A plan for compact accelerator-based neutron source and detector systems at RIKEN

Katsuya Hirota
RIKEN Radiation lab.

RIKEN group
Hirota : Hardware
Yamagata : Software
Ju : Simulation (poster)
Morita : Neutron imaging experiment (poster)
RIKEN Project

Neutron imaging technique

Applying to manufacturing technique
Quality control by small neutron sources at each factory
cheap price, easy to access, easy to handle

Applying to large scale structure materials
Measurement the bridge outdoors
stationary transportable

Aug 15-18, 2010, Beijing
Neutron source Plan (tentative plan)

- Developing an as possible small neutron source system
  The small machine is available to use for many factories.
- We also want to develop the transportable neutron source.

Accelerator

- Energy: proton 4-7 MeV
- Average current: 0.1 ~ 1 mA
- Power: ~ 7 kW
- Neutron target: Be
- Neutron energy: thermal (fast neutron for structural materials)
- Pulse beam
- Neutron flux: $10^5$ n/cm²/s @ sample position (L = 4 m)
  $10^9$ n/cm²/s @ moderator surface

Aug 15-18, 2010, Beijing
Commercial based accelerator

Model PL-7 Proton Linac

Proton Linac 3-MeV

Linac Systems 2.5MeV

AccSys 2MeV p+/d+ Linac
Target and Moderator system

- We calculated the neutron flux by using simulation code "PHITS"
- The detail shows at Poster (J. Ju)

This calculation shows the flux $3 \times 10^5$ n/cm$^2$/sec at L=5 m. (proton 5.4 MeV 1mA)

$\begin{align*}
7\text{MeV} & \quad 1\text{mA} : 6 \times 10^5 \\
4\text{MeV} & \quad 1\text{mA} : 0.9 \times 10^5 \\
0.1\text{mA} & : 6 \times 10^4 \\
0.1\text{mA} & : 0.9 \times 10^4
\end{align*}$
Fast neutron radiography

Aug 15-18, 2010, Beijing

[Diagram showing the process of fast neutron radiography, including an accelerator, Be target, concrete bridge pier, detector (Liq. Sintillator), and shield.]
The simulation of the neutron flight

Aug 15-18, 2010, Beijing

\begin{verbatim}
no. = 1, io = 1, ix = 1, it = 1
\end{verbatim}

\begin{verbatim}
emin = 0.0000E+00 [MeV]
emax = 2.0000E+01 [MeV]
xmin = -1.0000E+01 [cm]
xmax = 1.0000E+01 [cm]
part. = neutron
tmin = 0.0000E+00 [nsec]
tmax = 1.0000E+01 [nsec]
\end{verbatim}
Fast Neutron Imaging (simulation)

TOF image $\Delta t = 10\text{ns}$

10ns

100ns

150ns
Model of the Transportable Neutron Source

Is it available for PGAA? It is too weak to use radiography.

AccSYS PL-7 (7MeV, 150 µA). This is a maker product machine.
Development

• design of Neutron Source
  – small accelerator low energy and high current, short pulse, stable RF amplifier (Klystrode/Triode)?
  – target (heat, blistering, Li/Be), moderator
  – shield, Neutron Optics
  – Simulation (PHITS, GEANT4)

• Detector
  – Neutron I.I, Scintillator + CCD, GEM, $\mu$ PIC
  – fast neutron detector (liquid scintillator / $\mu$ PIC?)
  – resolution (time / spatial)

• Image Processing/ 3-D reconstruction/ Modeling technique
  – noise reduction, super-resolution, clearness, CT reconstruction

• Simulation • Prediction technology
  – Using VCAD software, Collaborate with Civil engineering
# Time table

- **October, 2009 ~**
  - Preliminary Experiment
    - at JRR-3, KUR, J-PARC, Linac (Hokkaido Univ.), CYRIC (Tohoku Univ.)
  - Committee of accelerator based neutron source project
- **January, 2010 ~**
  - Budget demanding
- **April, 2011 ~** Project Start
  - first neutron beam on March 2012?
  - thermal neutron radiography
  - Large Scale Structure Experiment (fast neutron radiography)、「
    - PGAA (Prompt Gamma Activation Analysis), Cl⁻ distribution in the concrete
  - phase contrast imaging
  - magnetic field measurement (polarization imaging)
  - strain, temperature measurement (pulse imaging)？
- **2016 ~**
  - applying manufacturing in the factory
  - mobile system, outdoors
  - flux increasing
Detector and other devices

High counting rate detector
Li Pixel Detector
by Hokkaido University

Scintillator: $^6\text{Li}$-glass (GS20)
16 × 16 pixels (2.1 × 2.1 × 1 mm²/pixel)
Effective area 50 × 50 mm²
Spatial resolution 3 mm
Efficiency 40% @ thermal neutron counting rate 2-3 Mcps/detector

TOF: available
**RPMT detector**


- **Scintillator:** ZnS/$^6$LiF $^6$Li-glasss
- **Effective area:** $35 \times 35 \text{mm}^2 (\phi 3 \text{ PMT})$
  $60 \times 60 \text{mm}^2 (\phi 5 \text{ PMT})$
- **Spatial resolution (FWHM):** $0.5 \sim 0.8 \text{mm}$
- **Efficiency:** $20-30\%$ at cold neutron
- **Counting rate:** $20\text{kcps} @ 10\%$ dead time

- **Compact DAQ system:** USB2.0 transfer
  $\rightarrow$ 100BASE network (NEUNET system at J-PARC)

- **Easy to use and good performance**
  - SANS (F-, mf-, vcn-), Spin Echo, Reflectometer, Pulse Imaging, ・・・

- **TOF:** available
Compact CCD System

This system is made for contrast imaging measurement at JRR-3 cold beam line (ULS).
- compact and easy handle
- use at very low background

CCD: 1/2inch 656 x 484 pixels
shutter: 1 μ sec - 3600 sec
data transfer: G bit ethernet
effective area: 53mm(H) x 40mm(V)
weight : 2kg (w/o shield)
spatial resolution : about 200 μ m

exposure time: 20sec @ 4.4 Å, 3x10^5 n/cm^2/s

TOF : not-available
Standard CCD system

This system is using for neutron radiography at JRR-3 thermal beam line (guide hall).
- old system (made about 7 years ago)
- liquid N₂ Cooling CCD

CCD: 1340 x 1300 pixels (VersArray/ Princeton)
data transfer: USB2.0
effective area: 50mm(H) x 50mm(V)
spatial resolution: about 200 μm

available to change another CCD

EMCCD:C9100-12
(Hamamatsu K.K.)
High sensitivity camera
512x 512 pixels
Thermal Neutron Radiography

- We are measuring at JRR-3 MUSASI port, $8 \times 10^5$ n/cm$^2$/s
- This flux is about one order stronger than our small neutron source.
- The exposure time is tens sec for radiography and less than one hour for CT.

pyramid-shape ion alloy

Test piece of CFRP

CT of concrete
Neutron Optics devices

RIKEN, KEK, JAEA, Hokkaido Univ.

Curved mirror

mf-SANS mirror

magnetic devices

material -lenses

Fresnel

Biconcave

Focusing-SANS

Double -Biconcave
Summary

- RIKEN Group is planning to construct an accelerator-based neutron source. The main purpose is thermal and fast neutron radiography.

**accelerator**
- energy: proton 4-7 MeV
- average current: 0.1 ~1mA, pulse beam
- power: 1~10 kW
- neutron target: Be / water moderator
- neutron energy: thermal and fast neutron
- neutron flux: about $10^5$ n/cm$^2$/s @sample position

There are some neutron detector for thermal neutron, but poor for fast neutron.
Collaborators


KEK: H.M. Shimizu, S. Satoh, S. Mutoh, T. Ino, K. Mishima

JAEA: T. Shinozaka, T. Oku, J. Suzuki, N. Metoki

PWRI: Y. Kimura

Hokkaido Univ.: Y. Kiyanagi, M. Furusaka, T. Kamiyama, F. Hiraga

Kyoto Univ.: Y. Iwashita

Tokyo Univ.: H. Yoshizawa, A. Momose, W. Yashiro

Hosei Univ.: F. Kimura

And many graduate school students

Thank you for your attention!