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NEUTRON RADIOGRAPHY RESEARCH ACTIVITIES AT KURRI

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ABSTRACT

The radiography facility for thermal neutron has been installed at the E-2 experimental hole of the Kyoto University Reactor (KUR) since 1974 and provided good characteristics.

To observe a dynamic event and to test many samples, the real-time neutron radioscopy (i.e. neutron television - NTV) system has been introduced to this facility since 1980 and practically applied to various applications with image processing techniques.

Recently a cold neutron beam hole (CN-2) has been available at the graphite column and preliminary radiographic tests were tried.

In this paper, these neutron radiography systems and brief explanations for some of applications at KURRI are described.

INTRODUCTION

At KURRI, neutron radiography has been researched since 1974. The KUR neutron radiography facility is installed at the E-2 experimental hole[1] and has the excellent characteristics. To observe dynamic phenomena and to test many samples quickly, the real-time neutron radioscopy system was introduced in 1980[2,3].

The NTV system has been practically applied to penetrating the side plates containing boron burnable poison to test MTR type fuel, to investigation of moving objects[4,5], to neutron computed tomography (NCT)[6,7], to visualization of particles motion in a spouted bed[8], and to visualization and analysis on air-water two-phase flow[9,10,11].

A cold neutron beam hole has been available for neutron radiography at the graphite column since 1989 and preliminary radiographic tests were tried[12,13].

The KUR is a joint use research reactor (5MW) for universities and research institutes in Japan. The facility is also used to study for graduated students[14,15] and overseas researchers. Therefore, many researchers have come to use this facility for various applications, for example;

- Standardization for Determining Image Quality[16],

from Department of Nuclear Engineering, Faculty of Engineering, Nagoya University, the Atomic Energy Research Laboratory, Musashi Institute Technology,

the Institute for Atomic Energy, Rikkyo University,
the Atomic Energy Research Institute, Kinki University,
the Japan Atomic Energy Research Institute (JAERI),
and the Radiation Center of Osaka Prefecture (now: Univ. of Osaka Prefecture),

- Heat Pipe[17], Testing of defects in Structural Materials[18], Track-Etch Method, Fluid Dynamics[19], Testing New Converters[20], NCT[21], Basic Research on Quantitative Neutron Radiography[22], Analysis of Distribution of Hydrogen in Palladium[23],

from Nagoya University,

- Development of the New Converters (Kasei Optonix, Ltd.)[24],
  Test of Imaging Plates (Fuji Photo Film Co., Ltd.)[25],
  Application to Archaeological Objects and Fine Arts (Gangoji Institute for Research of Cultural Property)[26,27],
  ^{124}Sb-Be Neutrons to CT for Iron Products[28], Core Detection in Turbine Blades, Some Parts of a Space Rocket,

from the Radiation Center of Osaka Prefecture (Univ. of Osaka Pref.),

- Accurate Measurements of Characteristics Factors at the E-2 Facility,

from the Institute for Atomic Energy, Rikkyo University,

- Visualization and Analysis of Particles Motion in a Spouted Bed[8],

from Department of Chemical Engineering, Faculty of Engineering, Kyoto University,

- Investigating Ceramics Structure to the Minutest Details,

from Department of Material Science, Faculty of Engineering, Tottori University,

- Preliminary Experiment Using Cold Neutrons[29,30],

from the Institute for Atomic Energy, Rikkyo University,
Nagoya University, University of Osaka Prefecture and JAERI.

Some researchers of KURRI also have the joint researches in this field at
the "YAYOI" Fast Neutron Source Reactor, University of Tokyo[31,32,33],
the Institute for Atomic Energy, Rikkyo University,
the Atomic Energy Research Laboratory, Musashi Institute of Technology,
the JRR-3M, Japan Atomic Energy Research Institute (JAERI),
the Nuclear Safety Research Reactor, JAERI,
and the Atomic Energy Research Institute, Kinki University.

The main subjects of research in progress are visualization and analysis on air-water two-phase flow, construction of the image data base system on neutron radiography, applications using cold neutrons and development of NTV system with high sensitivity and high resolution for fast and cold neutrons.

This paper describes the KUR neutron facilities and brief explanations for some of above applications.

THERMAL NEUTRON RADIOGRAPHY FACILITY

The KUR thermal neutron radiography facility has been installed at the E-2 experimental hole, which faces the heavy water tank (Fig. 1) and can produce thermal neutron flux with high quality for neutron radiography. It was originally prepaired for use to thermal irradiation experiments, and for neutron radiography use there were some problems, such as the need for collimator for better image quality and reducing the release of radioactive ^{41}Ar, and so on.

A divergent collimator of 5 cm input diameter (D) and 500 cm length (L) was used and the part of the collimator in the E–2 hole was in an aluminium plug to prevent the release of radioactive ^{41}Ar. As a gamma ray filter, bismuth 1 cm thick was placed in the Aluminum plug and a neutron shutter (B_4C) was used at approximately the middle of collimator. The thermal neutron radiography facility is shown in Fig. 2.

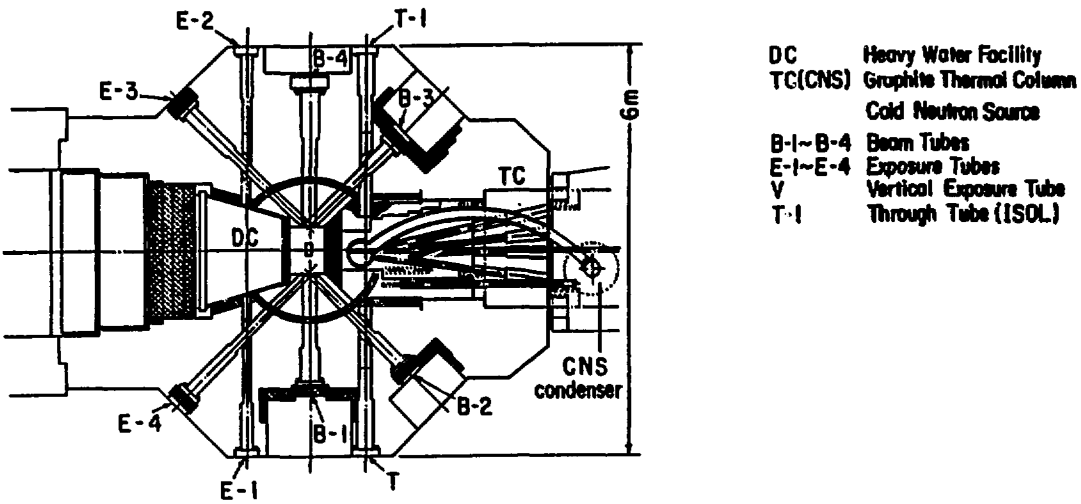

Figure 1. Horizontal View of the KUR Experimental Holes.

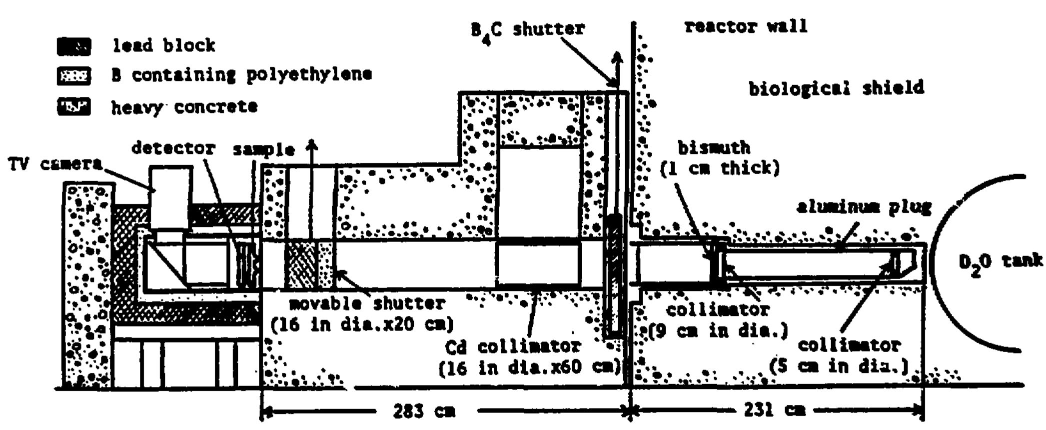

Figure 2. The KUR Thermal Neutron Radiography Facility.

After preliminary experiments to resolve these problems, the facility provided the following advantages;

(1) high neutron flux at the film position (1.2 x 10^6 n/cm^2·sec),
(2) *large Cd ratio measured with a gold foil (400),*
(3) low gamma ray dose rate (4.2 R/h),
(4) Large n/γ ratio (10^6 /cm^2·mR),
(5) large exposure are (16 cm in dia.),
(6) large collimation ratio (L/D 100).

These characteristics are summarized in Table 1.

As a converter for the film method, the gadolinium (Gd) converter with a vacuum cassette has been generally used with the highest resolution. Many commercialized intensifier screens for X-ray use, based on $Gd_2O_2S(Tb)$ such as KH, KO-500, KO-750, G-4 and G-8, are available with high sensitivity, and also can be used for electronic imaging.

Using a Gd direct film method with ASTM-75 and RISØ-81 Image Quality Indicators, NCSR values are satisfied 75-15-10 with ASTM-75; i.e. thermal neutron content 85 %, scattered neutron content 12 %, resolution indicator 11 and Category I (NCHG=65-6-6) with RISØ-81 is also satisfied; 79-7-7. Using KO-500B converter with SR film, NCSR values are 98.9 %, 8.8 %, 11 and NCHG values are 92.8 %, 7, 7.

Table 1. Characteristics of the KUR Thermal NRG Facility.

1. Reactor / Power	KUR / 5000(kW)
2. Peak ϕ_{th} in core	6 x 10^{13} (n/cm^2·sec)
3. Range of L	500 (cm)
4. Standard L / D	100
5. ϕ_{th} at film	1.2 x 10^6 (n/cm^2·sec)
6. Gamma dose rate	4.2 (R/h)
7. Cadmium ratio	400
8. Neutron/Gamma ray ratio	1.1 x 10^6 (/cm^2·mR)
9. Fim size available	16 (cm in dia.)
10. Beam uniformity	±3.5 (%)
11. ASTM-75 specification	85-12-11
12. ASTM(RISØ)-81 (NC-H-G)	79-7-7 (Category I)

COLD NEUTRON RADIOGRAPHY FACILITY

A cold neutron beam hole (CN-2) has been available at KURRI since 1989. The cold neutron source was installed in the graphite thermal column as shown in Fig. 1. The layout of cold neutron guide tube is shown in Fig. 3[12,13]. The characteristic wavelength is designed to be 2.6 Å. The imaging area is 10 mm (in width) x 74 mm (in Height) and the cold neutron flux is expected 1 x 10^7 n/cm^2·sec (>3 Å, at the exit of CN-2 guide tube). The image can be obtained by scanning a film in the cassette with fluence of about 10^9 n/cm^2.

The preliminary experiments are presented in detail in references[12,13]. In the near future, CN-3 beam hole in Fig. 3 will be arranged for neutron radiography.

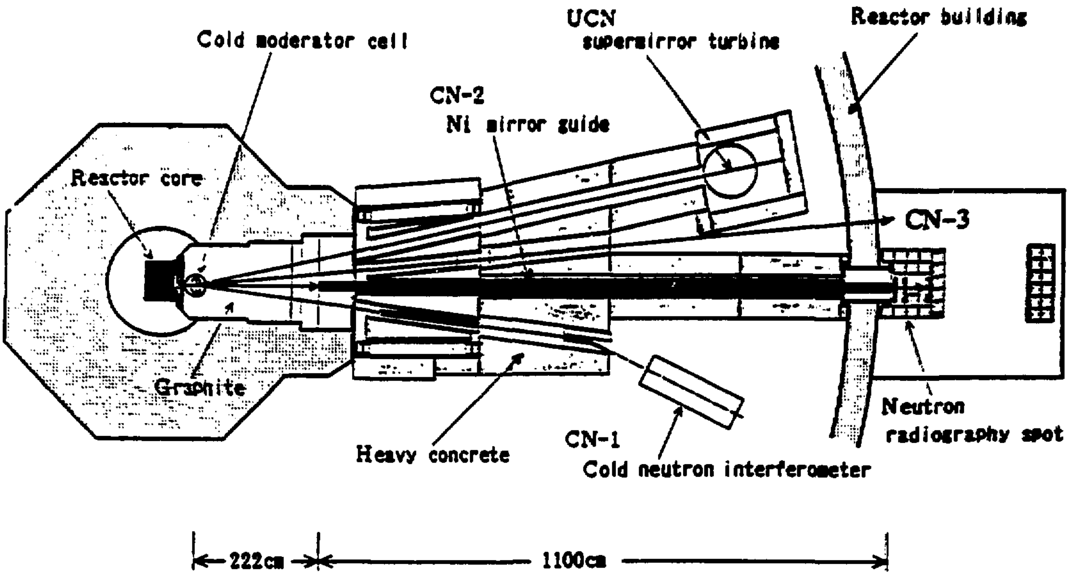

Figure 3. The KUR Cold Neutron Radiography Facility.

REAL-TIME IMAGING SYSTEM

A block diagram of KUR NTV system is shown in Fig. 4. A neutron radiographic image is directly taken from a neutron converter screen with a high sensitive camera (Image Orthicon tube or Silicon Intensifier Target (SIT) tube camera) without image intensifier.

The images from the TV system are digitized through the high speed video analog–digital converter (ADC) (1/30 sec/frame). The digitized images with pseudo color have resolution of 512 x 480 pixels, 256 gray scale and with a DMA interface (TVIP–4100–II). The digital images are fed to an image processing system and a high performance personal computer is connected with an interface.

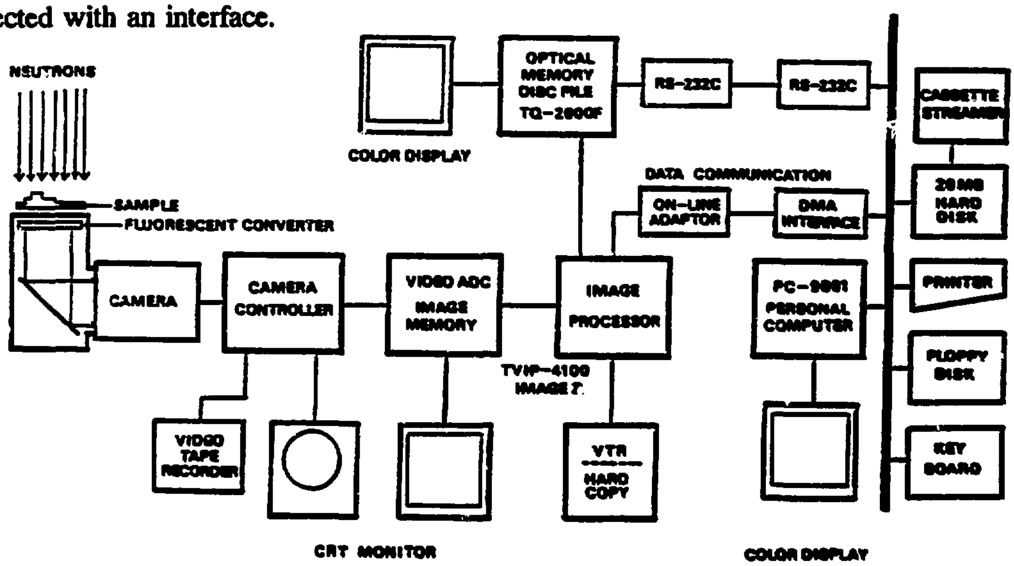

Figure 4. The KUR Neutron Radioscopy (NTV) System Block Diagram.

APPLICATIONS OF NEUTRON RADIOGRAPHY

Visualization on Gas-Liquid Two-Phase Flow[9,10,11]

The neutron radiography technique was introduced to visualize a gas-liquid two-phase flow in metallic duct, and measure the void fraction with use of image processing technique. The experiments were performed using the neutron radiography facilities at the E-2 hole of the KUR, the Nuclear Safety Research Reactor (NSRR) and the JRR-3M of JAERI.

The neutron radioscopy system produced video images with enough quality to delineate flow regimes. The average void fraction obtained with image processing technique agreed well with optical method and the conductance probe method. The relation between gas velocity and mixture volumetric flux was compared with the drift correlation. The agreement was good for wide liquid velocity range.

In the near future, it is expected to be able to calculate the interfacial area concentration with better quality images taken at the JRR-3M.

Some parts of these works were supported by the Grant-in-Aid for Scientific Research (A) from Ministry of Education, Science and Culture (1986-1987, 1989-1990).

This work is presented at this symposium (poster session #405), entitled "Visualization and Measurement of Fluid Phenomena Using Neutron Radiography Techniques" by K. Mishima et al.

Study of Liquid-Solid Two-Phase Flow[8]

Motion of solid particles in a spouted bed was visualized by using neutron radiography. Trajectories and velocity profiles of particles in annular region were obtained from the radiography. Result indicates that both the trajectory and radial profile of particle velocity normalized by mean velocity of fluid through nozzle are almost independent of height of packing and Reynolds number.

The profiles of packed density in a spouted bed were also investigated by neutron radiography and the availability of neutron radiography has been confirmed.

This work was supported by the Grant-in-Aid for Developmental Scientific Research from the Ministry of Education, Science and Culture (1990-1991).

International Cooperative Research Program

The Research Reactor Institute, Kyoto University and the Phoenix Memorial Laboratory (PML), the University of Michigan agreed to Memorandum to Promote Academic Cooperation and Exchange in November, 1987.

In the Memorandum it is written, "In order to facilitate academic cooperation and exchange in scientific and technical development on research reactors, their uses and related subjects, they will encourage in particular activities: all those activities shall be aimed exclusively at peaceful uses: (1) The exchange of research publications. (2) The exchange of researchers, technicians and students. (3) Joint research meetings. (4) Joint research. (5) Research by mutual use of facilities."

The joint research program was supported for three years by the Grant-in-Aid for International Scientific Research Program: University-to-University Cooperative Research from the Ministry of Education, Science and Culture (1990-1992).

At KURRI various applications have been studied by using the KUR and at the University of Michigan, PML, neutron radiography has also been used in the lubrication studies, spray patterns and spray dynamics, several phenomena in porous media, computer reconstructed neutron tomography, fluid flow studies, and structure and foreign material applications[34].

As the preliminary experiment for this program, visualization of air-water two-phase flow in a small diameter tube and a narrow rectangular duct was considered in 1991 and 1992. The various images of two-phase flow (bubbly, slug, churn and annular) were obtained with a LIXI NID system and an EMI system at PML. These images were improved by beam correction and averaging technique using Quantex QX-9200 image processing system. The images were sufficiently clear for observation of flow condition and it is expected the quantitative research on two-phase flow follows, such as the measurements viod fraction and rising velocity of bubbles. The feasibility of this study could be succeeded to a future program[35].

At present, neutron radiography has been used to inspect coking and foreign materials in a gas turbine engine nozzle.

Development of Imaging Techniques for Fast Neutron Radiography (FNR)[31,32,33]

Since 1986, researchers from various organizations frequently gathered at the YAYOI reactor and carried out the experimental program of fast neutron radiography. The YAYOI reactor is one of fast neutron source reactor for research purpose and an average energy of the neutron beam is estimated to be about 0.8 MeV and applicable to FNR. The neutron fluxes at the exit of the beam holes were measured to be 10^6–10^7 n/cm^2·sec (>1.3 MeV at 2 kW operation), and were expected to be able to apply to FNR. In the research programs, imaging techniques were successfully developed using not only CR-39 track detector for a direct imaging but also a fluorescent converter for an electronic real time imaging and for a film method.

Cold Neutron Radiography[12,13,29,30]

Output intensities of the cold neutron guide (CN-2) of KUR-CNS (Cold Neutron Source) were measured with neutron radiographic method. The intensity profiles of the cold neutron beam at various positions in front of the exit of CN-2 were radiographed and quantitatively measured from film optical densities. For the cold neutron source with liquid deuterium moderator, the peak intensity of the CN beam of the CN-2 was measured to be 1.1 x 10^7 n/cm^2·sec as 'thermal neutron intensity equivalent'. By using the CN beam, CN radiography was carried out with a scanning method of the imaging system. The images with high quality were obtained.

Spatial intensity profiles of a CN beam were measured about the CN-2 guide tube after passing through Be filters as a function of the Be thickness with use of an NR technique. Relative intensities of low energy cold (<5 meV) and high energy cold (5-12 meV) neutron components were analyzed along a horizontal axis on a section in the beam section[29].

Beam quality dependence regarding with effective total macroscopic cross sections was measured for Pb, Fe and Ti at the KUR (E-2, CNS), the JRR-3M (7R, CNS) and the Rikkyo Reactor[30].

CONCLUSION

KUR NR facilities and some of applications were presented. KUR NR facilities have enough characteristics for the film method. The NTV system also is sufficient for the stationary and moving samples, and has been used to various applications. The facilities are expected to use to further applications in the wider fields.

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