23/12/2020

Development of Pulsed Neutron Sources
パルス中性子源の開発

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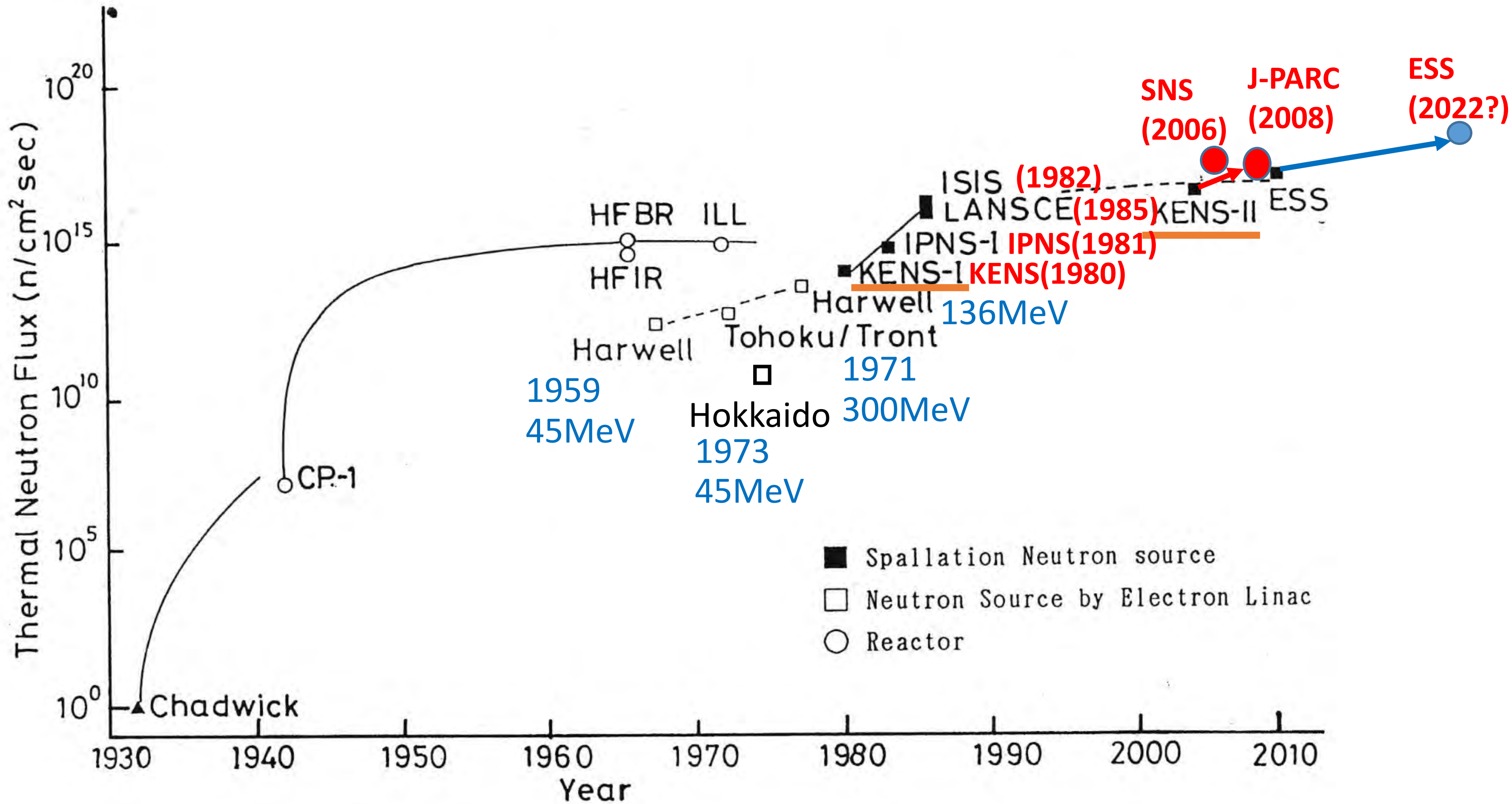
History of Pulsed Neutron Sources

(Change of plans from 1990)



Accelerator-driven Neutron Sources before KENS established in 1980 (Electron Acc.)

（Except for nuclear data measurements）

Hokkaido University

The Gaertner Linear Accelerator Center at Rensselaer Polytechnic Institute (RPI)

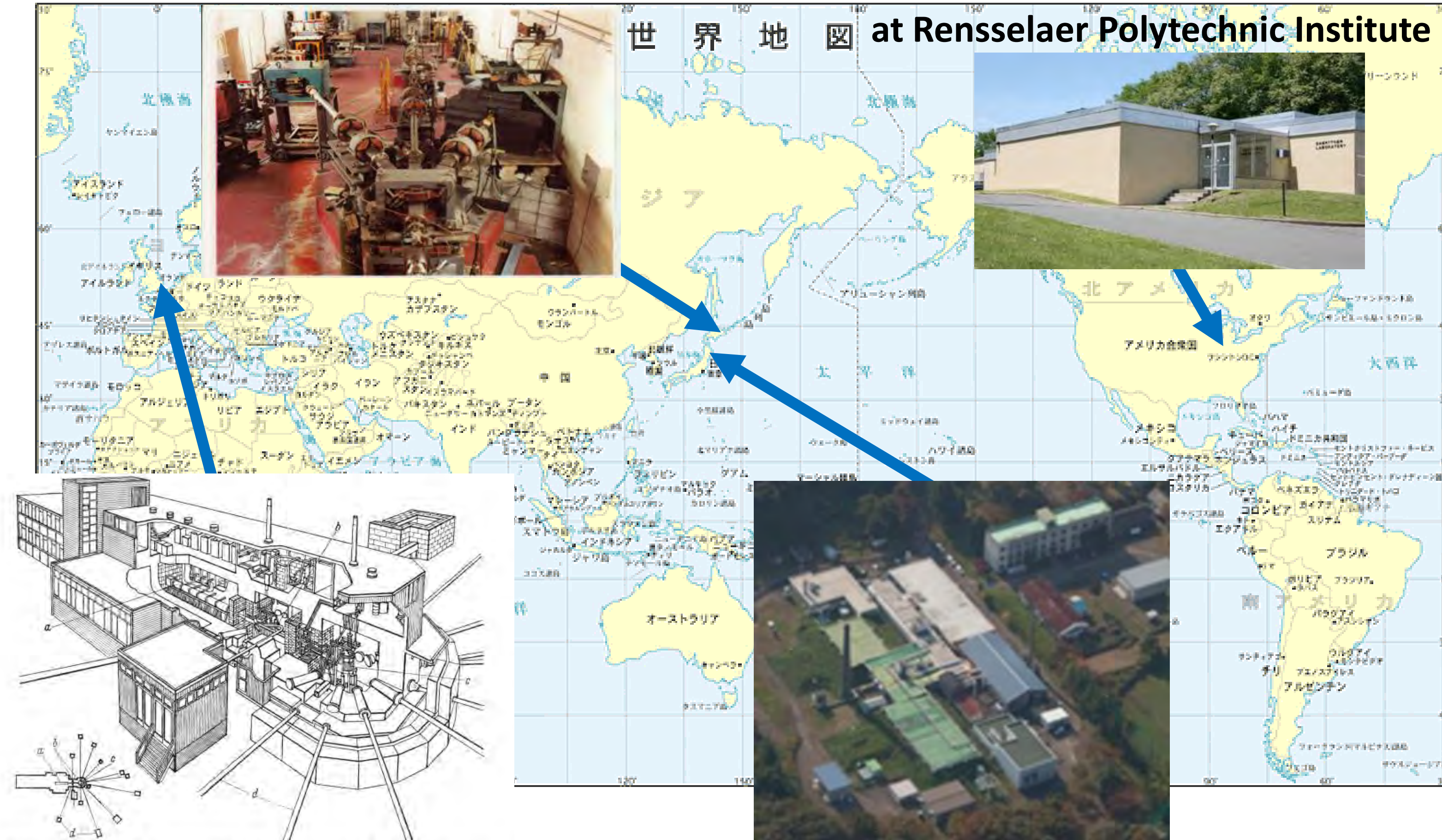


Fig. 2.5.5. The Harwell linear accelerator facility. a Accelerating waveguides; b auxiliary target; c main target with booster; d neutron flight channels (reproduced with the kind permission of E. R. Rae, Harwell)

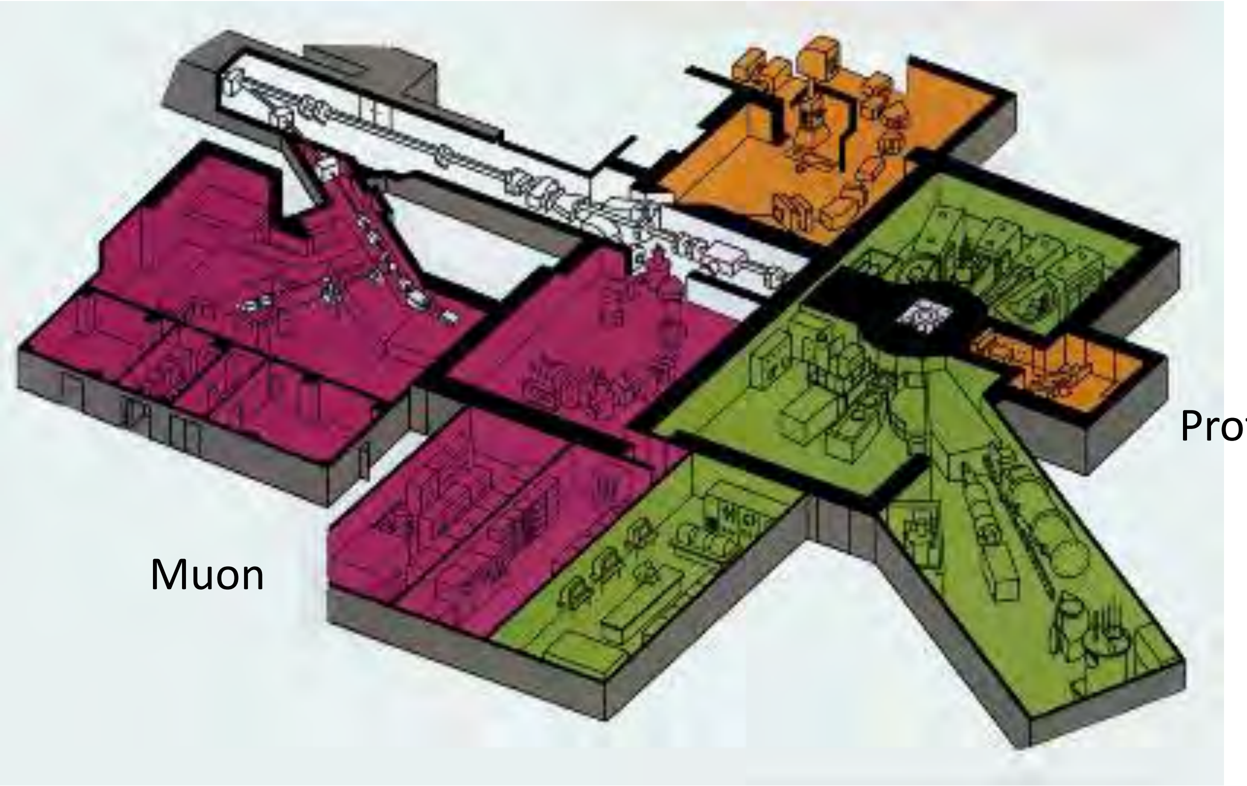
Harwell Linac
（opposite present ISIS）

Linac at Laboratory of Nuclear Science at Tohoku University (LNS)
（Present: Research Center for Electron Photon Science）

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

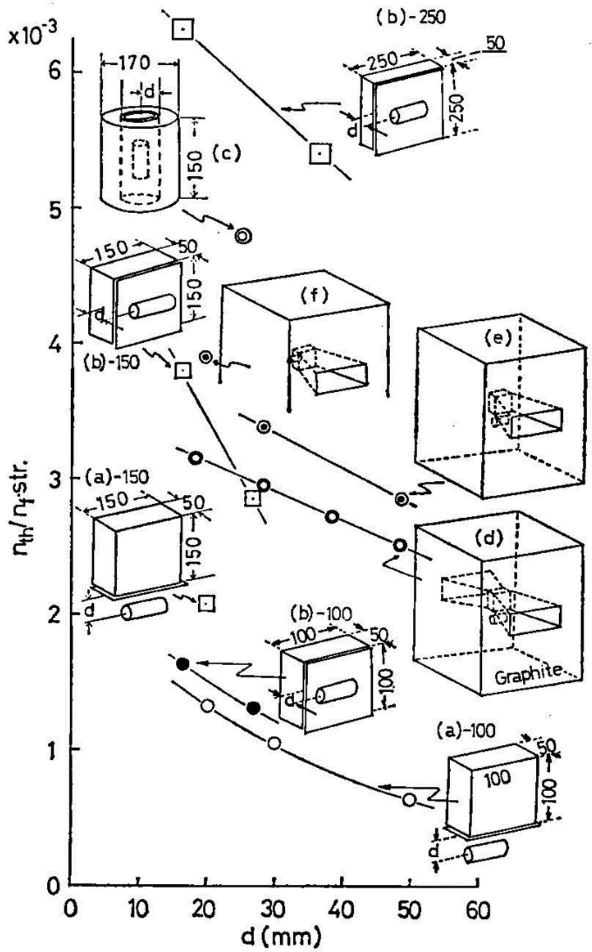


Proton therapy

Muon

https://www2.kek.jp/openhouse/1996/image/BSF/BSF7.gif

Coupling of Target-Moderator-Reflector research



横軸はターゲット中心から減速材までの距離,
縦軸はターゲットでの発生中性子1個当りの
熱中性子ビーム強度

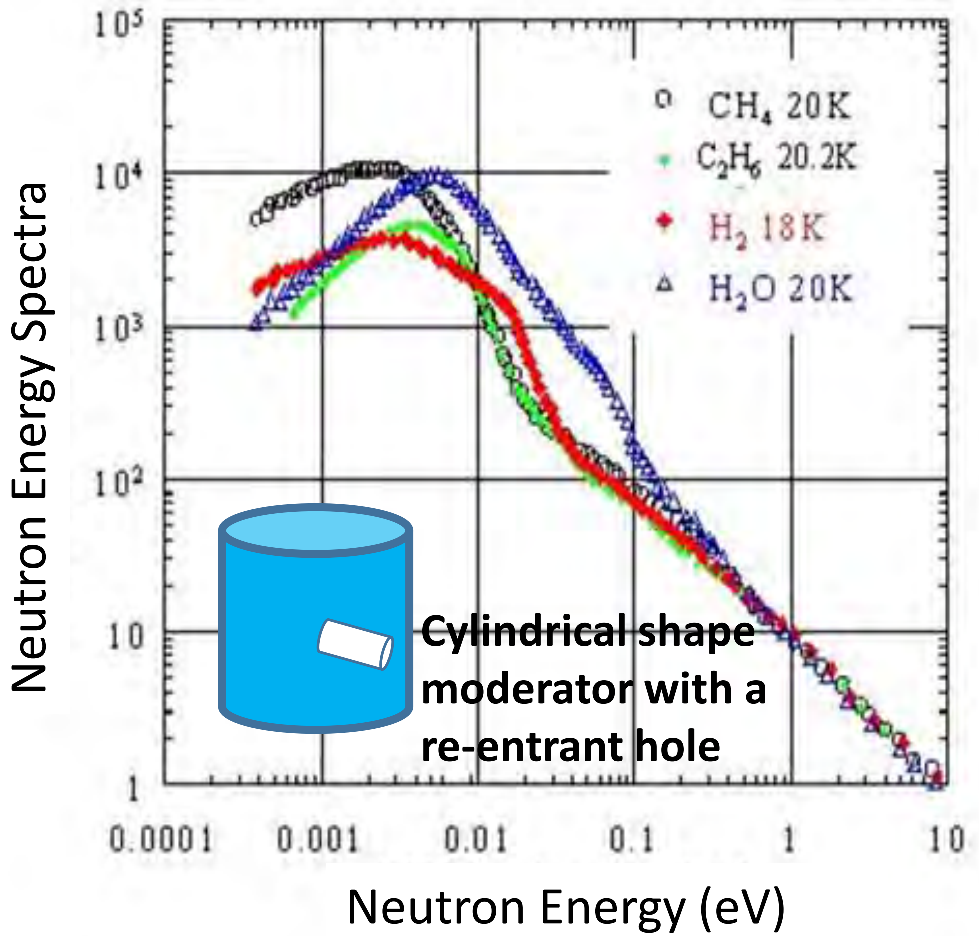
第3図 ターゲット・減速材・反射体
結合の最適化実験

Late Prof. Watanabe performed experiments using a RI neutron source.

スパレーション・パルス中性子源KENSとそれによる中性子散乱
渡邊昇、佐々木寛、石川義和

日本原子力学会誌 Vol. 23, No. 6 (1981) 389-398

Development of a Methane Cold Moderator at Hokkaido University

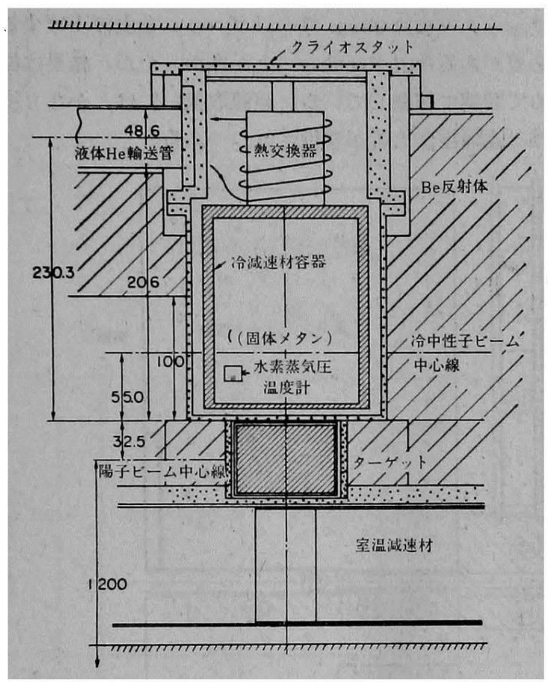


K. Inoue, N. Otomo, H. Iwasa and Y. Kiyanagi, J. Nuclear Science and Technology, Vol.11, No.5, pp.228-229, (1974)

KENS Neutron source

Cold source
Thermal source } Co-existence

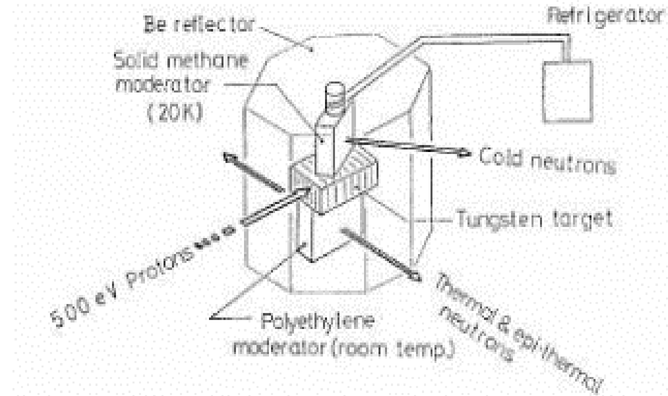
The first cold neutron source set at a dedicated neutron scattering experimental facility.
（There was an opinion a cold source was not necessary for neutron sources based on accelerators）
A wise decision by Professors Watanabe and Ishikawa



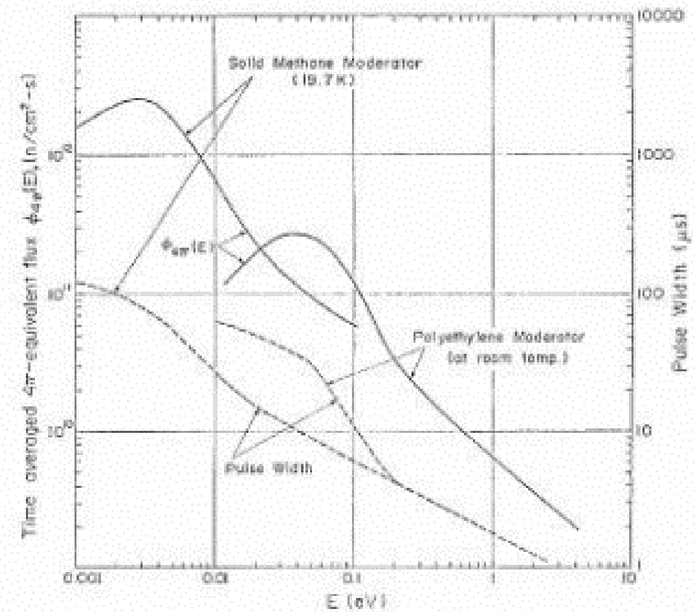
第4図　ターゲット周辺の断面図

渡邊昇、佐々木寛、石川義和

日本原子力学会誌 Vol. 23, No. 6 (1981)　389-398



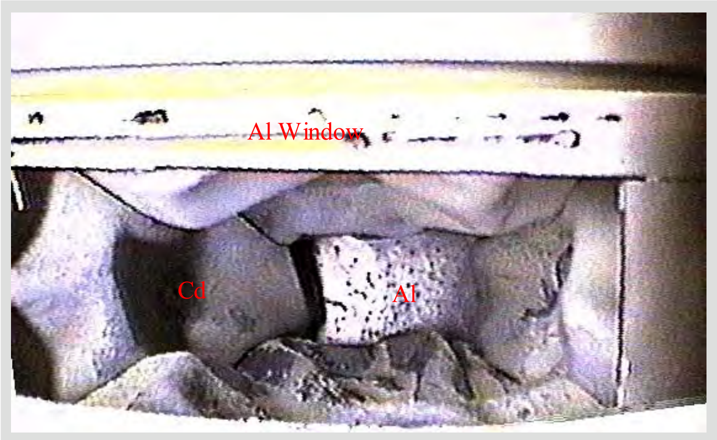
第1図　KENS中性子源の概念図. (渡辺　昇, 他: 日



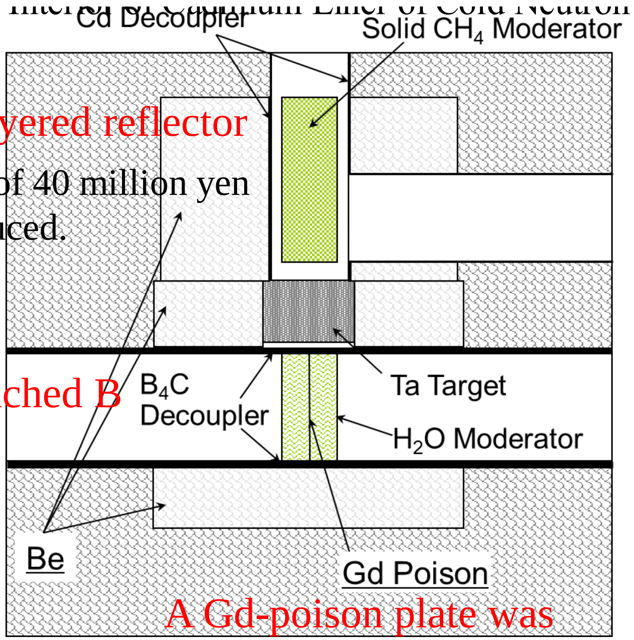
第2図　室温および冷減速材表面の時間平均 4π 等価中性子束およびパルス幅 (FWHM).

渡邊昇, 石川義和: 物理学会誌, 39, 826 (1984).

Conversion of KENS



Deformation of a cold neutron beam hole



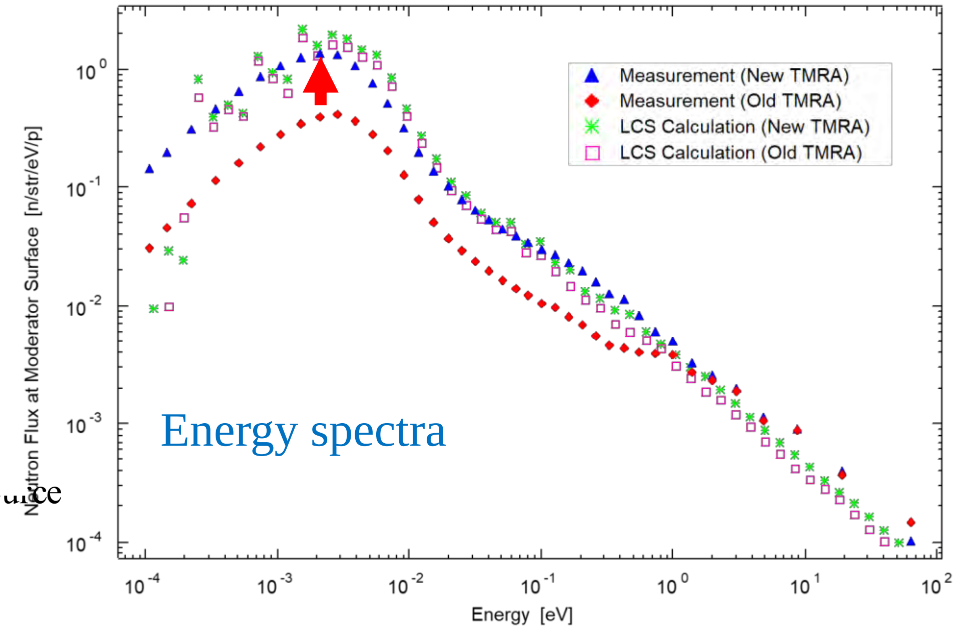
Be-C layered reflector

Be cost of 40 million yen was reduced.

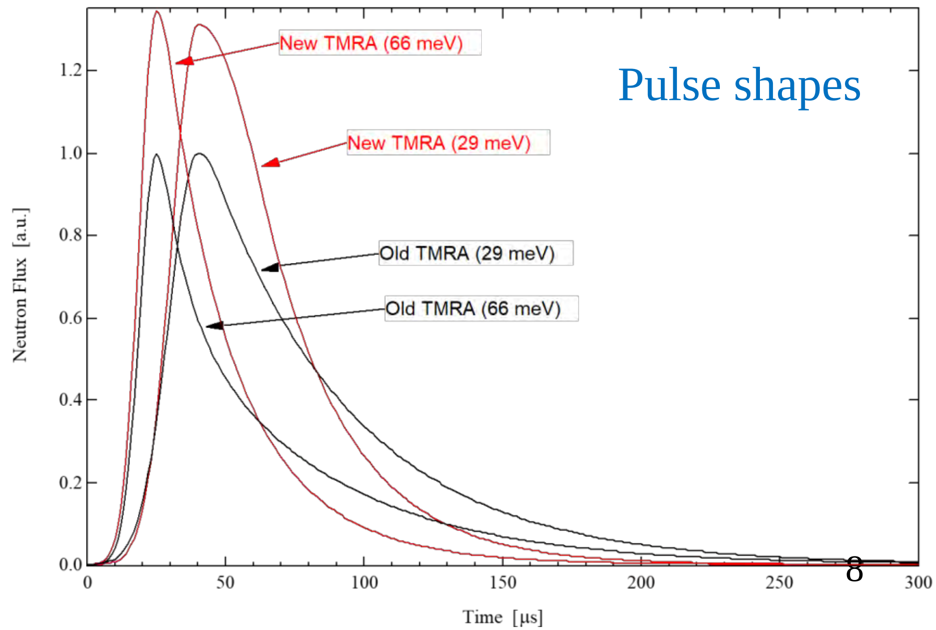
From enriched B to nat-B

A Gd-poison plate was

Improved TMRA



Energy spectra



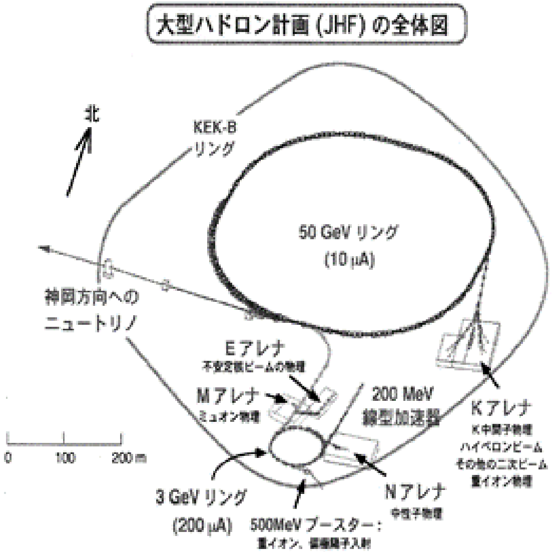
Pulse shapes

J-PARC/MLF

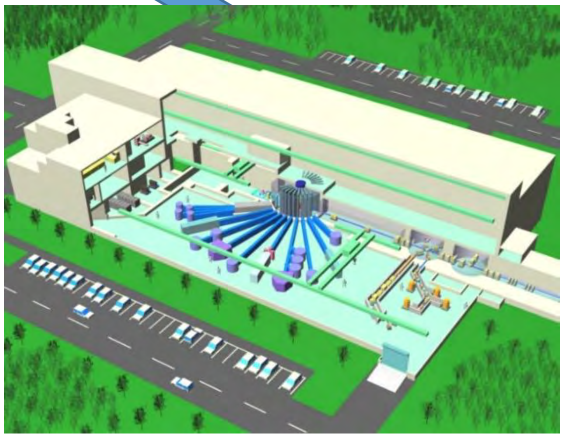
（From KEK side）

KENS→GEMINI（KENS-II)計画→N-Arena(JHP)→

N-Arena（JHF)　(~500kW)



J-PARC/MLF（１MW)



Neutron Science Research Center（８MW）

（From JAEA side）

Development of a coupled moderator

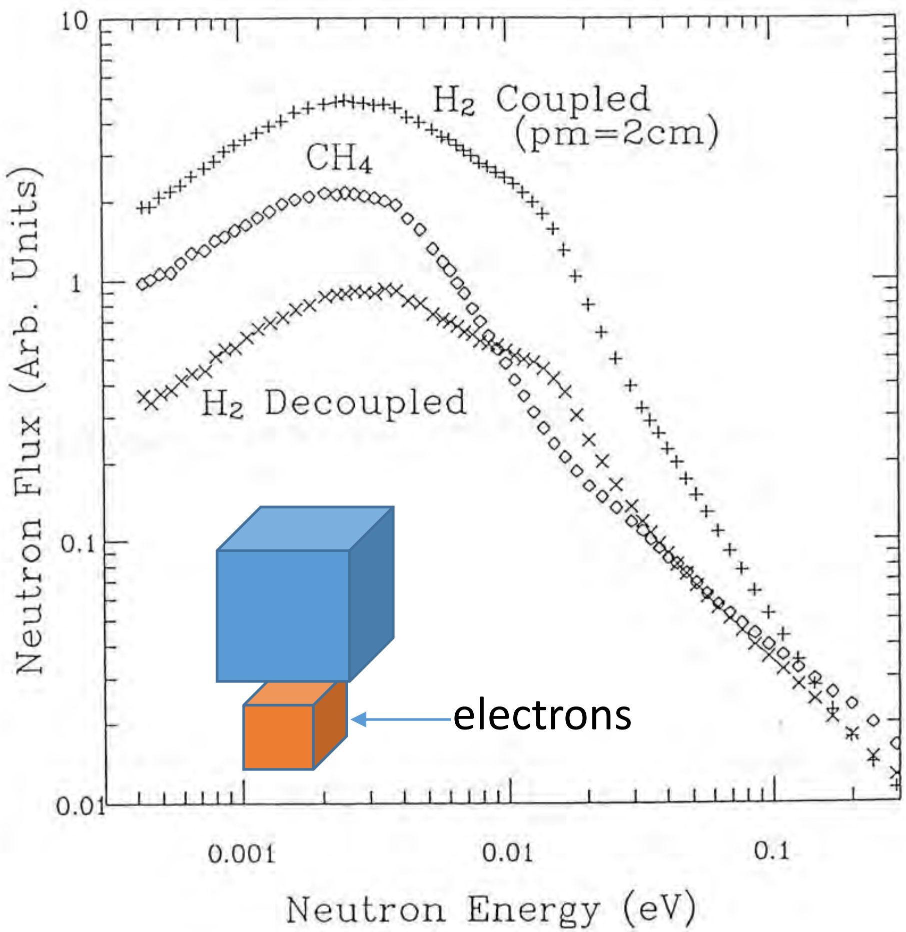


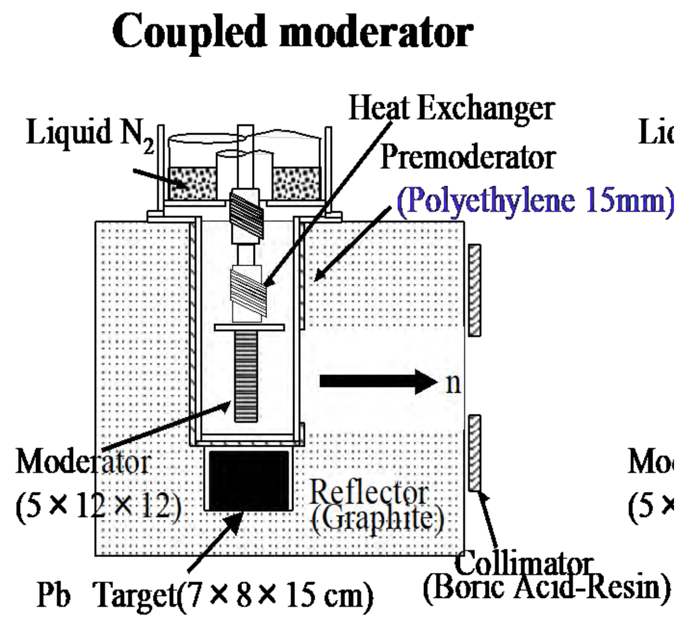
図6.12 カップリング型液体水素とデカップリング型固体メタンの中性子スペクトルの比較

Y. Kiyanagi, N. Watanabe and H. Iwasa, Nucl. Instrum. Methods Phys. Res. A312, pp.561-570, (1992)

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

Experiments at Hokkaido University

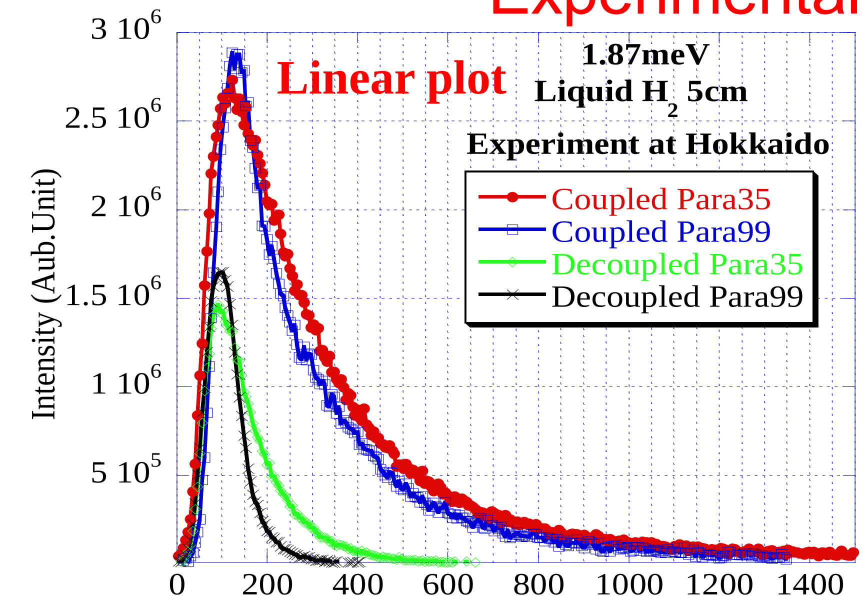
Normal hydrogen and methane

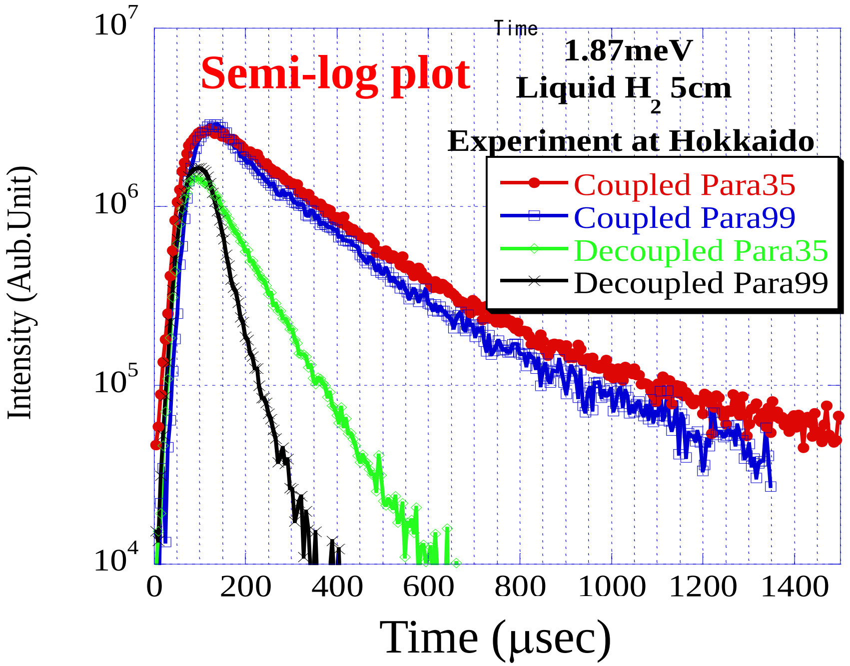


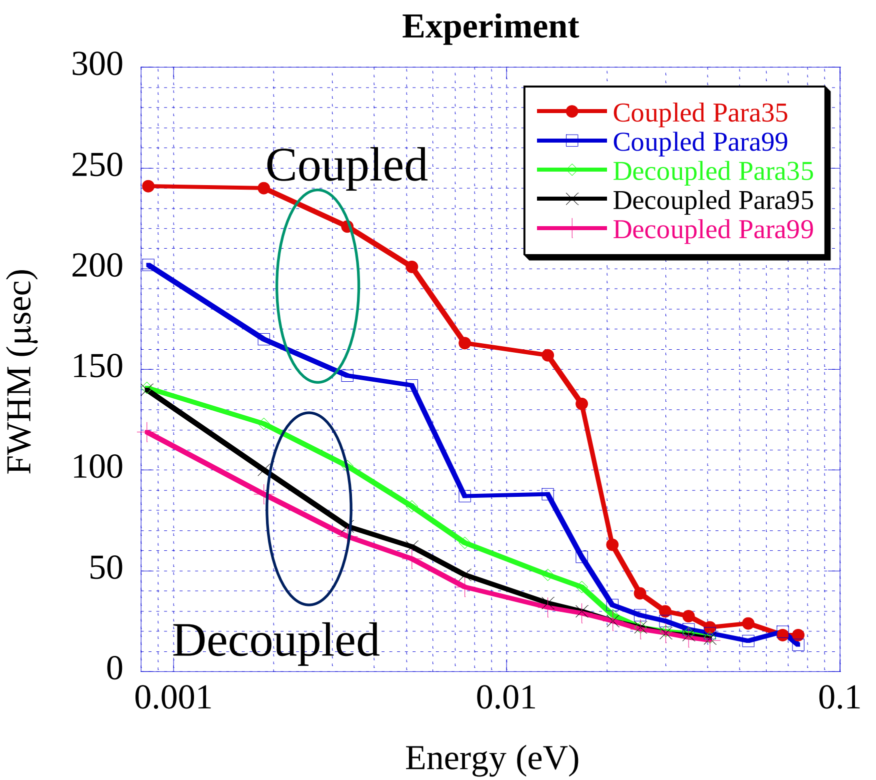
6 times higher intensity than the traditional one, and twice higher than a decoupled methane moderator.

Improvement of pulse shapes by using para-hydrogen

Experimental results @1.8meV



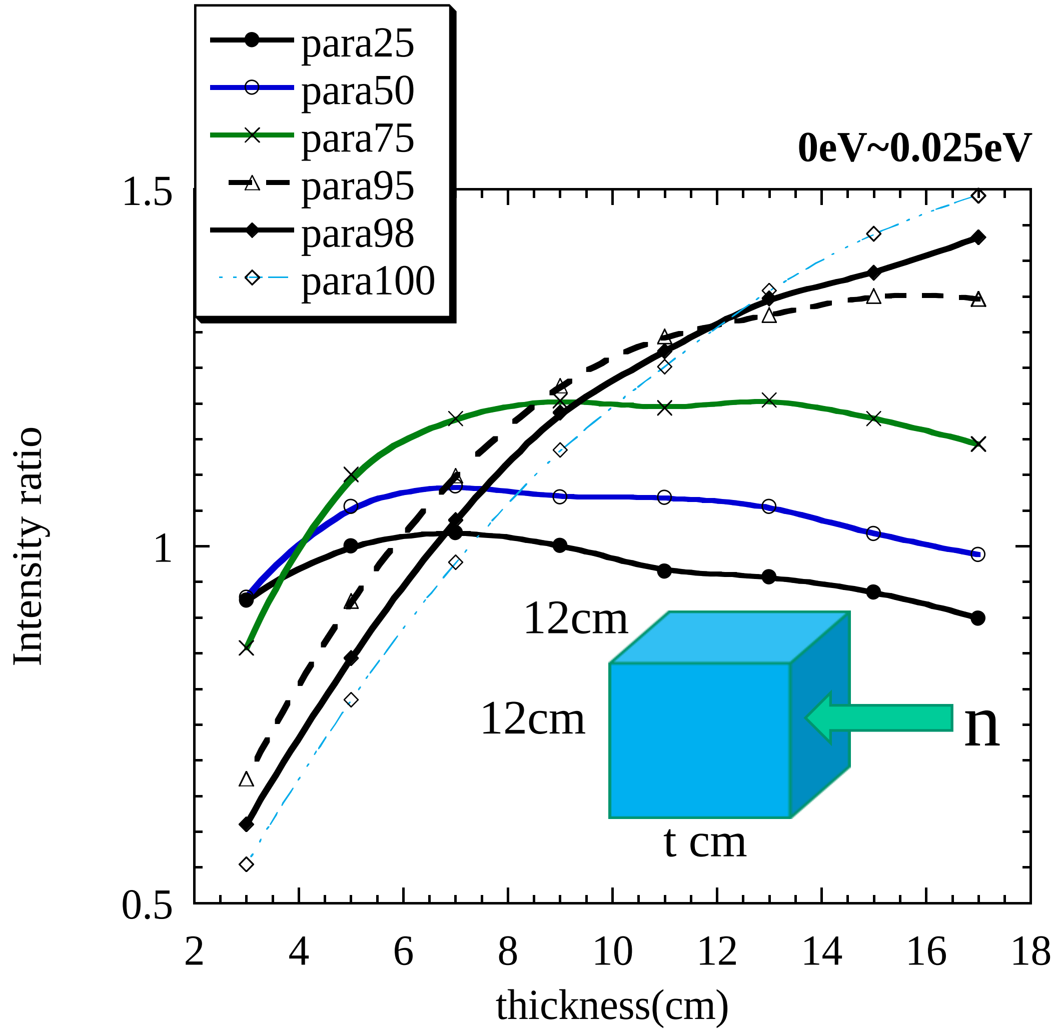




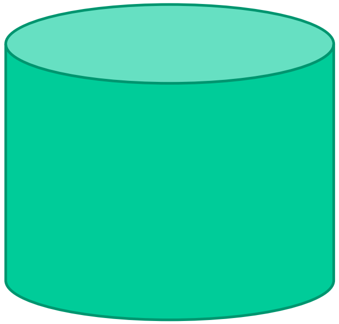
The pulse shapes are improved by using para-hydrogen, and increase of pulse peaks are also observed.

M. Ooi, H. Ogawa, T. Kamiyama, Y. Kianagi, Nucl. Instrum. Meth. A659, pp.61-68, (2011)

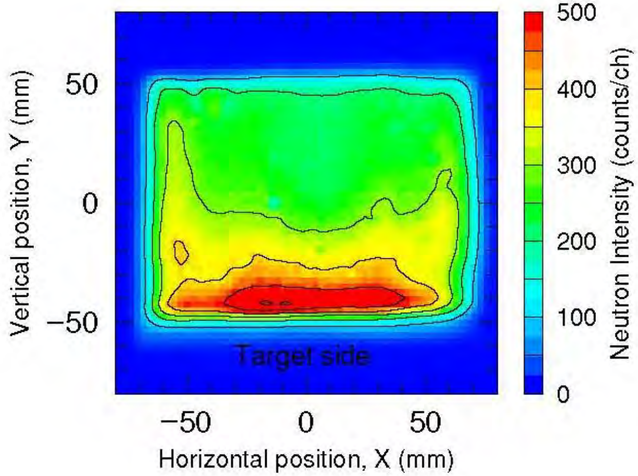
Increase of intensity by using a thick moderator



J-PARC coupled moderator



140 mm diameter x 100 mm height



Horizontal distribution
(measured at Hokkaido U.)

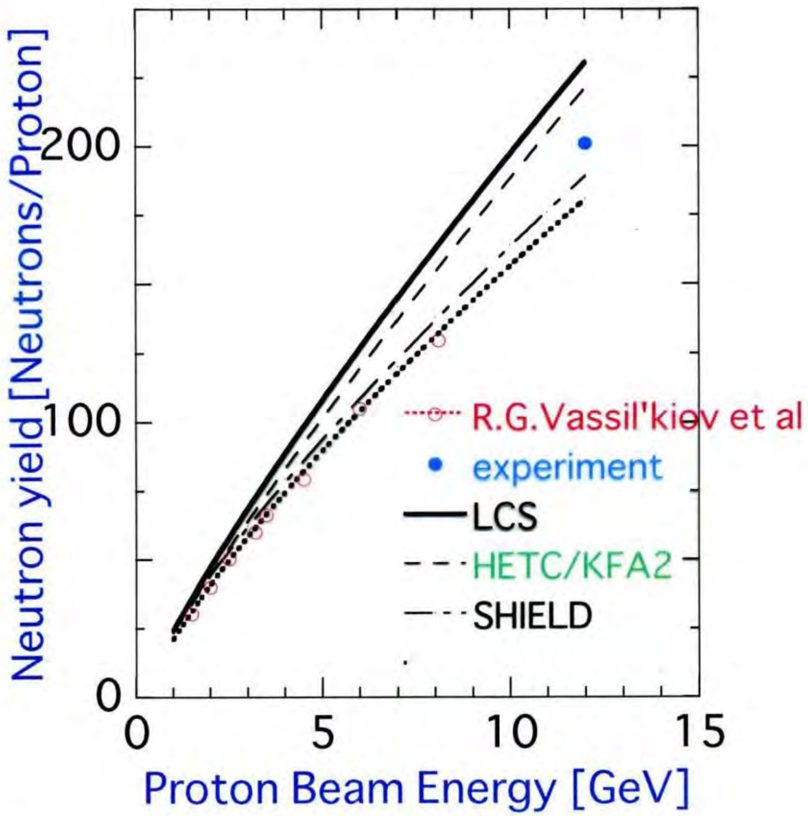
T. Kai, et al., JNST (2017)

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.



Total neutron yield for 20cm diam., 60cm long

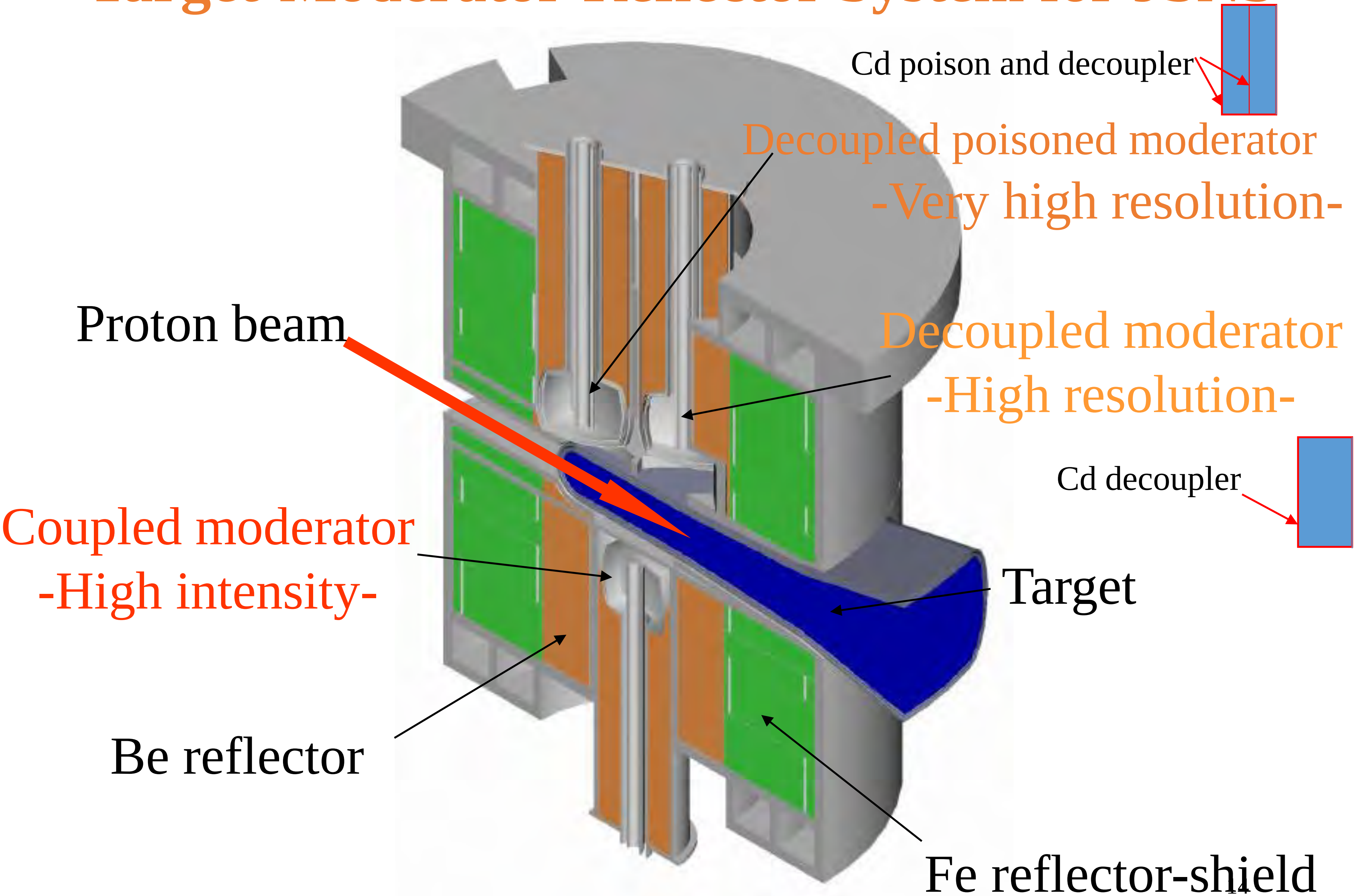
Mn bath experiment

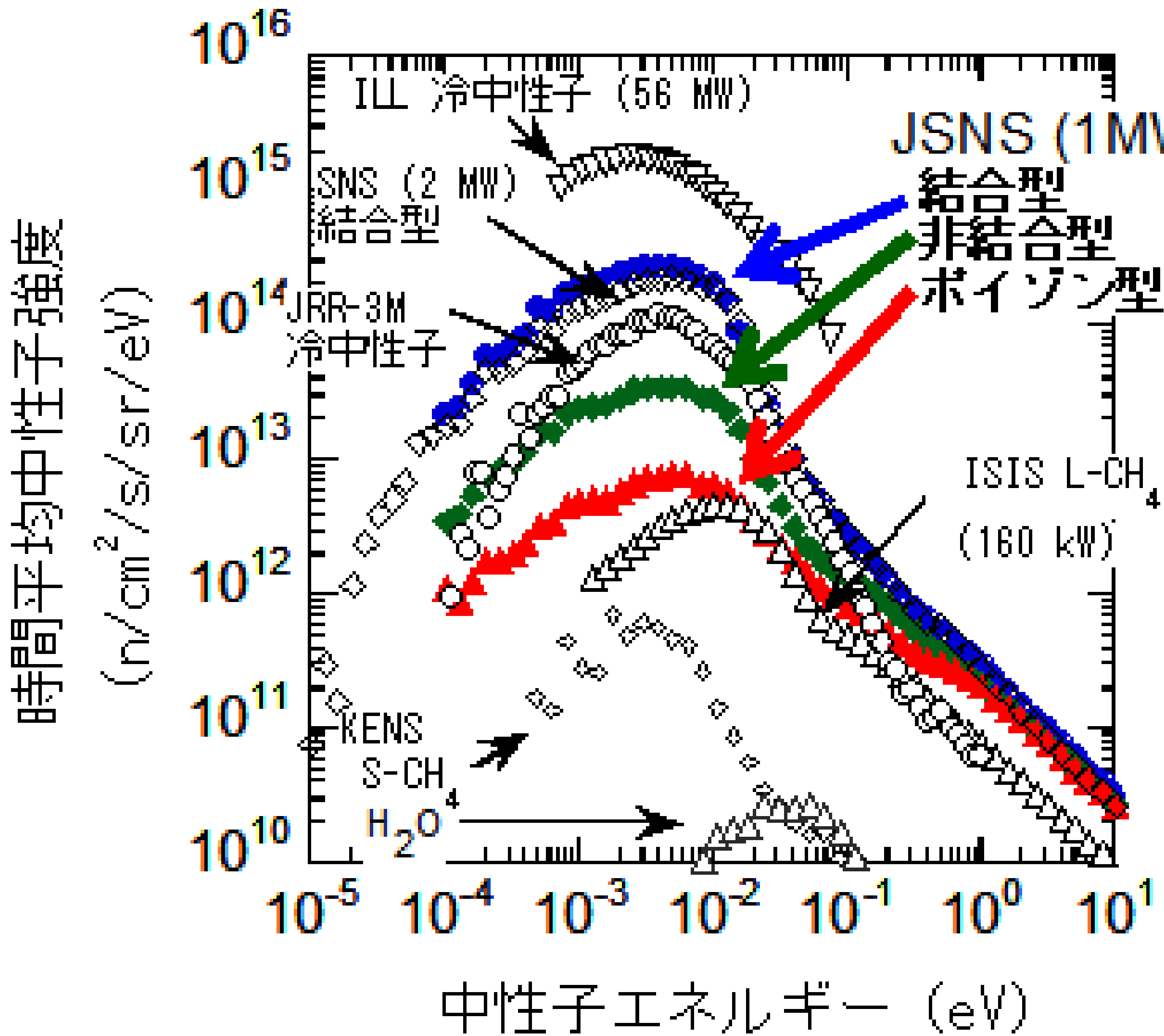
***3GeV was in an allowance level.**

***Target was mercury（G. Bauer)**

M. Arai, Y. Kiyanagi, N. Watanabe, **R. Takagi**, H. Shibazaki, M. Numajiri, S. Itoh, T. Otomo, M. Furusaka, Y. Inamura, Y. Ogawa, Y. Suda and S. Satoh: Neutron Production from Lead Targets for 12-GeV Protons, Journal of Neutron Research, Vol.8, pp.71-83, (1999)

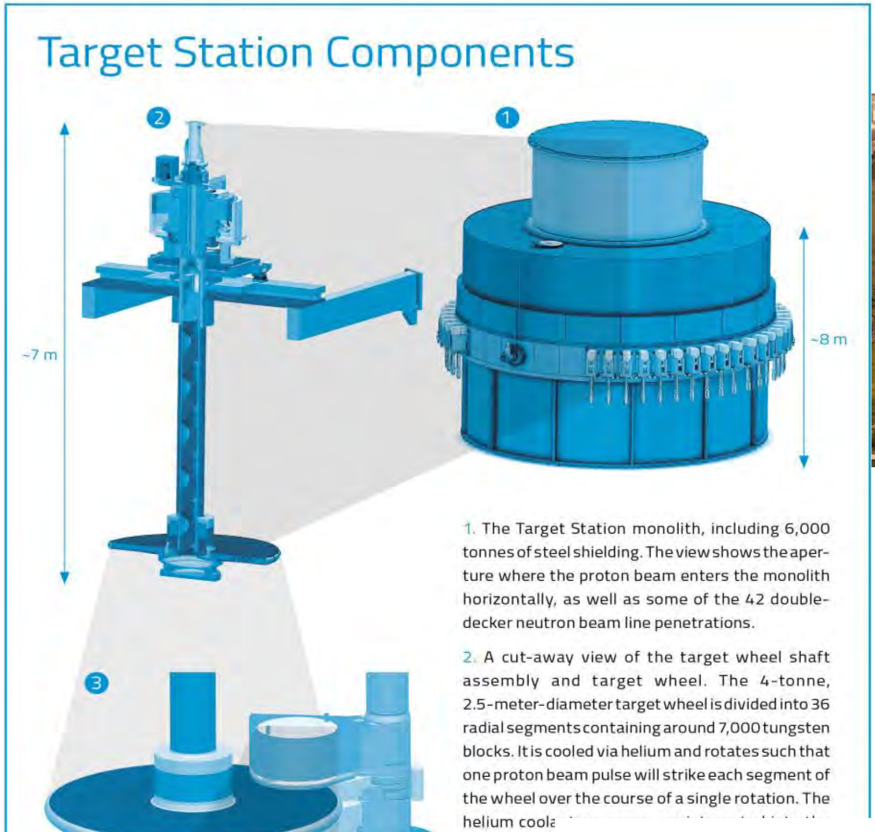
Target-Moderator-Reflector System for JSNS

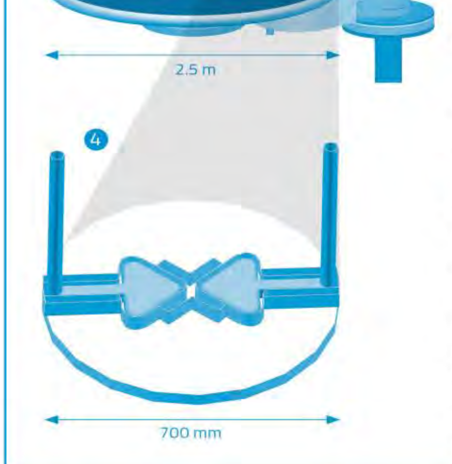




ILL 冷中性子 (56 MW)
JSNS (1MW)
結合型
非結合型
ポイゾン型
SNS (2 MW)
結合型
JRR-3M
冷中性子
ISIS L-CH_4
(160 kW)
KENS
S-CH_4
H_2O
時間平均中性子強度
($n/cm^2/s/sr/eV$)
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
中性子エネルギー (eV)

ESS@LUND





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 coola
shaft, as is t
for the whee

3. The moder
target whee
it. They can b
from the mo

4. The ESS "
the low-pro
within the re
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station will
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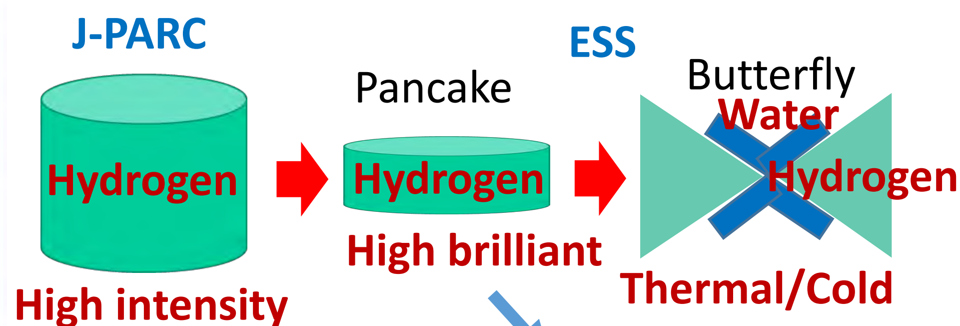
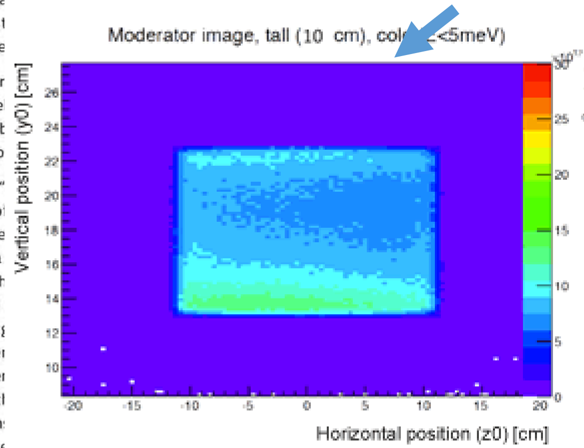
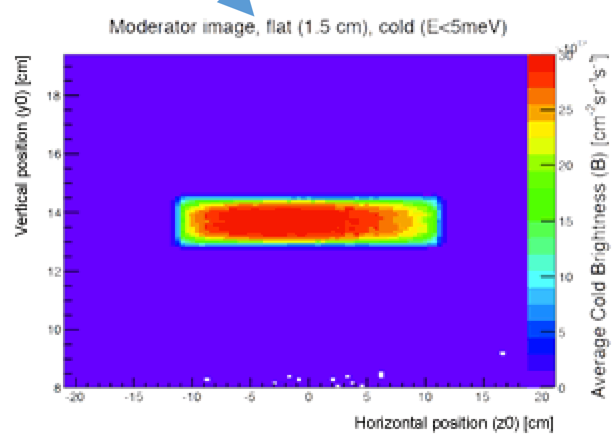
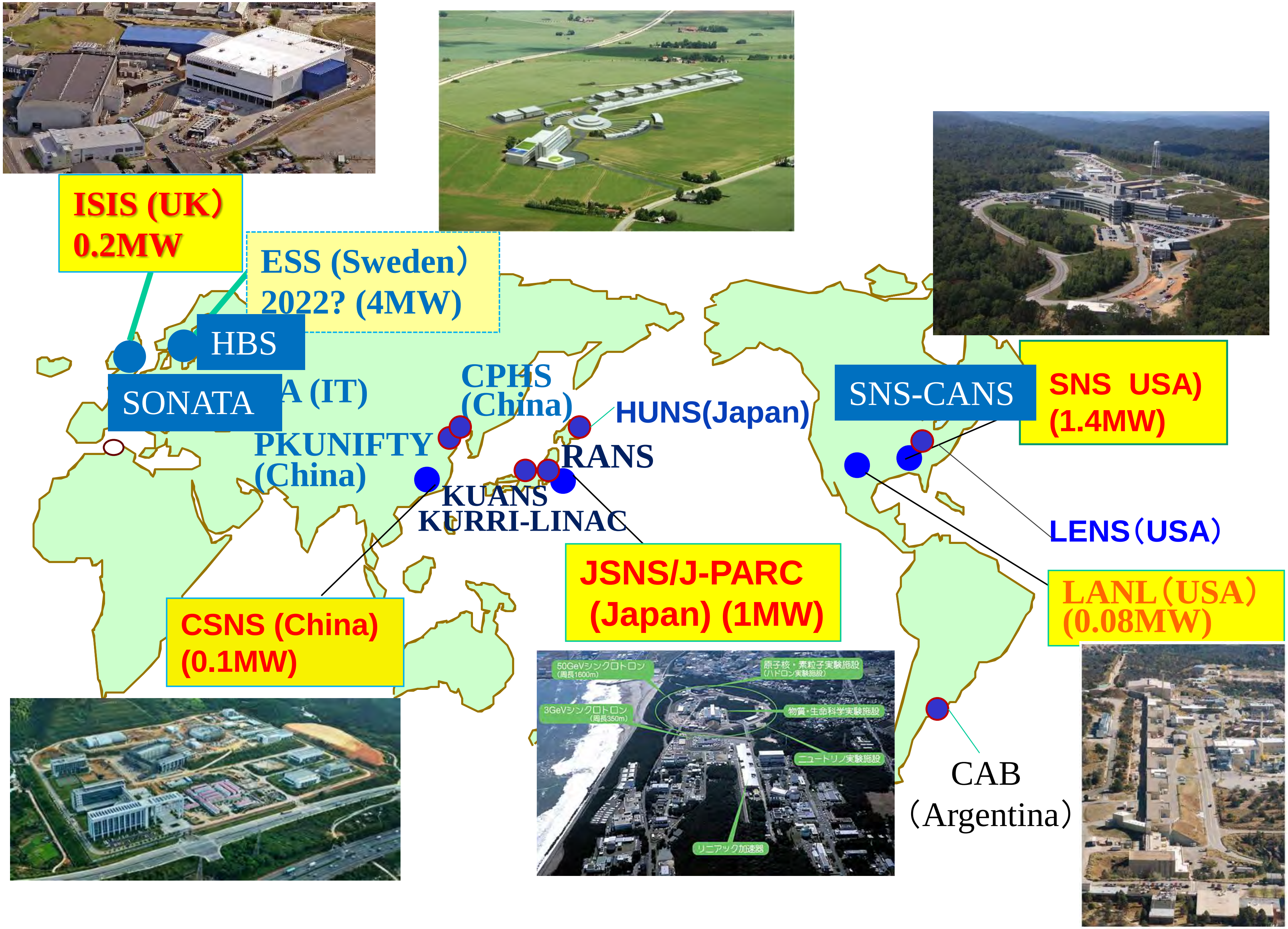






https://ess-public-legacy.esss.se/sites/default/files/target_station_jpg_full.jpg

Accelerator-driven Neutron Sources Worldwide



Neutron Sources in Japan (except for BNCT)

Hokkaid U.

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

Aomori prefecture

Aomori Prefecture Quantum Science Center(20MeV, 50μA)
6.1x10^5 n/sec/cm^2
Thermal neutron

RIKEN

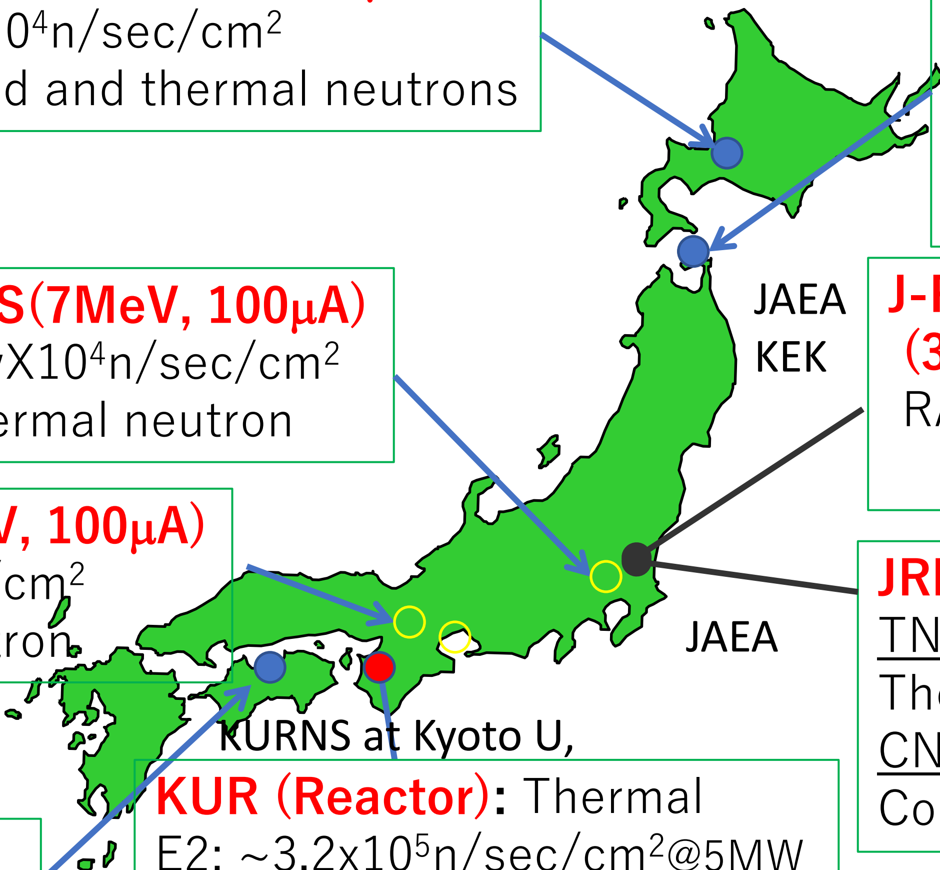
RANS(7MeV, 100μA)
$\sim$fewX10^4 n/sec/cm^2
Thermal neutron

JAEA
KEK

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

Kyoto U.

KUANS (3.5MeV, 100μA)
1.2x10^3 n/sec/cm^2
Thermal neutron



JAEA

JRR-3 (Reactor)
TNRF: $\sim 10^8$ n/sec/cm^2
Thermal neutron
CNRF: $\sim 10^7$ n/sec/cm^2
Cold neutron

KURNS at Kyoto U,

KUR (Reactor): Thermal
E2: ~ 3.2x10^5 n/sec/cm^2@5MW
B4: ~ 5x10^7 n/sec/cm^2@5MW

SUMITOMO

SHI-ATEX (18MeV, 20μA)
~ 2x10^5 n/sec/cm^2
Thermal neutron

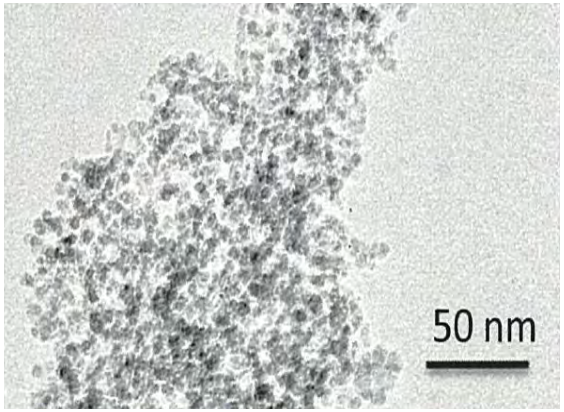
AIST **AISTANS**

KURNS LINAC: Thermal
2.3x10^4 n/sec/cm^2@100μA

KURNS Linac

Reflector for cold and very cold neutron source

Nano diamond



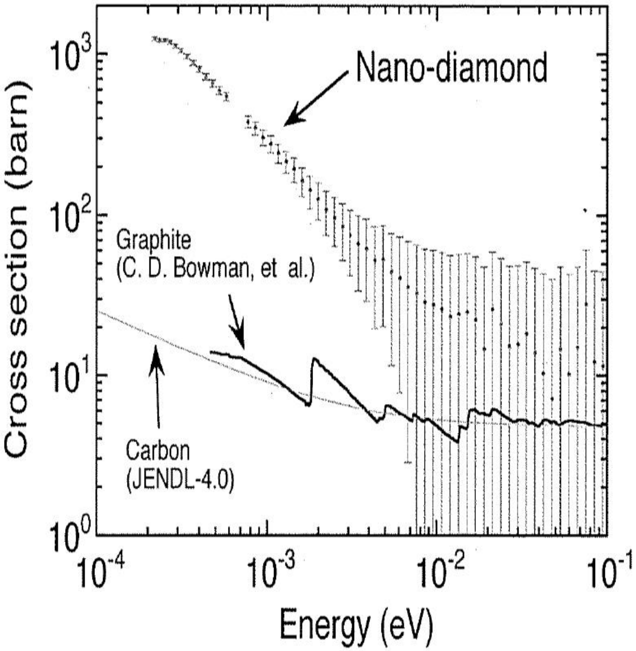


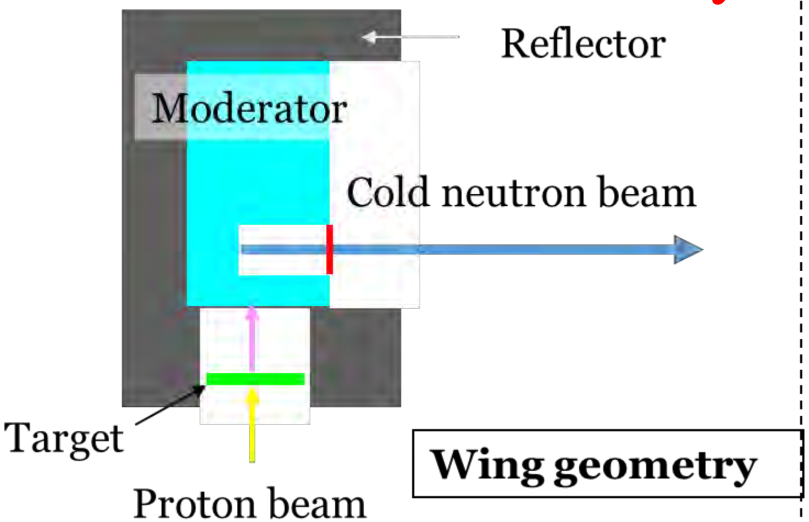
Fig. 8 Total cross sections of nano-diamond. Cross section of carbon (JENDL-4.0, [21]) and graphite (C. D. Bowman et al., [22]) are shown for comparison

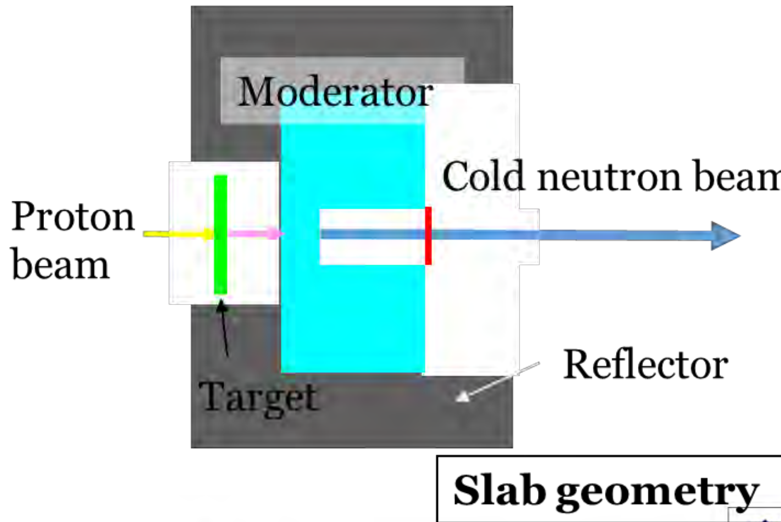
M. Teshigawara et al., NIM A Vol. 929 (2019) P. 113-120

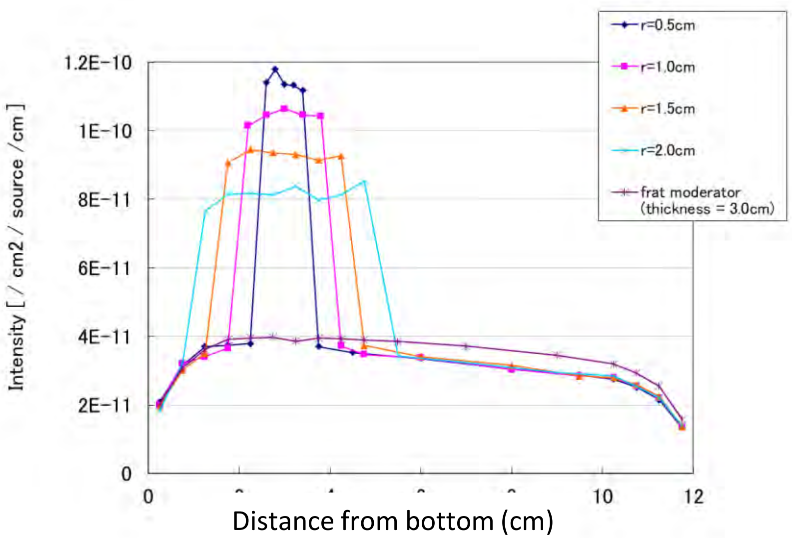
Moderator with a re-entrant hole

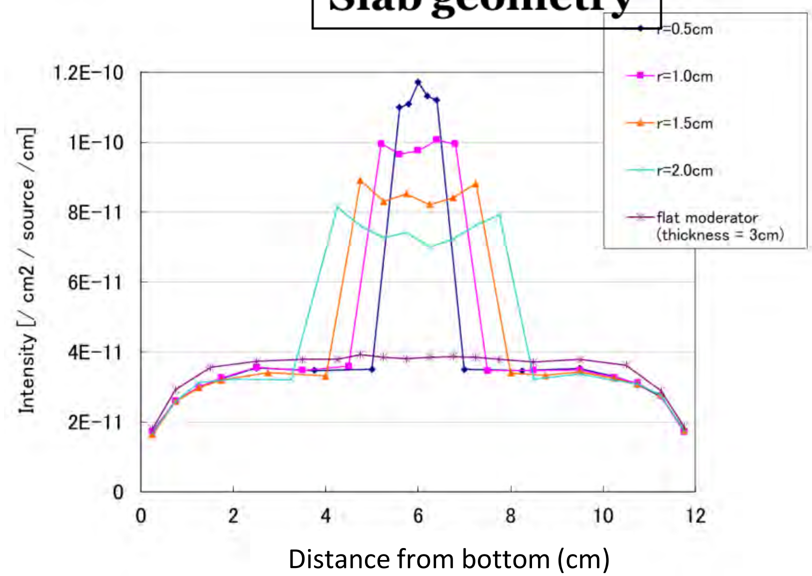
＊Intensity increase in a hole (for mfSANS, for example)

＊Simulation for a mesitylene moderator







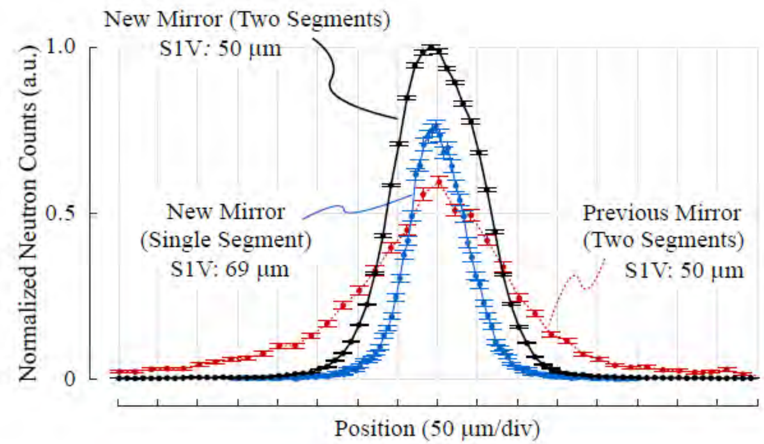


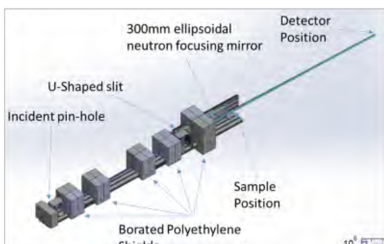
Simulations at Hokkaido University

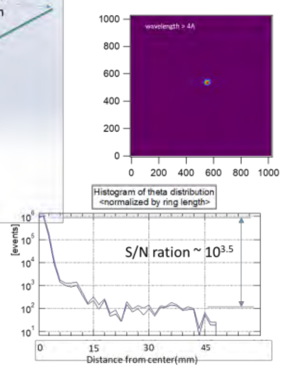
Neutron Focusing Mirror using a metal base

It can be placed near the moderator

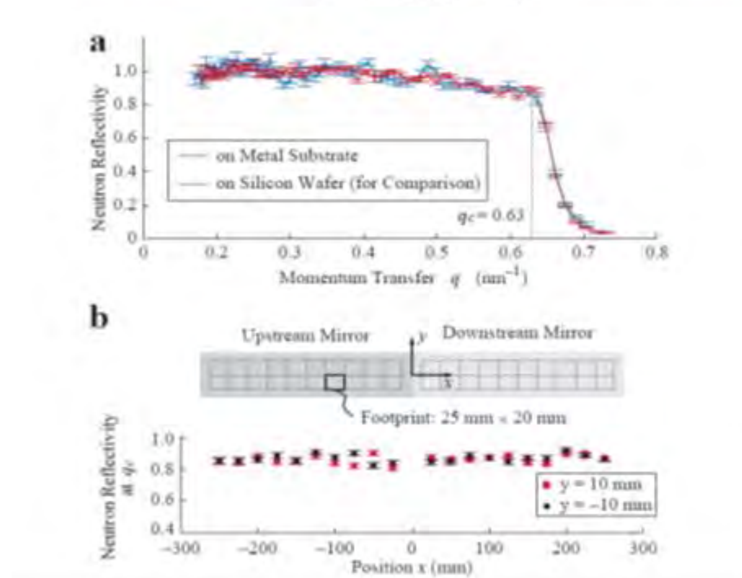
A fully-revolved 900mm ellipsoidal neutron focusing mirror for J-PARC BL-06 VIN ROSE







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

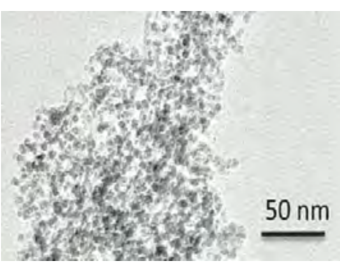
Beam transport

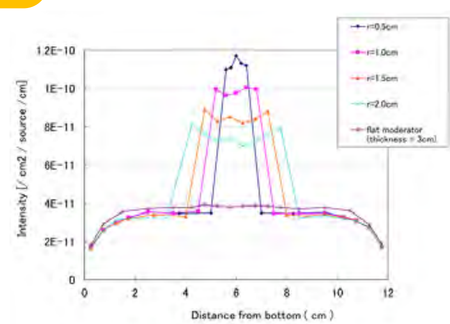
Compact
High Performance

Instrument

Detector

High Performance





Summary

- 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.