중성자 측정 표준과 중성자 표준장

2016 년 10월 26일

박 현서

발표내용

- 중성자 측정 표준 및 중성자장
- KRISS 연구내용
  - 동위원소 선원
  - 열중성자 선원
  - Workplace field
  - 단색에너지 중성자 선원 (가속기 발생)
- 향후 계획

Neutron 측정 표준의 역할

- Neutron field for calibration and test
  - Well defined neutron fields
  - Energy distribution of neutrons
  - Flux (or fluence) of neutrons

- Neutron measurement for the characterization of the neutron field

Standard Neutron field

ISO 8529 Reference neutron radiations

Reference Radionuclide neutron sources for calibrating neutron-measuring devices

Source	$\tau_{1/2}$	E_n (MeV)	$h_{\phi}(10)$ pSv*cm^2
$^{252}Cf(D_2O$moderated)	2.65	0.55	105
^{252}Cf	2.65	2.13	385
^{241}Am-B(α,n)	432	2.72	408
^{241}Am-Be(α,n)	432	4.16	391

Standard Neutron field

ISO 8529 Reference neutron radiation

Neutron radiations for determining the response of neutron-measuring devices as a function of neutron energy

E_n (MeV)	Method of production
Thermal	Moderated (Reactor, accelerator, RI source) neutrons
0.002	Scandium-filtered reactor beam or $^{45}Sc(p,n)^{45}Ti$
0.024	Iron filtered reactor neutron beam or $^{45}Sc(p,n)^{45}Ti$
0.144	Silicon-filtered reactor neutron beam or $T(p,n)^{3}He$, $^{7}Li(p,n)^{7}Be$
0.25	$T(p,n)^{3}He$, $^{7}Li(p,n)^{7}Be$
0.565	$T(p,n)^{3}He$, $^{7}Li(p,n)^{7}Be$
1.2	$T(p,n)^{3}He$
2.5	$T(p,n)^{3}He$
2.8	$D(d,n)^{3}He$
5.0	$D(d,n)^{3}He$
14.8	$T(d,n)^{4}He$
19.0	$T(d,n)^{4}He$

중성자공간선량당량계 (IEC61005)

Reference neutron radiation for general test

- 252Cf, 241Am-Be, D(d,n)3He
- Thermal or epi-thermal neutrons
- Workplace neutron fields

For variation of response

- thermal
- 1 neutron energy for 1keV ~50keV
- 1 neutron energy for 50 keV ~ 600 keV
- 1 neutron energy for 1 MeV ~ 5 MeV
- 1 neutron energy for 13.5 MeV ~ 16 MeV

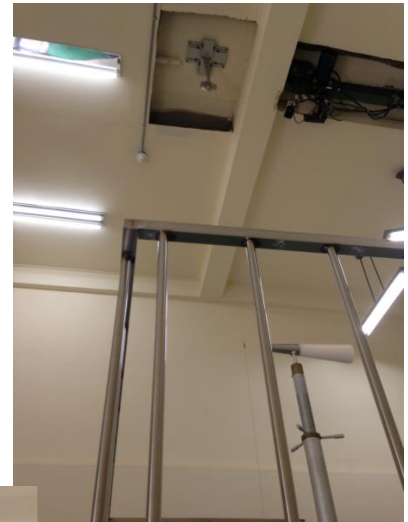
개인선량계 시험 (IEC61526)

Neutron response : 0.025eV ~ 15 MeV

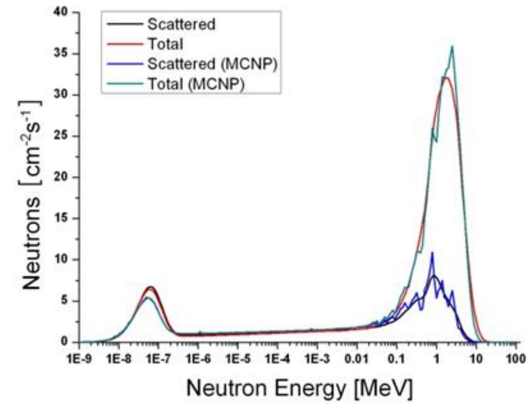
시험용 중성자선원

- thermal
- 1 mono-energy for 10keV~100keV
  - Workplace field로 대체 가능
- 3 mono-energy for 100 keV ~ 1 MeV
- 3 mono-energy for 1 MeV ~ 10 MeV
  or 2 mono-energy + ^{252}Cf(or ^{241}Am-Be)
  - 1개 에너지 work place field or broad source로 대체 가능
- 1 mono-energy for 10 ~ 15 MeV
- If response range is above 15 MeV, 1 shall be used

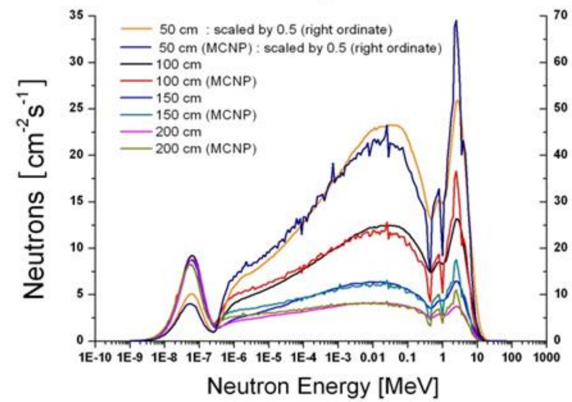
Standard Neutron field at KRISS



Bare ^{252}Cf
Measured with BSS / calculated by MCNP5

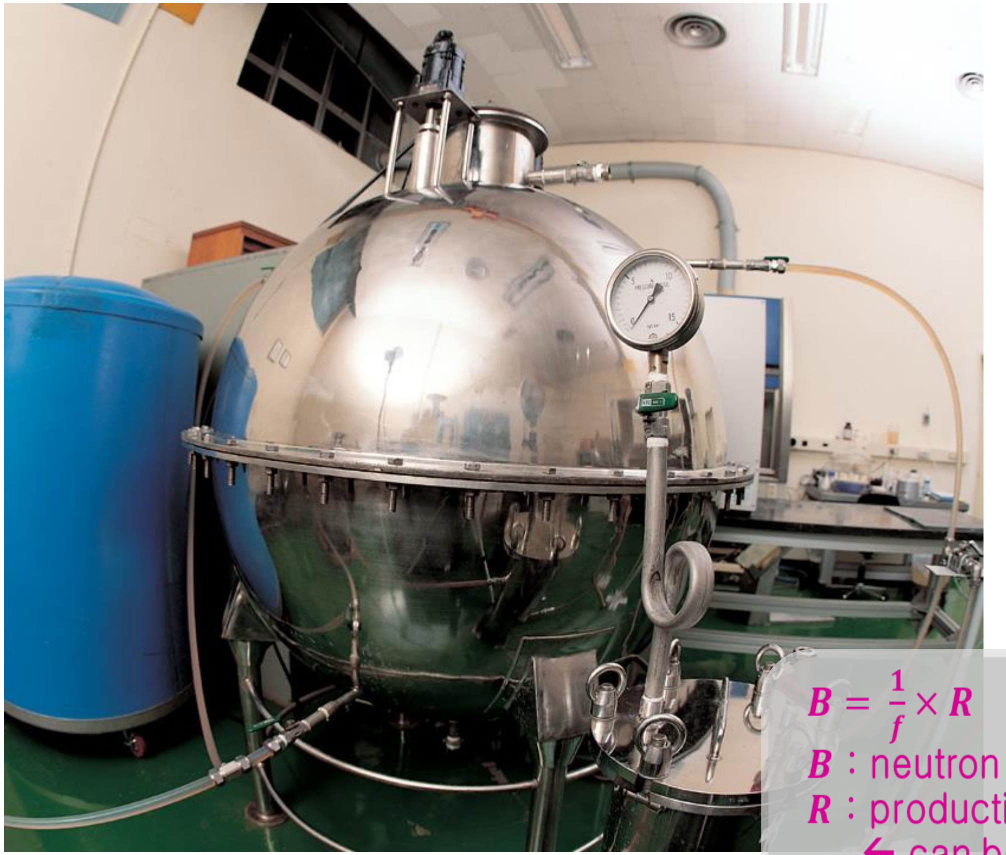


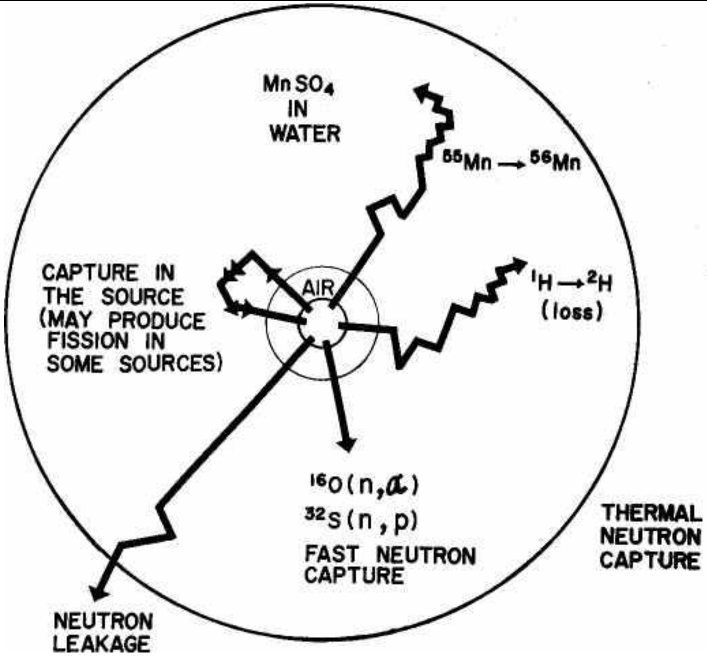
D_2O moderated ^{252}Cf
Measured with BSS / calculated by MCNP5



Neutron emission rate 측정

Manganese Sulphate Bath system
For absolute measurement of Neutron emission rate



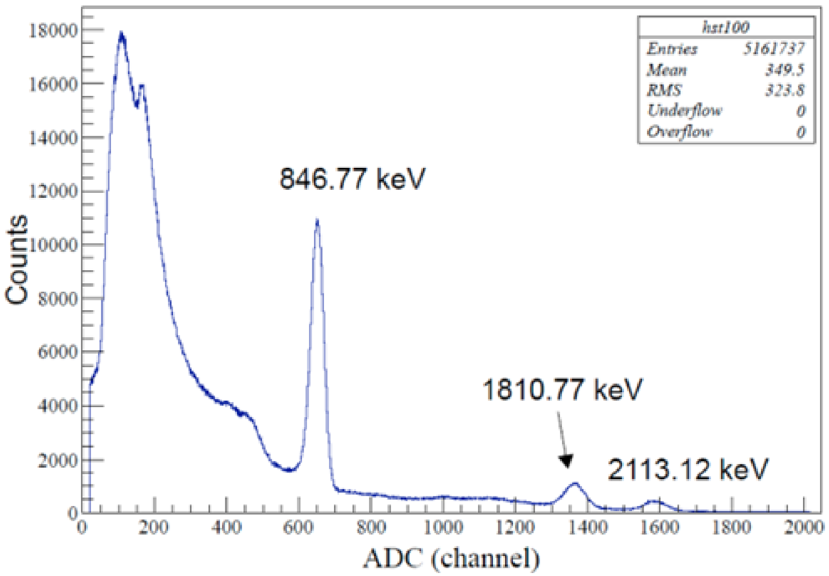


$$B = \frac{1}{f} \times R$$

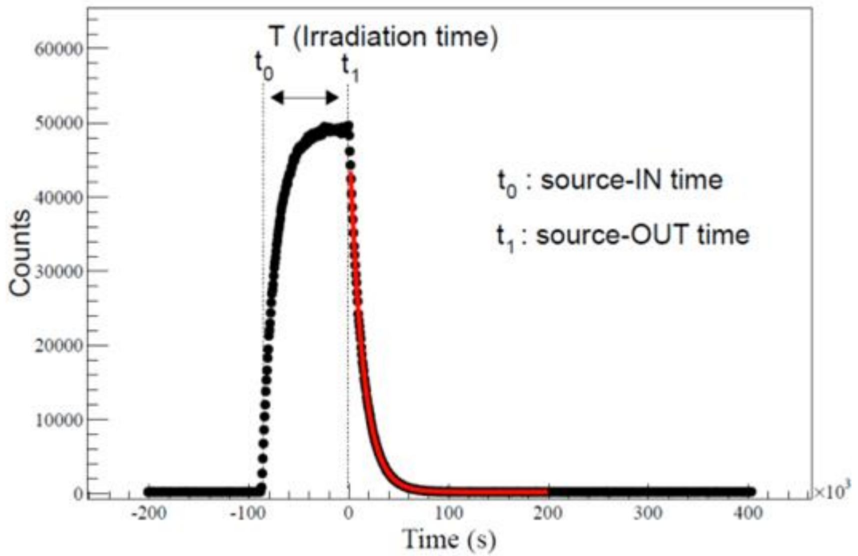
B : neutron emission rate
R : production rate of ^{56}Mn
← can be calculated from the saturated activity of ^{56}Mn
f : neutron capture probability by ^{55}Mn

γ from ^{56}Mn decay

^{56}Mn gamma spectrum



Gamma count rates

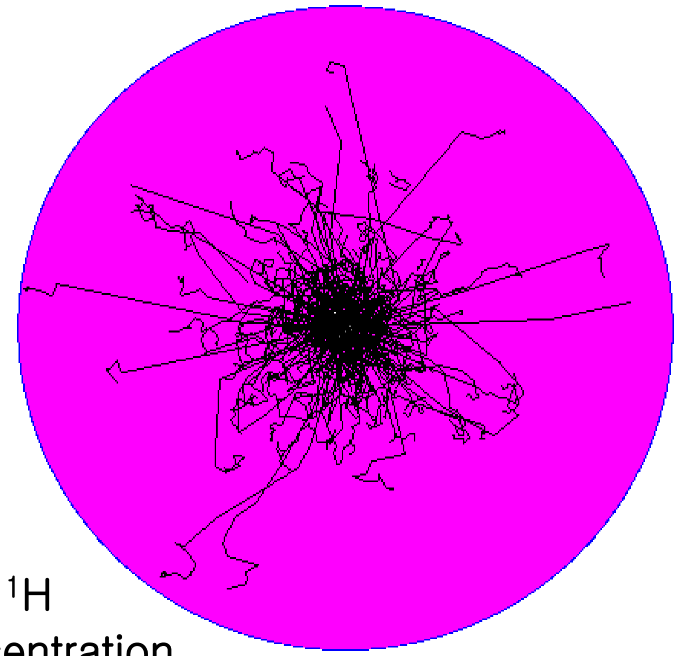


$$B = \frac{1}{f} \times R$$

B : neutron emission rate
R : production rate of ^{56}Mn
← can be calculated from the saturated activity of ^{56}Mn
f : neutron capture probability by ^{55}Mn

Neutron capture probability by ^{55}Mn

	Prob. Which ONE neutron captured by ^{55}Mn
Cf252-I	0.10508
Cf252-II	0.10485
AmBe (5Ci)	0.10186
AmBe (100mCi)	0.10261



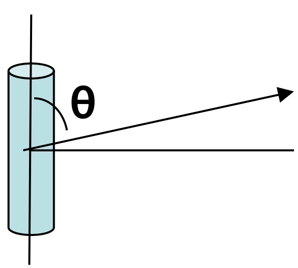
Uncertainty : 0.5% from cross section ratio of ^{55}Mn and ^{1}H
0.15% from the uncertainty of the ^{55}Mn concentration

$$B = \frac{1}{f} \times R$$

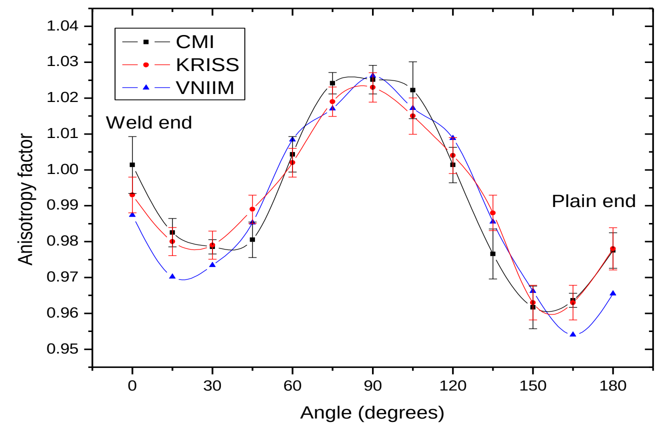
B : neutron emission rate
R : production rate of ^{56}Mn ← from the saturated activity of ^{56}Mn
f : neutron capture probability by ^{55}Mn
← estimated by MCNP calculation

Neutron emission rate 국제비교

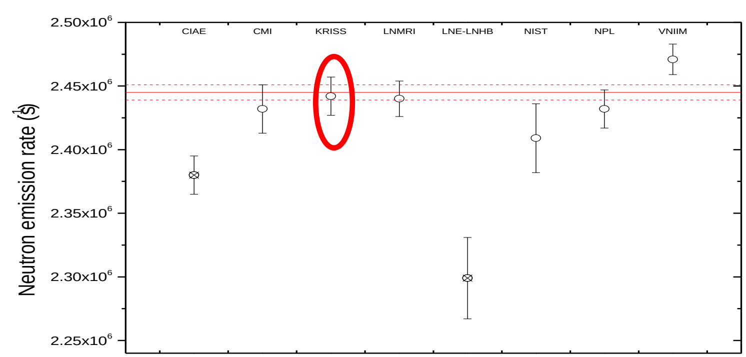
Manganese Sulphate Bath system
For absolute measurement of Neutron emission rate



Anisotropy for $^{241}Am/^{9}Be$: CCRI(III)-K.9

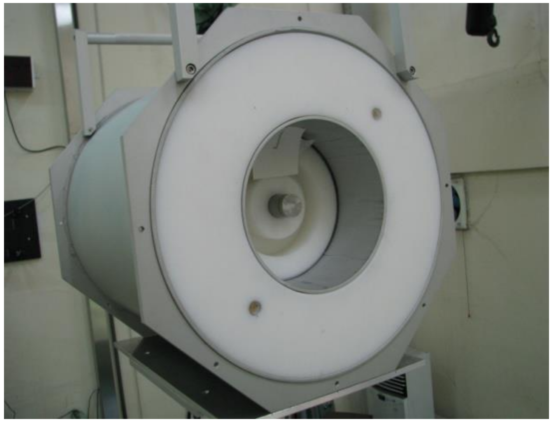


Emission Rate for $^{241}Am/^{9}Be$: CCRI(III)-K.9

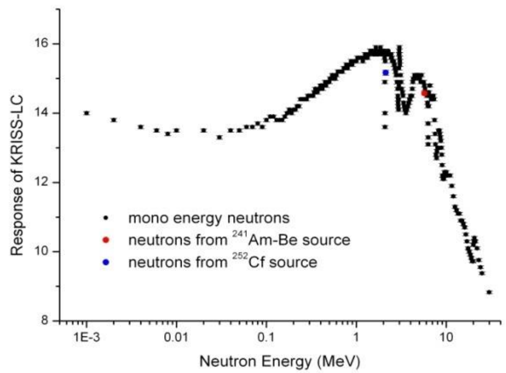


Fluence rate measurement : Long counter

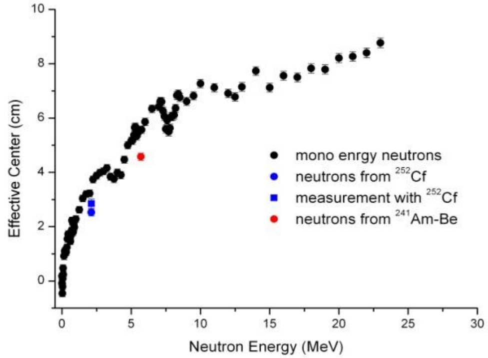
Long Counter for the neutron fluence measurement



Response function of KRISS-LC



KRISS-LC Effective center



Neutron fluence : $\phi = \boldsymbol{M/R}$ at r (distance from the source to the effect center of LC)

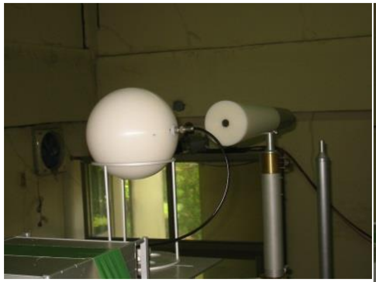
$\boldsymbol{M}$: Count rate measured by Long counter (1/s)

$\boldsymbol{R}$: Response of Long counter (cm^2)

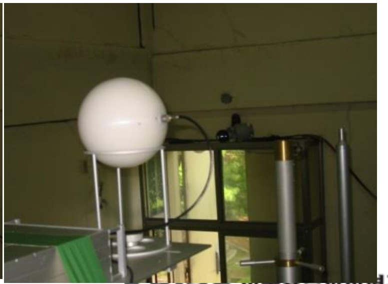
Practically, the count rate should be like

$$\boldsymbol{M = M_{total} - M_{scattered}}$$

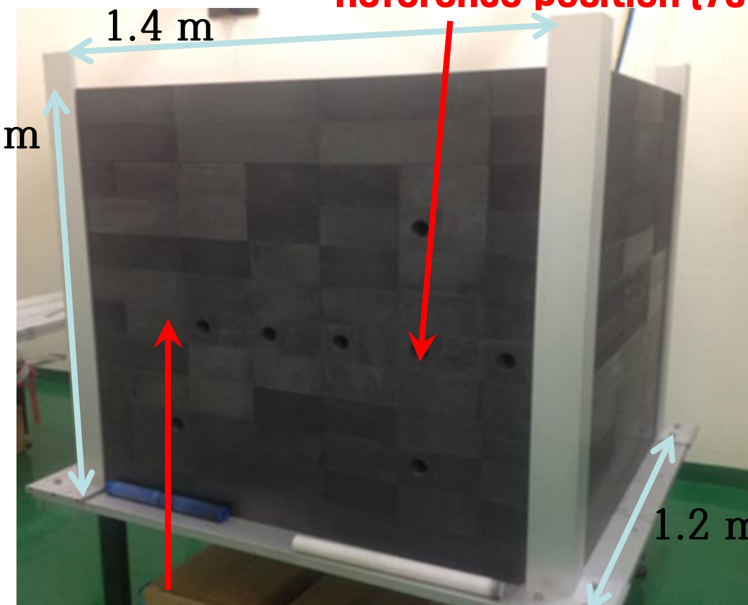
$\boldsymbol{M_{scattered}}$

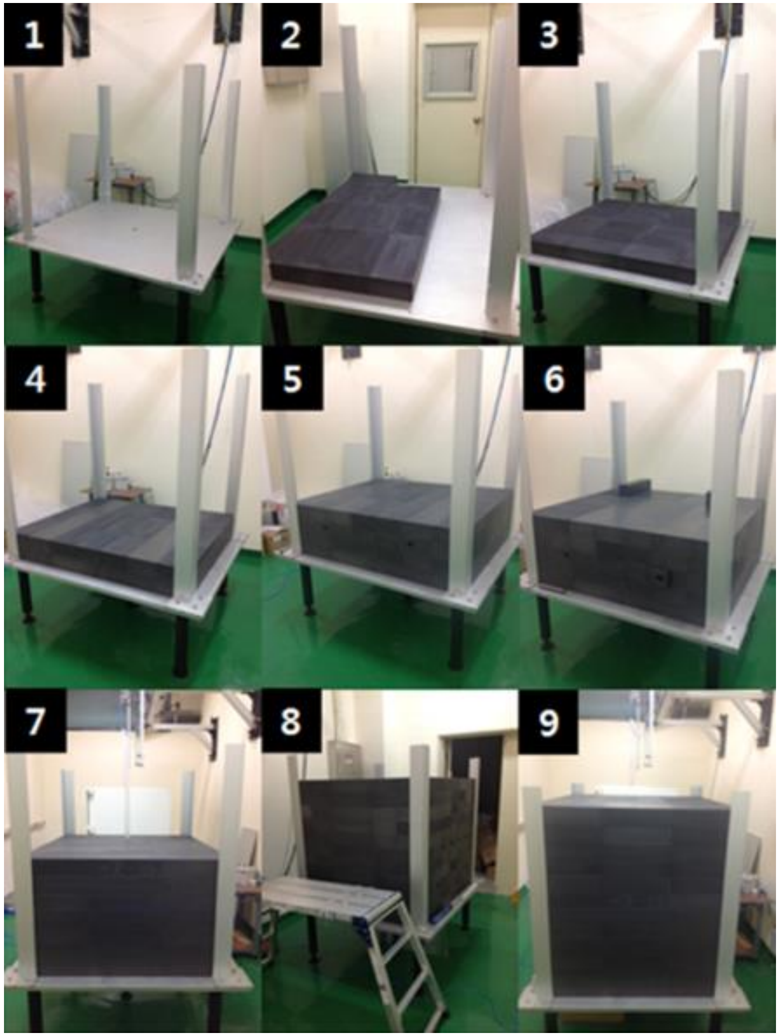


$\boldsymbol{M_{total}}$



Thermal neutron field at KRISS

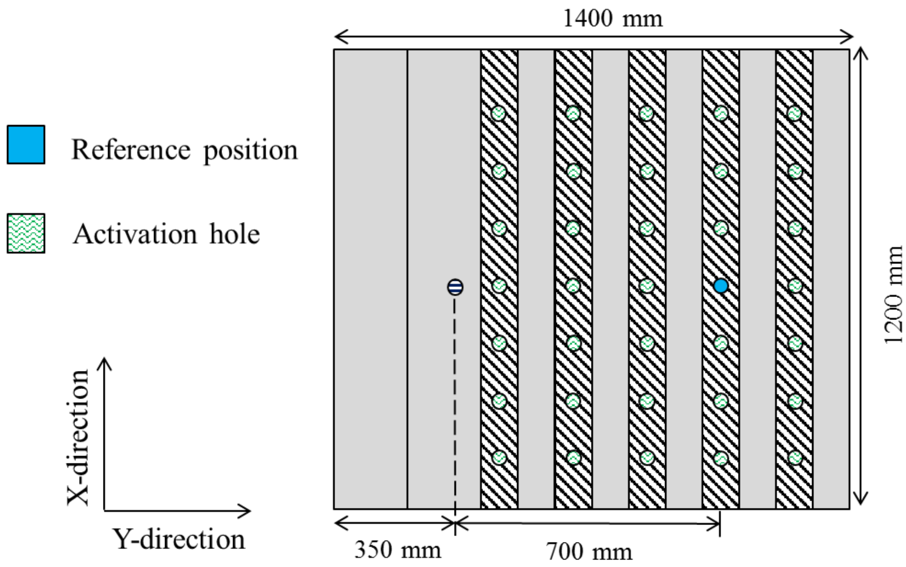


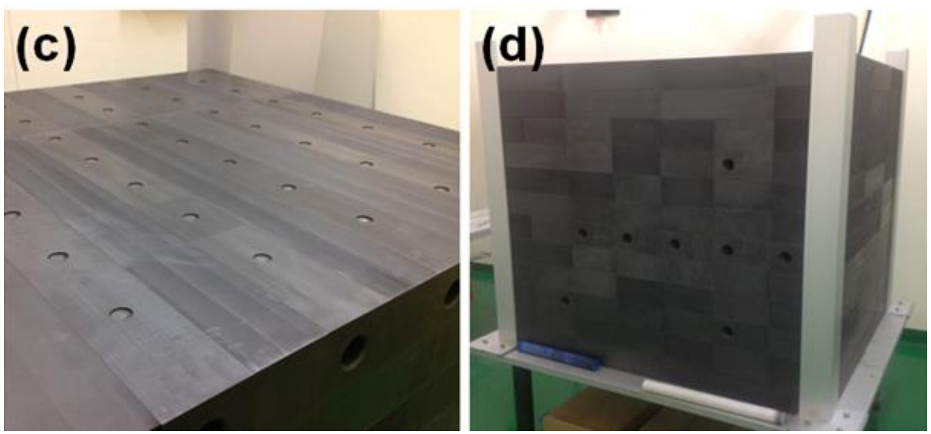


고순도 그래파이트 파일 제작

- 1.4 m x 1.2 m x 1.2 m (239개 블록)
- 보론 불순물 함유량 0.628±0.028 μg/g
  PGAA 방법으로 분석
- 기타 불순물 검사 : GDMS 법으로 검사
- 밀도 측정 : 139개 블록 질량/부피 측정
  1.786 ±0.015 g/cm^3
- 중성자 선원 :^{241}Am-Be(α,n) 선원

Thermal neutron field at KRISS





To specify neutron field

1. Monte-Carlo Simulation with MCNP
   : neutron energy distribution
   and various correction factors

2. Measurement
   with Gold foil activation method
   : neutron fluence rate

$$n + {}^{197}Au \rightarrow {}^{198}Au$$

$$D = N\sigma_0 n v_0 \rightarrow \quad \phi_w = n v_0 = \frac{D}{N\sigma_0}$$

Neutron energy distribution(MCNP)

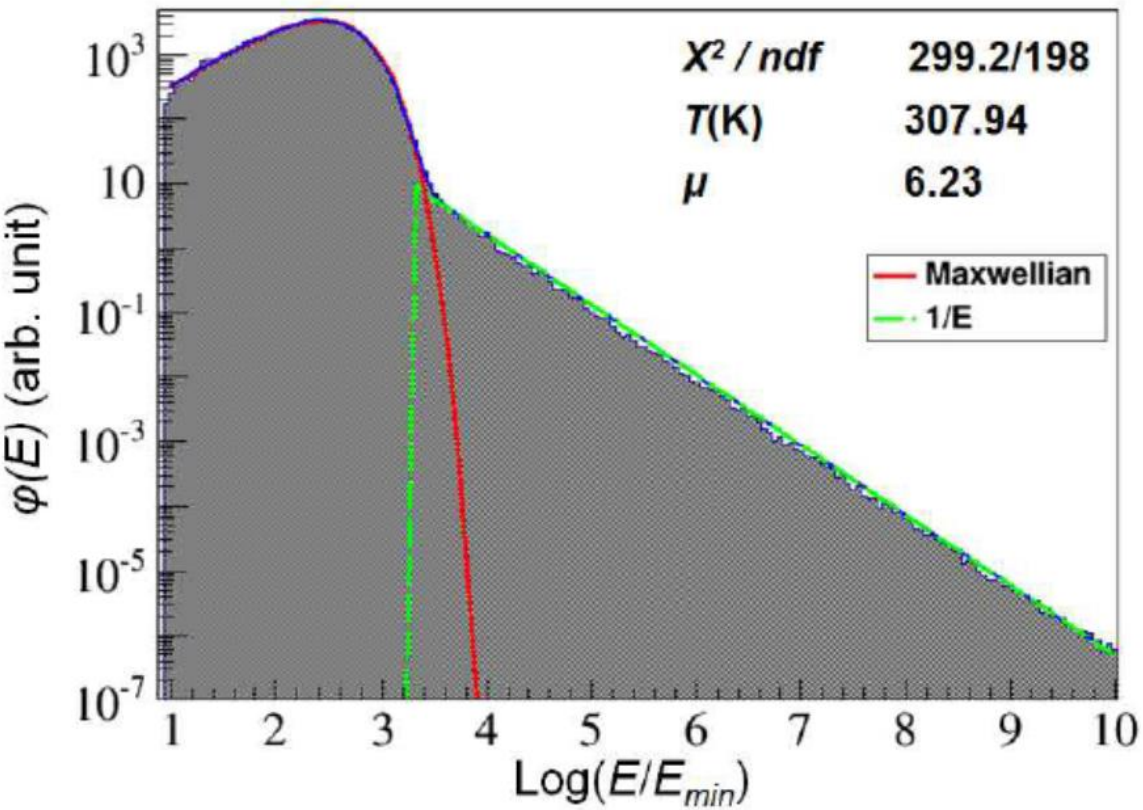
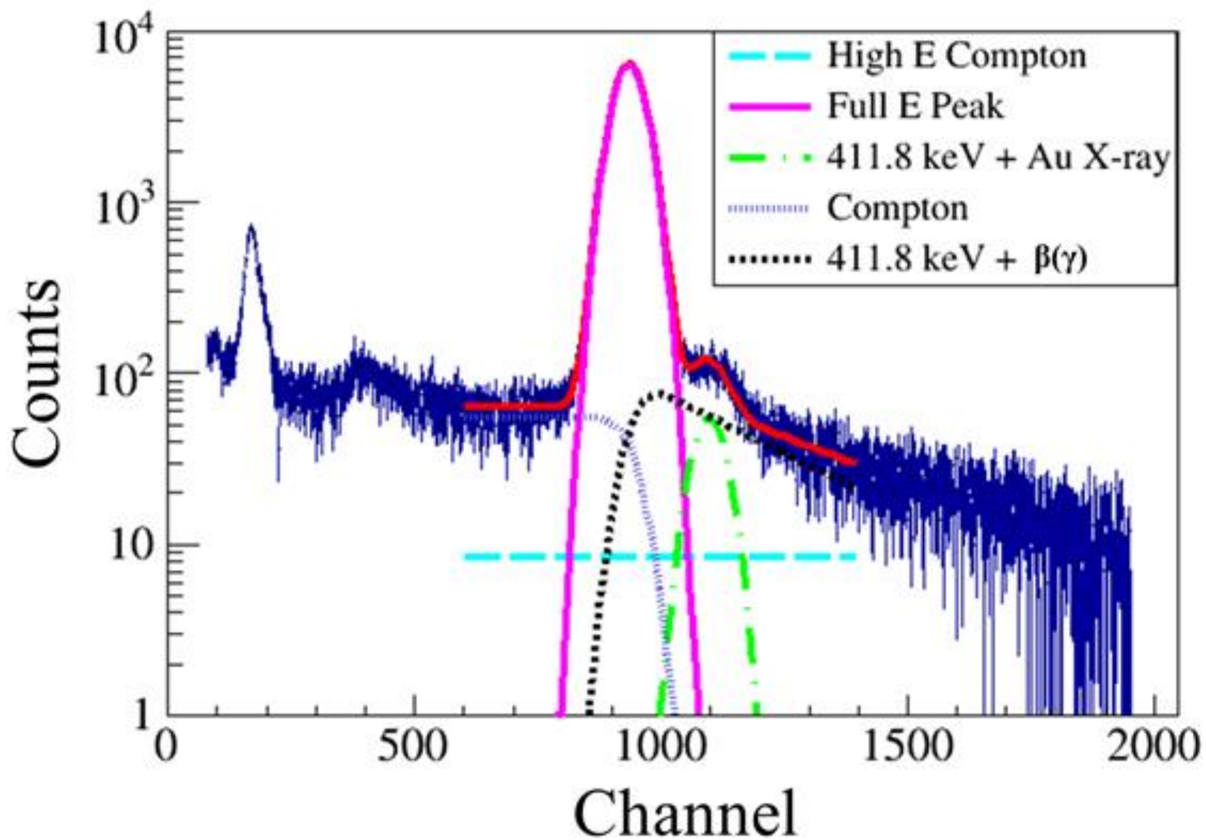


Figure 4.2. Fitting the spectrum obtained from MCNPX (E_{min} = 10^{-4} eV)

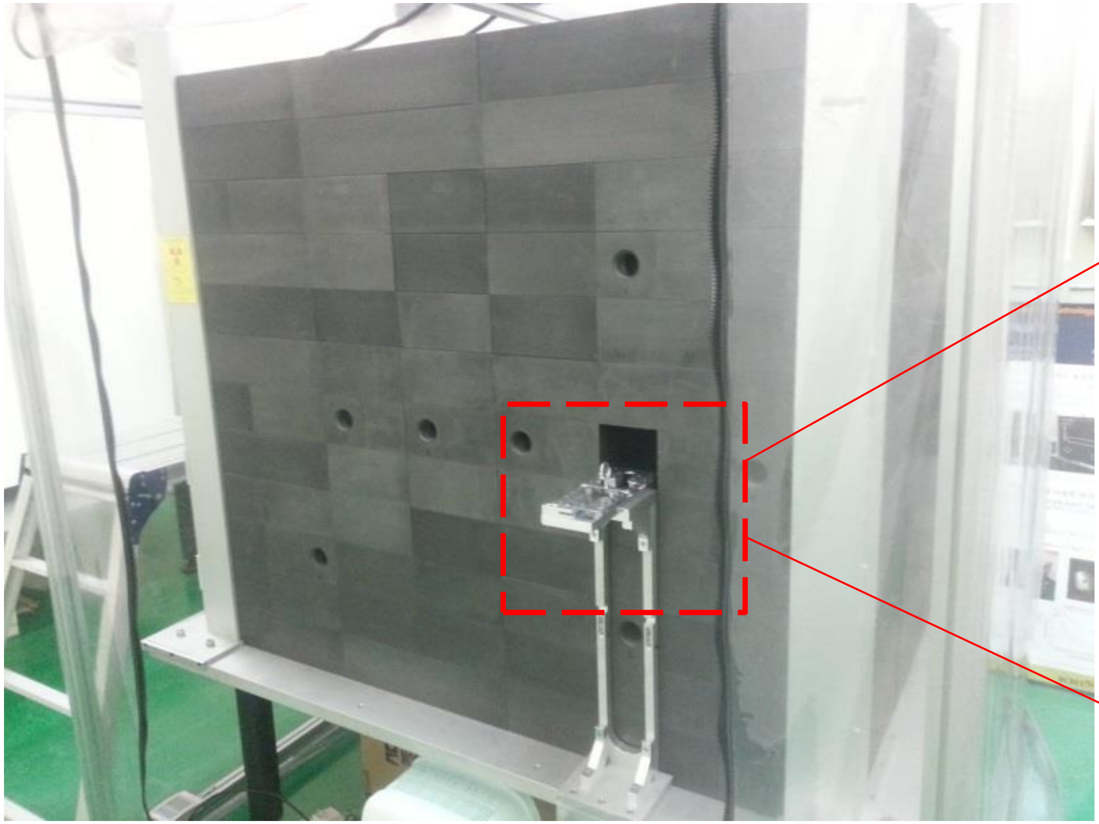
Gamma energy spectrum from ^{198}Au decay



Thermal neutron fluence

	Unit	Value	Uncertainty (%)
D_0	Bq/mg	0.6749	0.28
D_0(Cd)	Bq/mg	0.0161	1.06
T	K	308	2.00
μ		6.3	50.0
φ_M	$cm^{-2}s^{-1}$	2683.8	
$\varphi_{1/E}$	$cm^{-2}s^{-1}$	14.5	
φ_{th}	$cm^{-2}s^{-1}$	2698.3	1.5

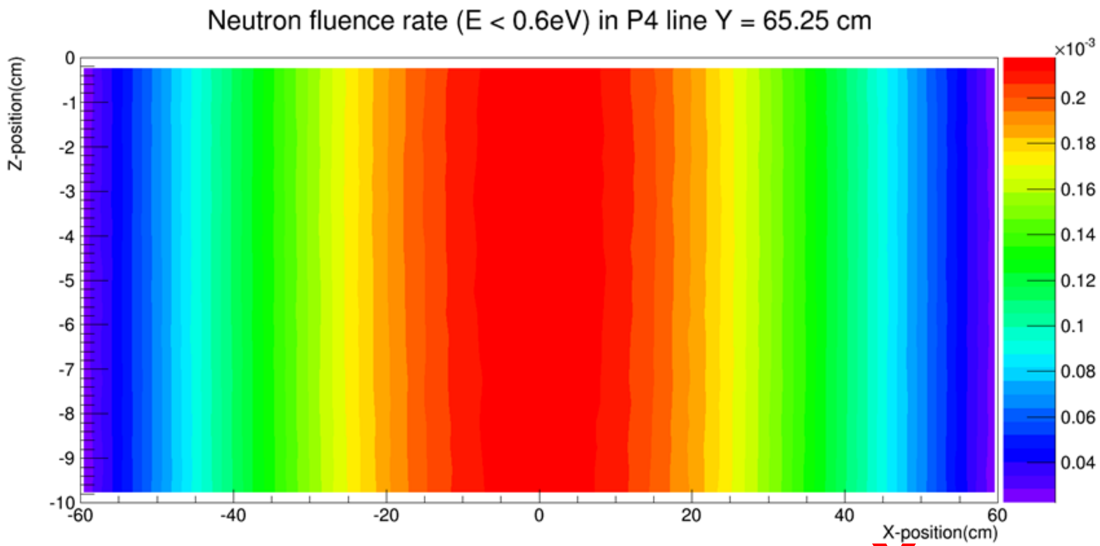
Thermal neutron field at KIRSS



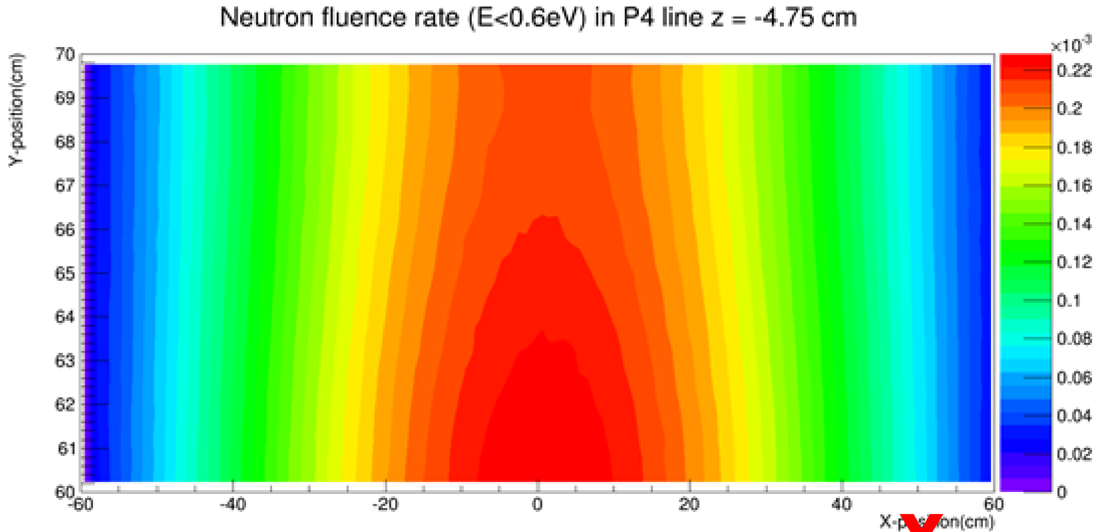
Thermal neutron fluence inside cavity

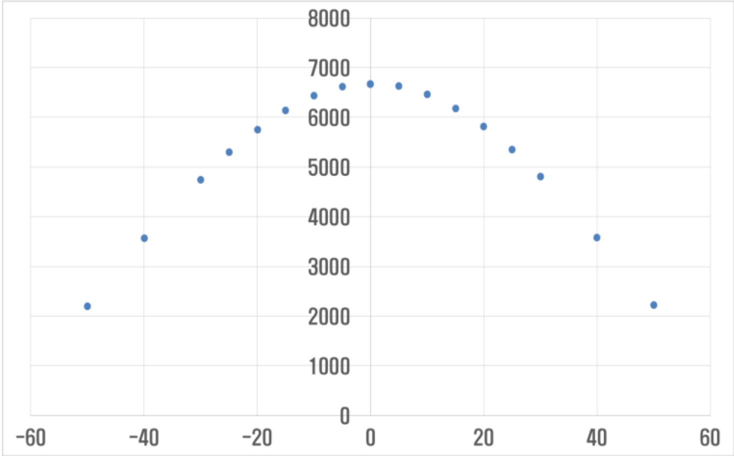
	Unit	Value	Uncertainty (%)
D_0	Bq/mg	0.6040	0.33
D_0(Cd)	Bq/mg	0.0186	2.01
T	K	311	2.00
μ		6.3	50.0
φ_M	cm^{-2}s^{-1}	2354.4	
$\varphi_{1/E}$	cm^{-2}s^{-1}	16.8	
φ_{th}	cm^{-2}s^{-1}	2371.2	1.5

Thermal neutron field inside cavity

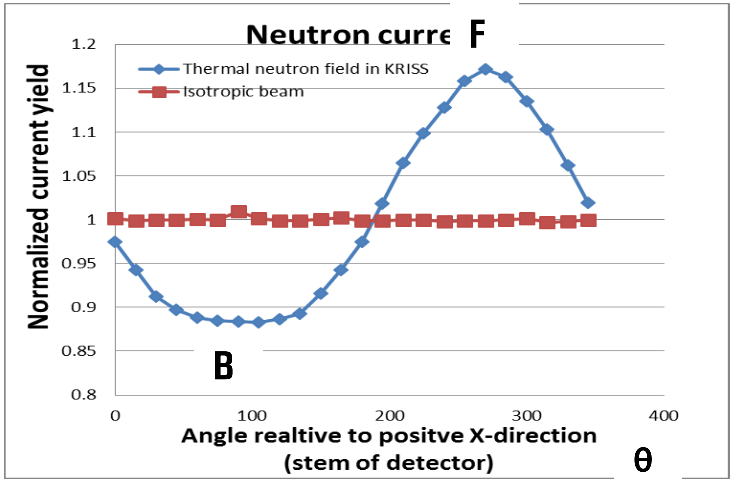


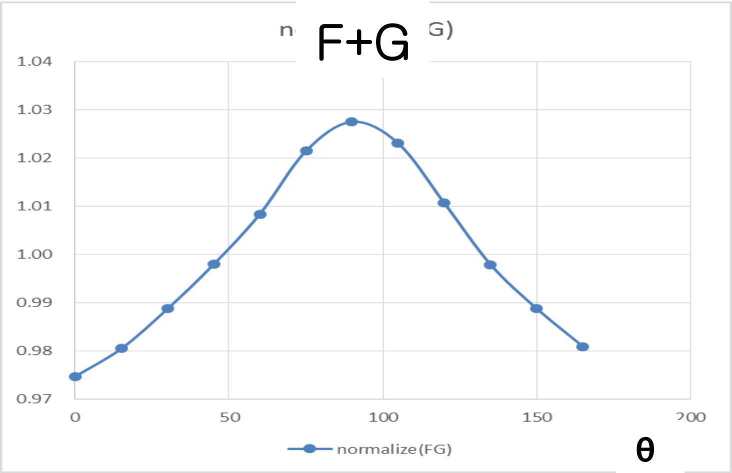
Uniformity check

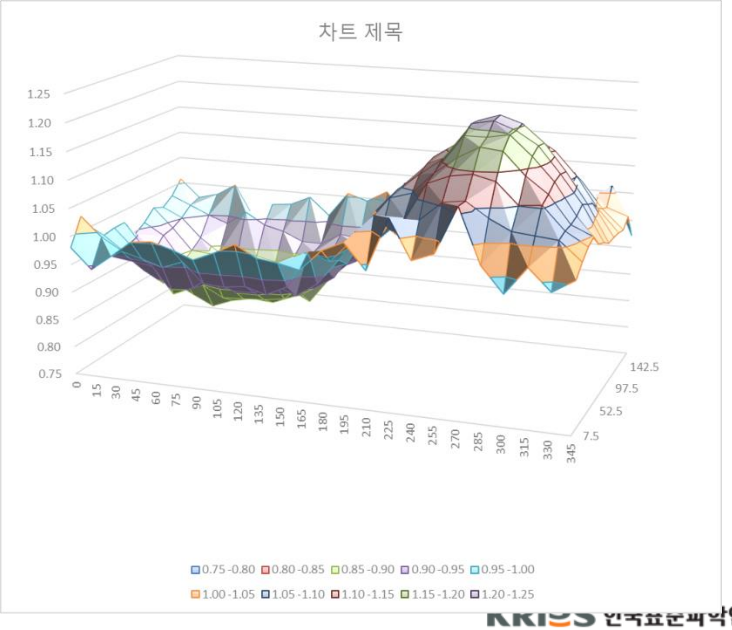




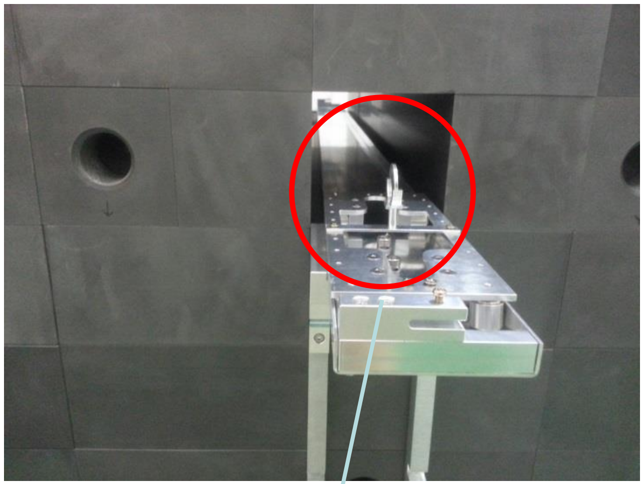
Isotropy of thermal neutron inside



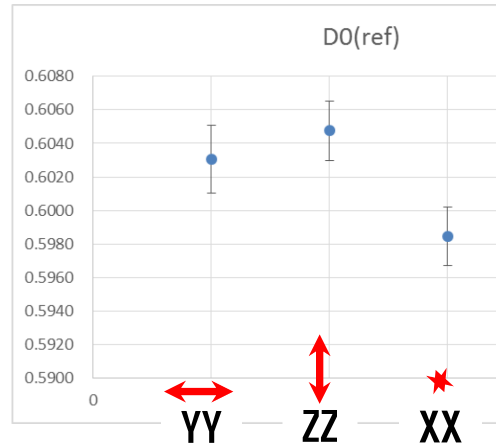




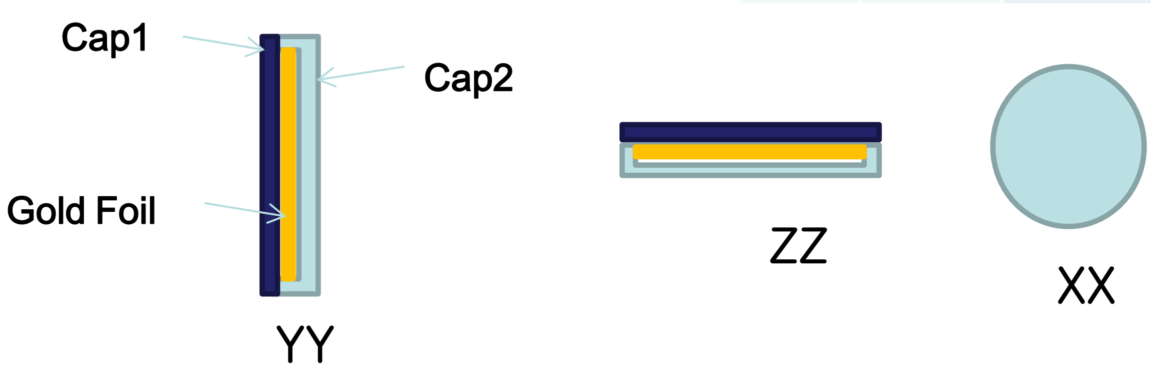
Isotropy of thermal neutron inside cavity



Gold foil (20μm thick, radius 1cm)
in case (Case1+Case2)
made of Al and/or Cd
Cap1 : side of 241Am-Be source
Cap2 : opposite side



Cap1	Cap2	Specific activity ^{198}Au	Relative to the ref case (A)
Al	Al	0.6031 (0.3%)	1
Al	Cd	0.3245 (0.4%)	53.8%
		0.2540 (0.4%)	42.1%



SP9 sensitivity

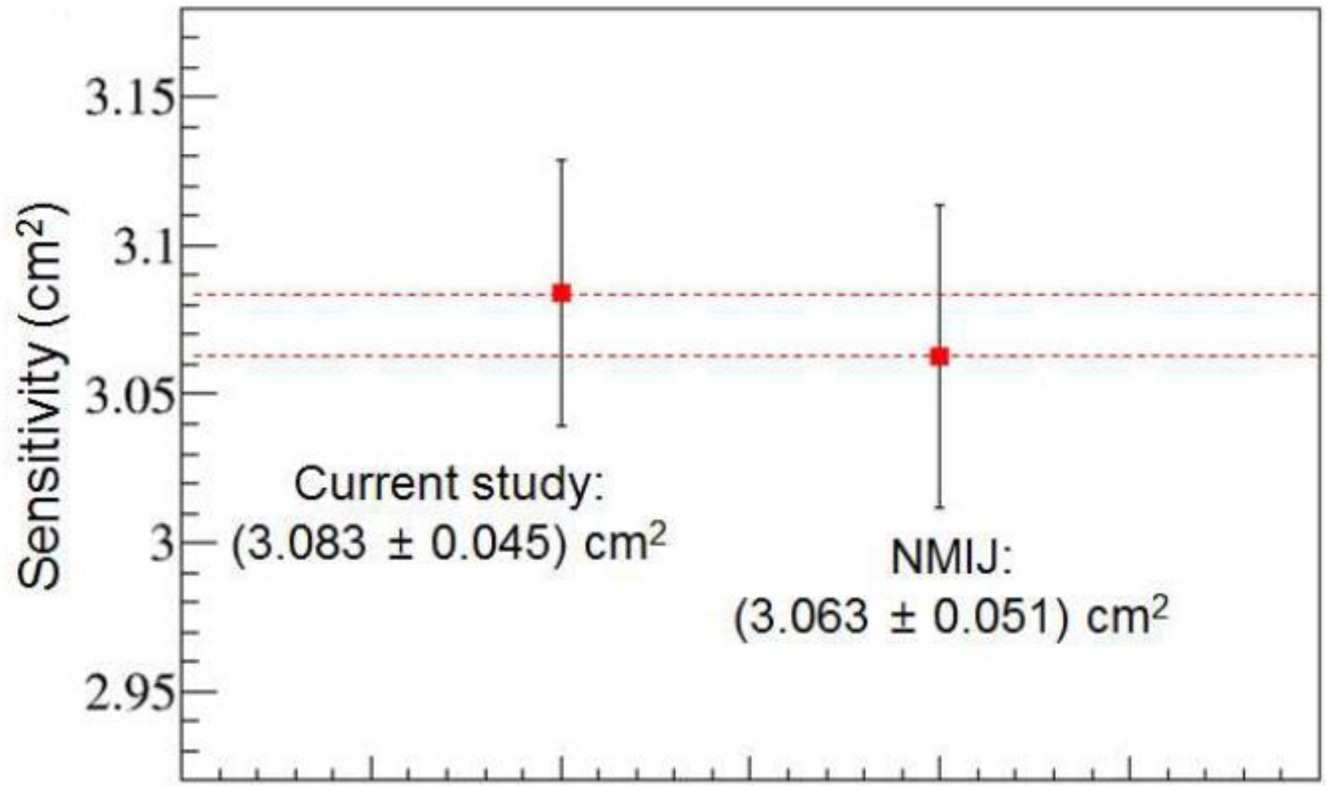
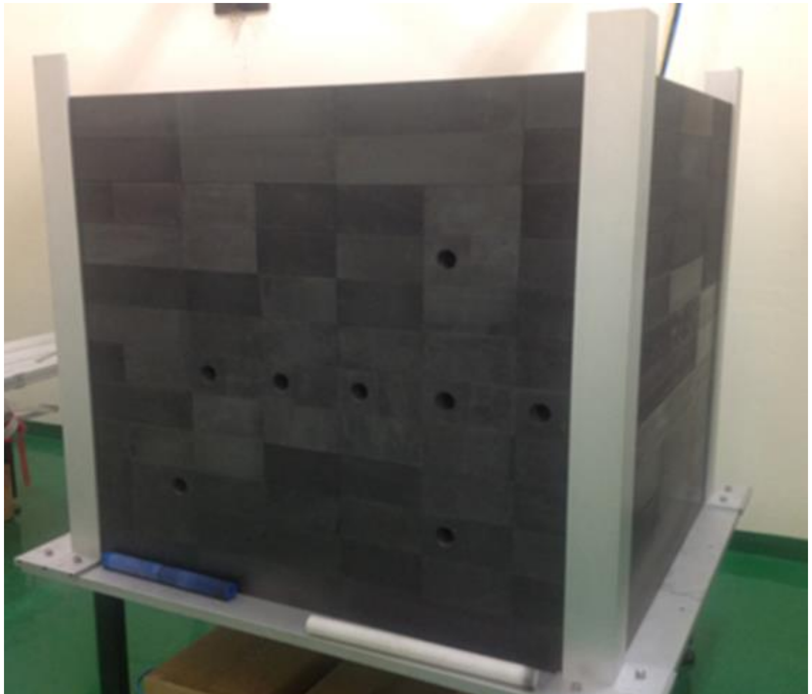
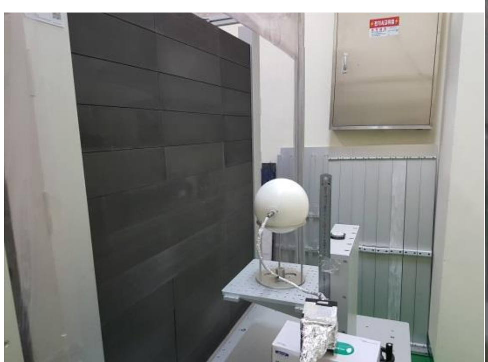


Figure 5.6. Determined sensitivity using the developed thermal neutron field and the certified sensitivity from NMIJ; $R_{ref} = R_{th} \times \prod_{i=1}^{3} k_i$

outside graphite pile



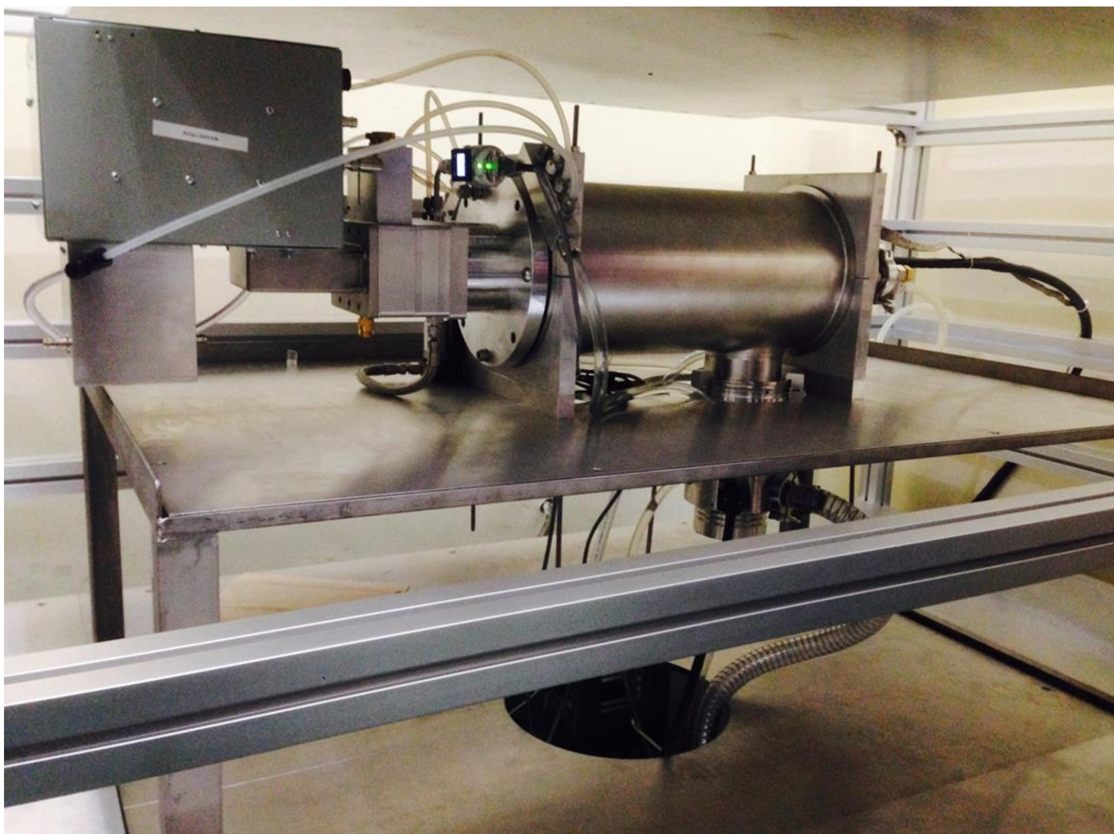
	Unit	Value	Uncertainty (%)
Counts	1/s	185.4	0.62
Counts(Cd)	1/s	0.7	1.6
R_{SP9}	cm^2	2.810	1.6
에너지 차이(k1)		1.0	0.5
입사각차이(k2)		1.034	0.33
공동/오픈(k3)		1.028	0.68
φ_N	$cm^{-2}s^{-1}$	61.8	2.0



Neutron generator at KRISS

Neutron generator

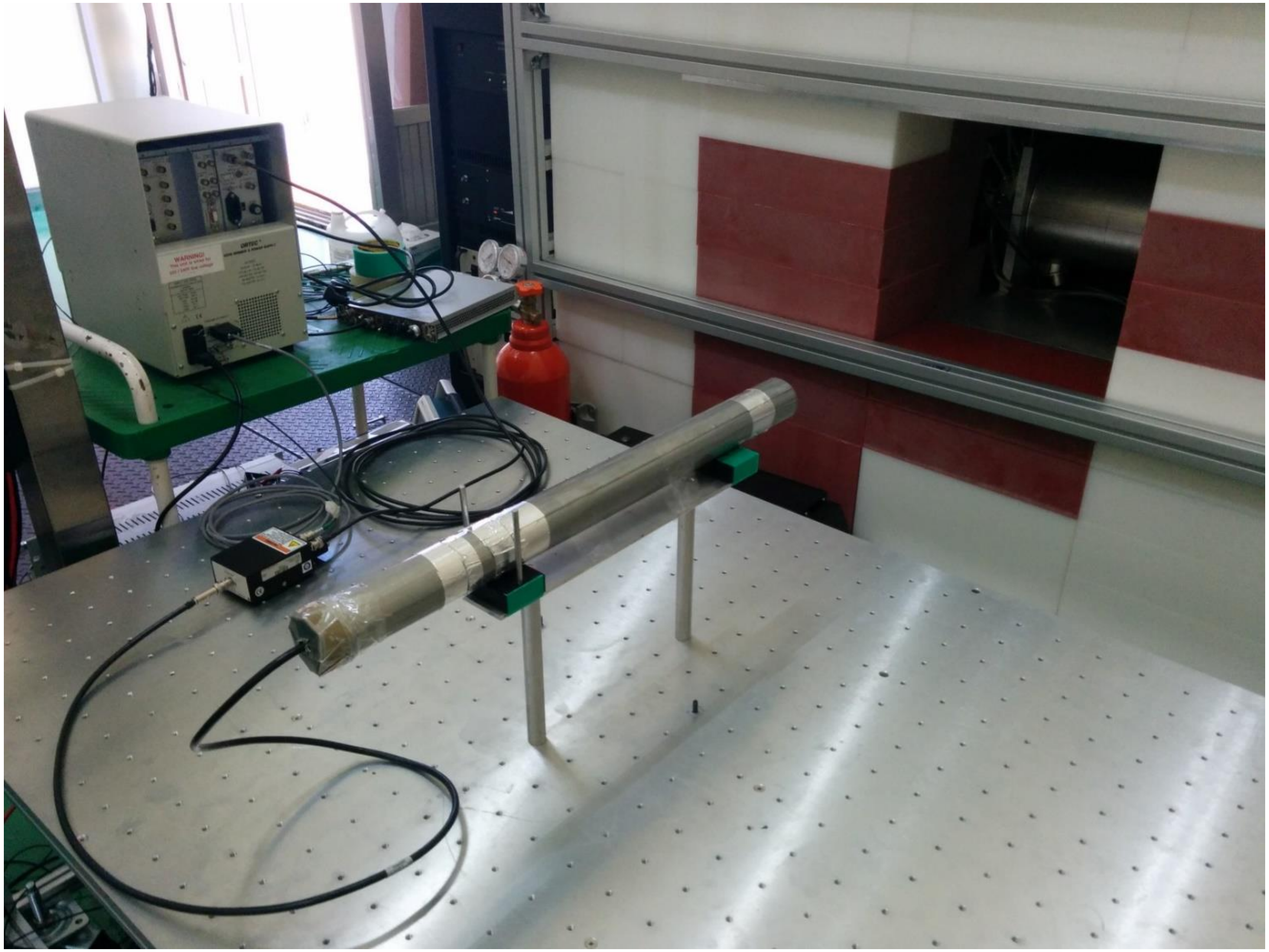
- Produced by Adelphi (DD-109 model) :
  - d(d,n)t reaction, (E_d = 85~125 keV)



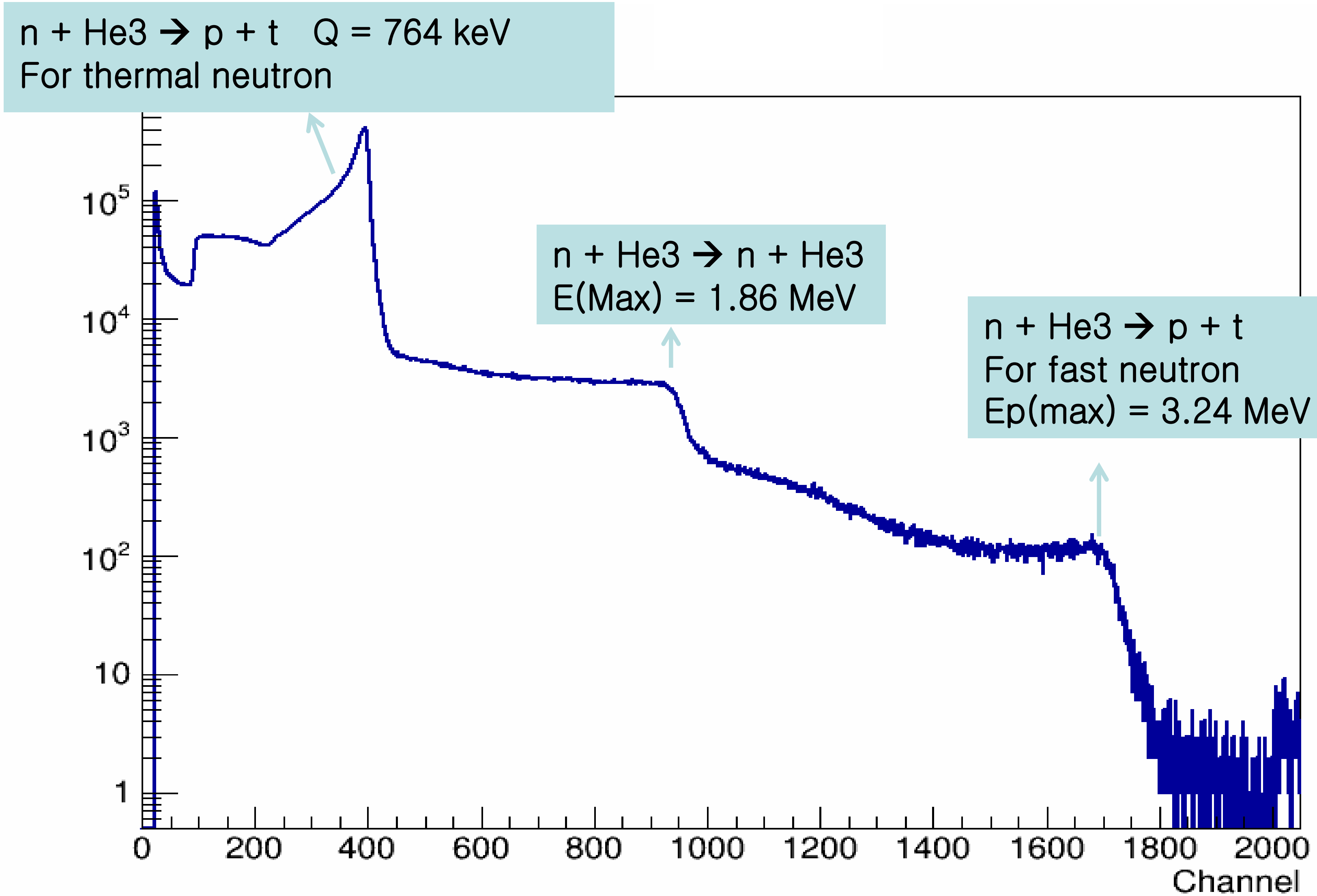
Neutron generator at KRISS

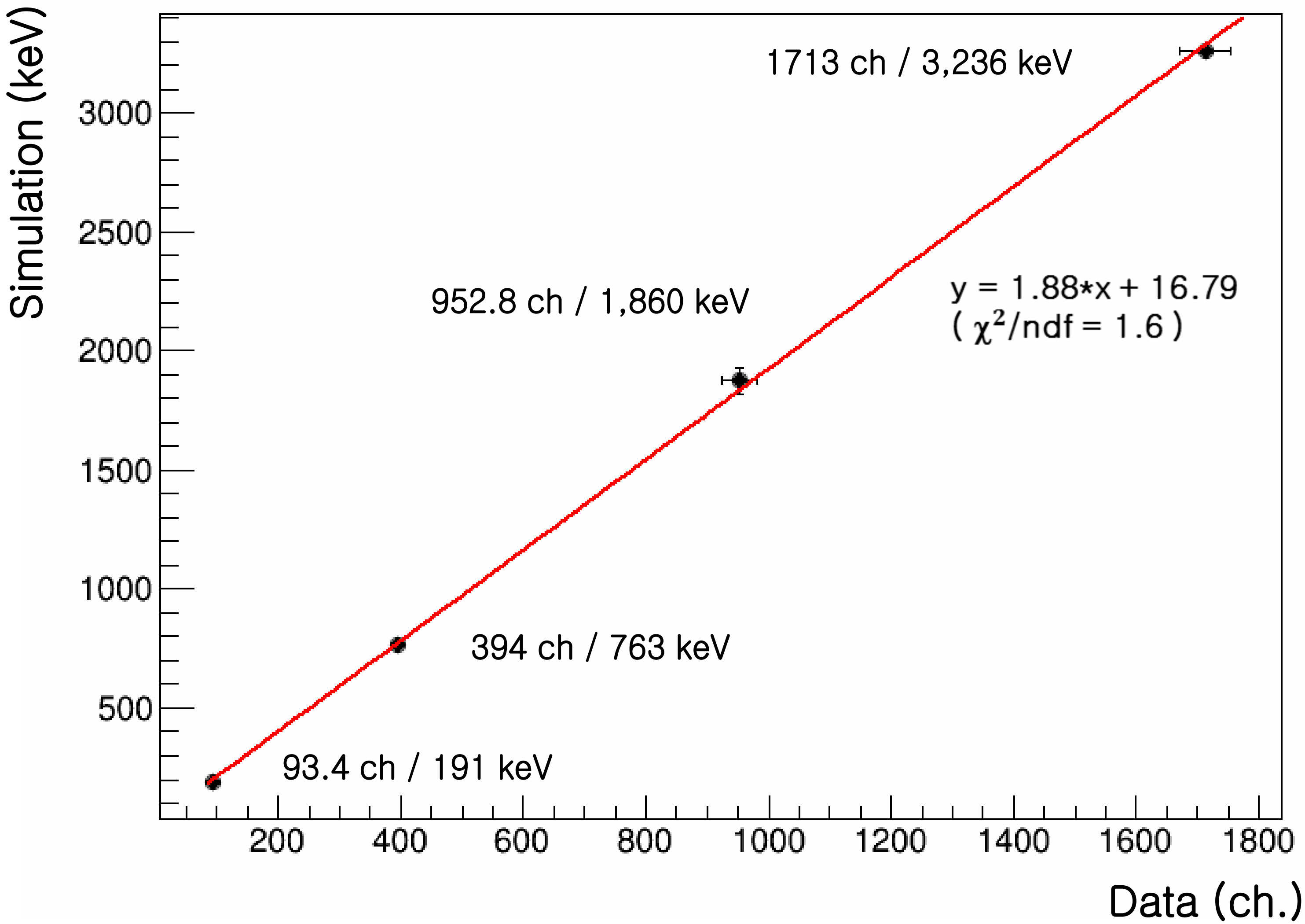
^{3}He proportional counter for neutron energy measurement

→ E_n = 2.46 MeV



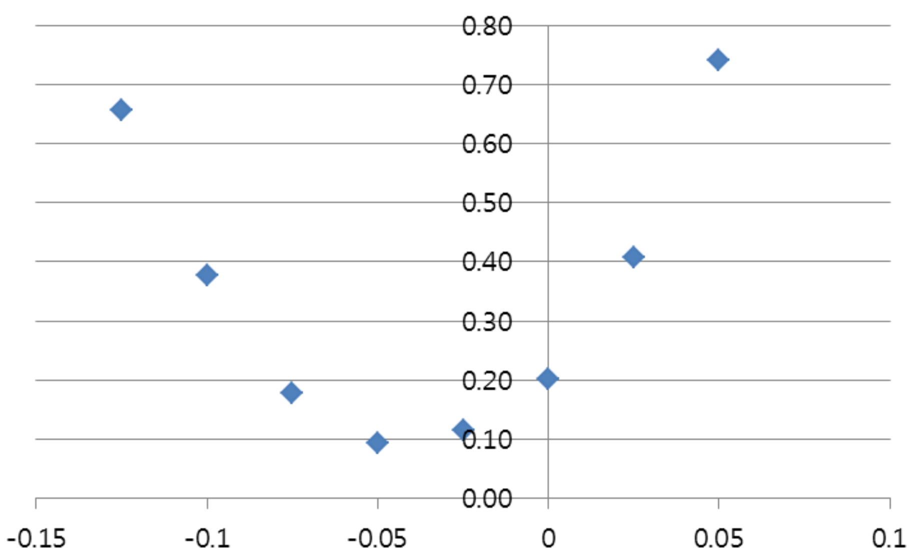
He3 detector spectrum





Simulation (keV)
3000
2500
2000
1500
1000
500
200
400
600
800
1000
1200
1400
1600
1800
Data (ch.)
1713 ch / 3,236 keV
952.8 ch / 1,860 keV
394 ch / 763 keV
93.4 ch / 191 keV
y = 1.88*x + 16.79
(χ²/ndf = 1.6)

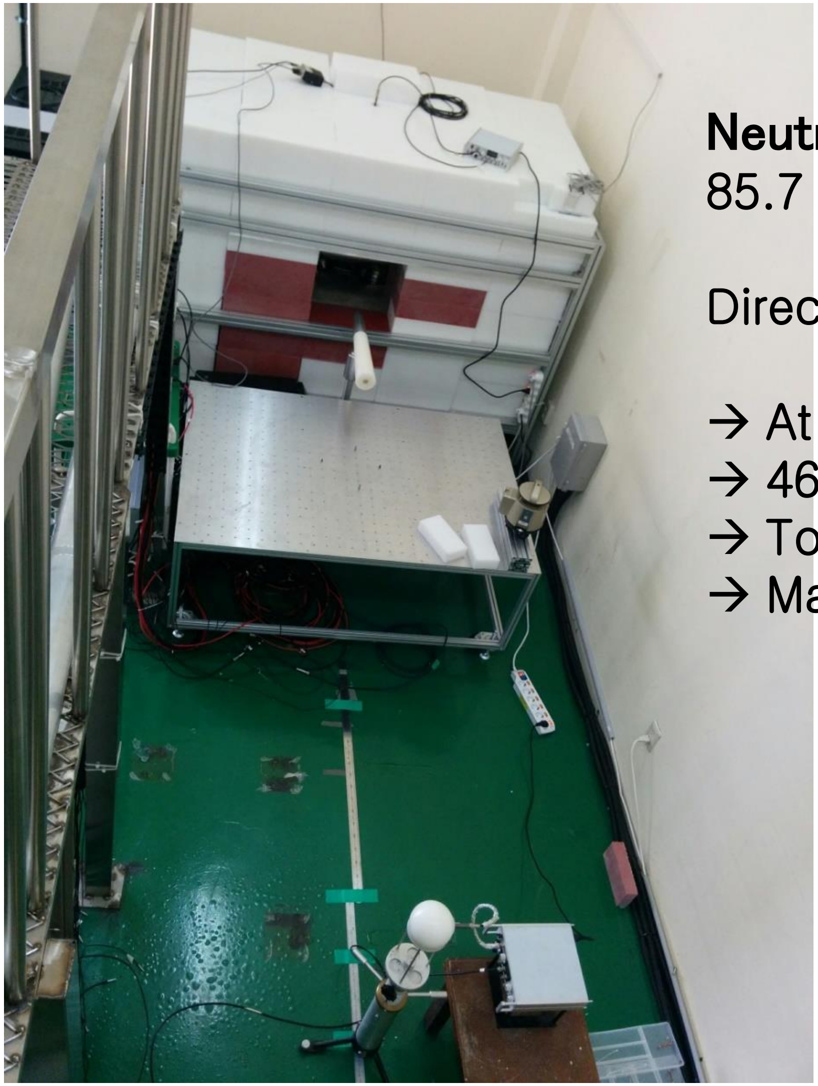
Energy difference (MeV)	Proton escape		Thermal n full energy peak		3He recoil		p+t full energy peak		Const.	Slope	χ^2/ndf
	Data	Sim	Data	Sim	Data	Sim	Data	Sim			
− 0.1						1785		3136	17.46	1.86	**0.38**
− 0.05						1823		3186	14.54	1.89	**0.09**
± 0	93.4	191	393	763	953	1860	1713	3236	11.67	1.92	**0.20**
+ 0.05						1898		3286	8.78	1.94	**0.74**
+ 0.1						1936		3333	5.99	1.97	**1.57**



Neutron Beam energy
= 2.43 ± *** (MeV)

X axis : Neutron energy difference
Y axis : chi-sqr / ndf

Neutron generator at KRISS



Neutron fluence measurement with BS
85.7 ± 2.7 (3 %) /cm²/s at 3.5 m from the target

Direct vs scatter = 1 : 1 at 3.5 m

→ At 1.5 m, Direct vs scatter = 5 : 1 (expected)
→ 460 /cm²/s
→ Total emission rate = ~ 1.5 x10^8 /s
→ Max power : we can have 5 times more

Plan for new laboratory

2017 ??

Low Scatter Neutron Irradiation Room
12 m x 12 m x 12 m

2018 ??

Cockcroft–Walton
Accelerator (500 kV)

2019-2020??

2.5 MeV & 14.8 MeV 단색중성자 표준장 확보