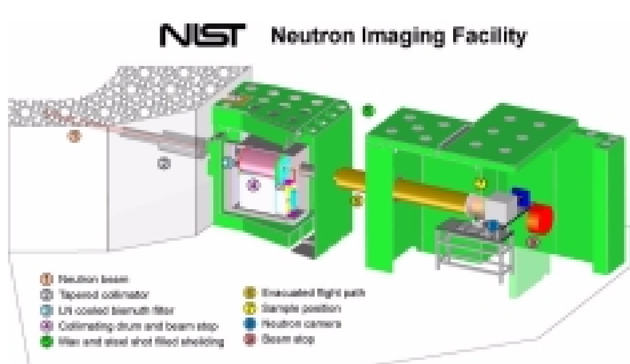


**Figure 2.** New Neutron Imaging Facility Online at NIST

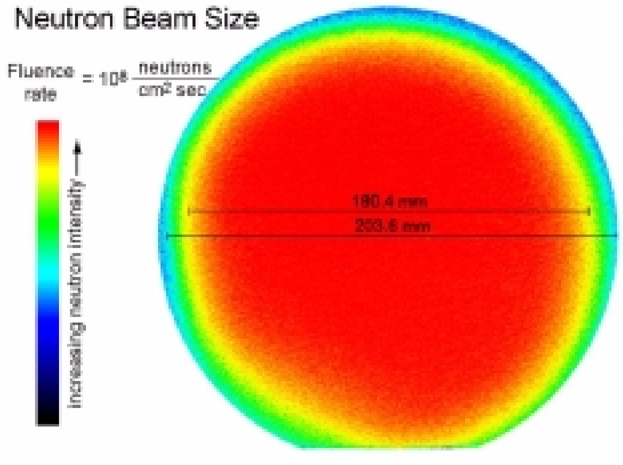


**Figure 3.** Neutron Beam Size and Intensity Distribution (Beam diameter in the uniform region is about 18 cm.)

developers. The results of these tests are currently being evaluated for the design of future tests. Currently, the facility provides hydrogen (currently 1.2 liters/minute), air and nitrogen gasses for users of the facility. Users are required to provide a fuel cell controller to match the fuel cell used in the facility. We shall incorporate a generic single cell fuel cell controller to the setup in the very near future.

## Results

An example neutron image is shown in Figure 4. In the image, the gas distribution system of a fuel cell shows up as the serpentine race tracks. The purpose of these channels is to distribute gas evenly to the membrane and to act as a drain for water coming out. In these images, the neutrons easily penetrate the fuel cell when dry. As the fuel cell runs, water builds up and appears as a darker shadow region. Computer analysis, shown as the colorized (bottom) image in Figure 4, allows the dry cell to be removed, revealing only the water formation in both the flow channels and the gas diffusion media. In Figure 4, large amounts of water appear as red, and dry regions appear as black.

At the imaging station, the largest fuel cell that can be imaged is about 20 cm x 20 cm. A sample of larger length can be imaged section by section through translation of the sample. The fuel cells also can be single-stack or multi-stack. The facility will

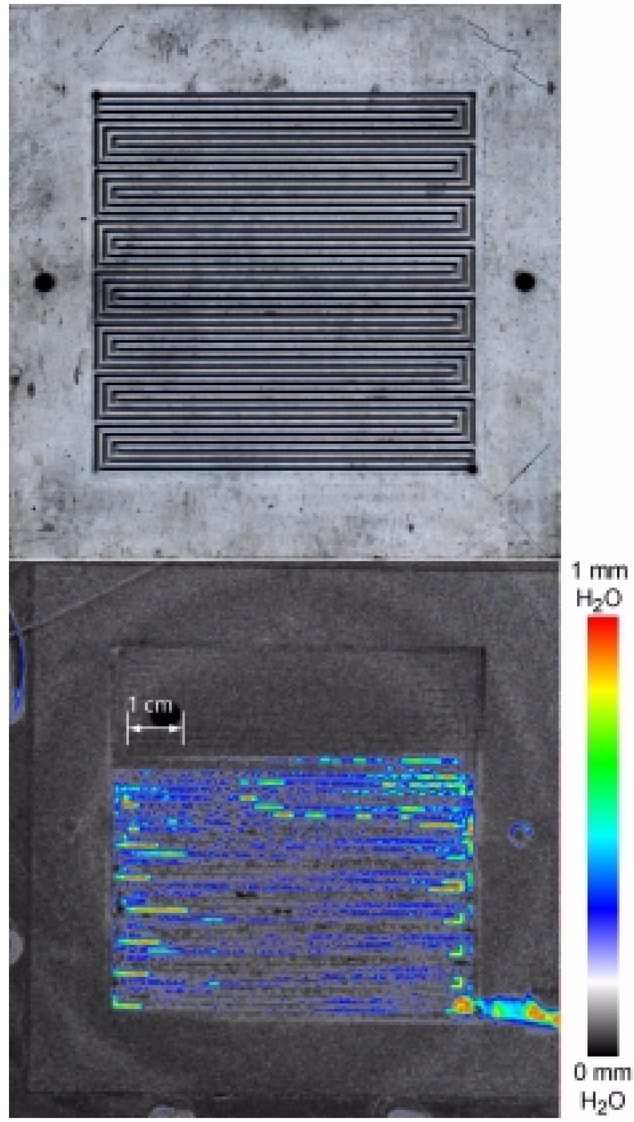


**Figure 4.** (Top) Photo of the Graphite Flow Channels; (Bottom) Processed Neutron Image of the Water Formed During Operation of the Cell

operate as a user facility where proposals submitted will be required to be reviewed for merit before allocating beam time. A generic fuel cell test station will be available for general use, but users will be free to bring their own if needed.

## Conclusions

- A neutron imaging facility now exists at NIST.
- High neutron flux of about $10^8$ $sec^{-1}cm^{-2}$ has been achieved.

- High spatial resolution of 20 µm - 200 µm has been achieved.
- In-situ analysis of fuel cell water management using neutron imaging is now possible.
- Near real time analysis of fuel cell operation is now possible.

## FY 2003 Publications/Presentations

1. Invited talk at 'Plug Power', Albany, NY, March 2002. 'Investigation of fuel cell water transport using thermal neutron imaging techniques.'

2. Presentation at DOE fuel cell conference, Denver, CO, May 2002. 'High flux thermal neutron imaging station for fuel cell research.'

3. Invited talk at Argonne National Laboratory, Argonne, IL, June 2002. 'Neutron imaging technique to determine diffusion co-efficient of Li ions in Li ion conductors.'

4. Invited talk at Dupont, Wilmington, DE, February 2003. 'NDE of fuel cell via neutron imaging.'

5. "In-situ neutron imaging techniques for evaluation of water management systems in operating PEM fuel cells", Submitted to "Journal of Power Sources."