Development of Pulsed Neutron Sources

パルス中性子源の開発

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History of Pulsed Neutron Sources
(Change of plans from 1990)
Accelerator-driven Neutron Sources before KENS established in 1980 (Electron Acc.)

- Harwell Linac (opposite present ISIS)
- Hokkaido University
- Linac at Laboratory of Nuclear Science at Tohoku University (LNS) (Present: Research Center for Electron Photon Science)
- The Gaerttner Linear Accelerator Center at Rensselaer Polytechnic Institute (RPI) (Except for nuclear data measurements)
National Laboratory for High Energy Physics: KEK
（Now, High Energy Accelerator Research Organization）

Booster Synchrotron Utilization Facility

KENS: KEK Neutron Source （KEK中性子源）

Green area

Proton therapy

Muon

https://www2.kek.jp/openhouse/1996/image/BSF/BSF7.gif
Late Prof. Watanabe performed experiments using a RI neutron source.
Development of a Methane Cold Moderator at Hokkaido University

KENS Neutron source

Cold source
Thermal source

Co-existence

The first cold neutron source set at a dedicated neutron scattering experimental facility. (There was an opinion a cold source was not necessary for neutron sources based on accelerators)

A wise decision by Professors Watanabe and Ishikawa


渡邊昇, 石川義和: 日本原子力学会誌 Vol. 23, No. 6 (1981) 389-398
Conversion of KENS

Deformation of a cold neutron beam hole

Energy spectra

Pulse shapes

From enriched B to nat-B

A Gd-poison plate was inserted.

Improved TMRA

Be-C layered reflector

Be cost of 40 million yen was reduced.
J-PARC/MLF

(From KEK side)
KENS → GEMINI (KENS-II) 計画 → N-Arena (JHP) → N-Arena (JHF) (~500kW)

Neutron Science Research Center (8 MW)
(From JAEA side)
Development of a coupled moderator

Methane cannot be used under high radiation field.
A traditional hydrogen moderator gave lower intensity than methane.

Experiments at Hokkaido University

**Normal hydrogen and methane**

**Coupled moderator**

6 times higher intensity than the traditional one, and twice higher than a decoupled methane moderator.

Improvement of pulse shapes by using para-hydrogen

Experimental results @1.8meV

The pulse shapes are improved by using para-hydrogen, and increase of pulse peaks are also observed.

Increase of intensity by using a thick moderator

J-PARC coupled moderator

140 mm diameter x 100 mm height

Horizontal distribution
(measured at Hokkaido U.)


https://doi.org/10.1080/00223131.2017.1394235
Proton energy 3 GeV was appropriate?

Verification of neutron yield using 12 GeV p

At that time the NMTC code result indicated level off trend over around 3 GeV.

*3GeV was in an allowance level.
*Target was mercury (G. Bauer)

Target-Moderator-Reflector System for JSNS

- Coupled moderator
  - High intensity
- Decoupled poisoned moderator
  - Very high resolution
- Decoupled moderator
  - High resolution
- Proton beam
- Be reflector
- Fe reflector-shield
- Cd poison and decoupler
- Cd decoupler
ESS@LUND

Target Station Components

1. The Target Station monolith, including 6,000 tonnes of steel shielding. The view shows the aperture where the proton beam enters the monolith horizontally, as well as some of the 42 double-decker neutron beam line penetrations.

2. A cut-away view of the target wheel shaft assembly and target wheel. The 4-tonne, 2.5-meter-diameter target wheel is divided into 36 radial segments containing around 7,000 tungsten blocks. It is cooled via helium and rotates such that one proton beam pulse will strike each segment of the wheel over the course of a single rotation. The helium cool shaft, as is for the wheel.

3. The mode target wheel. They can from the mc.

4. The ESS the low-pro within the ring wheel. To a determine I station will cans, arrange water mode like hydroge slow down the. The neutron suitable for.

J-PARC
Hydrogen
High intensity

ESS
Butterfly
Water
Hydrogen
Thermal/Cold

Pancake
Hydrogen
High brilliant

https://ess-public-legacy.esss.se/sites/default/files/target_station_jpg_full.jpg
Accelerator-driven Neutron Sources Worldwide

**ISIS (UK)**
- 0.2 MW

**ESS (Sweden)**
- 2022? (4 MW)

**JSNS/J-PARC (Japan)**
- 1 MW

**CSNS (China)**
- 0.1 MW

**CPHS (China)**

**HUNS (Japan)**

**KUANS KERRI-LINAC**

**PKUNIFTY (China)**

**CPHS (China)**

**HBS**

**SONATA**

**LANL (USA)**
- (0.08 MW)

**SNS USA**
- (1.4 MW)

**LENS (USA)**

**CAB (Argentina)**

**KURRI-LINAC**

**Accelerator-driven Neutron Sources Worldwide**

**PKUNIFTY**
Neutron Sources in Japan (except for BNCT)

Hokkaido U.

**HUNS (32MeV, 100μA)**
- Cold and thermal neutrons
  - \(~10^4\) n/sec/cm\(^2\)

RIKEN

**RANS (7MeV, 100μA)**
- Thermal neutron
  - \(\sim\text{few} \times 10^4\) n/sec/cm\(^2\)

Kyoto U.

**KUANS (3.5MeV, 100μA)**
- Thermal neutron
  - \(1.2 \times 10^3\) n/sec/cm\(^2\)

**KUR (Reactor):**
- Thermal
  - E2: \(~3.2 \times 10^5\) n/sec/cm\(^2\) @5MW
  - B4: \(~5 \times 10^7\) n/sec/cm\(^2\) @5MW

Aomori prefecture

**J-PARC (3GV, 333mA)**
- **RADEN:** Cold neutron
  - \(\sim 10^8\) n/sec/cm\(^2\)
- **TNRF:** \(\sim 10^8\) n/sec/cm\(^2\)

**JRR-3 (Reactor)**
- **CNRF:** Cold neutron
  - \(~10^7\) n/sec/cm\(^2\)

SUMITOMO

**SHI-ATEX (18MeV, 20μA)**
- \(~2 \times 10^5\) n/sec/cm\(^2\)

**KURNS LINAC:**
- Thermal
  - \(2.3 \times 10^4\) n/sec/cm\(^2\) @100μA

AIST

**AIST ANS**
For the Future

Reflector for cold and very cold neutron source

Nano diamond

![Nano diamond image](image)

50 nm

**Figure 8** Total cross sections of nano-diamond. Cross section of carbon (JENDL-4.0, [21]) and graphite (C. D. Bowman et al., [22]) are shown for comparison.

M. Teshigawara et al., NIM A Vol. 929 (2019) P. 113-120
Moderator with a re-entrant hole

* Intensity increase in a hole (for mfSANS, for example)

* Simulation for a mesitylene moderator

Simulations at Hokkaido University
Neutron Focusing Mirror using a metal base

It can be placed near the moderator

A fully-revolved 900mm ellipsoidal neutron focusing mirror for J-PARC BL-06 VIN ROSE

A 300mm ellipsoidal neutron focusing mirror for focusing SANS beamline at RANS

RIKEN Yamagata group
T. Hosobata et al., Vol. 27, No. 19 / 16 September 2019 / Optics Express 26807
Total optimization using recent technology

Optimization from a neutron source to detection.

Target
Moderator
Reflector

Beam transport

Instrument

Compact
High Performance

Detector

High Performance
• History of pulsed neutron sources

  (Large facility)

  LNS at Tohoku U. → KENS → JSNS/J-PARC

  HUNS at Hokkaido U.

  (Compact facilities)

  KUANS → RANS → AISTANS

  (JCANS: Japan Collaboration on Accelerator-driven Neutron Sources)

• It is expected that new technologies promote optimization of the compact neutron sources and lead to contribution to a next generation large facility.