理研小型中性子源RANSにおける冷中性子源と集光ミラー開発

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講演概要

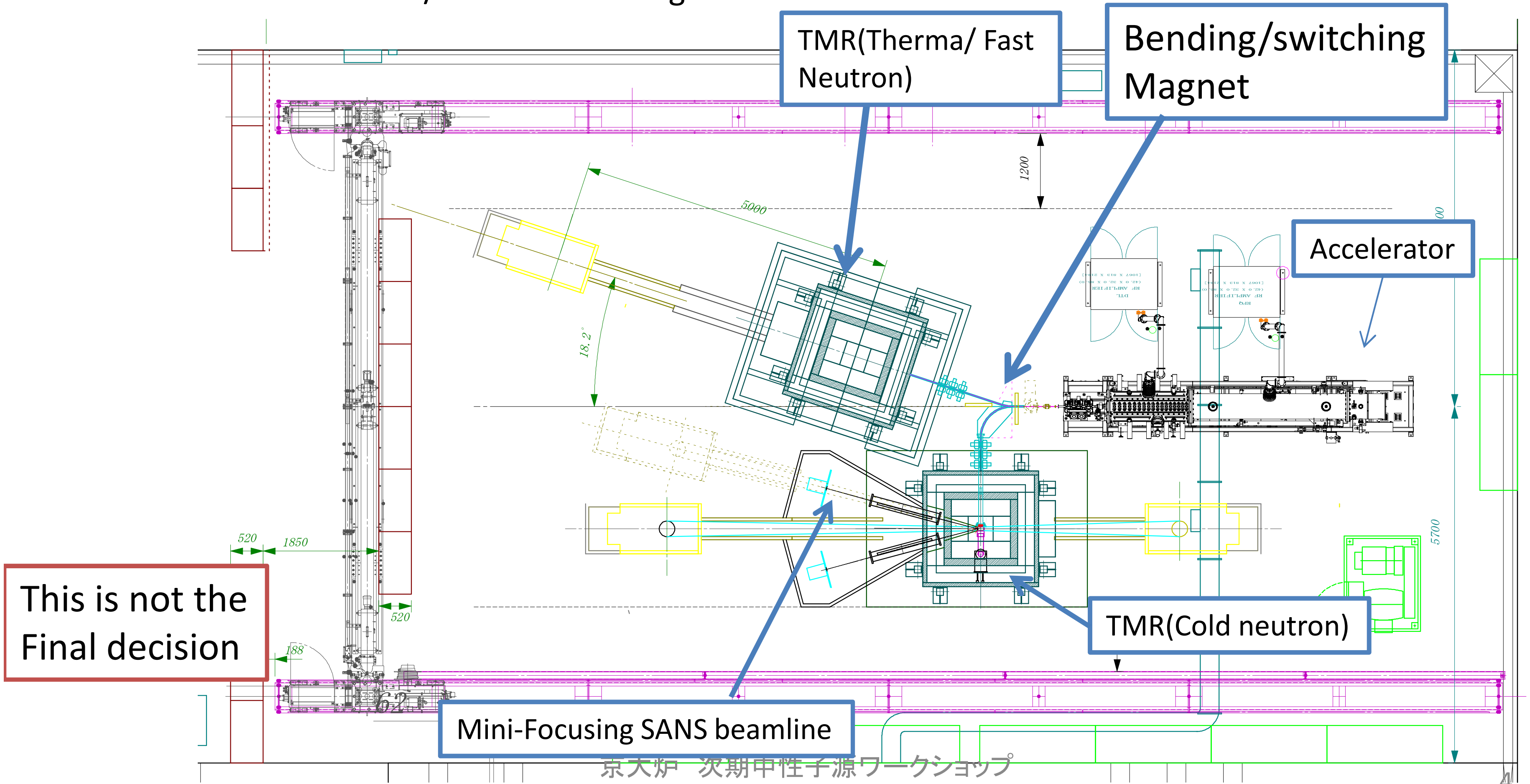
- （理研小型中性子源RANSの現状）
- 冷中性子源開発の現状
- 中性子集光光学素子開発

Cold Neutron Source development for Compact Accelerator-driven Neutron Sources

- Cold neutron beam has important applications in industries like SANS.
- Liquid para-H_2 or solid methane are known to have good performance in cold neutron generation, but they are explosive gases.
- Easy-to-use cold neutron source is preferable for compact neutron source.
- Methyl benzene derivatives are known to have relatively good performance as cold moderator, but performance improvements are necessary.

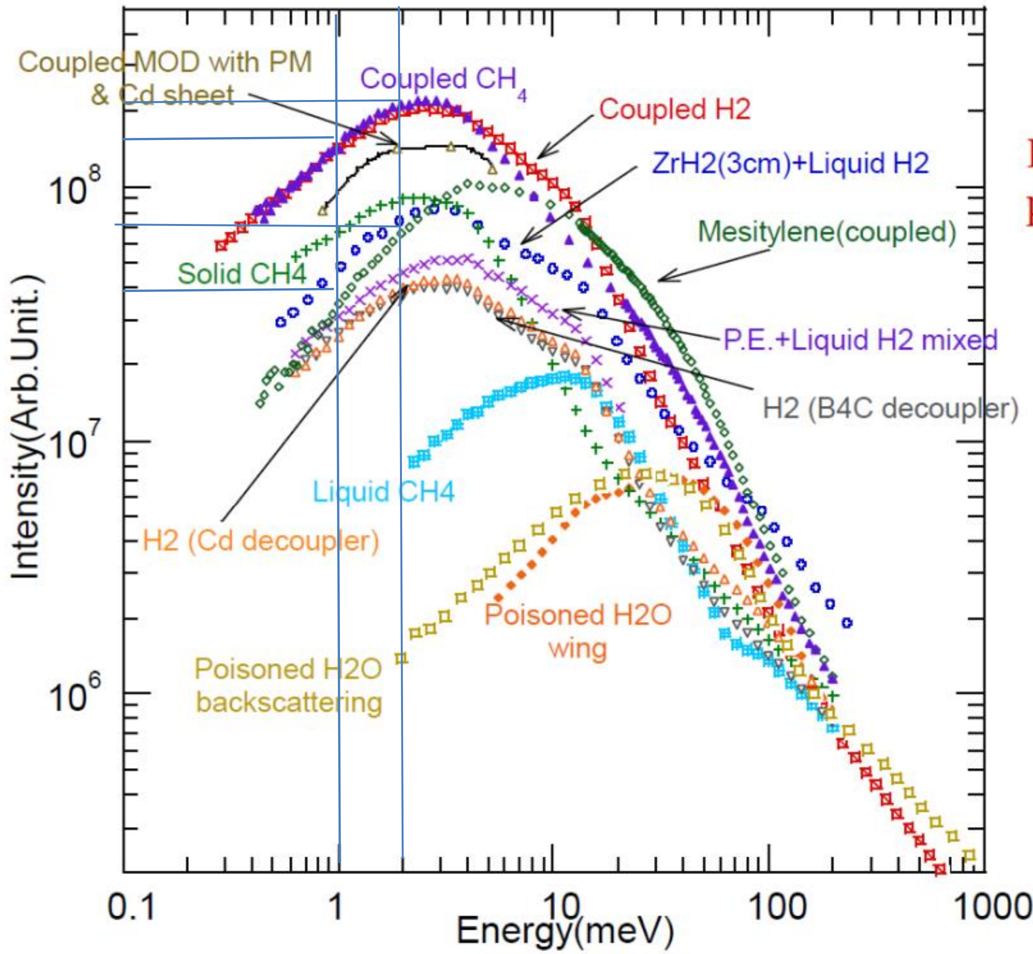
Outline of plans for RANS Phase-II

- Cold neutron target station will be constructed
- Neutron scattering beamline including mf-SANS(mini focusing Small angle neutron scattering)
- Mesitylene-based cold moderator
- Thermal/Fast neutron target station will be maintained

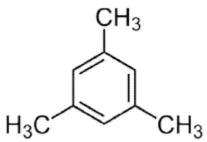


Cold neutron moderator materials

- Solid Methane(CH4): best material for cold moderator with high flux of low energy neutrons. Explosive Gas.
- Para Liquid H2: almost same performance as CH4: explosive Gas
- Mesitylene: neutron flux at 1meV(9A) is about 1/5 of solid CH4. Burnable liquid. Good radiation resistance.
- Mesitylene seems to be good material for compact neutron source, but improvement in low energy neutron flux is required.



H_2: 35% para

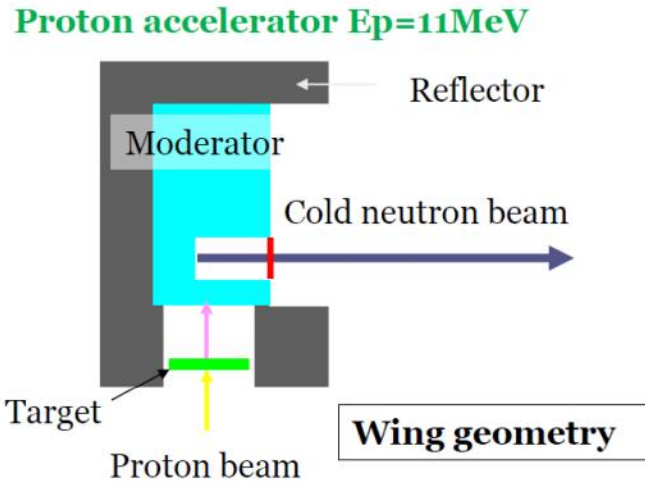


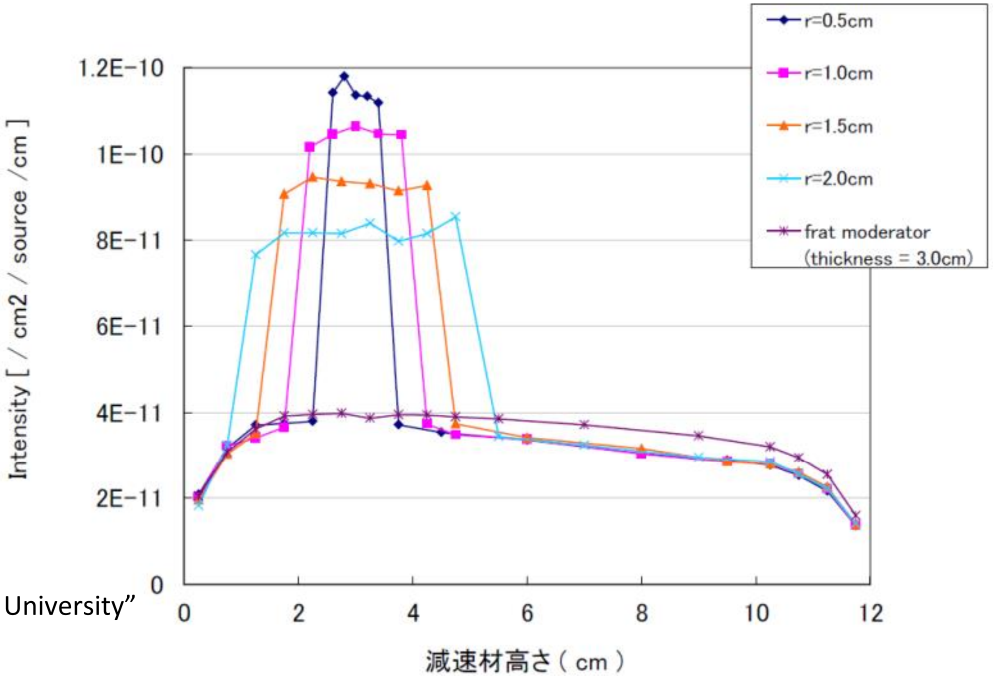
Mesitylene

Cold neutron spectrum with various moderator materials

Y.Kiyanagi, “Review of Grooved Moderator Study at Hokkaido University”
IAEA meeting 2011 Nov. より

Effect of grooved moderator





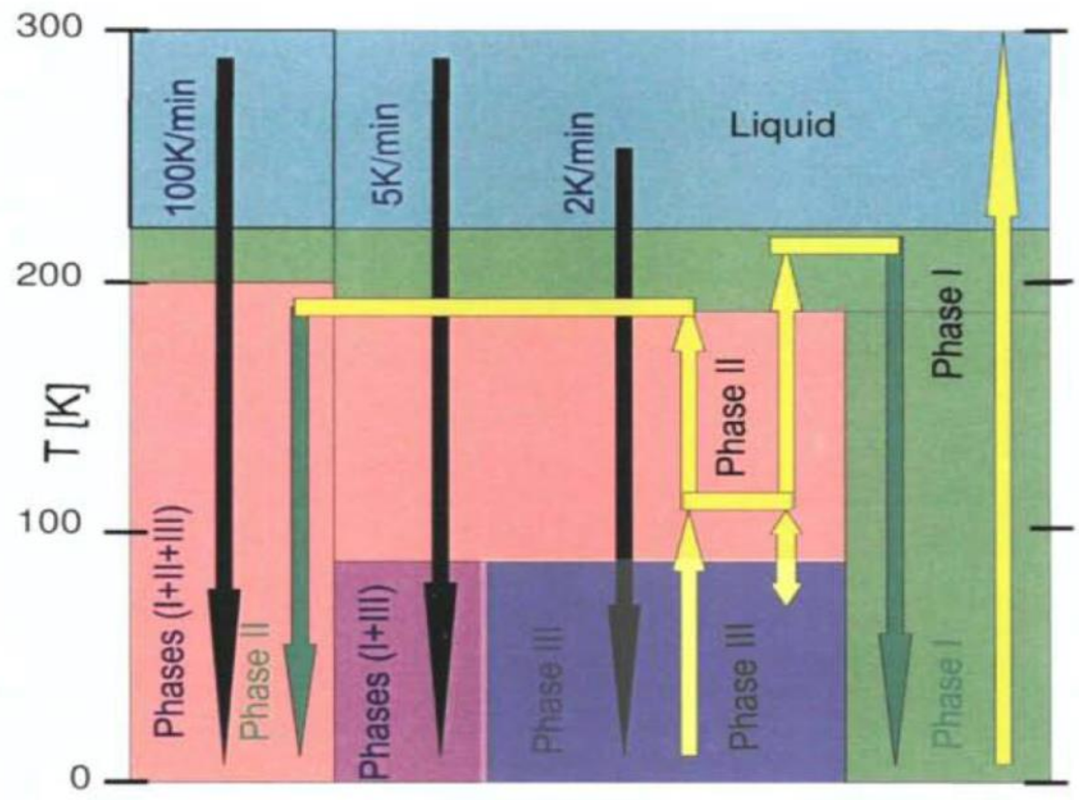
Y.Kiyanagi, "Review of Grooved Moderator Study at Hokkaido University"
IAEA meeting 2011 Nov. より

Cold neutron flux can be increased by the factor of 3 using groove(?)

Detailed study using Mesitylene based cold neutron moderator is necessary.

Cooling characteristics of mesitylene

- Mesitylene is know to have three different solid phase (I,II,III)
- Phase I is generated by annealing above 200K for several hours
- Phase I is expected to show better performance in low energy neutrons



I.Natkaniec et al. , ACoM Meeting Prceedings (2002)

Also, mixture of metyl-benzene derivatives such as 3:1 mixture of mesitylene and m-xylene is reported to make glassy solid regardress of cooling speed, which will be preferable for cold neutron moderator.
I.Natkaniec et al., Physica B 350(2004) e651-653

Radiation damage

Preliminary

- 放射線による減速体の分解・水素発生
  - 固体メタン(10^{12}n/cm^2/s)では、数か月で交換？
  - メシチレンは、水素生成量が固体メタンの1/80、m-xylene+mesitylene(1:3)は、水素生成量が1/180とされている。

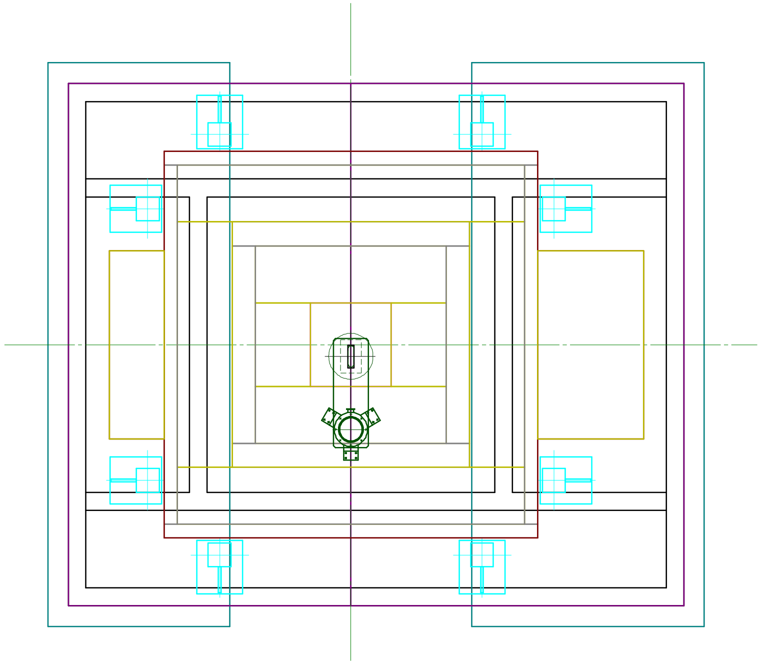
- 放射線分解による水素発生量
  - 固体メタン：　6x10^{-7}mol/J (dose <1kJ/g)
  - メシチレン: 3.9x10^{-8} mol/J
  - メシチレン＋トルエン（１：１）：　1.8x10^{-8} mol/J
  - メシチレン＋m-xyxlene (3:1):　3.3x10^{-9}mo/J(?)

出典：E.P.Shablin, “Pelletized Cold neutron moderators for the IBR-2M reactor”, UCN&CN Physics and Sources, (2007)

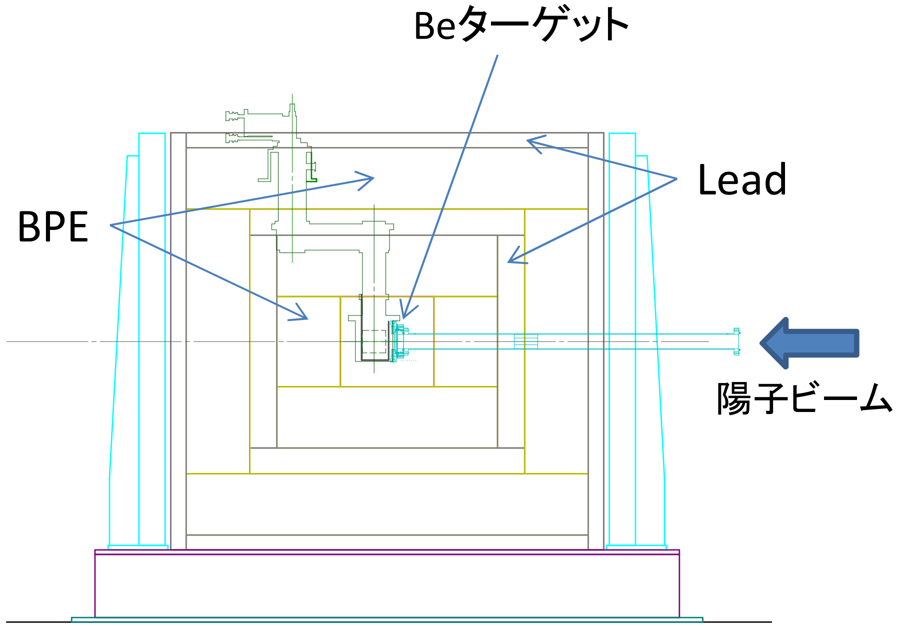
- 仮に、RANS ターゲット付近の放射線量を500Gy/h １年間の運転時間を2000時間とすると、水素ガスの生成量は、1kgあたり3x10^{-3} mol, 標準状態で73mLとなる。このため、モデレータ容器内に、40mL程度の空洞を設けておけば、圧力上昇は2気圧程度に抑えることが可能で、完全密閉型が実現可能？

詳細検討必要

RANS ターゲットステーションへの実装



上面図



側面図

- L字型の冷熱伝達バーにより中性子線の遮蔽性能を向上させる。
- GMクライオクーラーの放射化を防止する。
- ターゲット近傍の長寿命放射化物を最小限に抑える。

Cold neutron source development at RIKEN

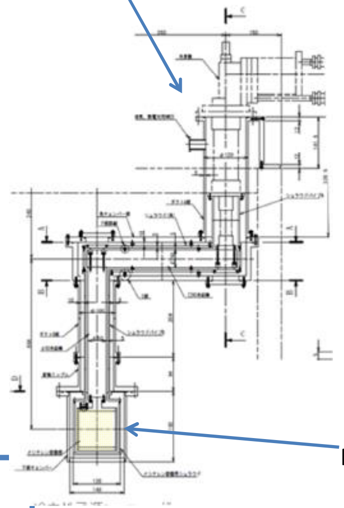
Preliminary

GM cycle He cryo cooler

Stand for Test experiments

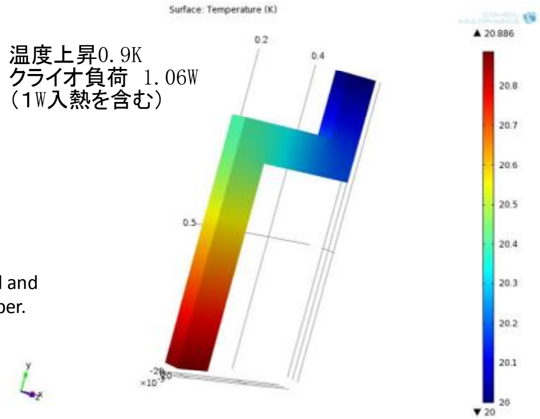
Moderator cavity (Mesitylene)

Closed cycle GM cryocooler



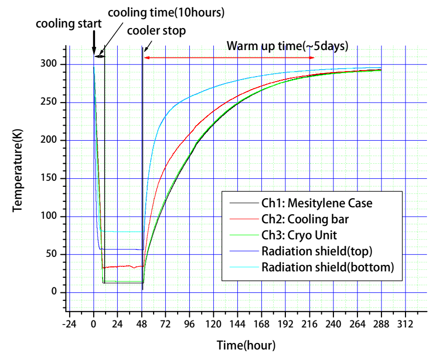
Cooling bar, radiationshield and vacuum chamber.

Moderator （Mesitylene casing)



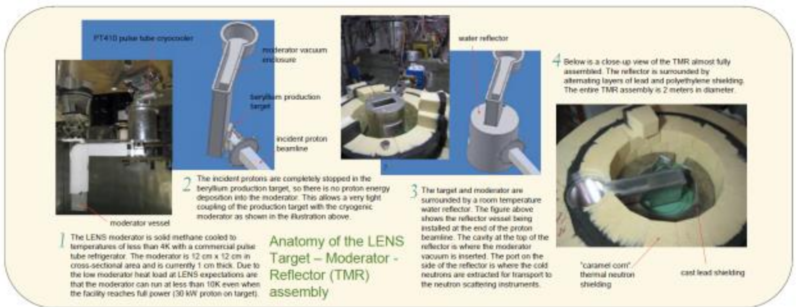
Cooling simulation by FEM

冷却テスト



到達温度約12K（メシチレン容器底部）

常温→12K: 約10時間
12K→常温：約5日間

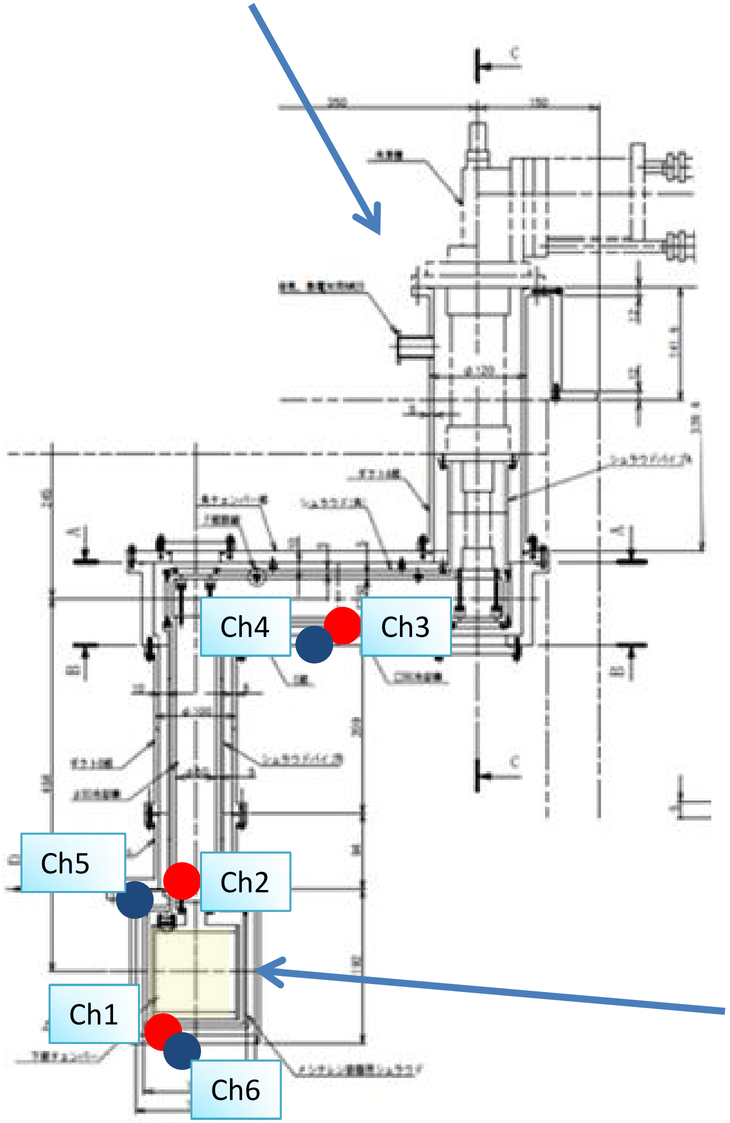


Developments are Made following the Indiana University LENS

Temperature sensors

- Common cold temperature sensor such as silicon diode may be damaged by radiation by neutrons.
- Negative resistance germanium sensor (cernox form Lake shore) and platinum resistance sensor is used for monitoring temperature, which is resistant to radiation damage.
- 3 sensors of each kind are place on the top and bottom of the moderator case. Cernox sensor is used for monitoring 2nd stage, platinum sensor is used for 1st stage.

Closed cycle GM cryocooler



Cooling bar, radiationshield and vacuum chamber.

Moderator (Mesitylene casing)

● Cernox sensor: 1.4K-350K Ch1-Ch3

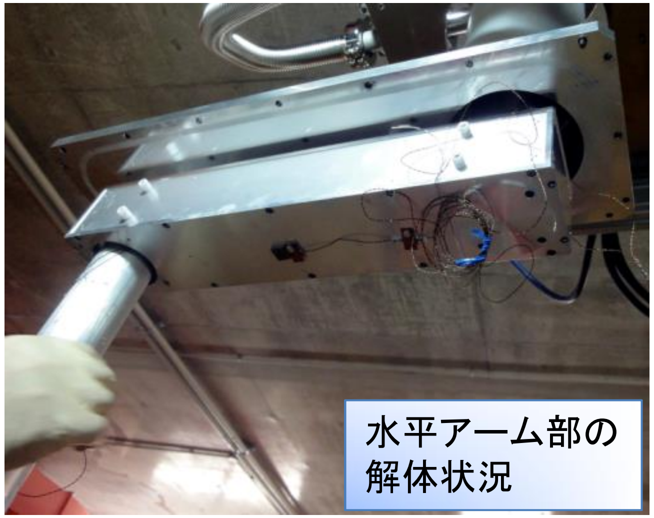
● Platinum sensor 30K-600K Ch4-Ch6

Structure of cooling chamber

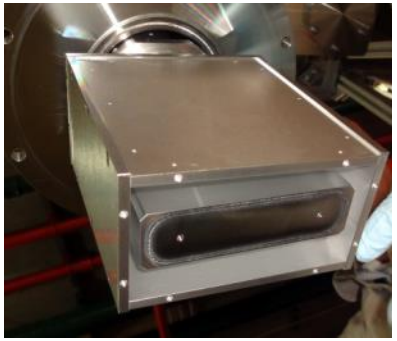
メシチレン容器外観

注入口

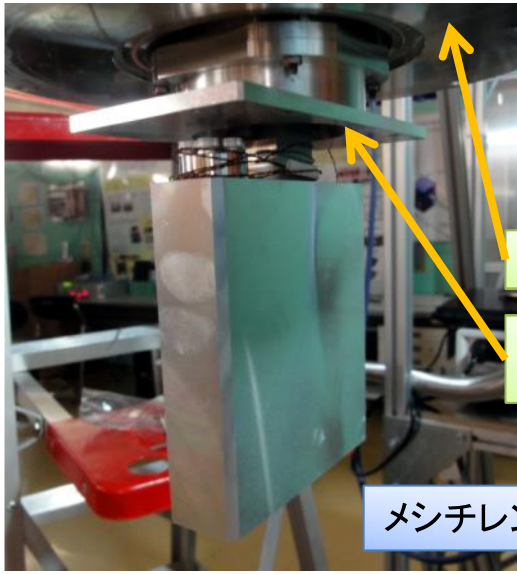
フランジとアルミガスケット



水平アーム部の解体状況



メシチレン容器底部
（ラディエーションシールドの底を開けたところ）

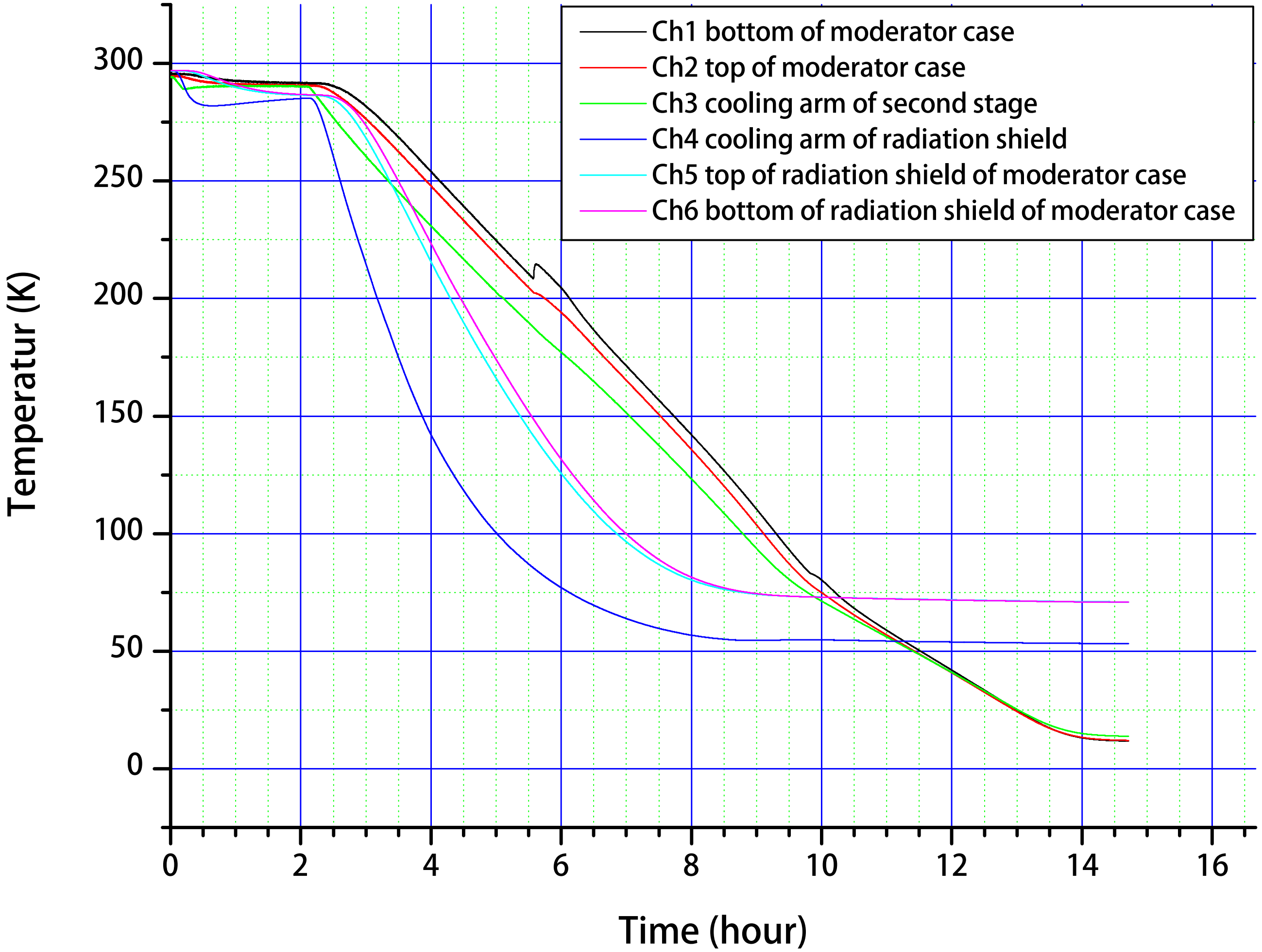


真空容器フランジ

ラディエーションシールド上部フランジ

メシチレン容器の取り付け状況

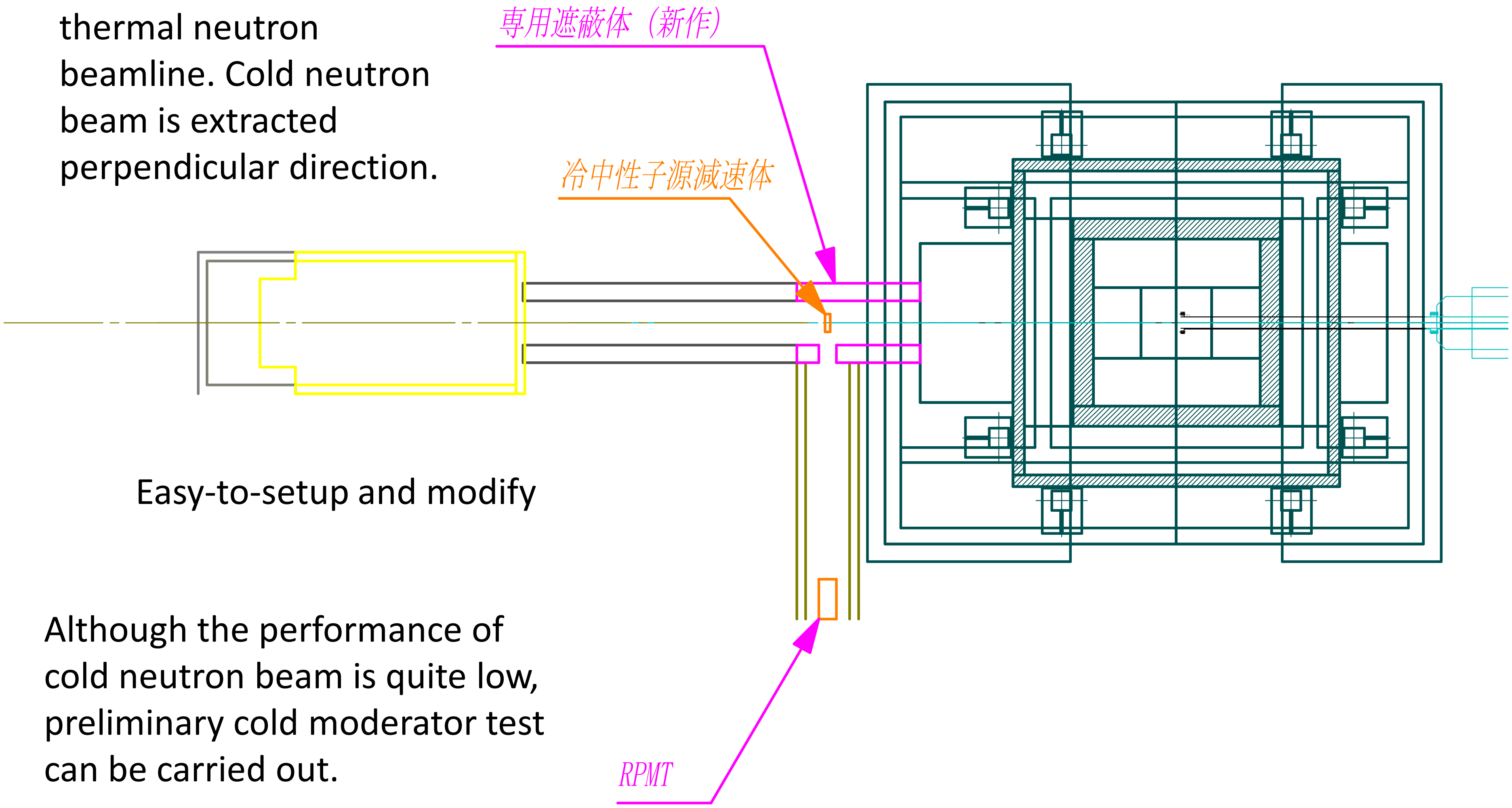
Cooling characteristics



- Temperature difference of ch4 and ch5/6 is due to radiation heating from 300K, which coincides with FEM simulation result (about 20K).
- Temperature rise at 2nd stage by radiation heating is less than 1K, which again coincides with FEM simulation result.

Cold neutron source test at RANS

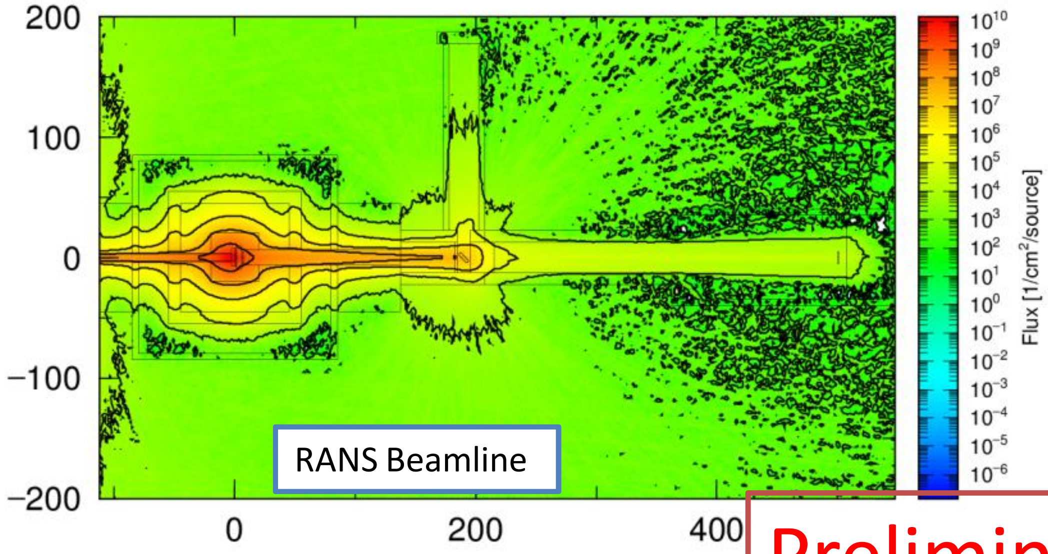
Cold neutron moderator is placed at the exit of thermal neutron beamline. Cold neutron beam is extracted perpendicular direction.

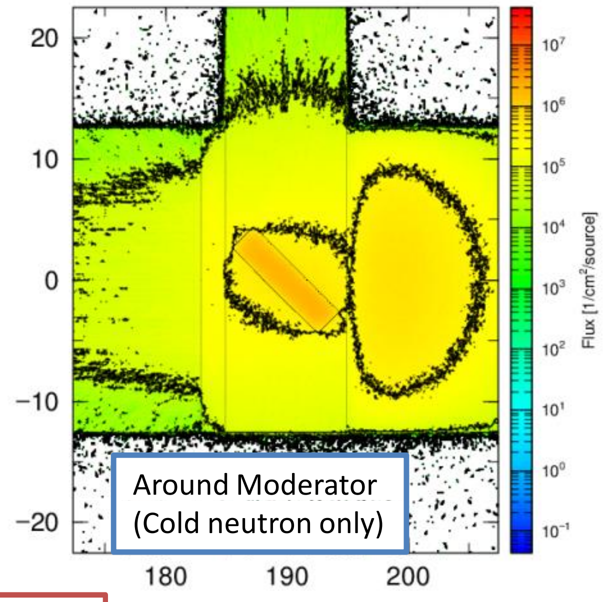


Easy-to-setup and modify

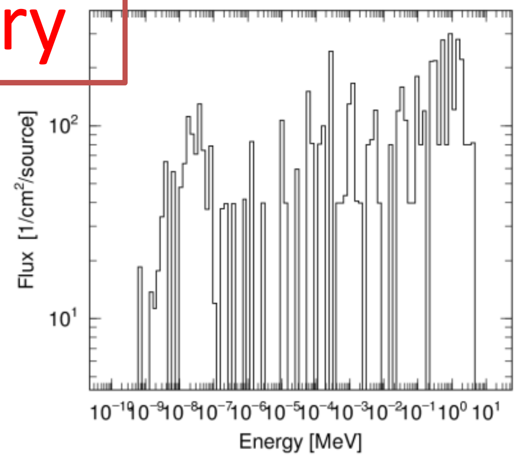
Although the performance of cold neutron beam is quite low, preliminary cold moderator test can be carried out.

Neutronic simulation by PHITS code (Preliminary experiments at RANS)





Preliminary



Energy distribution at detector

・Cold moderator test simulation using RANS configuration data.

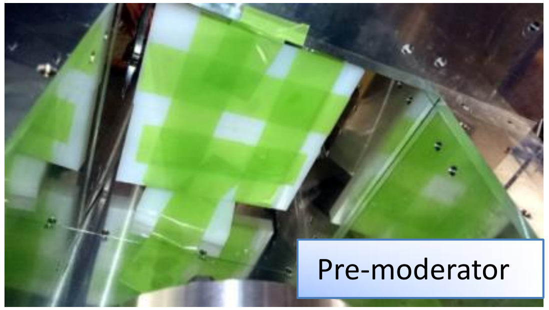
・Mesitylene Scattering Kernel(20K)was provided by Prof. Kiyanagi and Dr. Granada

・Cold neutron yield is expected to be $1.5\times10^2 n/cm^2/s$ at 100uA

•Simulation still need to be verified.

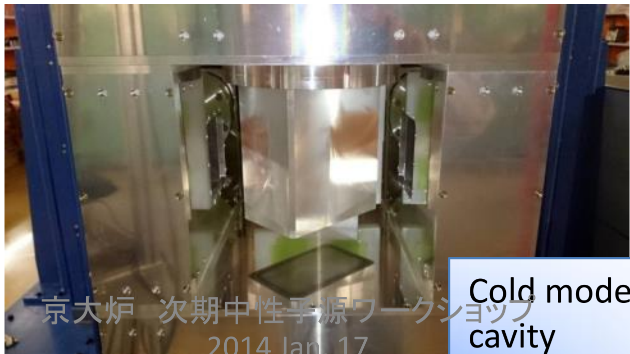
Experimental setup

Experiment at RANS beamline

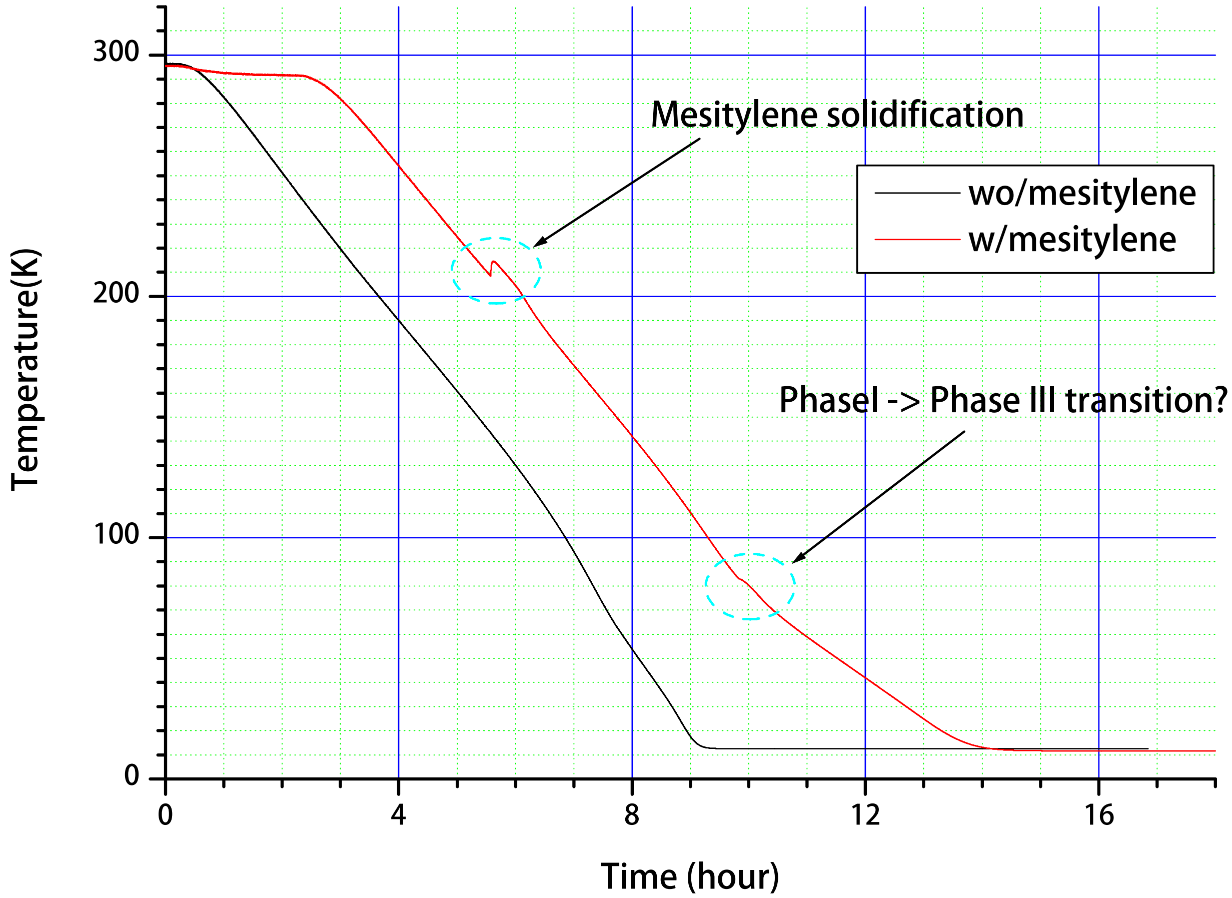

Pre-moderator


Cold moderator setup construction


Completed setup

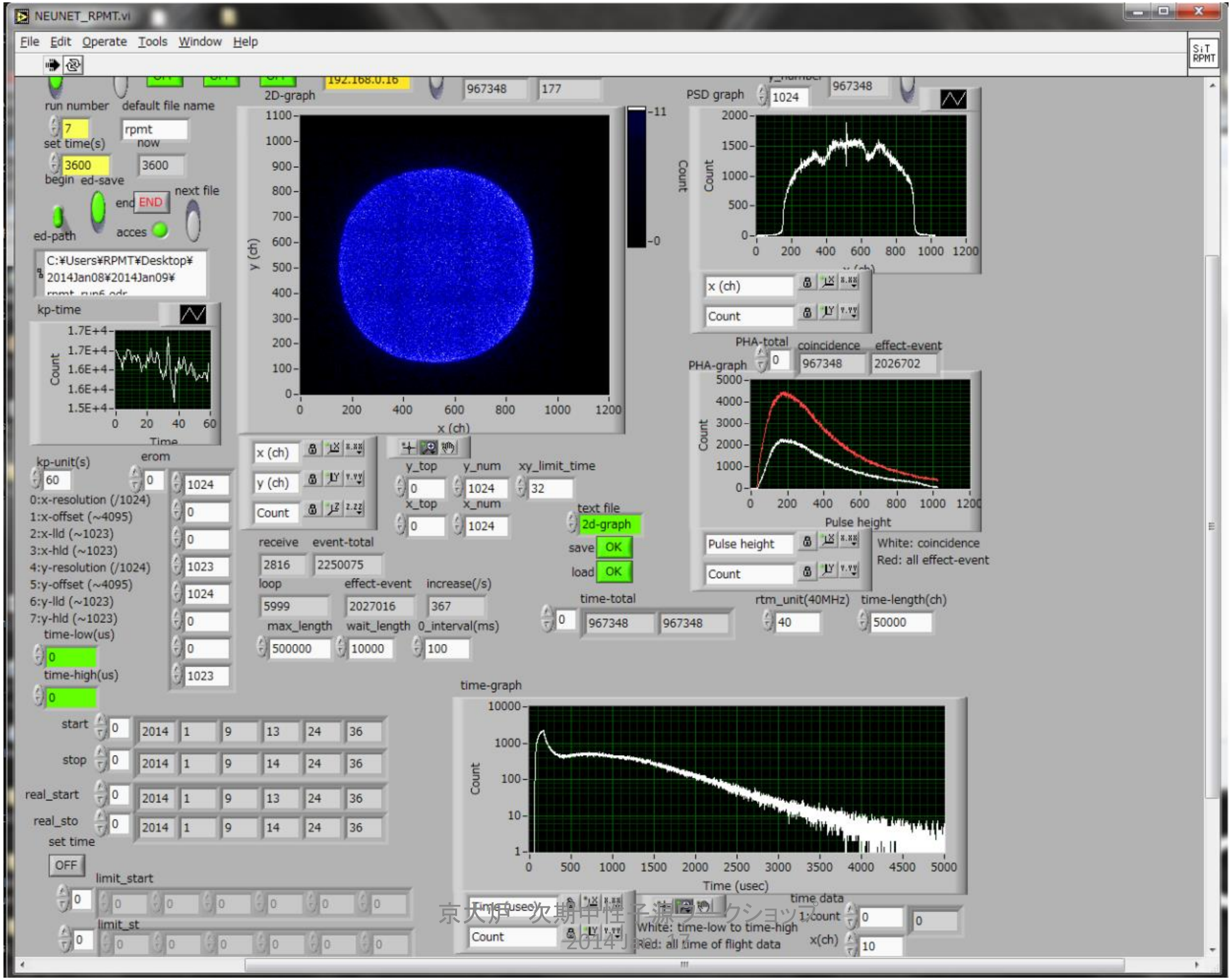

Cold moderator cavity

Cooling of mesitylene



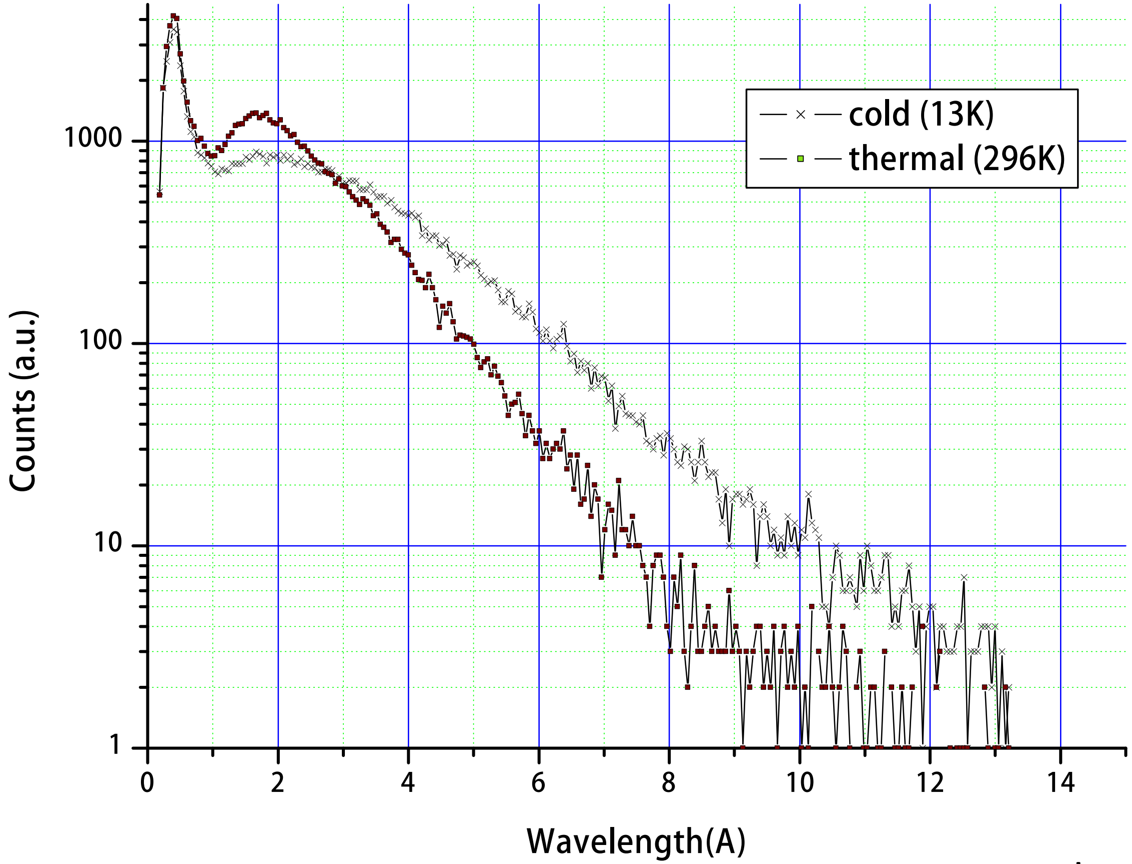
•Cool down from ambient temperature takes about 10 hours
•Temperature change due to Mesitylene solidification and phase change are observed.
•Cool down speed is about 0.4K/min. Final product is estimated to be phase III.

Measurement by RPMT



Experimental result

Preliminary



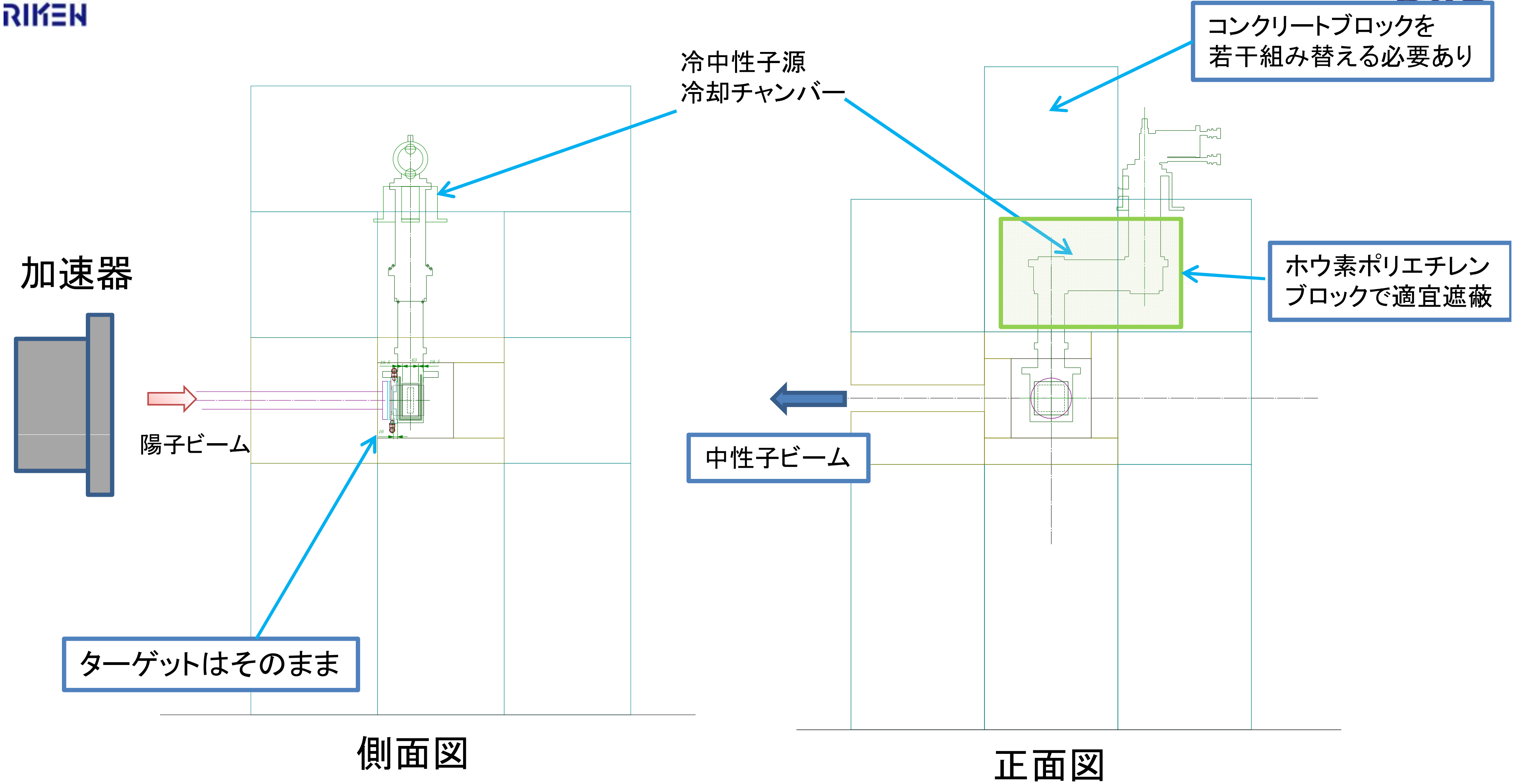
Beam current:
20uA (avr)
8mA(peak)
100us pulse width
20Hz rep. cycle
3600sec

Using RPMT detector
^{6}LiF+ZnS(Ag) 0.4mm

Total cold neutrons (0.5-5meV)
13K: 7.6x10^{4} n (0.42n/cm^{2}/s)?
296K : 2.6x10^{4}n (0.14n/cm^{2}/s)

- Energy distribution is compared by TOF
- Mesitylene temperature 296K and 13K
- There were x1.8 gain at 4A, x6 gain at 8A

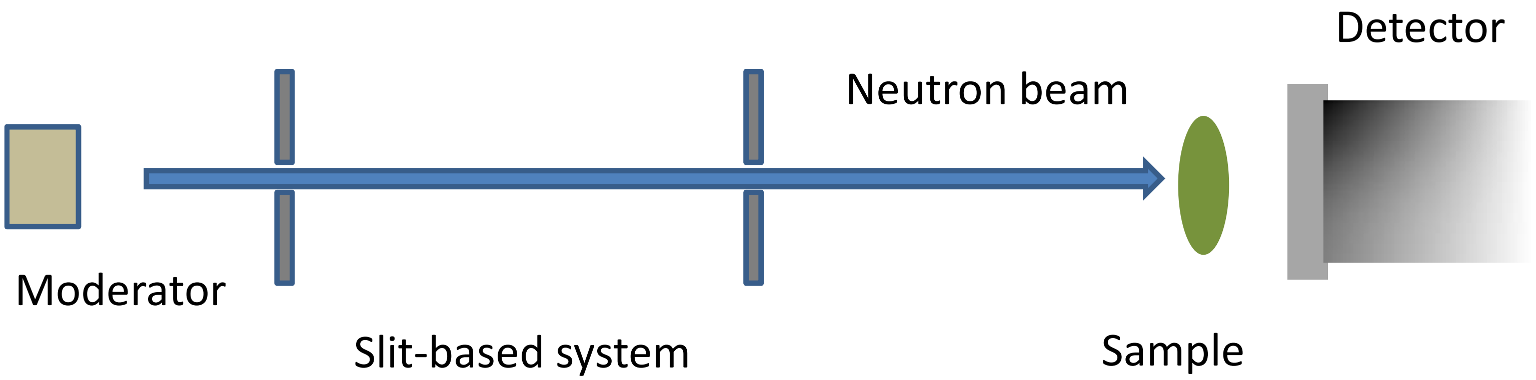
KUANSへの組み込み（案）

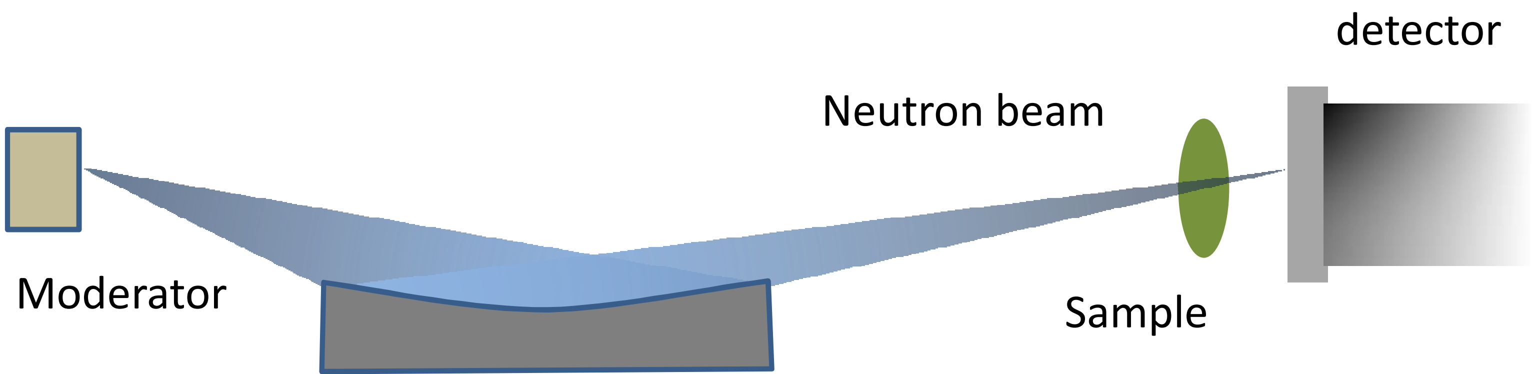


おそらく、$10^3 n/cm^2/s$ぐらいの冷中性子が得られる？

PHITSシミュレーション：現在鋭意構築中

Neutron Focusing Optics





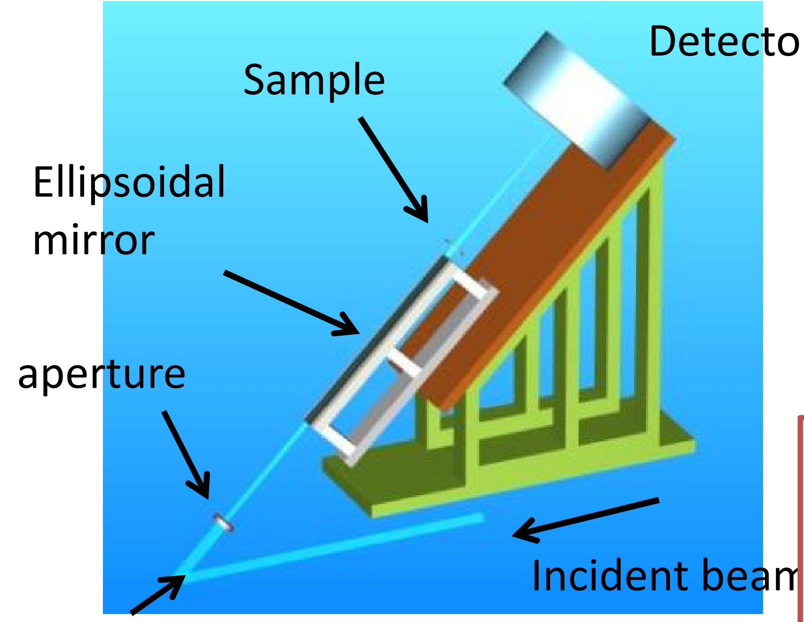
Focusing mirror

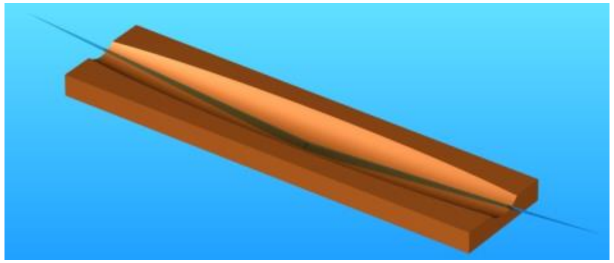
- Smaller spot size
- Smaller beam line
- Virtually higher intensity

Focusing SANS

mini focusing small angle neutron scattering instrument (mf-SANS)

mf-SANS at JRR-3（by Prof.Furusaka et al.）





Ellipsoidal mirror (0.9m) for mf-SANS

Using ellipsoidal focusing mirror, focused neutron beam is used for SANS

Expected to be effective in steel, polymer and biomaterials.

Issues in manufacturing ellipsoidal mirror:

・Reduction of diffuse scattering:
Surface roughness lowered (<5A)
・Maintain profile accuracy
Multi-segmented mirror assembly problem
・Uniform multilayer coating for supermirror
Multi-segmented structure for uniform coating
・Reduction of manufacturing time and cost

A new approach: neutron focusing mirror by metallic substrate

Glass substrate

Advantage:

- Good surface roughness
- Good profile accuracy and stability

Problem

- Manufacturing time :long
- Difficult to withstand profile accuracy and surface roughness
- Brittle, easy to break
- Fixture, holding :difficult
- Assembly of multi-segment: difficult

Metallic substrate

Advantage

- Easier to manufacture
- Fixture, holding : easy
- Strong, hard to break
- Environment, radiation resistant
- Multi-segment assembly : easier

Problem

- Surface roughness: worse (polycrystalline)
- Profile accuracy : worse (by creep deformation, thermal deformation)

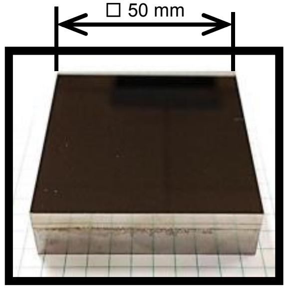
•Metallic substrate (Al-basd or SUS based) with amorphous Nickel plating solve the problem
•Multiple-segmented structure will solve coating issues

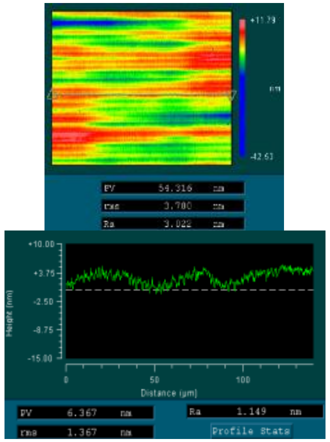
加工方法の比較

- ガラス
  - 素材切り出し（外注）→粗研削（#325,ダイヤモンド）→中仕上げ（#1200）→仕上げ(#4000) 粗さRa 0.5~1μmぐらい（細かいすりガラス状）→研磨（外注）
  - 研削工程：　砥石取り付け→ツルーイング→バランス取り→ドレッシング→砥石形状計測→あたり取り→加工開始（３日間）
  - 加工時間（例：300x50mmミラー）：粗加工：送りピッチ0.5mm,切込み50um,除去量20mm, 研削速度4000mm/min(合計１００時間）　中仕上げ：切込み5μm、送りピッチ50μm、除去量0.5mm(250時間）　仕上げ：切込み2μm、送りピッチ10μm、除去量0.1mm(625時間）
  - 単純計算での加工日数：３日間x３＋100時間＋２５０時間＋625時間＝約50日間（１０週間）　これに外注研磨時間（２～３か月）が加わる→半年間
- 金属ミラー
  - 素材作成（外注）→粗加工（マシニングセンター）→超精密切削１→メッキ外注→超精密切削２→超精密研磨
  - 加工時間：（300x50mmミラー）：粗加工：送りピッチ１mm,切込み5μm、除去量0.1mm,切削速度2000mm/min(合計5時間）、中仕上げ:送りピッチ0.2mm, 切込み5μm、切削速度2000, 除去量5μm（合計2.5時間）、仕上げ：送りピッチ0.01mm(25時間）
  - 加工日数：　5時間＋２．５時間＋２５時間＋研磨６日間＝９日間
- 実際は、ガラスの場合は、加工のやり直しなどが発生する
- 双方とも段取り時間は含まれていない

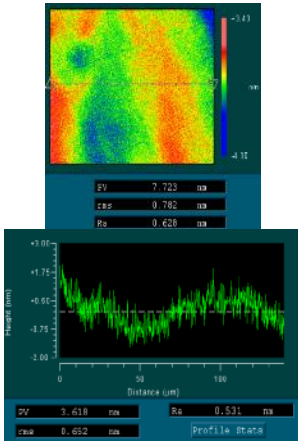
Development of metallic substrate mirror (progress)

- Metallic substrate (SUS) + Amorphous Ni-P plating

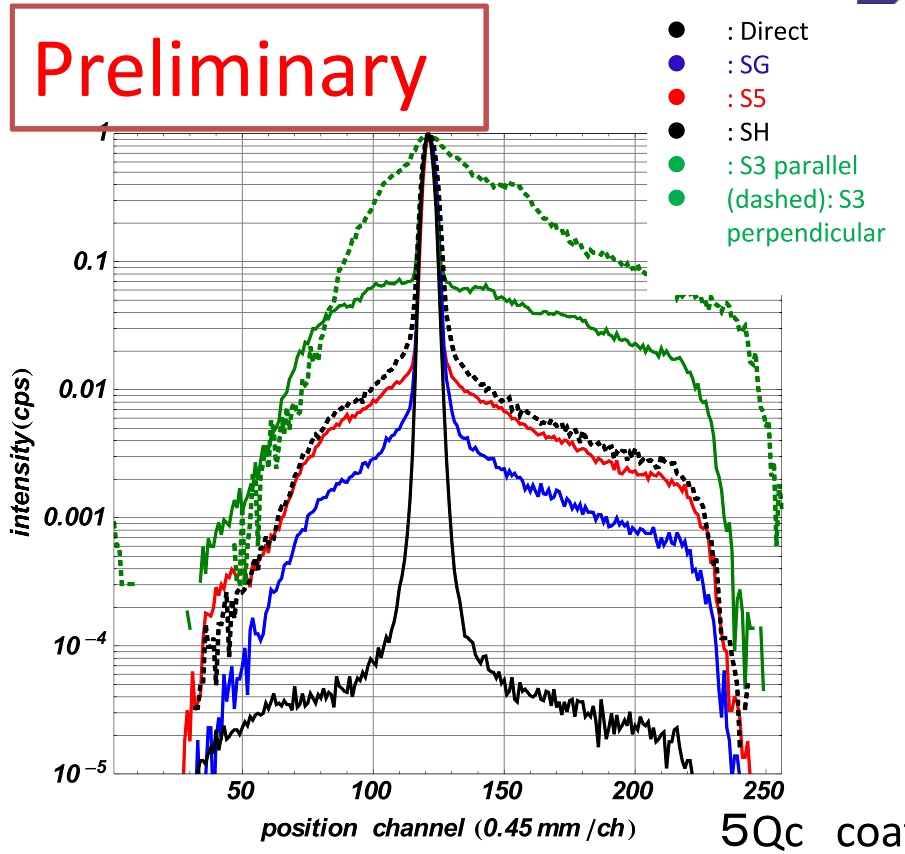




Single crystalline diamond turning
Rrms=3.0nm



Precision polishing
Rrms=7.2 Å



5Qc coating

- Diffuse scattering intensity compared with peak:

SG : $6.0*10^{-3}$ S5 : $1.5*10^{-2}$ SH : $2.0*10^{-2}$

S3(parallel) : $7.0*10^{-2}$ S3(perpendicular)

Small ellipsoidal mirror
Prototype (100mm)

Future R&D for mesitylene-based cold neutron source

- Optimization: simulation + experiment
  - Geometry
  - Groove (re-entrant hole)
- Consideration of metylbenzen derivative mixture
  - m-xylene + mesitylene mixture ?
  - Annealing effect?
- Test of radiation damage and hydrogen generation
- Combination with optics
  - Guide tube directly connected to cold moderator?
  - Ballistic Guide?
  - Direct extraction of beam using ellipsoidal mirror

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- Target /moderator simulation: Hokkaido University , Prof. Kiyanagi, Prof. Kamiyama, Prof. Kino, Dr. Hiraga, U of Tokyo, Dr. Mishima, U of Nagoya Prof. Shimizu
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- KUANS R&D: Kyoto University: Prof. Nagae, Prof. Tazaki
- Neutron radiography at KUR: Prof. Kawabata, Prof. Saito, Dr. Ito, (24P-7 etc)
- ＪＲＲ－３ Radiography experiments: JAEA Dr. Metoki, (2009A-A35 etc)
- VCAD system research program: RIKEN Dr. Makinouchi, Dr. Yokota, Dr.Sunaga, Mr. Mihara, Osaka Univ. Dr. Sera