VIII-Ⅱ-1.　Project Research

Project 12

PR12

Development on Neutron Imaging Application

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OBJECTIVES AND ALLOTED RESEARCH SUBJECTS :

The aim of this project research is the development on neutron imaging and its application.

ARS-1 Development on neutron imaging application in KUR

ARS-2 Visualization of liquid-metal two-phase flow by using neutron radiography

ARS-3 Visualization of two-phase flow in a polymer electrolyte fuel cell

ARS-4 Neutron radiography on tubular flow reactor for supercritical hydrothermal synthesis of nanoparticles

ARS-5 Quantitative Evaluation of void wave propagation in oscillatory flow by using neutron radiography

ARS-6 Appropriate soil thickness for neutron imaging of water movement to facilitate phytoremediation study

ARS-7 Neutron imaging of industrial components and simulation using VCAD system

ARS-8 Continuous measurement of water in cement during hardening

ARS-9 Three dimensional high-resolution neutron computed tomography at Kyoto University Research Reactor (KUR)

MAIN RESULTS AND THE CONTENTS OF THIS REPORT :

M.Kanematu et. al (ARS-1) studied the physical process of the spalling phenomenom when the exposure of concrete structures to unexpected high temperature, such as during fire accidents. They applied neutron radiography to detect the hydraulic behavior under rising high temperatures to understand the spalling phenomenon of high strength concrete, focusing on the differences between the normal concrete and polymer fiber concrete.

Y.Saito et al. (ARS-2) have developed an imaging system to obtain dynamic information on such multiphase flows in a metallic duct by neutron radiography. It has a better efficiency to visualize liquid-metal two-phase flow at a high frame rate (>100fps). Experiments were performed at the B-4 supermirror neutron guide facility of the Kyoto University Research Reactor (KUR).

N.Takenaka et al. (ARS-3) visualized the water flow in a polymer electrolyte fuel cell. Fuel gas (hydrogen gas) and oxidant gas (air) are supplied to a polymer electrolyte fuel cell (PEFC). Protons pass through the proton exchange membrane (PEM), and combine with oxygen to form water in the cathode reaction site. As water management in the PEFC is important, and water distributions during the operation have been measured.

T.Tsukada et al. (ARS-4) conducted the in-situ neutron radiography of mixing behavior in the reactor and at the process conditions, which were used practically to synthesize metal-oxide nanoparticles. A variety of metal-oxide nanoparticles have been synthesized by supercritical hydrothermal synthesis. It is important to acquire the correct knowledge about the mixing behavior of cold aqueous feed solution and supercritical water in a hydrothermal reactor for the design and optimization of the process. Therefore, they used neutron radiography to visualize the flow in a tubular flow reactor for supercritical hydrothermal synthesis, and investigated the effects of fluid flow rates and temperature of supercritical water on the mixing behavior in the reactor

N.Umekawa et al. (ARS-5) conducted the Critical Heat Flux (CHF) experiment under oscillatory flow conditions, and the void fraction was measured simultaneously by using the neutron radiography. In designing boiling systems, CHF is a very important factor. When flow instabilities, such as density wave oscillation occur under certain operating conditions, CHF is drastically decreased with an increase of oscillatory amplitude and oscillatory period. In order to clarify this phenomenon, the void wave propagation was studied.

U.Matsushima et al. (ARS-6) measured the appropriate thickness of saturated gray lowland soil that is basic data for investigating water movement in the soil by neutron imaging. It is important to investigate the pathways of heavy metals, such as cadmium, from soil to plants in order to study phytoremediation.

Y.Yamagata et al. (ARS-7) have constructed a cooled CCD based neutron imaging device at E-2 radiography port and tested the performance using various industrial components. Besides, captured images are process by VCAD software, which is developed at RIKEN. VCAD system can handle three dimensional data of "real" object, which usually contains profile errors or defects inside. By using VCAD software, three dimensional images are reconstructed based on neutron radiography data.

T.Numao et.al (ARS-8) did not submit their report.

H.Kagawa et al. (ARS-9) have been working to refine neutron radiography, where the use of high accuracy X-rays mainly due to CT enables improved visibility. In this case, they decided to perform image acquisition CT, to consider the applicability of equipment, space components and parts inspection.

採択課題番号 23P12 中性子イメージングの高度利用 プロジェクト

（京大・原子炉）川端祐司

PR12-1 Experimetal Research on the Hydraulic Behavior of High Strength Concrete under High Temperature

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INTRODUCTION: The exposure of concrete structures to unexpected high temperature, such as during fire accidents, may lead to *spalling*, fracture of the heated surface. Because this phenomenon is more critical in high strength concrete, a small amount of polymer fiber is used as a countermeasure to prevent the formation of the fractural stresses.

The physical process of the spalling phenomenon is assumed to be due to the gas pressure build-up inside the porous media, restrained thermal interaction close to the heated surface or the simultaneous action of both[1]. However the mechanism of this phenomenon has not been fully elucidated yet, because it is difficult to measure the moisture behavior that is thought to be a key parameter to explain the explosive pressure formation.

In the present research, we applied neutron radiography to detect the hydraulic behavior under rising high temperatures to understand the spalling phenomenon of high strength concrete, focusing on the differences between the normal concrete and polymer fiber concrete.

EXPERIMENTS: The 100x100x200 mm^3 prisms were sawn from a concrete block with a water cement ratio of 18% and polypropylene(PP) fiber volume ratio of 0.1%. After demolding at 24 hours, the prisms were submerged in water at 20±2°C for 28 days and then cured at atmospheric conditions of 20℃ and 40%RH. The initial water contents of the concrete samples were controlled by oven-dry under 105°C for two days.

The neutron radiography facility in the B-4 beam hole of KUR was used. A neutron radiograph was obtained every 15 seconds during the heating experiment under 5MW operation. A Liquefied Petroleum(LP) gas burner was used to raise the surface temperature to 1000°C in 30 seconds and was held at 1000°C for the remainder of experiment. To prevent direct heating from the lateral side, the sample was sealed with heat-resistant bricks and fixed in an aluminum cell as shown in Fig.1.

RESULTS: As shown in Fig. 2, the moment of spallation of ordinary concrete can be clearly observed by the neutron radiography, and the hydraulic behavior under the fire condition can be examined by the intensity analysis of the images. The result shows that the hydraulic movement in fiber concrete is comparatively high, which means the PP fiber in concrete melts at the high temperature (at about 165°C) and forms relief paths which prevent the formation of evaporative pressure of moisture.

REFERENCES:

[1] F.J.Ulm, O. Coussy, Z.P. Bazant, J. Eng. Mech. **125**(3) (1999)272-282.

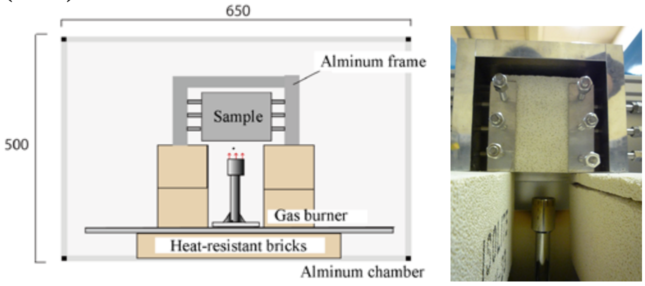
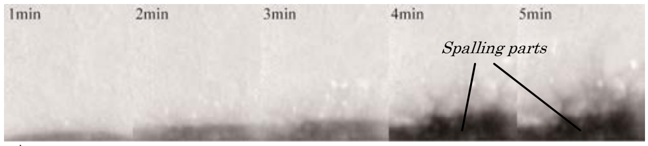
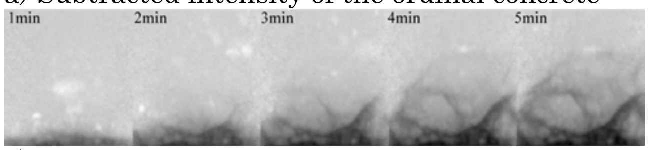


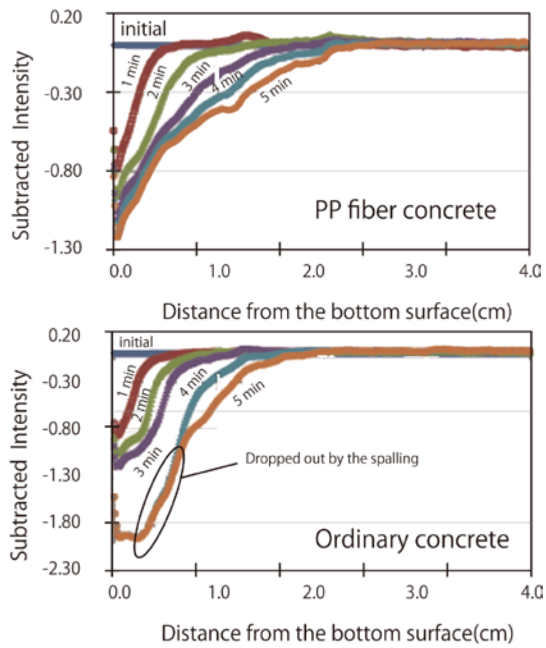
Fig. 1. Experimental setup of the heating element



a) Subtracted intensity of the ordinal concrete



b) Subtracted intensity of the PP fiber concrete



c) above:PP fiber concrete, below:ordinary concrete

Fig. 2 The hydraulic behavior of concrete

採択課題番号 23P12-1 KUR における中性子イメージング適用分野拡大に関する研究 プロジェクト
（京大・原子炉）川端祐司、斉藤泰司、（東京理科大学・理工）兼松 学、榎村 剛
（東大・工）田村正道、土屋直子

PR12-2 Visualization of Liquid-Metal Two-Phase Flow by Using Neutron Radiography

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INTRODUCTION: Neutron radiography is a powerful tool for fluid flow visualization as well as multiphase flow research [1]. Multiphase flows in a metallic duct have been visualized clearly by using neutron radiography (NR). However, it would be still difficult to obtain dynamic information on such multiphase flows by NR, because of insufficient neutron flux from neutron sources and poor efficiency of imaging devices. In this work, we are trying to develop an imaging system, which has a better efficiency to visualize liquid-metal two-phase flow at a high frame rate (>100fps). Experiments were performed at the B-4 supermirror neutron guide facility of the Kyoto University Research Reactor (KUR)[2].

EXPERIMENTS: Figure 1 shows the schematic of the imaging system tested at the B-4 experimental room. The imaging system consists of a NR converter (^{6}LiFZnS(Ag)), a dark box, a macro lens, an image intensifier, and a high-speed video camera (Motion Pro Y-4, IDT Co. Ltd.). The imaging system has no optical mirror to reduce the optical loss in the dark box and was inclined 45 degree against the beam direction.

The imaging system was applied for an air-water two-phase flow in a small tube and a liquid-metal two-phase flow in a metallic tube during a 5MW operation at the KUR. The neutron flux at the exit of the B4 suppermirror tube was about 5×10^7(n/cm^{2}s).

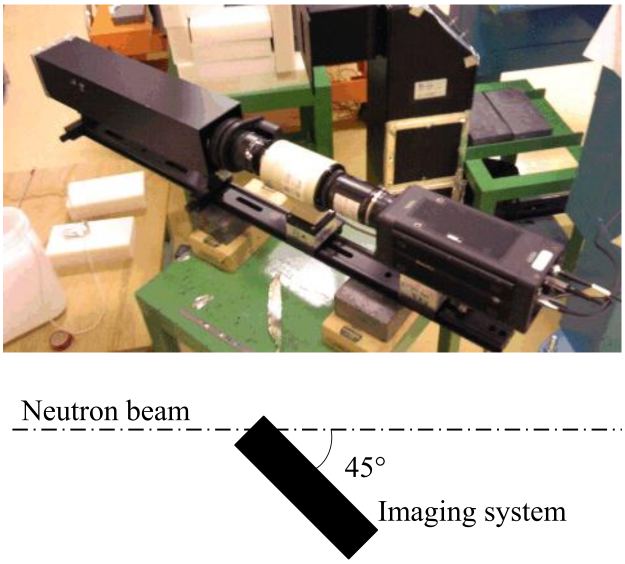

Fig.1 NR imaging system.

RESULTS: As shown in Figs. 2 and 3, clear two-phase flow behaviors in a small stainless tube were visualized by using the imaging system developed in this study. Figure 4 shows the liquid-metal two-phase flow. As shown in these figures, it was confirmed that the new imaging system can visualized clearly multiphase flows at the B4 facility of the KUR.

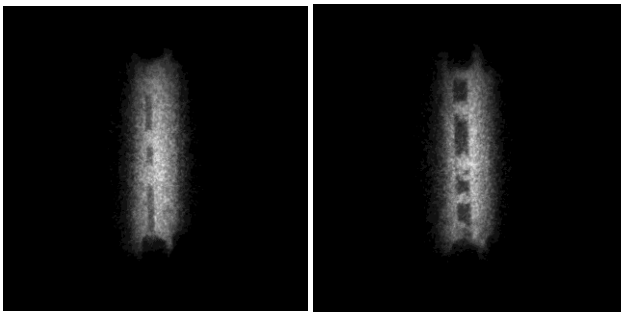

Fig.2 Air-water two-phase flows in small tubes (O.D.=2 and 4mm).

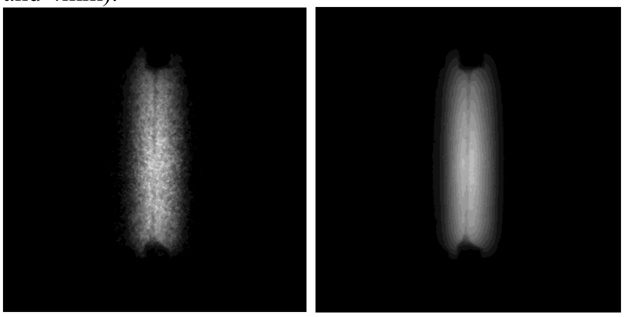

Fig.3 Air-water two-phase flow in small tube (O.D.=1mm) and the time-averaged image.

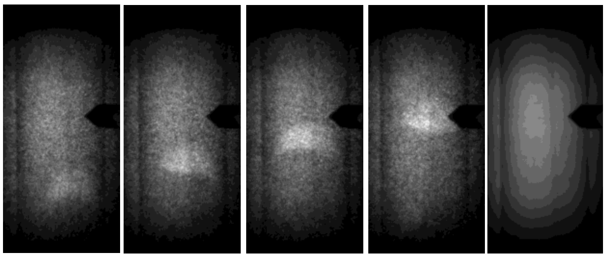

Fig.4 Liquid-metal two-phase flow in a stainless tube (O.D.=30mm) and a time-averaged image.

REFERENCES:

[1] Y. Saito *et al*., Nucl. Instr. Meth. Phys. Res. A, **542** (2005) 168-174.

[2] T. Akiyoshi *et al*., J. Nucl. Sci. Tech., **29** [10], (1992) 939 – 946.

採択課題番号 23P12-2　　液体金属流れの可視化計測に関する研究　　プロジェクト
（京大・原子炉）齊藤泰司、川端祐司

PR12-3 **Visualization of Two-phase Flow in a Polymer Electrolyte Fuel Cell**

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INTRODUCTION: Fuel gas (hydrogen gas) and oxidant gas (air) are supplied to a polymer electrolyte fuel cell (PEFC). Protons pass through the proton exchange membrane (PEM), and combine with oxygen to form water in the cathode reaction site. The generated water must be supplied appropriately to the membrane for protons conduction. On the other hand, the generated water may affect the fuel cell performances because of blocking the oxygen from reaching the cathode reaction site. Therefore, water management in the PEFC is important, and water distributions during the operation have been wide concern. Measurements of water behavior in a PEFC were carried out by using neutron radiography.

EXPERIMENTS: Neutron radiography system at B-4 port in KUR was used for visualization. A Gadolinium type neutron color image intensifier (UltimageTM n γ type (Gd-Type2), Toshiba Corp.) with 4 inch view size and a CCD camera (Alta U16, Apogee Inst.) with pixel area of 4096 × 4096 and gray scale of 12 bit were used. Pixel size was 6.8 μm/pixel. Exposure time was 10 seconds and the measurement interval was 10 s. The cell was rotated 90° using a rotating table during the interval. Hence, water distributions in the in-plane and through-plane directions were alternately obtained every 20 s. Fig.1 shows schematic of a PEFC. Geometry of the PEFC is horizontal 9-parallel gas channels with equal width and depth of 1 mm. The L/D was set at 600 using a vertical slit with width of 3 mm. Experimental conditions were a current density of 210 mA/cm2, a hydrogen flow-rate of 28 cc/min (utilization of 10%), and an air flow-rate of 66 cc/min (utilization of 10%).

RESULTS: Figure 2 shows water distributions in-plane and through-plane directions at elapse times of around 8 min and 23 min. After the 23 min, power generation stopped because of water plugging in the channel. Water behavior during the PEFC operation, the accumulation process from the gas diffusion layer (GDL) to the channels, and size of the water accumulation were confirmed as follows. Water generated in the GDL at the cathode and evacuation into the channels started around 5 min. Water tended to accumulate at the edge of the channels, and accumulated as water drops in the channels. The size of the water drops grew up to 1 mm which is the same size as the channel width and height. When the water drops grew up to the 1 mm, power generation stopped because of blocking the air supply.

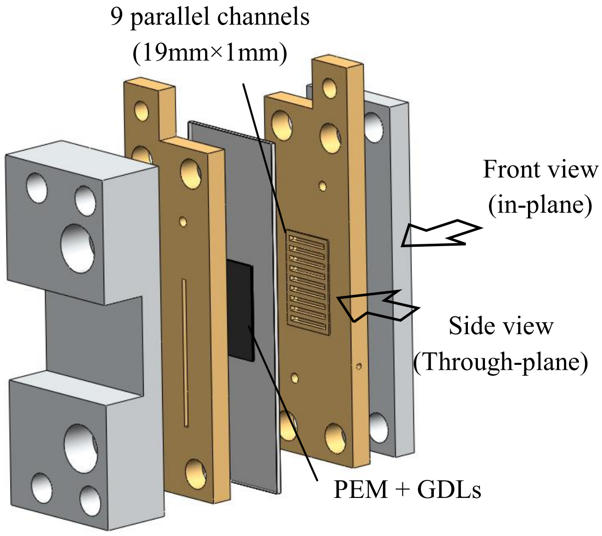

Fig.1. Schematic diagram of a PEFC.

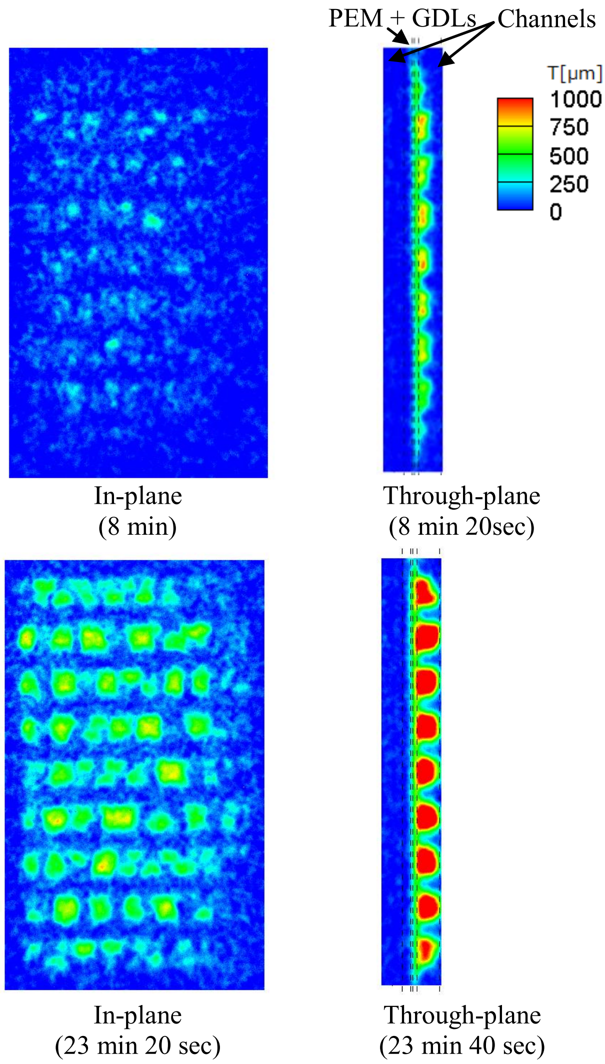

Fig.2. Water distributions in a PEFC.

採択課題番号 23P12-3　　中性子ラジオグラフィによる沸騰二相流の研究　　プロジェクト
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PR12-4 Neutron Radiography on Tubular Flow Reactor for Supercritical Hydrothermal Synthesis of Nanoparticles

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[1]IMRAM, Tohoku University
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INTRODUCTION: Recently, a variety of metal-oxide nanoparticles have been synthesized by supercritical hydrothermal synthesis [1]. For the design and optimization of the process, it is important to acquire the correct knowledge about the mixing behavior of cold aqueous feed solution and supercritical water in a hydrothermal reactor. Therefore, we used neutron radiography to visualize the flow in a tubular flow reactor for supercritical hydrothermal synthesis, and investigated the effects of fluid flow rates and temperature of supercritical water on the mixing behavior in the reactor [2]. In this work, in-situ neutron radiography of mixing behavior in the reactor and at the process conditions, which were used practically to synthesize metal-oxide nanoparticles, were conducted.

EXPERIMENTS: The tubular flow reactor consists of stainless steel 1/8-inch tubes and a tubing connector at which water at room temperature (cold water), corresponding to the feed aqueous solution, is mixed with supercritical water. In the experiment, pressure in the reactor was set to be 25 MPa, and the temperatures of supercritical water T_{scf} were 658 and 666 K. The flow rates of supercritical water Q_{scf} were 8 and 12 g/min, and the range of cold water Q_{rt} was between 1 and 6 g/min. The tubing connector in the reactor, i.e., the mixing part, was irradiated by neutron beam at 5 MW power for flow visualization, where the attenuation coefficient of neutron beam for supercritical water is lower than that for cold water depending on their density. The density of water is approximately 0.3 g/cm^3 at 658 K, and approximately 1 g/cm^3 at room temperature, respectively.

RESULTS: Fig. 1 shows the distributions of average water density at the mixing part in the flow type reactor, where the distributions were obtained by applying the appropriate image-processing technique to the neutron radiography [2]. It is found that the cold water, feed aqueous solution, flows down along the right side wall, and that the density-stratified layer of two fluids is generated in the feed line of cold water.
Fig. 2(a) shows the effect of Q_{rt} on the distributions of water density along the vertical white line in Fig.1 for Q_{scf} = 8 g/min. From the figure, the water density increases after mixing with cold water, and the tendency becomes more remarkable as Q_{rt} increases. Fig. 2(b) shows the effect of Q_{rt} on the distributions of water density along the horizontal white line in Fig.1 for Q_{scf} = 8 g/min. The water density increases rapidly near the right side wall. The high density region becomes thicker as Q_{rt} increases. These distributions of water density correspond to the temperature distributions in the reactor.

CONCLUSIONS: In this work, it was demonstrated that the mixing behavior of aqueous feed solution and supercritical water in a tubular flow reactor used practically to synthesize metal-oxide nanoparticles can be visualized by neutron radiography.

REFERENCES:
[1] T. Mousavand *et al.*, *J. Mater. Sci.*, **41** (2006) 1445.
[2] S. Takami *et al.*, *J. Supercrit. Fluids*, **63** (2012) 46.

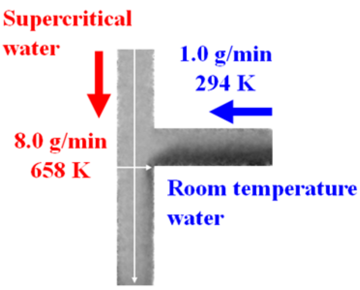

Fig.1. Distributions of average water density at mixing part in the tubular flow reactor.

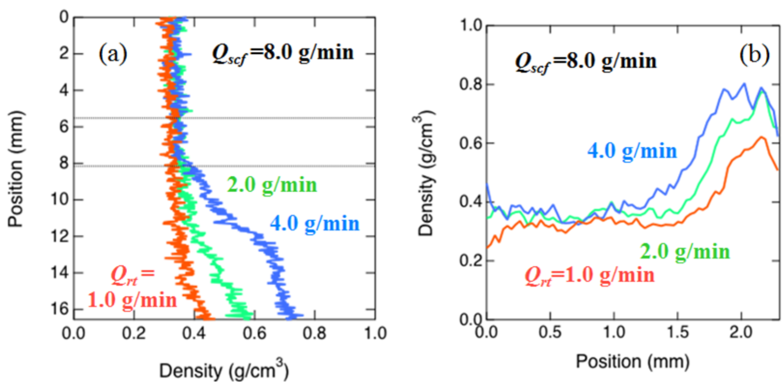

Fig.2. Effect of Q_{rt} on the vertical and horizontal distributions of water density in the reactor for Q_{scf} = 8 g/min.

採択課題番号 23P12-4　中性子ラジオグラフィを利用した超臨界水反応場の in-situ 観察　プロジェクト
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（神戸大院・工）杉本勝美、竹中信幸、（京大・原子炉）齊藤泰司、川端祐司

PR12-5 **Quantitative Evaluation of Void Wave Propagation in Oscillatory Flow by Using Neutron Radiography**

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INTRODUCTION: In designing boiling systems, Critical Heat Flux (CHF) is a very important factor.
When flow instabilities, such as density wave oscillation occur under certain operating conditions, CHF is drastically decreased with an increase of oscillatory amplitude and oscillatory period [1]. In order to clarify this phenomenon, it is important to understand the void wave propagation. In this investigation, the CHF experiment was conducted under oscillatory flow conditions, and the void fraction was measured simultaneously by using the neutron radiography.

EXPERIMENTS: An experimental apparatus was a vertical forced convective boiling system of ion-exchanged water. Test section was made of stainless tube with I.D. 5.0 mm, O.D. 7.0 mm and 1000 mm in heated length. It was uniformly heated by Joule heating of DC power. The boiling experiment was conducted under arbitrary oscillatory flow condition by means of mechanical flow oscillator. The experimental conditions were as follows; the system pressures were 0.3, 0.47, and 0.55 MPa, the averaged mass flux G_0 was set to 300 kg/m^{2}s, the oscillation period τ was 4 s, and the ratio of oscillation amplitudes $\Delta G/G_0$ were 1.0 and 1.5.

As a neutron source, Kyoto University Research Reactor (neutron flux was 5×10^7 n/(cm^{2}s) at the port exit under 5 MW operation) was used. In the visualization procedure, the short exposure period (0.03 s) images were taken synchronized with the flow oscillator. By integrating of these 34 same phase images, the image which has the enough dynamic range was reconstructed. In this way, the pseudo-time continuous data of void fraction could be obtained.

RESULTS: In Fig.1, the quantitative evaluation result of the void fraction is shown with the orifice output which corresponds to the inlet flow rate. As shown in these figures, the void fraction fluctuation under oscillatory flow conditions can be clearly visualized by this image processing.

In Fig.2, the wall temperature, the void fraction, the inlet mass flux and the differential pressure across the test section are drawn. In the figure, calculation results of the Lumped-parameter model [1] are also drawn. These results include the very important information to estimate the boiling two-phase flow phenomena under unstale flow condition. The more detail discussion will be reported elsewhere.

REFERENCES:

[1] M. Ozawa *et al*, Trans IChemE, **79** (2001) 389-401.

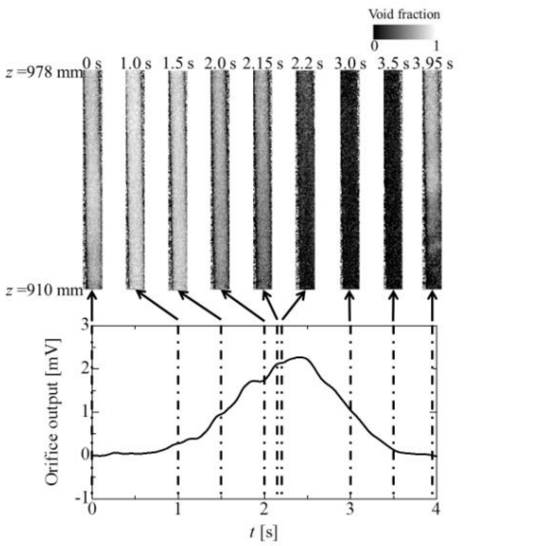

Fig.1 Visualization image
(τ = 4 s, $\Delta G/G_0$ = 1.0, q = 124.8 kW/m^2, x_{eq} =0.009)

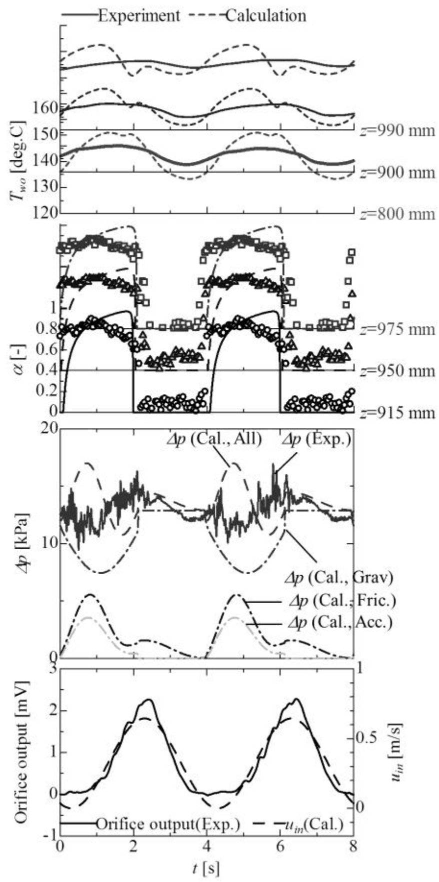

Fig.2 Comparison with the simulation results.
(τ = 4 s, $\Delta G/G_0$ = 1.0, q = 124.8 kW/m^2, x_{eq} =0.009)

採択課題番号 23P12-5 強制流動沸騰系における管内液膜挙動の定量評価に関する研究 プロジェクト
（関大）梅川　尚嗣、小澤　守、網　健行、廣瀬　拓哉、中村　祥太、阪倉　一成、藤吉　翔太、松本　亮介、吉村　智也（京大・原子炉）川端　祐二、齊藤　泰司、沈　秀中

PR12-6 **Appropriate Soil Thickness for Neutron Imaging of Water Movement to Facilitate Phytoremediation Study**

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[3]Research Reactor Institute, Kyoto University

INTRODUCTION: It is important to investigate the pathways of heavy metals, such as cadmium, from soil to plants in order to study phytoremediation. A possible pathway of cadmium is via the plant intake of water containing dissolved cadmium. The mass flow of cadmium due to plant intake was observed in rhizosphere [1]. Neutron imaging is a good tool for observing water movement from soil to plant roots. However, the distance that a neutron beam can penetrate moist soil is limited because of the large cross section of hydrogen. The present report aims to present the appropriate thickness of saturated gray lowland soil that is basic datafor investigating water movement in the soil by neutron imaging.

EXPERIMENTS: Gray lowland soil, which is widely distributed in alluvial lowlands, valley plains, and alluvial fans, was employed as the soil sample. A quartz glass container with a wedge-shaped cross section was filled with water-saturated gray lowland soil (Fig. 1). Because of the wedge-shaped cross section, the irradiated sample thickness varied continuously across the width of the obtained neutron image. The experiments were performed using the neutron tomography instrument setup in the E2 beam hole at KUR. The irradiation time for capturing neutron image was 10 min.

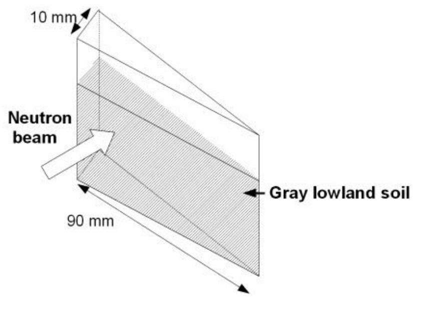

Fig. 1. Schematic diagram of the sample container.

RESULTS: As shown in Fig. 2, soil particles were trapped in the small space between the quartz glass walls. The particles were ellipsoidal, and the average length of the major axis of the particles that could be individually distinguished in the image was 2.0 mm, with a standard deviation of 0.2 mm. Bcrecause of the varying relationship between the particle size and the space between the walls, the soil particles arranged themselves into different numbers of layers aoss the width of the container. Until about 3 mm from the apex of the wedge, the soil formed a single layer. Beyond 3 mm, two or more were formed, and the number of layers depended on the filling factor. The increase in attenuation from left to right in Fig. 1 resulted from an increase in the number of soil particle layers.

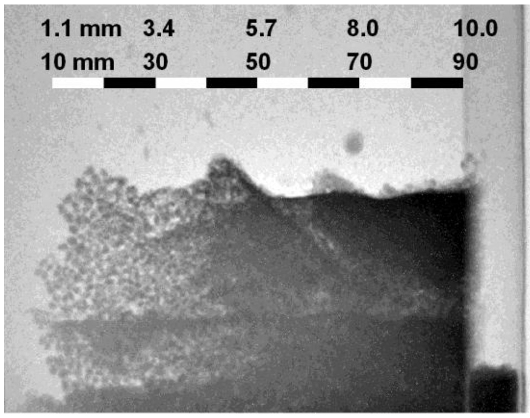

Fig. 2. Neutron image of gray lowland soil. Upper scale: space between glass walls; lower scale: distance from the joint of walls.

The linear absorption coefficient changes with the density of the irradiated material. However, the filling factor should also be considered when discussing soil particles. Irregularities in the filling factor of the soil particles caused fluctuations in the apparent linear absorption coefficient (Fig. 3). The apparent linear absorption coefficient increased with the thickness. Removing the kinetic restriction imposed by the walls resulted in proper filling of the soil particles. Therefore, although neutron penetration decreases with moist soil thickness, this relation only holds when the particles are filled properly.

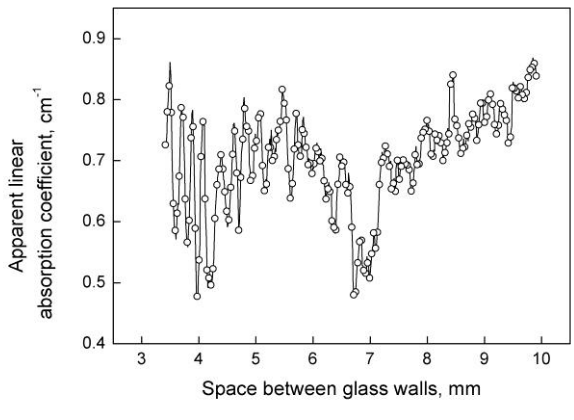

Fig. 3. Relationship between apparent linear absorption coefficient and space between glass walls.

REFERENCE:

[1] T. Hashimoto *et al.*, **Annu. Meet. Jpn. Soc. Sci. Plant Nutr.** (2011) Tsukuba.

採択課題番号 23P12-6 中性子ラジオグラフィの植物研究への応用 プロジェクト
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PR12-7 Neutron Imaging of Industrial Components and Simulation using VCAD System

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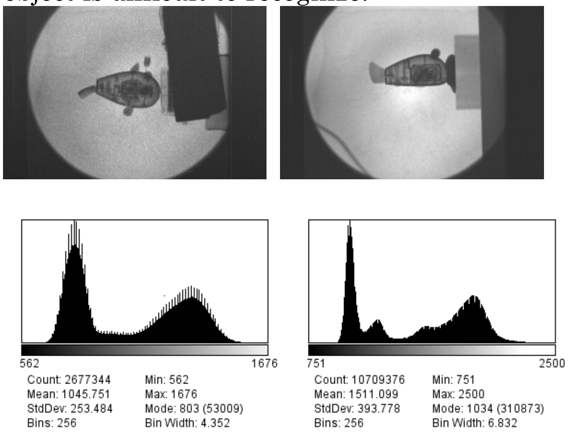
INTRODUCTION:
Non-destructive testing of industrial components is becoming important for recent production engineering. The purpose of such testing includes the quality control of the product to lower the production cost, to maintain reliability and safety, to realize ecological performance. Neutron radiography has advantage over X-ray that heavy metals like steel, nickel or tungsten can be well penetrated, while light elements like hydrogen gives better contrast so that liquid inside metal structure or composite materials can be observed with better precision.

The authors have constructed a cooled CCD based neutron imaging device at E-2 radiography port and tested the performance using various industrial components. Besides, captured images are process by VCAD software, which is developed at RIKEN. VCAD system can handle three dimensional data of "real" object, which usually contains profile errors or defects inside. By using VCAD software, three dimensional images are reconstructed based on neutron radiography data.

EXPERIMENTS:
A cooled CCD based neutron imaging device was constructed. It has ^{6}LiF/ZnS based scintillator with thickness of 100micrometer and area of 150x150mm. The cooled CCD camera has 4008x2672 pixels. This resulted in the equivalent pixel size at scintillator of about 50 micrometer.

Fig. 1 shows images and intensity histograms taken by cooled CCD camera. Although this is taken at 1MW operation, the intensity of direct beam just beside the object is about 1600 with 2x2 binning mode at exposure of 10 seconds. With 1x1 binning mode, pixel intensity of 2500 was obtained at exposure of 1min. This cooled CCD has 16bit pixel depth, so maximum intensity is 65535. Those results indicate that only 2 to 4 % of full intensity is obtained using this condition. It may be necessary to give several minutes exposure to obtain sufficiently good image. Photos shown in Fig.1 are processed and intensity and contrast are adjusted, otherwise, the image of the object is difficult to recognize.



2x2 binning(2004x1336) 10sec　1x1 binning 1min (4008x2672pixel)

Fig.1 Images by cooled CCD (KUR E-2port 1MW)

Image intensity and contrast adjusted

A number of industrial samples are captured by this camera and some images are processed to construct 3D images. Fig. 2 shows the image of Li-ion battery used by a camera. The shape of right side battery is normal but the shape of left side one is little bit expanded. The electrolyte of the battery can be well observed by neutron radiography. Fig.3 shows neutron radiography image of ice and water. The density difference between ice and water can be observed. Image intensity and contrast are adjusted in these images.

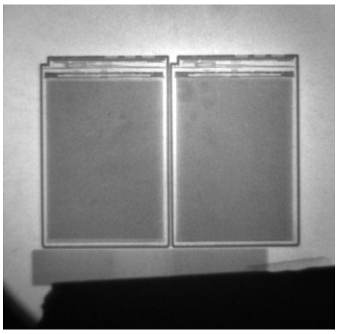


Fig.2 Li-ion batteries

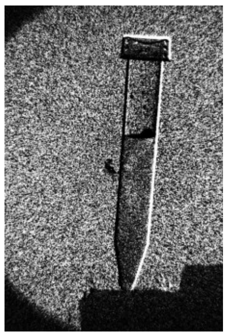


Fig. 3 Ice and Water

採択課題番号 23P12-7　　中性子ラジオグラフィによる工業製品の内部情報取得と　プロジェクト
ＶＣＡＤによるシミュレーション
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PR12-8

Measurement of Water Content in Hardened Cement Paste by Neutron Imaging

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INTRODUCTION: In this study, we investigated a method to quantify the amount of free water content in the hardened cement paste which was changed every moment in the drying process using neutron radiography. In addition, in the same environmental conditions, the water loss was measured by gravimetry method (Electronic balance) and the drying shrinkage were measured by differential transformer transducer to examine the validity of this method.

OUTLINE OF EXPERIMENT

Outline of neutron radiography examination: Measurement of neutron radiography in this study was carried out at E2 port in KUR. Table 1 shows the specifications of neutron radiography facility.

Experimental method: Figure 1 shows an Outline of measurement system. Also, the experiment overview was as shown in Table 2. In addition, the thin wall cylindrical specimen was in Fig. 2.

Experimental result and consideration: Water content of specimen(W/C=30%) obtained by neutron radiography were examine by comparing water loss in specimen measured with electronic balance.

The influence such as neutron scatterings was received in the neutron radiography at 3cm in the distance of the specimen and the converter. Therefore, the calculation value by 10cm which is the distance by the influence is not received is necessary. Therefore, mass attenuation coefficient λ_w=3.0154(cm^2/g) of water in 10cm which had been obtained for previous research was used.

Variation for water content for each unit volume(=Bulk density of water in paste (g/cm^3)), $\Delta\rho_w$ is shown as Eq.(1)

$$\Delta\rho_w = \frac{\Delta P_w}{\lambda_w \delta_w} \qquad (1)$$

Where, ΔPw: Variation in attenuation factor (difference at time t=0 and time t=t), λw: Mass attenuation coefficient (cm^2/g) and δw: Bulk thickness (Matrix thickness) (cm)

ΔP_w was calculated using this equation the result comes out as Fig.3. Water content calculated with Eq.(1) and the water loss by the gravimetric method is the tendency to the agreement was obtained.

Table1. Specifications of the neutron radiography facility

Thermal Neutron Flux	3.2×10^5 (n/cm^2・sec)
L/D	100
Cadmium Ratio	400
n/γ Ratio	1.1×10^6(n/cm^2・mR)
Converter	Fluorescent converter（^{6}LiF/ZnS : Ag)
pixel number	2048×2048pixel (16bit)
Resolution	approximately 80~100μm/pixel
Lens	85mm
Power (MW)	1
Camera system	RIKEN system
Expose time	30 seconds

Table2. Experiment overview

Specifications of Thin-wall cylindrical specimen	Water cement ratio (%)	30, 40
	Shape (mm)	Height:100, Thickness:1, Outer diameter:15
	Cement type	Ordinary Portland Cement
The number of specimen	Neutron irradiation	30%: 1, 40% :1 The distance between specimen and Converter:3cm
	Gravimetry of water loss	30% :1
	Drying shrinkage	30% :2, 40%: 2
Experiment environment ;temperature-humidity		25˚C, RH55%

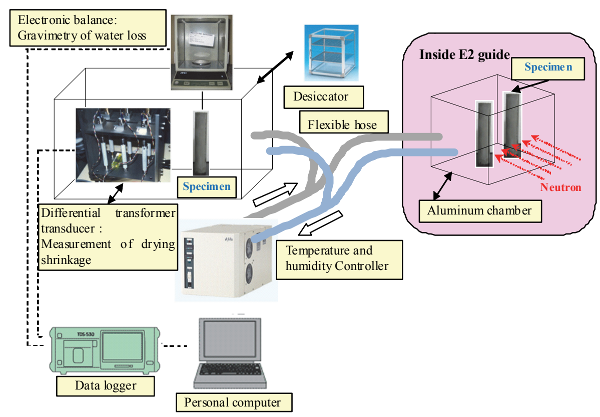
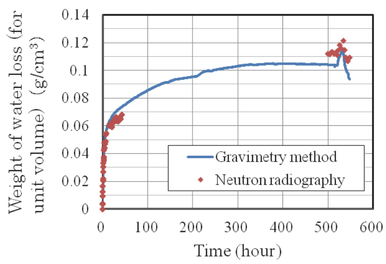


Fig.1. Outline of measurement system.



Left; Fig.2. Thin-wall cylindrical specimen.
Right; Fig.3. Comparison of aging variation of water loss weight for each unit volume calculated from gravimetric method and neutron radiography.

It is thought that the neutron radiography method enables the quantification of the water content in hardened cement paste.

採択課題番号 23P12-8　中性子イメージングを用いたセメント硬化体中の水分測定　プロジェクト
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（理化学研究所）広田克也、森田晋也、山形　豊

PR12-9 Three Dimensional High-Resolution Neutron Computed Tomography at Kyoto University Research Reactor Institute (KUR)

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INTRODUCTION: Neutron radiography can reveal invisible objects using X-ray technology. However, the resolution of neutron radiography is generally low, therefore, it is said that the neutron radiography is unsuitable for the detailed inspection of industrial products. We have been working to refine neutron radiography, where the use of high accuracy X-rays mainly due to CT enables improved visibility. In this case, we decided to perform image acquisition CT, to consider the applicability of equipment, space components and parts inspection.

EXPERIMENTS: We constructed a high-resolution neutron CT system and carried out neutron experiments at the B4 port of KUR in the Kyoto University Research Reactor Institute. Fig.1 shows an overview of the CT imaging system used on this experiment. The neutron imaging device adopted was the Toshiba Ultimage™. This Toshiba color neutron imaging device was used to convert the images which were recorded by a digital SLR (EOS 5D Mark II) using a commercially available product. The color Image Intensifier(I.I.) is a Gd-type neutron color image intensifier with an input sensitive area 4 inches in diameter. Tie digital camera can be replaced by the ALTA U16 (4096 x 4096 pixels, CCD) from the original set of EOS 5D Mark II (5616 x 3744 pixels, CMOS). Using this system, precise neutron transmission images with a gap of 12.5μm in the ASTM-SI indicator could be recognized. The three dimensional neutron CT reconstruction image successfully demonstrated its usefulness. However, the parallelism of the B-4 neutron beam port is poor, hence a collimator was added between the port and I.I. to improve the neutron beam parallel quality. If we use a pinhole collimator, the resolution will improve, but the noise of the imaging system will also increase, which will impair visibility.

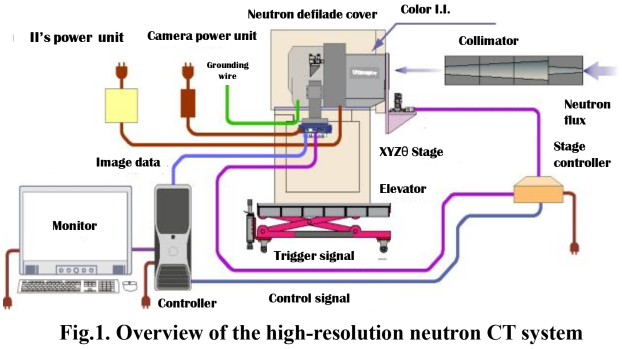

Fig.1. Overview of the high-resolution neutron CT system

A lot of phenomena, caused by contamination of the seal points of the propulsion systems, significantly impact on the satellite system. However, such contamination is too small to be discovered by nondestructive external inspection, hence the need for high resolution inspection. The seal is made of polymer material in most cases. Polymer material cannot be visualized by X-ray inspection. However, neutron radiography is possible to visualize the existence of polymer material. In addition, the seal is covered with more complex metal parts and observation itself is very difficult. CT technology can be used to enhance the visibility of complex shapes observed. We can obtain CT images with high resolution neutron radiography, and evaluate the potential for observation by neutron radiography and CT of complex-shaped propulsion system components. Neutron radiography also visualizes the fluid inside the valve. The differential signal between the image containing fluid and the vacant image reveals a flood image. The images taken are shown in Fig.2.

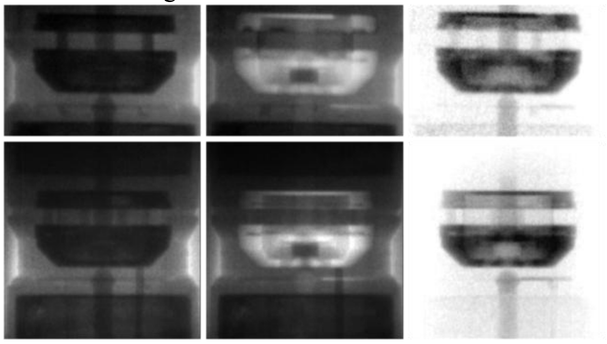

Fig.2. Solenoid valve neutron radiographies obtained at B4 port of KUR. (a,b,c):EOS camera system, (d,e,f):ALTA camera system

RESULTS: The differential images were processed on the CT process and shown in Fig. 2 and 3. Metallic parts were visualized well, but for measurement of seal geometry, targeted in this experiment, the evaluation of the deformation was insufficient. This was due to poor neutron beam quality, hence a higher quality neutron source is desired.

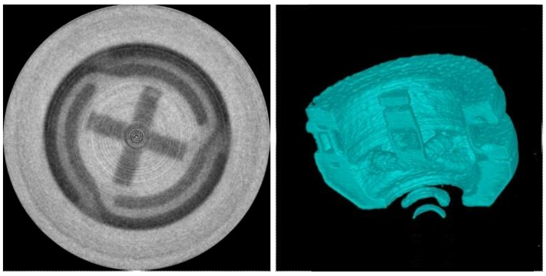

Fig. 3. The fluid CT tomogram results of ALTA

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[2] K.Kushiki, *et al.*, On-Board Energetic Equipment, Avignon, 2004.
[3] T.Nagata, *et al.*, 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, 9 - 12 July, Sacramento, California, (2006), AIAA 2006-4876.

採択課題番号 23P12-9　京大炉（KUR）を利用した人工衛星用触媒分解特性の可視化技術に関する研究　プロジェクト
（京大・原子炉）川端祐司、斉藤泰司、関本 俊（JAXA）香河英史、長田泰一、升岡正、梶原堅一
（都市大）畑亮介、持木幸一