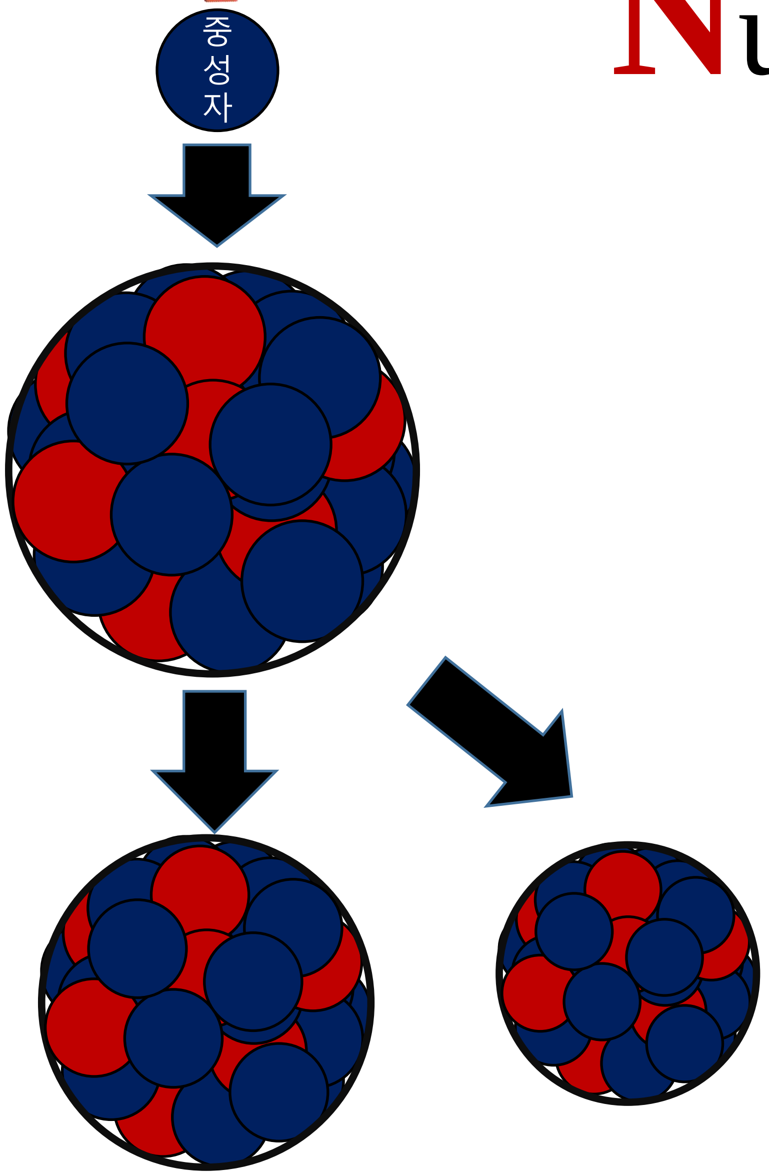
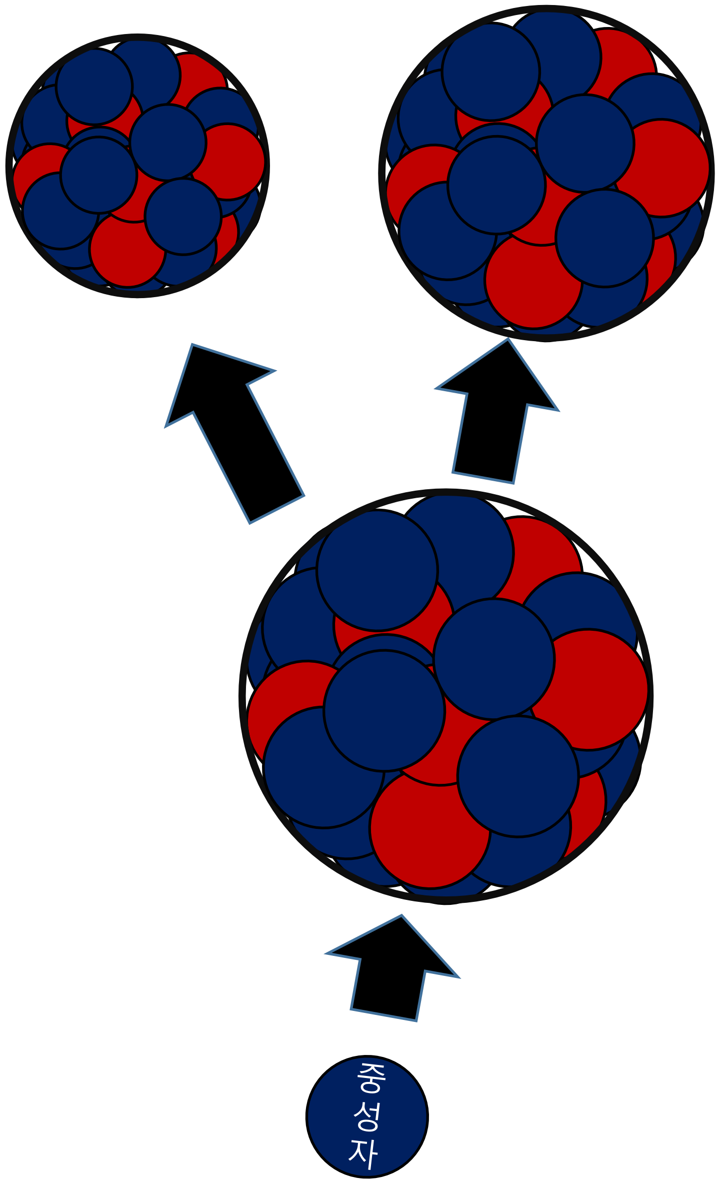
Nuclear Data Production System at RAON



Heavy Ion Meeting
26 Aug. 2023

Beomkyu Kim
Sungkyunkwan Unversity

Needs for the Nuclear Data



- Nuclear Data (핵데이터)
  - **Not only** in nuclear astrophysics
  - 수십 MeV 에너지 영역의 중성자 유도 단면적 핵 데이터는 **불충분하며 불확도가 큼**
  - 물성변화시험, 국방, 비파괴검사, 반도체 검사 등 다양한 분야에서 고속 중성자 관련 핵 데이터에 대한 수요가 증가하고 있음
  - 가속기구동 시스템(ADS), 방사성 폐기물 처리, 의료/산업 동위원소 생산 등 다양한 응용 분야에서 정밀한 핵 데이터 확보가 요구됨

사용후 핵연료

nDPS Nuclear Data Production System

- 경수로 vs 중수로
  - 경수로형 핵연료는 U-235(우라늄-235)의 농축도가 3~5% 정도인 농축 우라늄을 사용
  - 중수로형 핵연료는 U-235 함유량이 0.7%인 천연 우라늄 사용
  - 경수로형 핵연료는 다발당 우라늄 무게가 450kg 정도이며 4년 정도 사용
  - 중수로형 핵연료는 다발당 우라늄 무게가 19kg 정도이며 9개월 정도 사용
  - 10년 정도 냉각된 중수로형 사용후핵연료의 경우 동일 조건의 경수로 사용후 핵연료 대비 열 발생량은 1/10, 방사능은 1/20 수준임

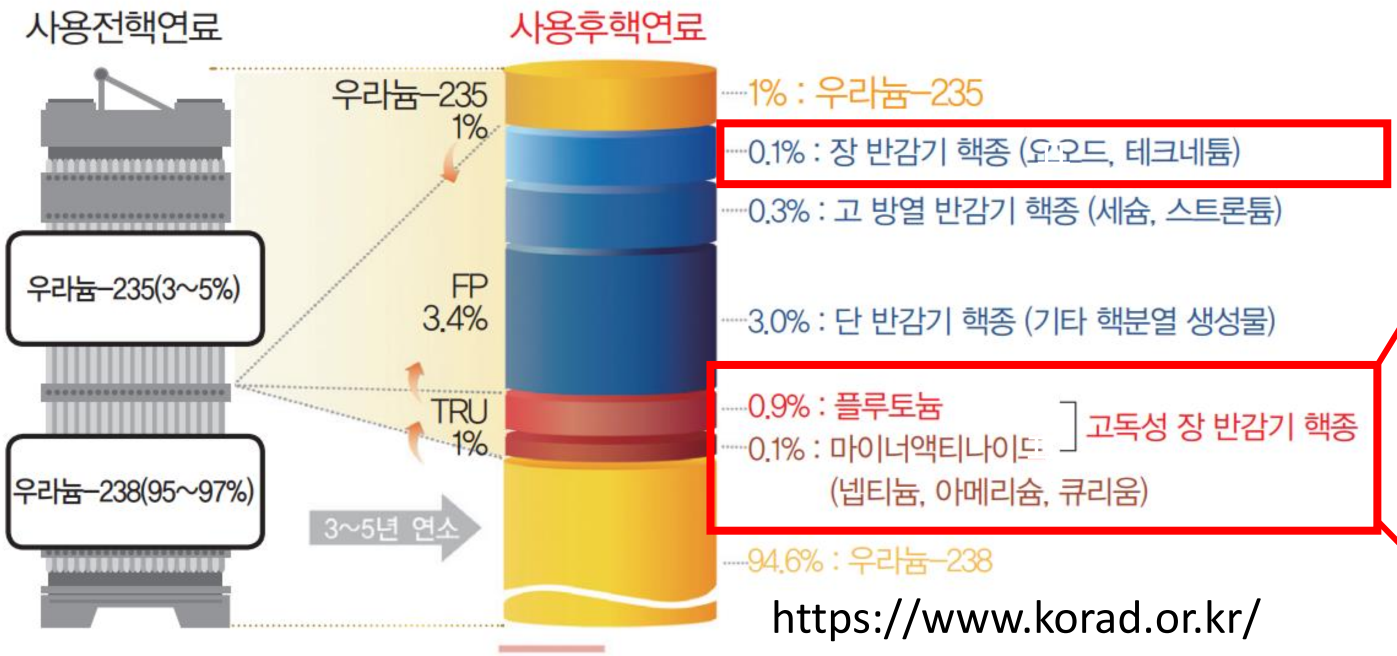
구 분	경수로형 핵연료	중수로형 핵연료
국내보유 원전	20기	4기
개발국가	미 국	캐나다
냉각재	경수(H_2O)	중수(D_2O)
사용연료	저농축우라늄(U-235 : 3~5%)	천연우라늄(U-235 : 0.7%)
연료 교체주기	18개월마다 1/3씩 교체	매일 일정량(16다발) 교체
연평균 사용후핵연료 발생량	약 400톤 (약 20톤/기)	약 350톤 (약 90톤/기)
원자로 형태	수직 (1개의 원통용기)	수평 (380개의 압력관)
핵연료 다발 모양	 – 길이 : 약 400cm – 폭 : 20cm – 무게 : 약 450kgU	 – 길이 : 50cm – 직경 : 10cm – 무게 : 약 19kgU

※ 중수(D_2O)는 경수(H_2O)보다 중성자를 덜 흡수하기 때문에 U-235(우라늄-235)의 농축도가 낮아도 됨.

https://www.korad.or.kr/

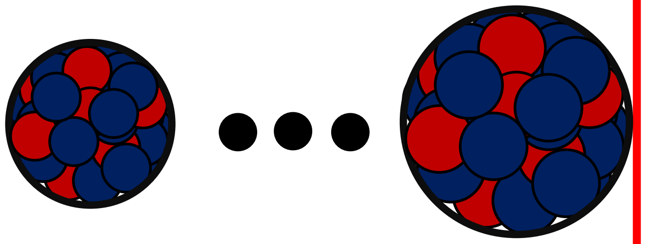
사용후 핵연료

- Nuclear Data (핵데이터)
  - 사용후 핵연료 처리를 해결할 수 있는 가속기 구동 핵변환 기술 대두 (고속 임계로, 가속기구동 미임계로



https://www.korad.or.kr/

악티나이드



$_{89}\mathrm{Ac}$ ... $_{103}\mathrm{Lr}$

마이너 악티나이드:
악티나이드 – $_{92}$ Ur, $_{94}$ Pu

  - 단순 저장하는 현재 사용후 연료저장 방법은 1%에 불과한 장반감기 핵종과 마이너 악티나이드 때문
  - 악티나이드: Pu 238 (100년) → Am (천년) → Pu (240, 239), Cu (245) → Np (237, 200 만년)
  - 원자로 정지후 약 7%, 1시간 후 1.5%. 1주일 0.4%, 1주일 후 0.2%, 사용후연료저장조에서 1년이상 냉각 (발전소에서 20년 이상 보관)

사용후 핵연료

- Nuclear Data (핵데이터)
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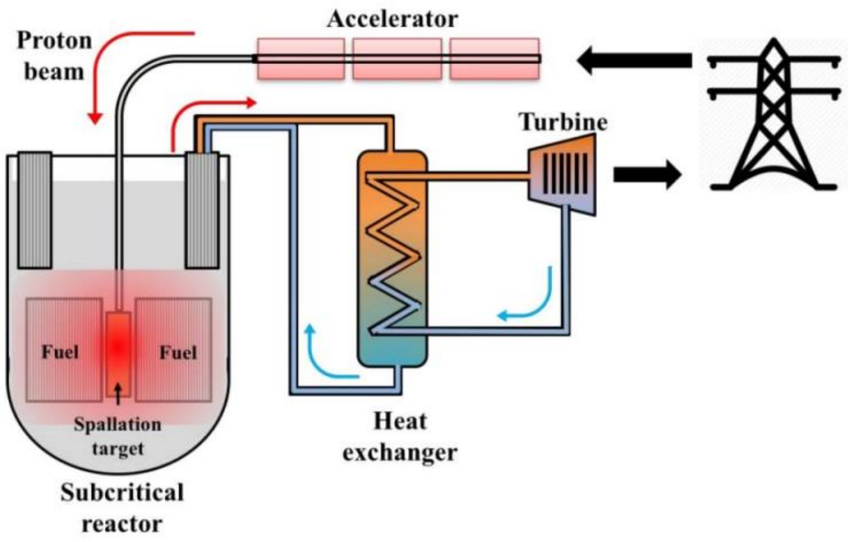
Isotope	Decay type	Half–life (yr)	Radiotoxicity (Sv/g)
^{79}Se	$\beta-$	6.5×10^{42}	8.259
^{90}Sr	$\beta-$	29	1.269×10^{5}
^{93}Zr	$\beta-$	1.5×10^{5}	1.045
^{94}Nb	$\beta-$	2.0×10^{4}	1.410×10^{1}
^{99}Tc	$\beta-$	2.1×10^{5}	6.056×10^{-1}
^{107}Pd	$\beta-$	6.5×10^{6}	1.048×10^{-3}
^{126}Sn	$\beta-$	1.0×10^{5}	6.306
^{129}I	$\beta-$	1.6×10^{7}	2.696×10^{-1}
^{135}Cs	$\beta-$	2.3×10^{6}	8.532×10^{-2}
^{137}Cs	$\beta-$	30	4.190×10^{4}
^{151}Sm	$\beta-$	89	1.281×10^{2}

Radiological properties of Long-lived Fission Products

가속기 구동 미임계로

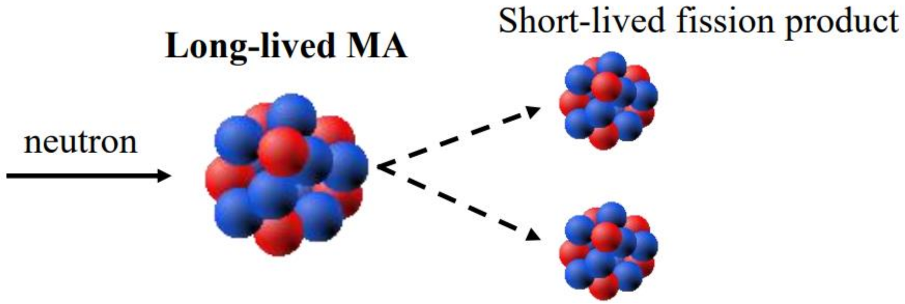
- 가속기구동 미임계로

Accelerator-Driven System



- Sub-critical reactor
- Neutron source using a proton accelerator
- Spallation neutron target system
- Transmutation of long-lived MA and fission product
- Fast-neutron reactor

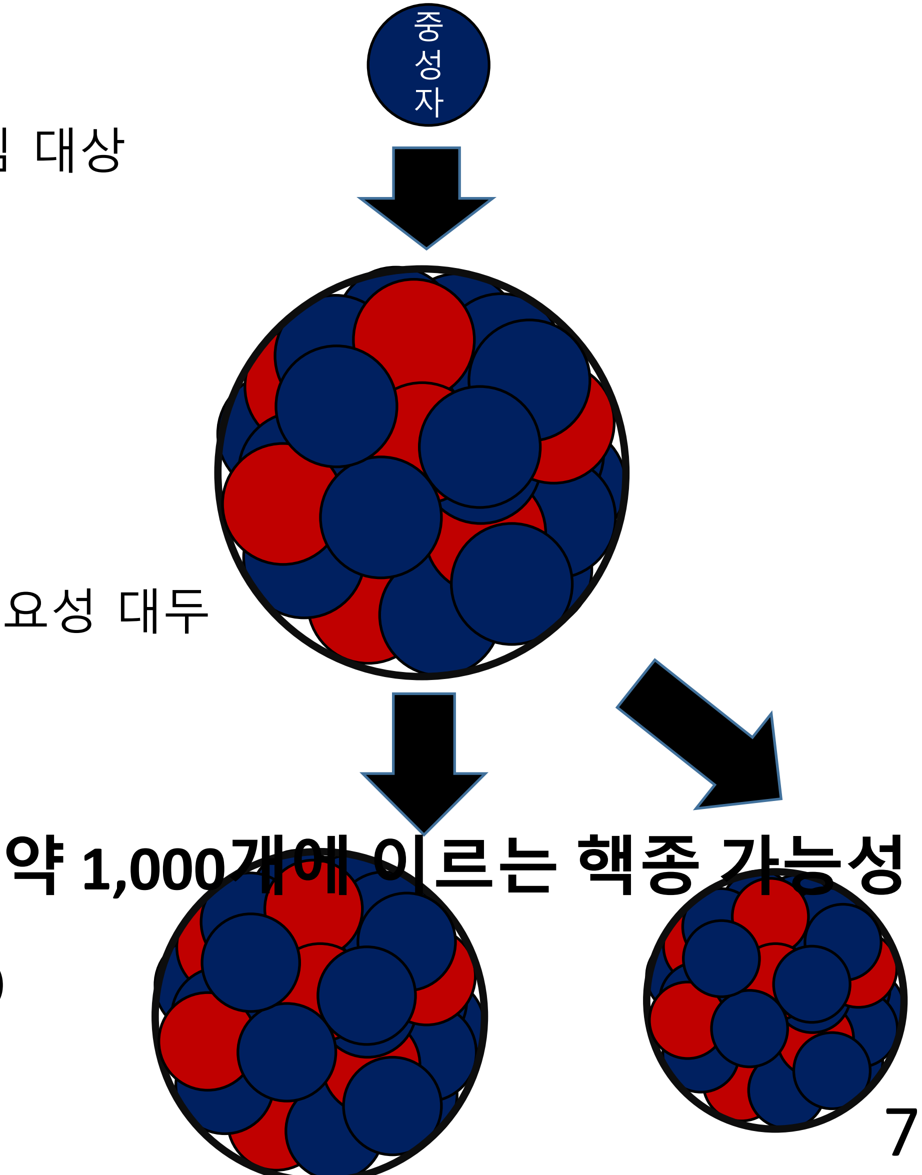
Transmutation of nuclear waste



- ADS에서의 Nuclear data의 필요성
  - Essential information to Minor Actinides and Fission products
  - Reactor structure materials
  - Altogether needs fast-neutron induced information (or reactions)

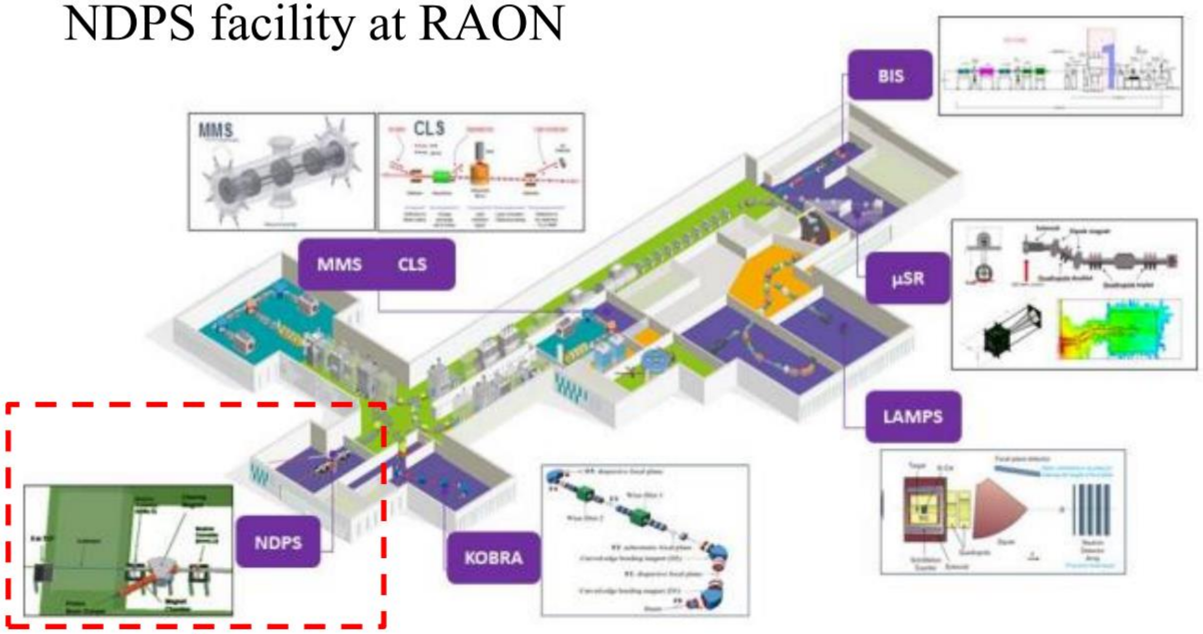
핵데이터 당면 과제

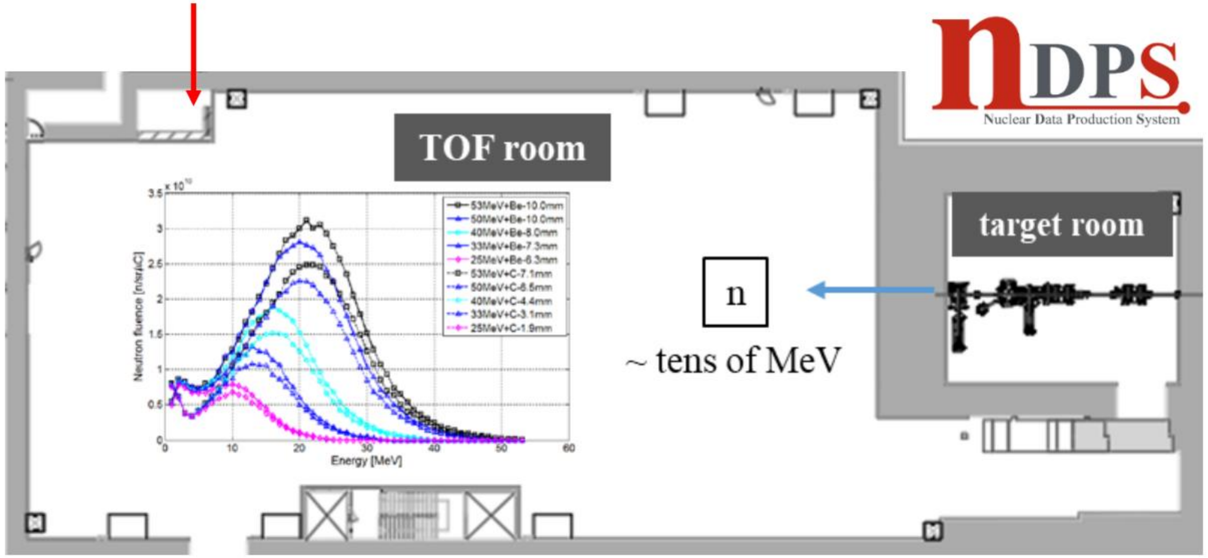
- 핵분열: 1938 발견, 그러나 여전히 많은 연구가 필요
- 기술적인 문제
  - 과거 에너지가 낮은 열중성자 (eV~keV)에 의한 핵분열이 관심 대상
  - 현재: 고에너지 중성자에 의한 핵분열 데이터가 필요
- 물리적인 문제
  - 약 1,000개에 이르는 핵분열 생성물
  - 핵분열 underlying dynamics는 여전히 연구가 미비한 상황
  - 핵분열후 마아너 악티나이드 핵변환(핵연료재순환)에 연구 필요성 대두
- NDPS 관측대상
  - 약 1,000개에 이르는 핵분열 후 핵종들의 종류 특정
  - 사전 및 사후 핵분열 핵종 산출량
  - 즉발중성자 중첩도 및 즉발핵분열 중성자 에너지 분포 (PFNS)
  - 총 운동에너지 및 감마선 측정



NDPS 장치

NDPS facility at RAON

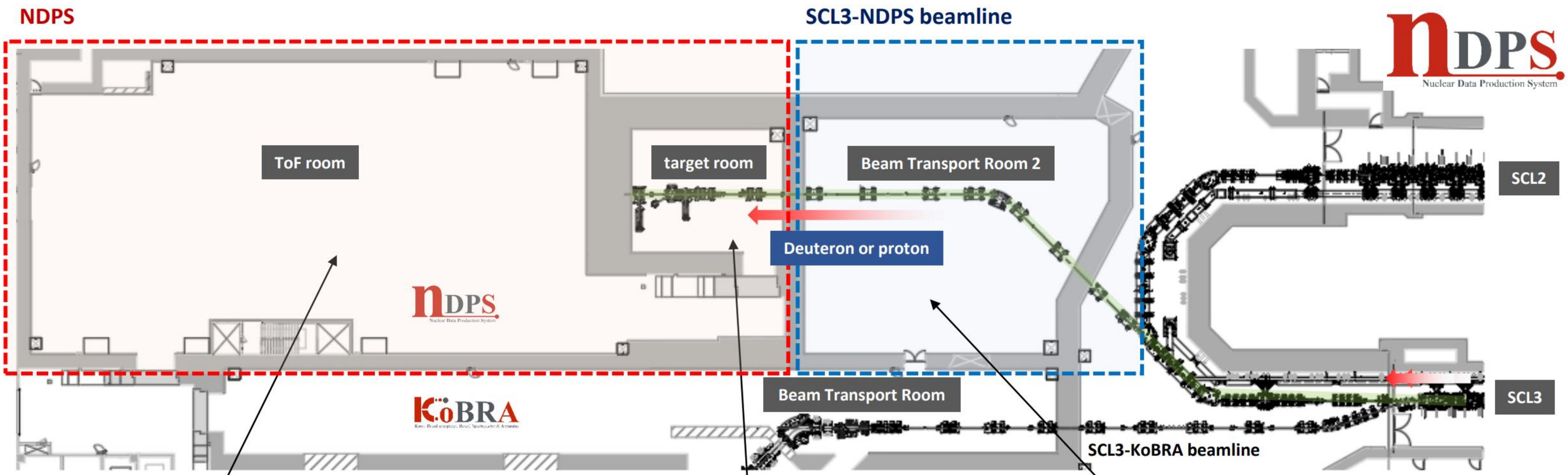




Nuclear **D**ata **P**roduction **S**ystem at RAON

- Neutron cross sections are the fundamental quantity not only for basic sciences but also for various application.
- By using neutrons, cross section of (n, f), (n, γ), (n, xn)
- Nuclear data for fast nuclear reactor systems.
- Nuclear data related to medical isotope production.

- Protons and deuterons up to 82.7 MeV and 97.8 MeV.
- Beam current ~ 10 μA
  Beam repetition rate is < 200 kHz
  Pulse width is 1 ns (FWHM)
- Li(p,n) for quasi-monoenergetic neutrons
  C(d,n) for white neutrons

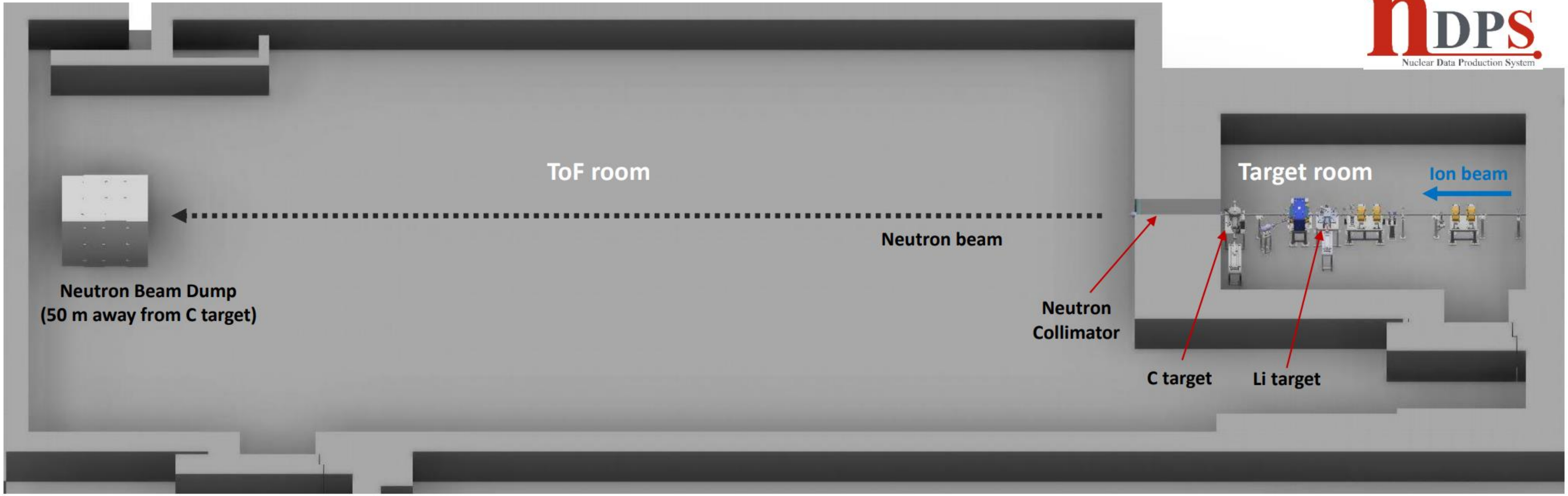

NDPS
SCL3-NDPS beamline
ToF room
target room
Beam Transport Room 2
Deuteron or proton
SCL2
SCL3
Beam Transport Room
SCL3-KoBRA beamline
Nuclear Data Production System

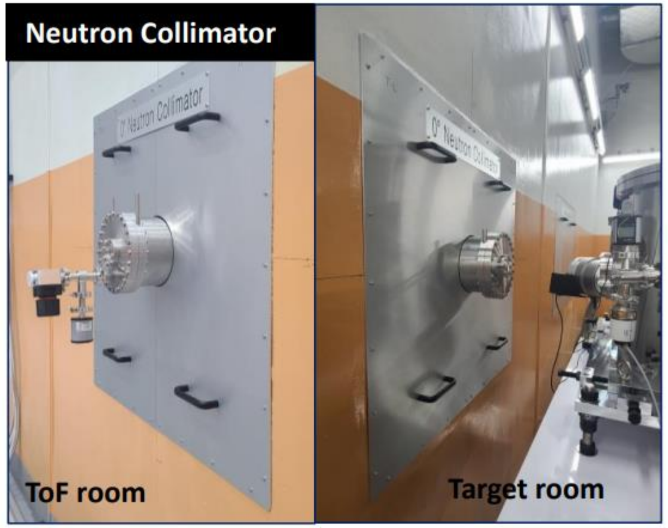

중성자 측정실 ToF room
2020.10


표적실 Target room
2020.10


빔수송실2 Beam transport room2
2020.10

nDPS
Nuclear Data Production System

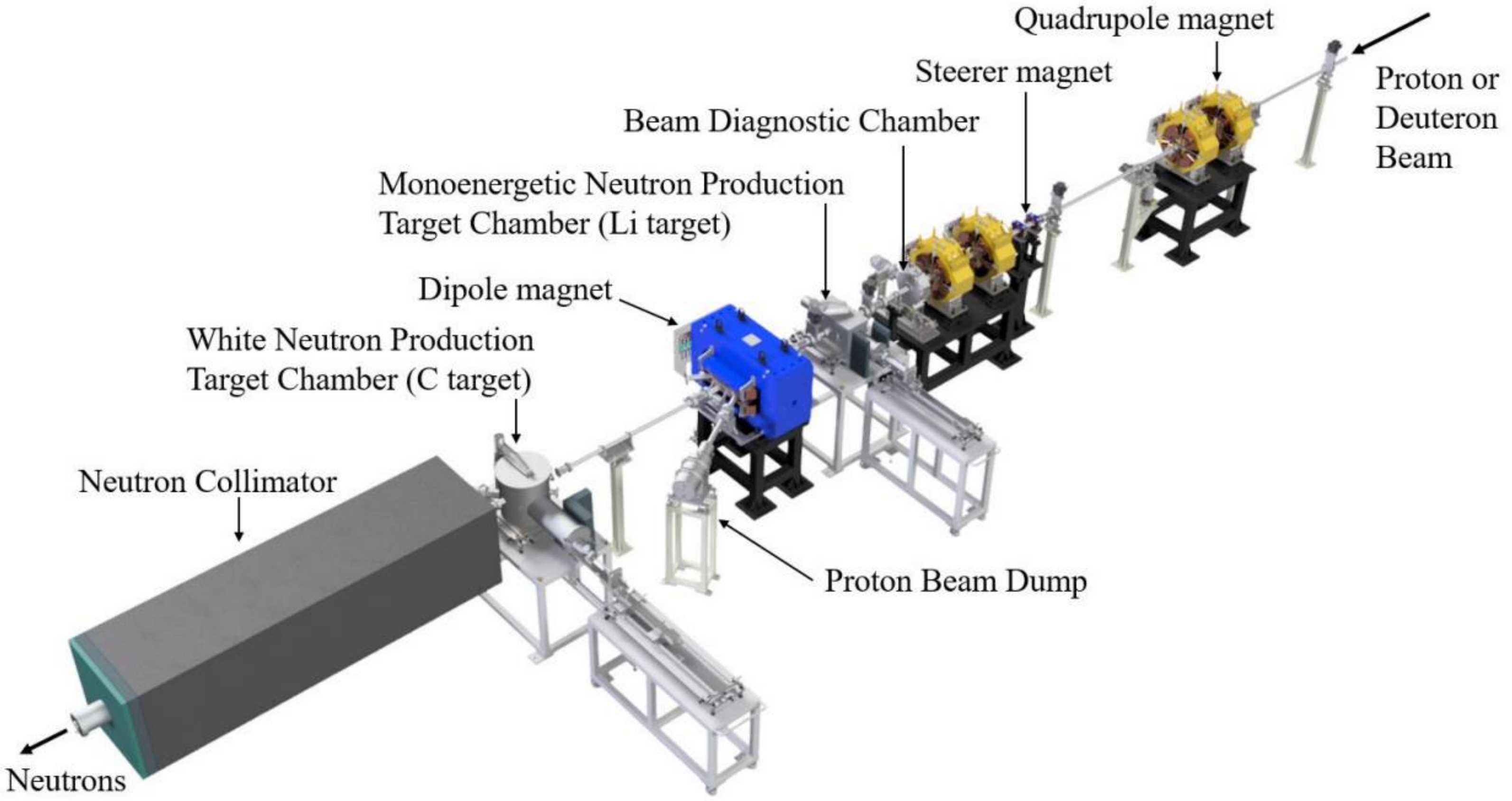




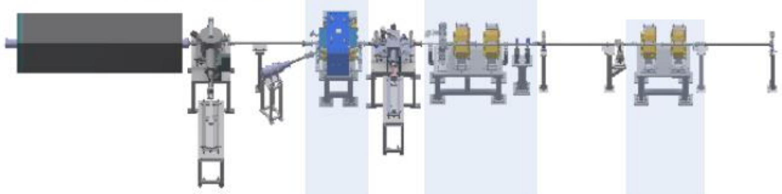
Nuclear Data Production System

❖ **Specification of NDPS**

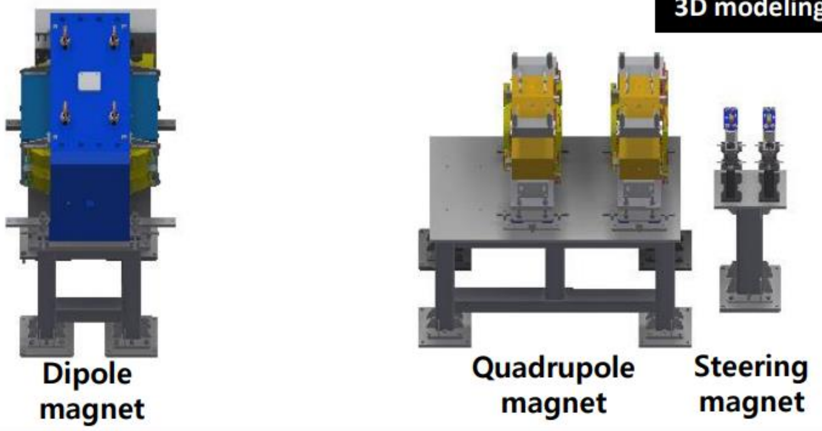
Beam ion	Proton, deuteron
Maximum Beam energy	49 MeV/u for deuteron 83 MeV/u for proton
Maximum Beam current	~10 μA
Target	**C** for white neutron **Li** for monoenergetic neutron
Bunch length	~ 1 nsec
Repetition rate	1 – 200 kHz
Flight length	5 – 40 m
Neutron flux	~ 10^8 cm^{-2} sec^{-1} at 5 m



Magnet



3D modeling



Specification

1. Dipole magnet (1 ea)

Pole gap	80 mm
Maximum field	1.2 T
Effective length	570 mm
Power	17.6 kW

2. Quadrupole magnet (4 ea)

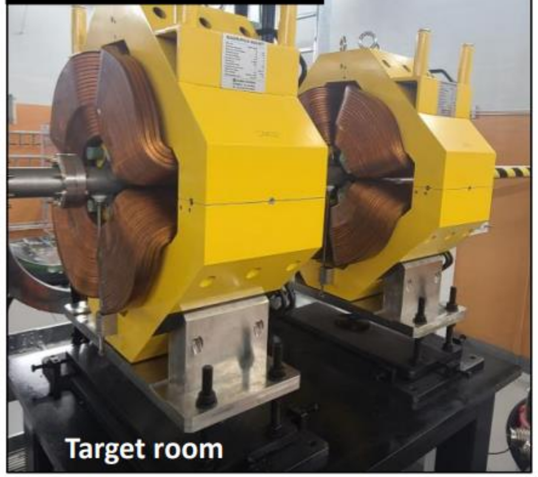
Aperture	70 mm
Max. gradient field	10 T/mm
Effective length	300 mm
Power	0.6 kW

3.Steering magnet (2 ea)

Pole gap	80 mm
Max. field integral	2.518 T mm
Power	22 W

Dipole magnet

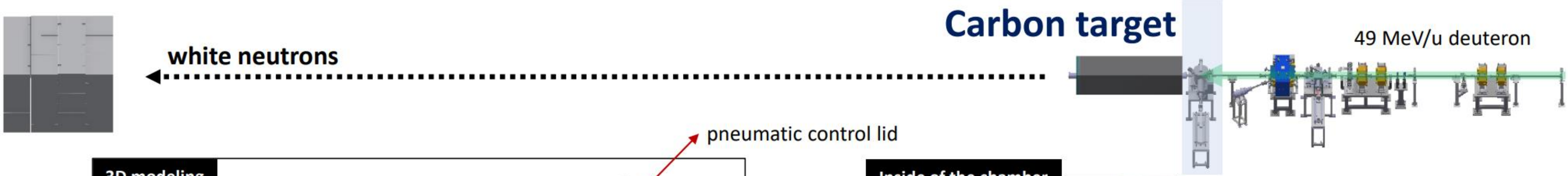
Quadrupole magnet

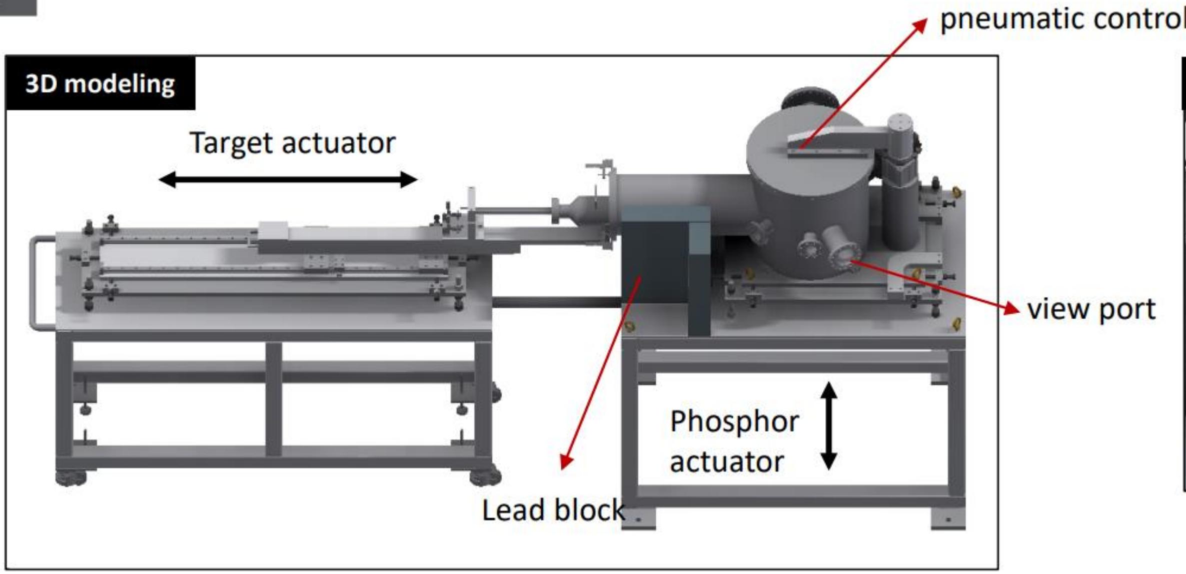


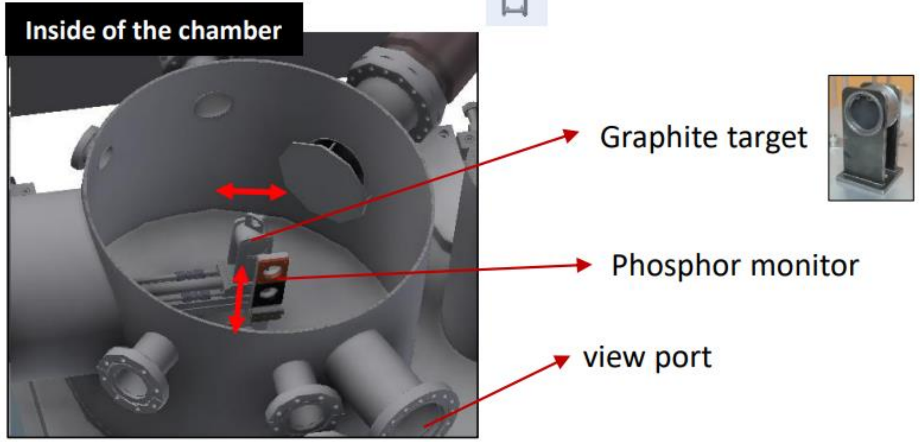
steering magnet

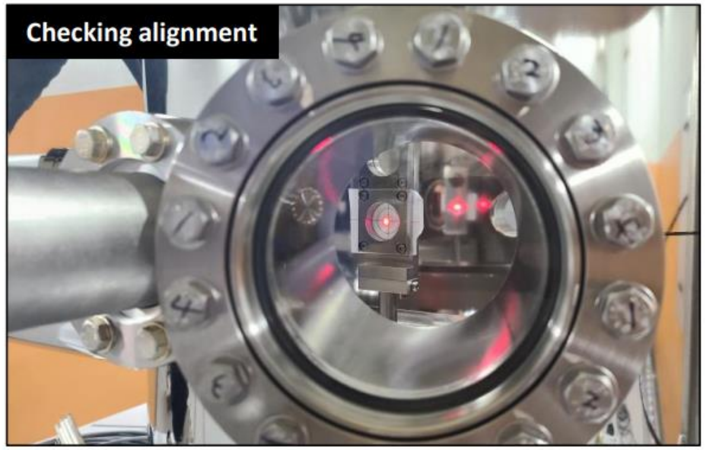
Power supply

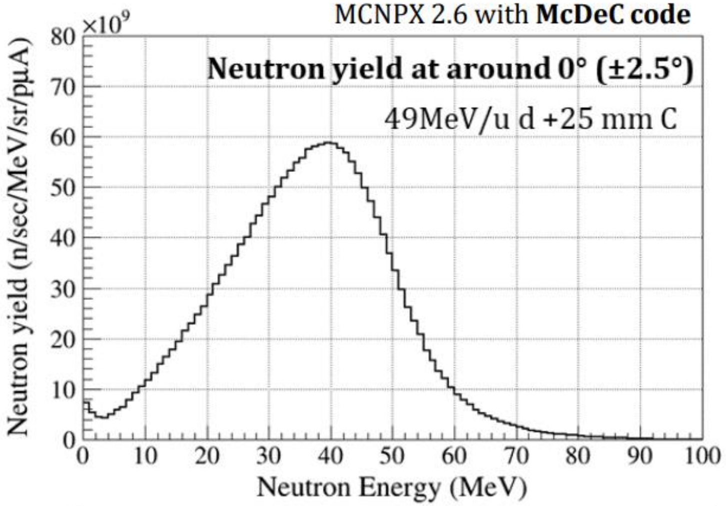
OPI program for the remote control







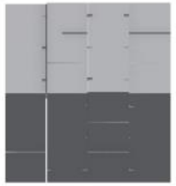




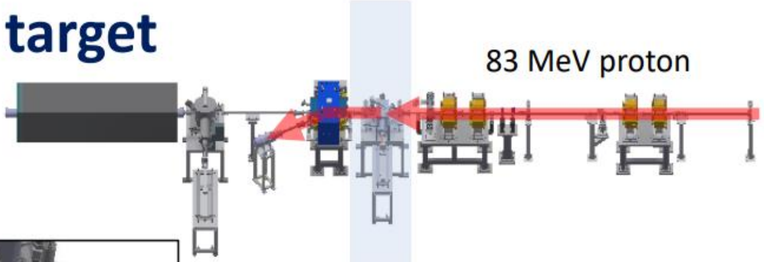
Neutron intensity at the end of the collimator

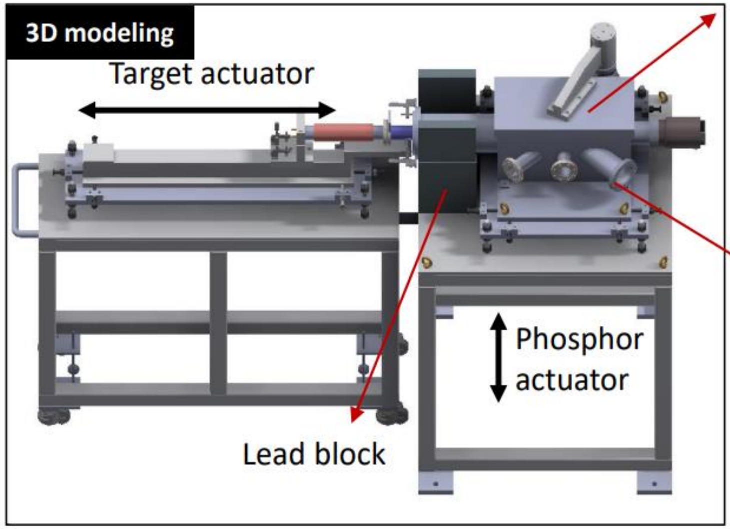
$\simeq$ **10^8 neutrons/cm^2/sec for 10 pμA**

Lithium target



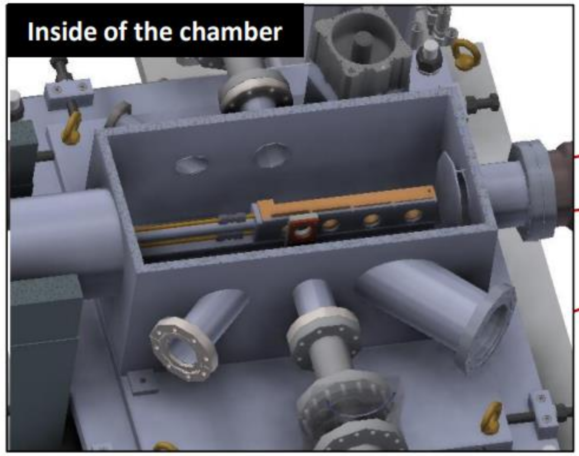
Monoenergetic neutrons





pneumatic control lid

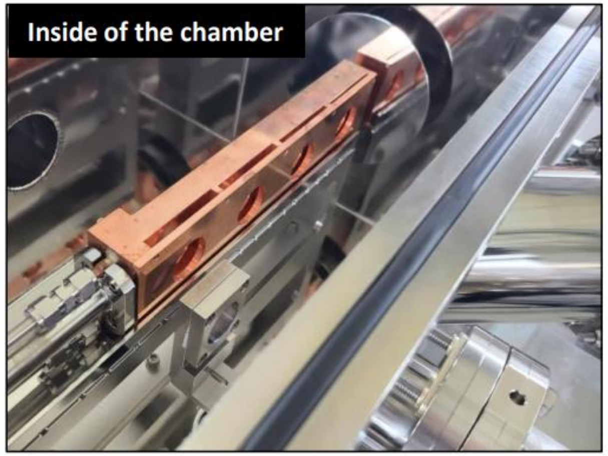
view port

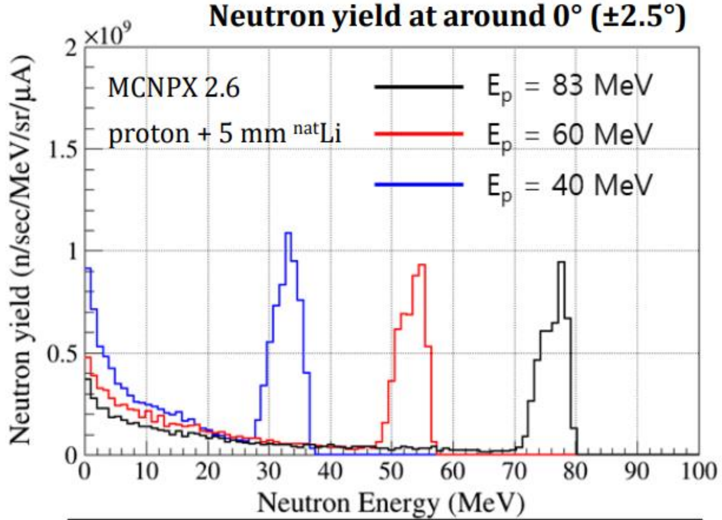


Lithium target

Phosphor monitor

View port

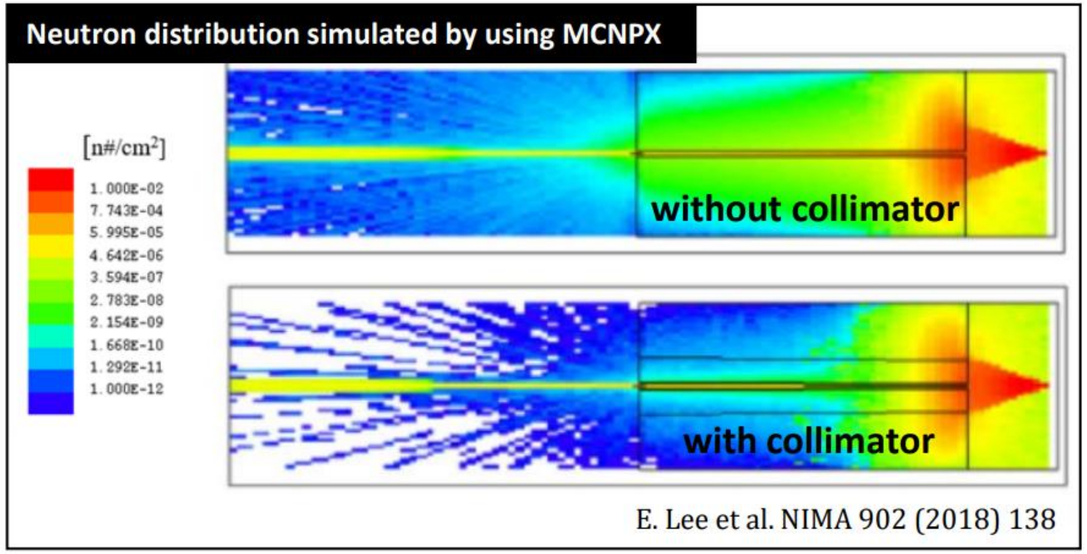


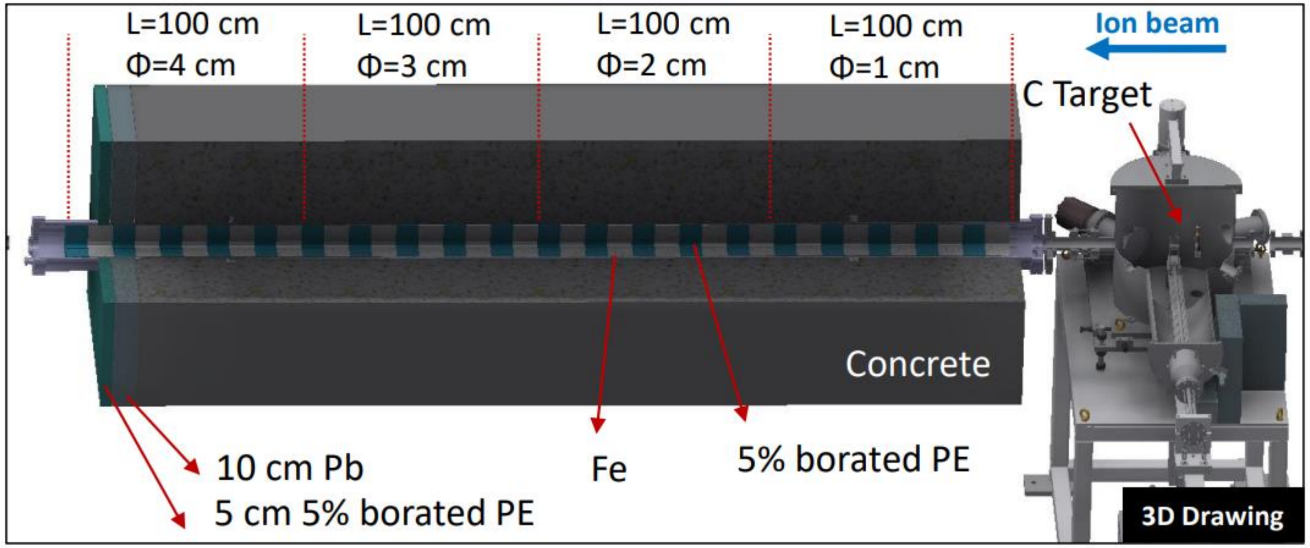


Neutron intensity at the end of the collimator

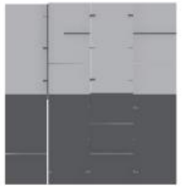
$\simeq 10^5$ **neutrons/cm²/sec for 10 pμA**

Neutron Collimator





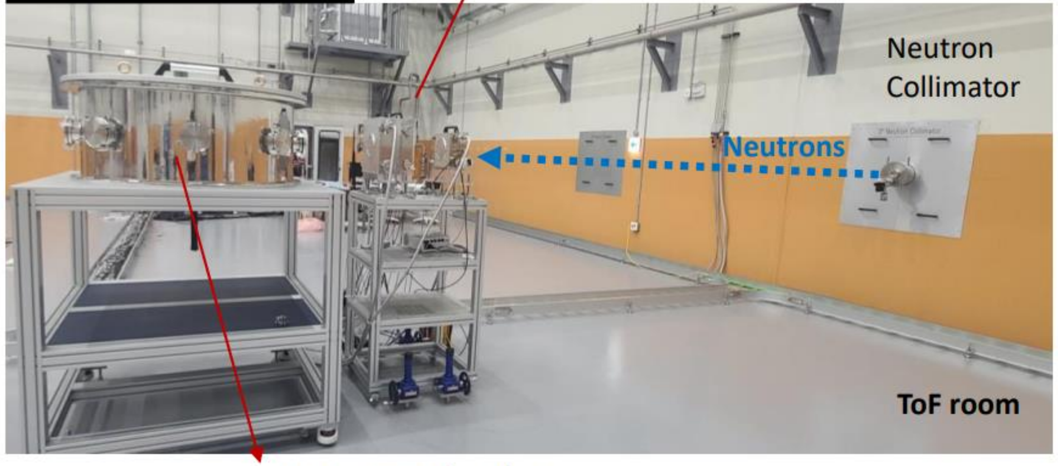
Detector



Kwangbok Lee “Detection system for low energy experimental facility” (07.21)

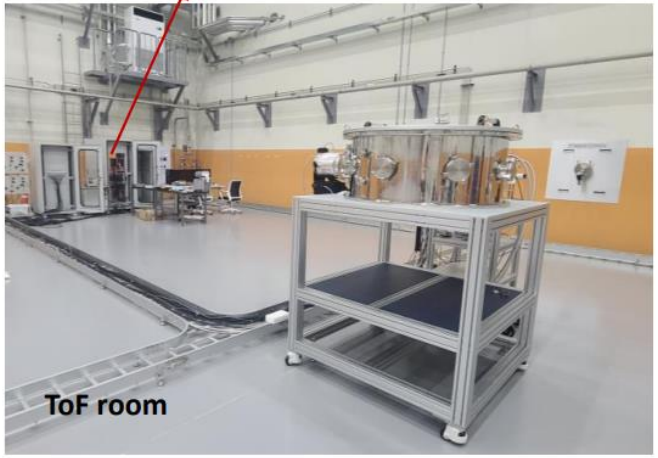
Detectors in ToF room

Monitoring detectors
(PPAC, GEM or Micromegas)

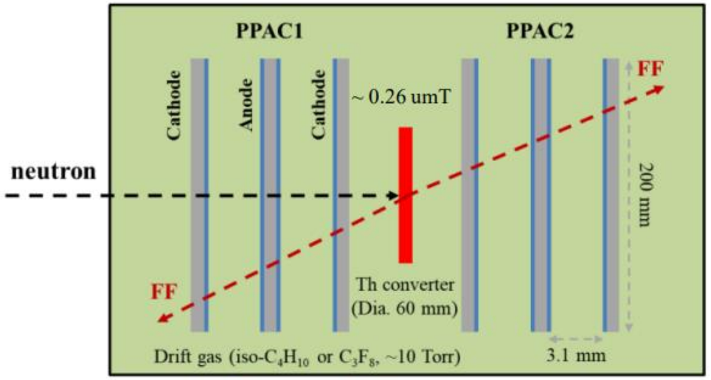


Fission exp. chamber

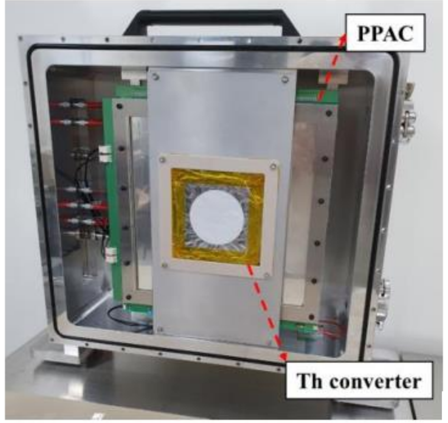
DAQ rack



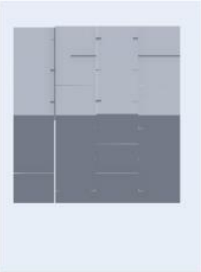
PPAC (Parallel Plate Avalanche Counter)



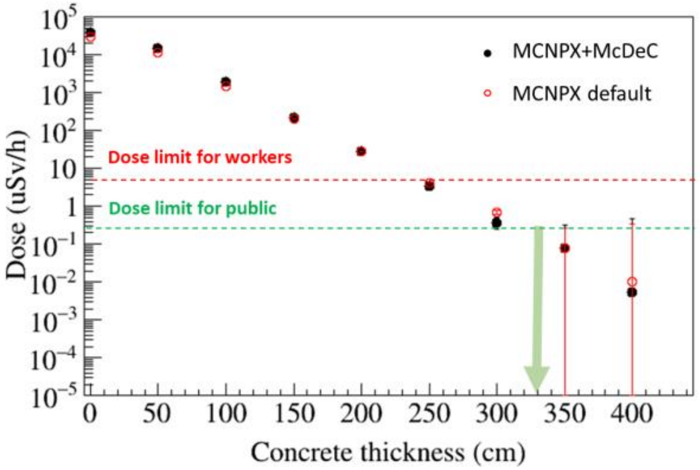
From D. Moon (SKKU)



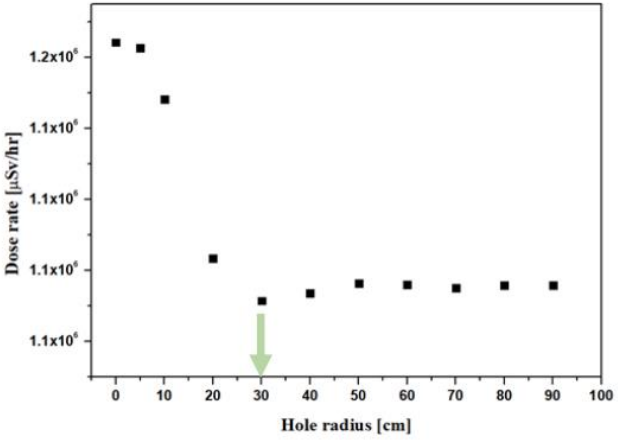
Neutron Beam Dump



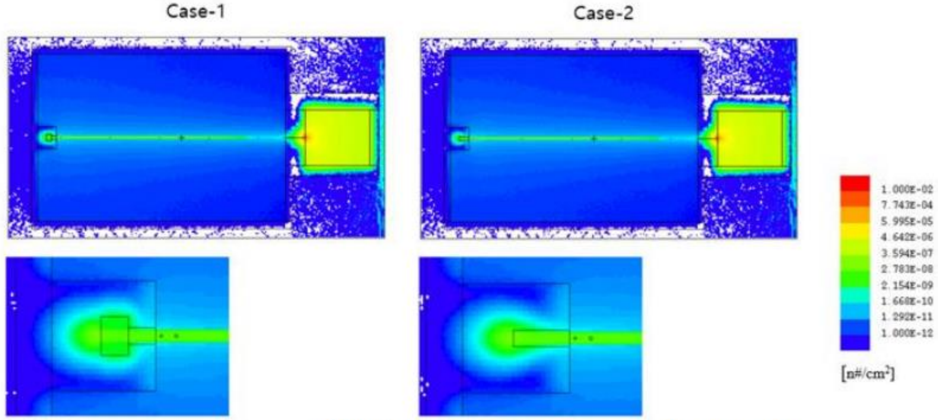
Dose calculation with the concrete thickness change



Dose calculation with the different hole radius



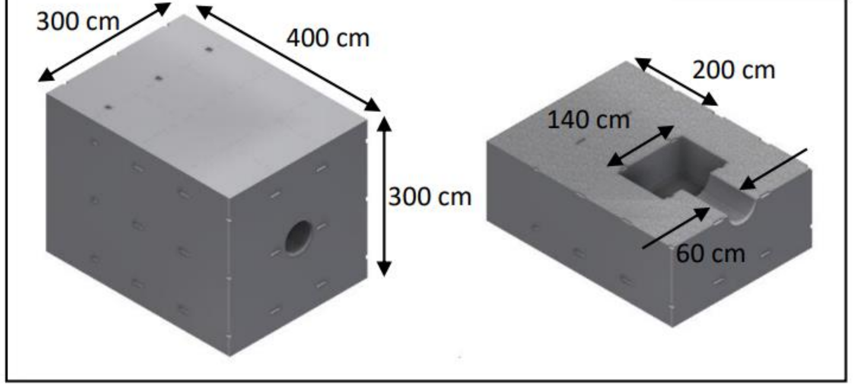
MCNP simulation with the different beam dump structure



※ Scattered neutrons: case 1 < case 2

- ❖ Concrete thickness = 330 cm
  - Beam dump = 200 cm
  - Wall thickness behind the dump 130 cm
- ❖ Hole radius = 30 cm
- ❖ Dump structure → case 1

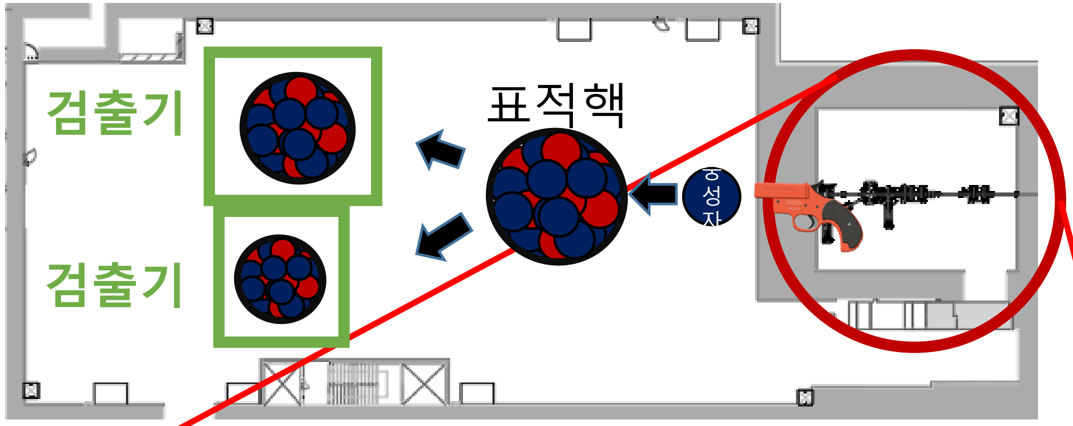
3D Drawing

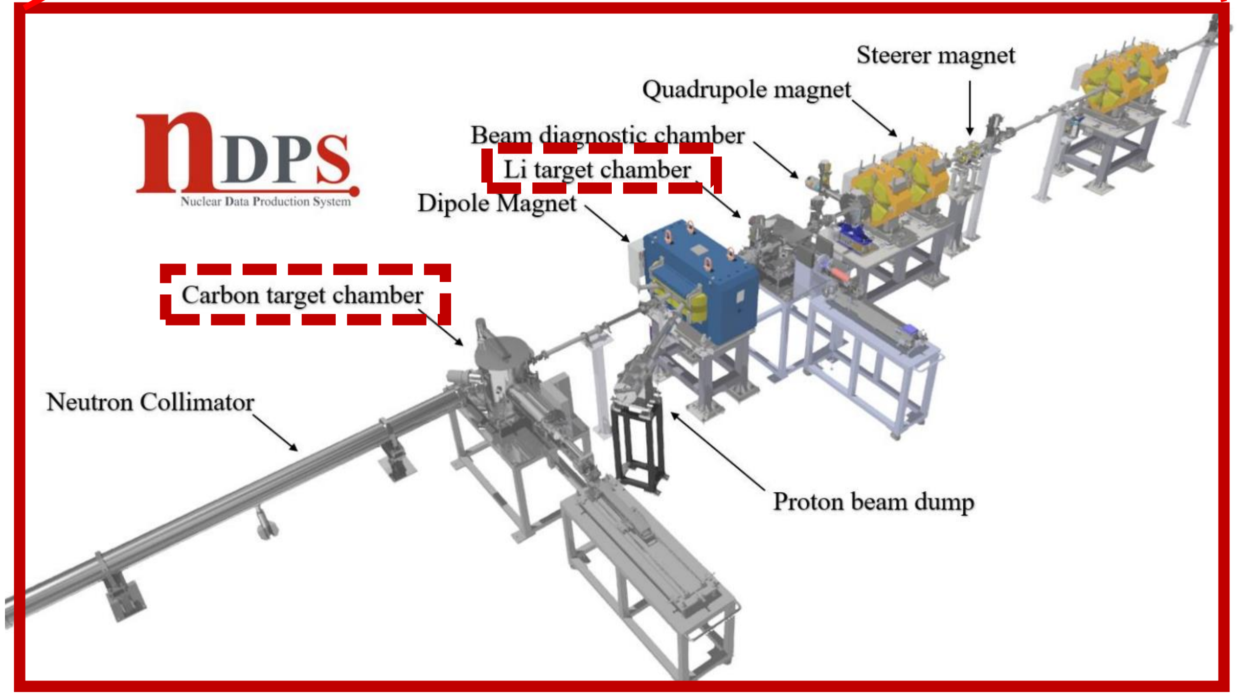


Photo

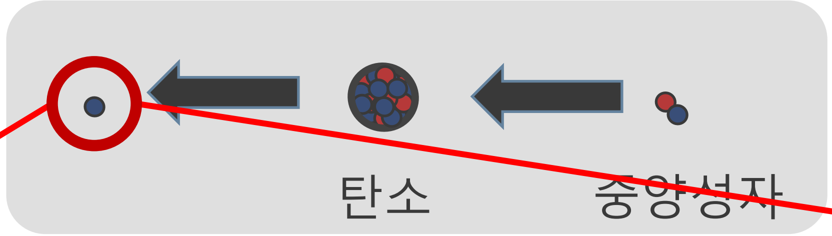
Simulation results from S. C. Yang (KAERI)

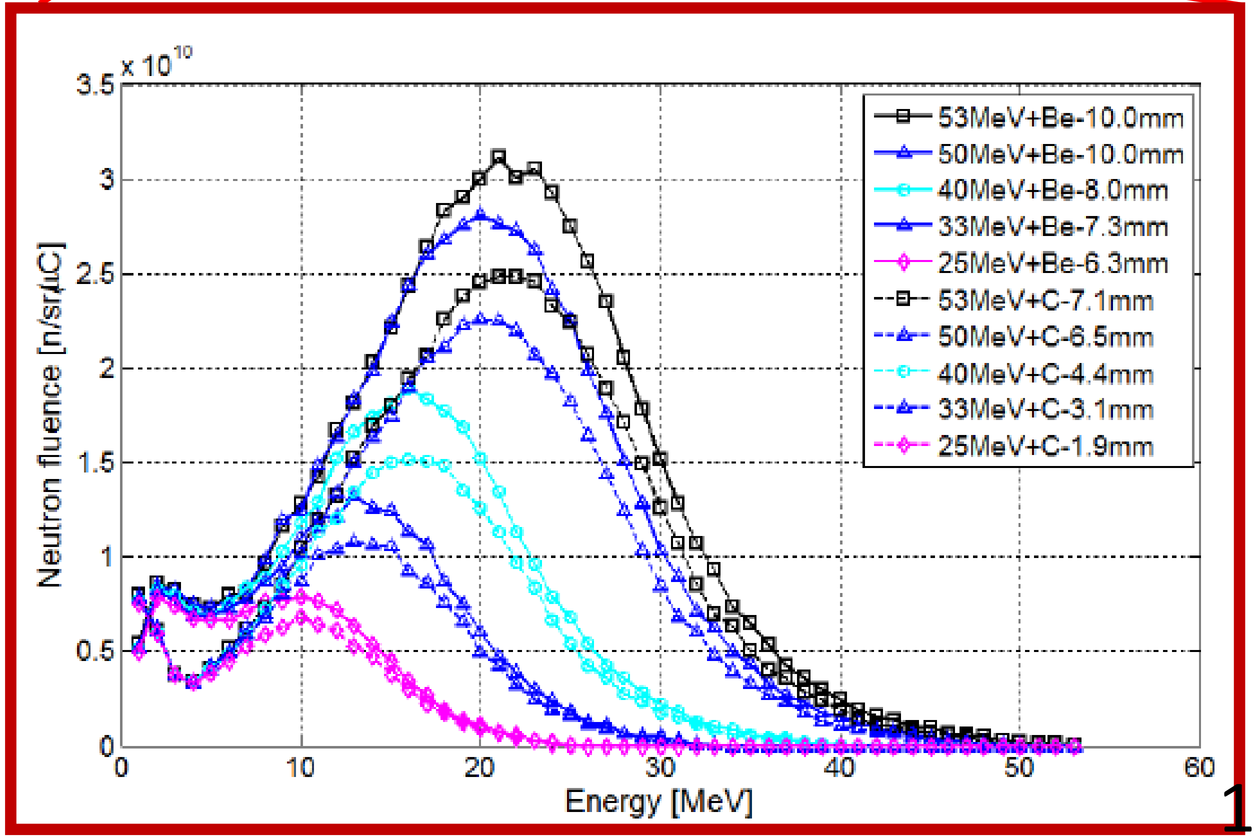
NDPS 장치





- 생성 중성자 에너지분포





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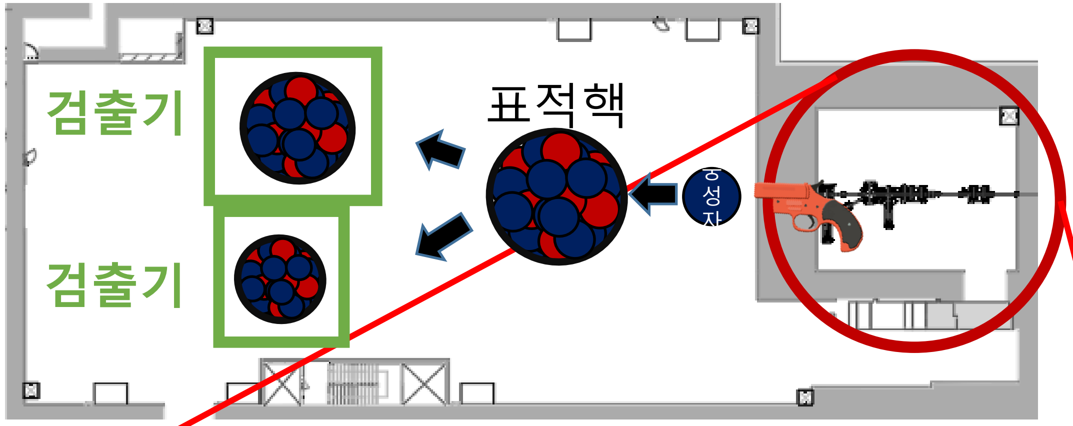
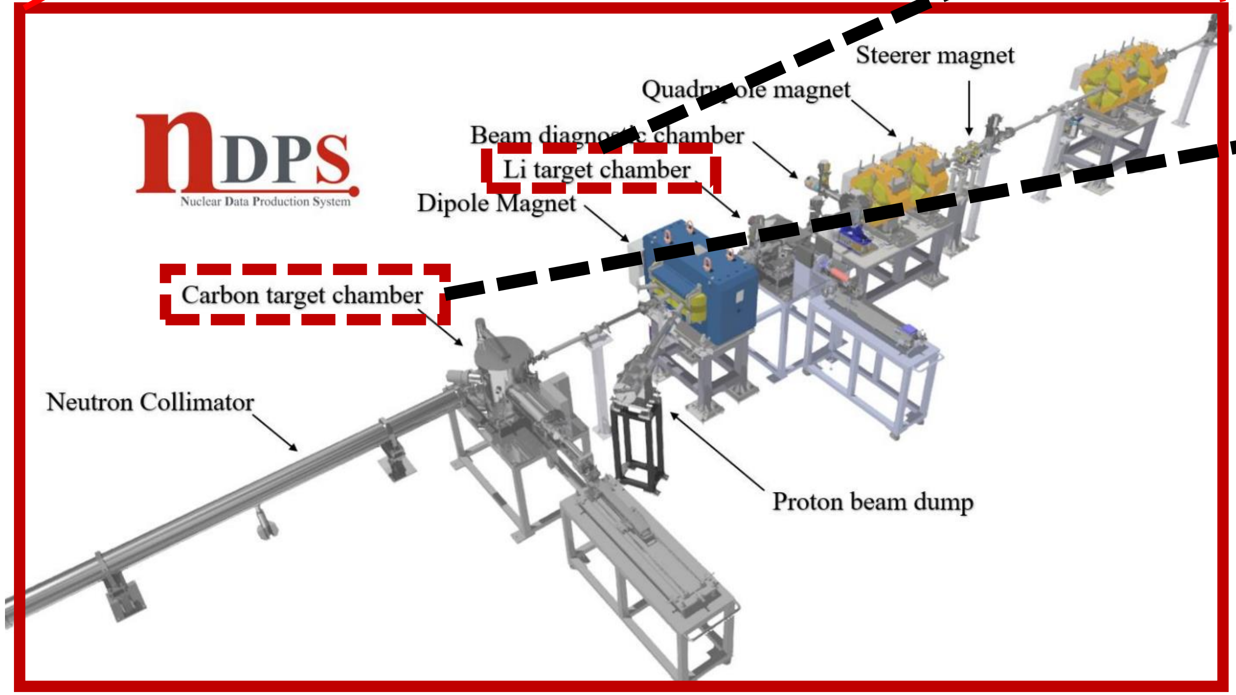
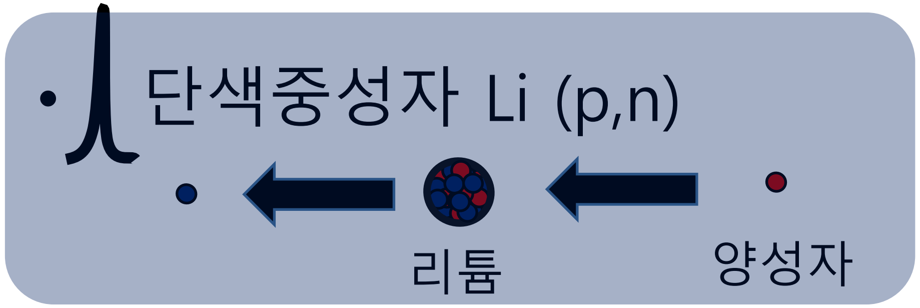
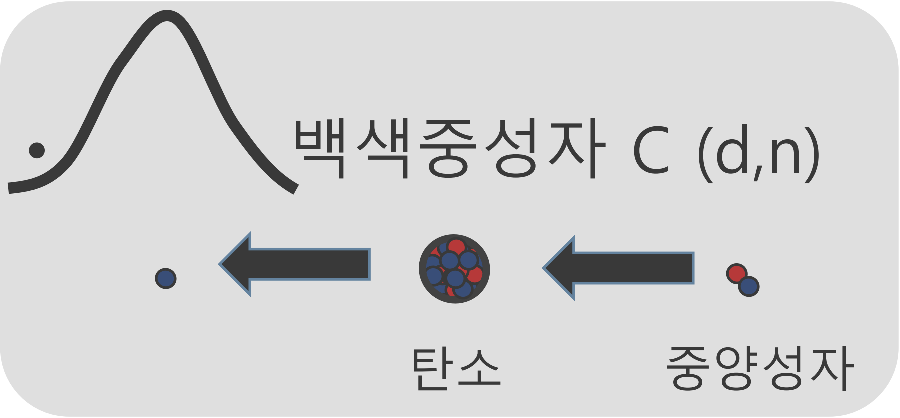




- 중성자 생성





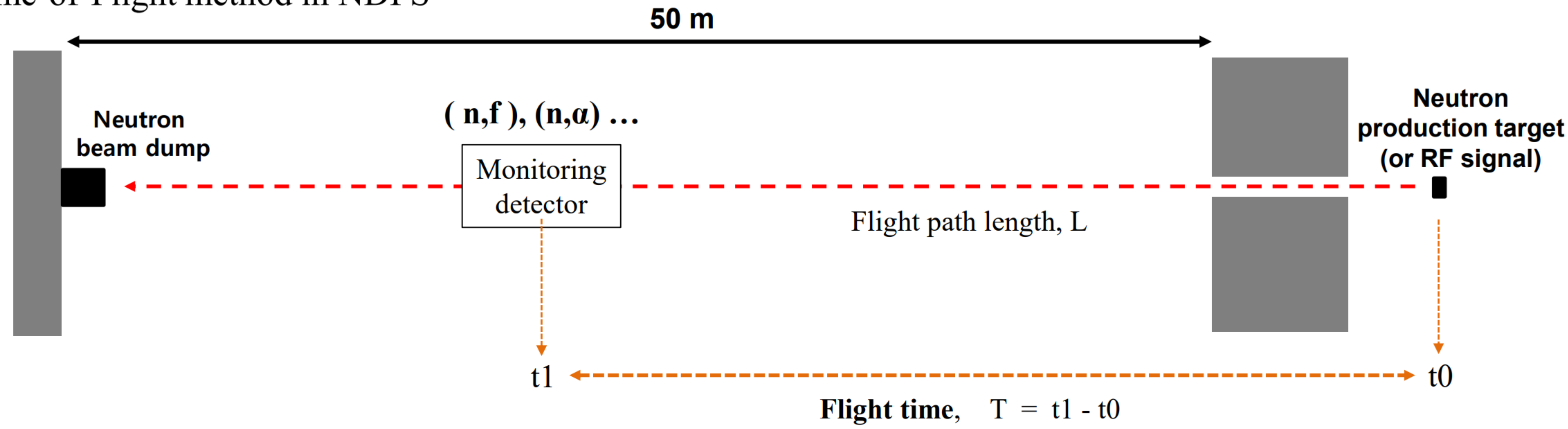
Primary beam	Beam energy [MeV]	Beam intensity [#/sec]	Beam power [kW]	Target			Neutrons [#/sec]
				Material	Density [g/cm^3]	Thickness [mm]	
d	97.8	7.68E+13	1.20	C	2.253	25	1.25E+13
p	82.7	9.74E+13	1.29	Li	0.534	2 ~ 7	9.21E+11

Repetition rate: 1 kHz ~ 500 kHz, Pulse width: 1~2 ns

NDPS 장치

Nuclear Data Production System

Time-of-Flight method in NDPS



Neutron energy

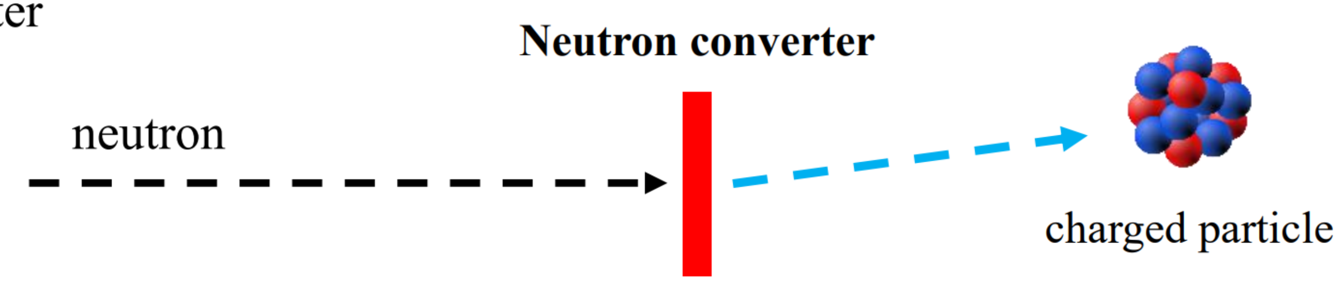
$$E_n = m_n c^2 \left(\frac{1}{\sqrt{1 - \left(\frac{L/T}{c}\right)^2}} - 1 \right)$$

Neutron production target

- **Li(p,n)** for quasi-monoenergetic neutrons
- **C(d,n)** for white neutrons

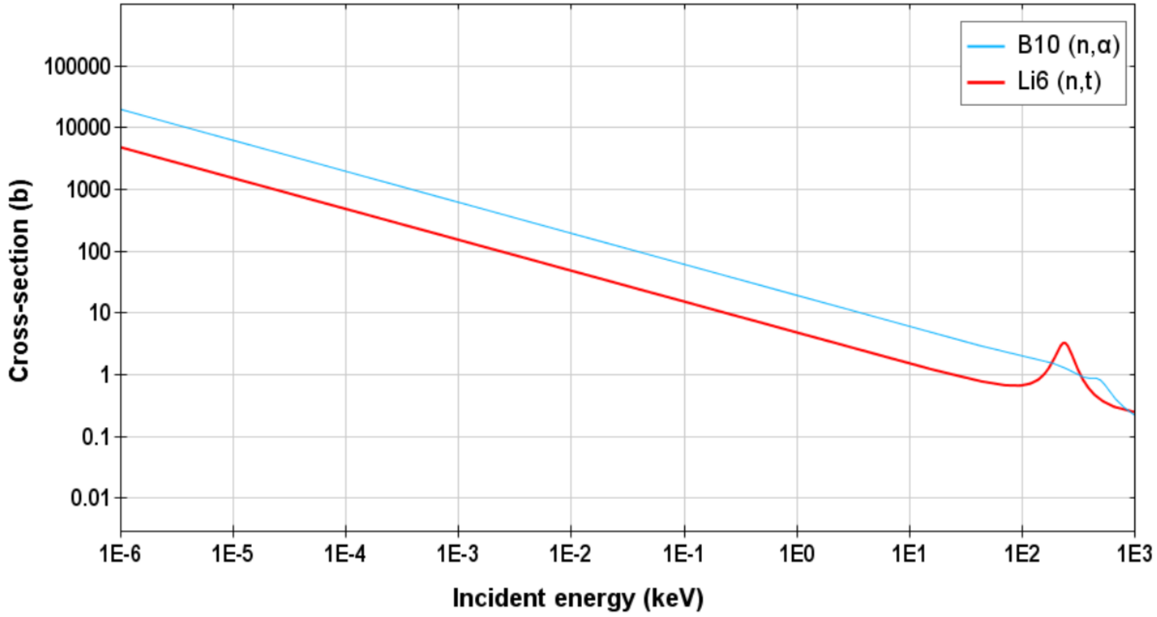
NDPS 장치

Fast-neutron converter

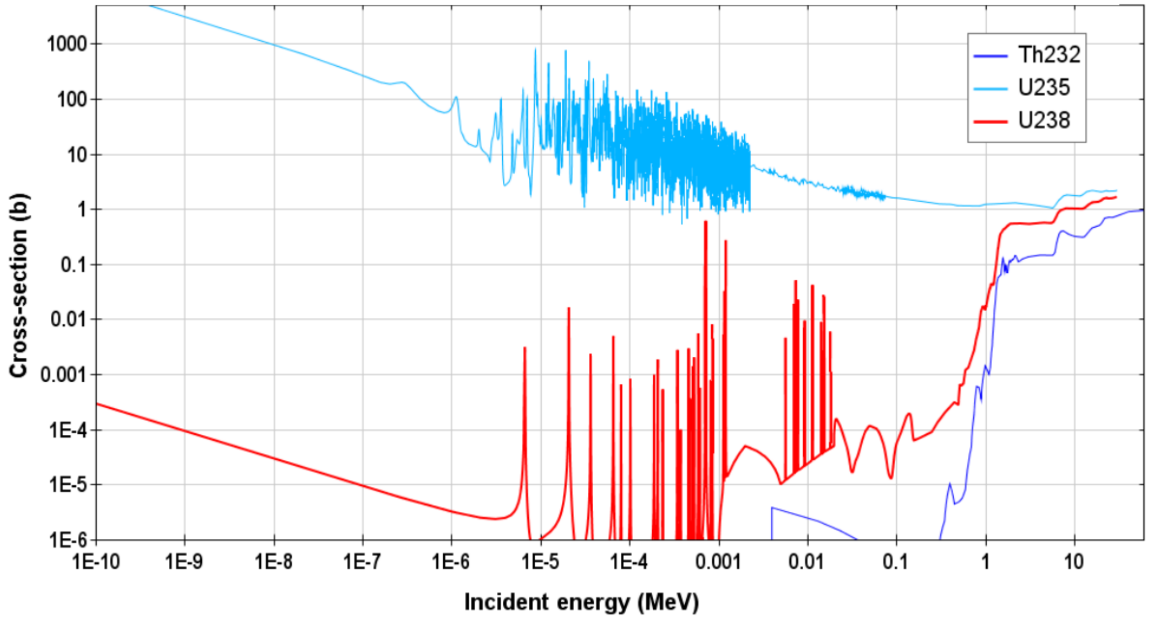


Neutron-charged particle conversion reaction

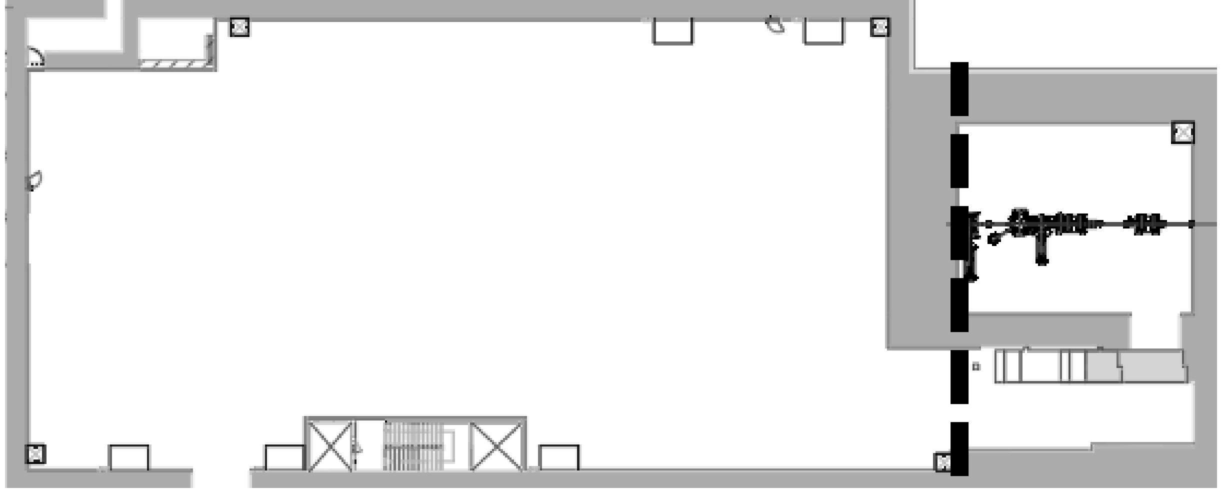
$^{10}B(n,\alpha)$ / ^{6}Li (n,t) cross section
for **low energy neutron**

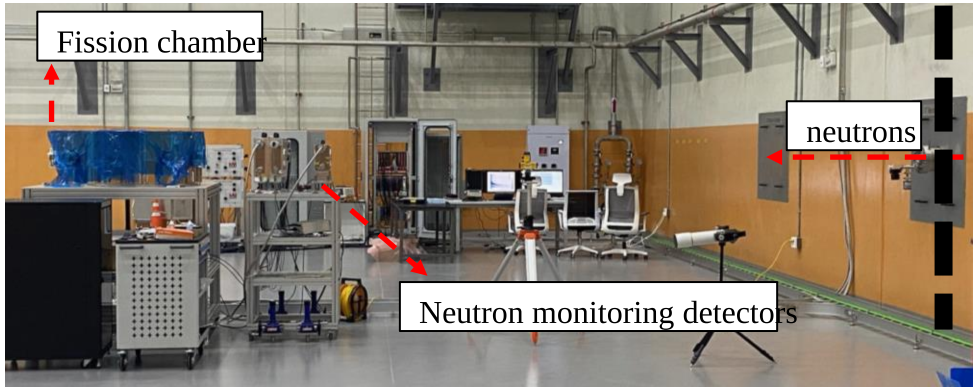


Neutron-induced fission cross section
for **high energy neutron**

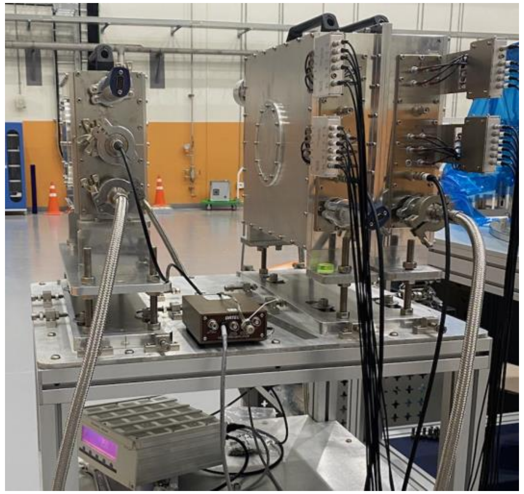


NDPS 장치

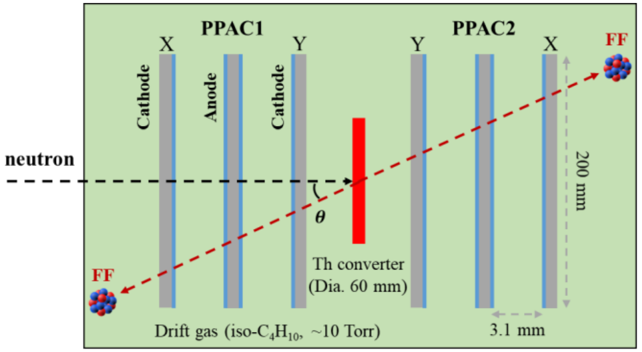




MICROMEGAS & PPAC

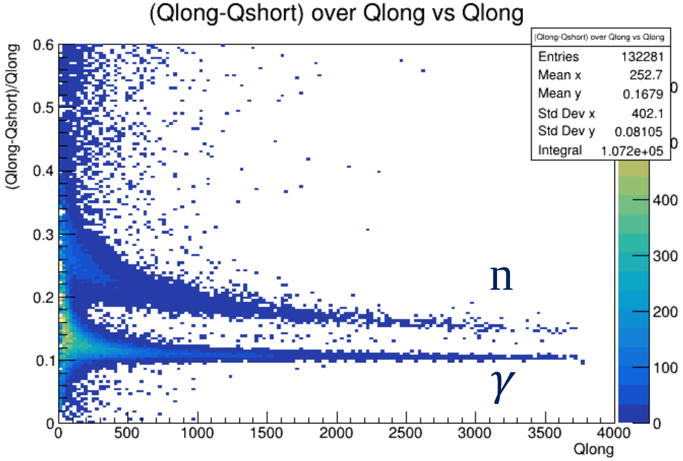


Parallel Plate Avalanche Counter

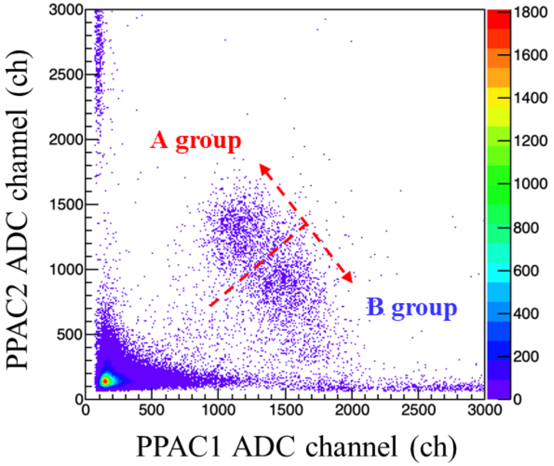


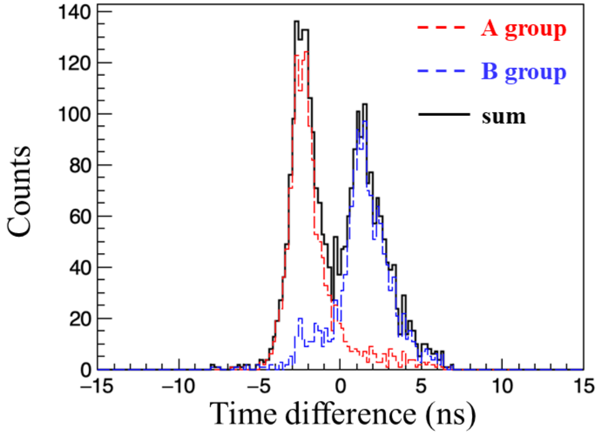
Liquid scintillator

K.B. Lee (IBS)



Neutron monitoring experiment

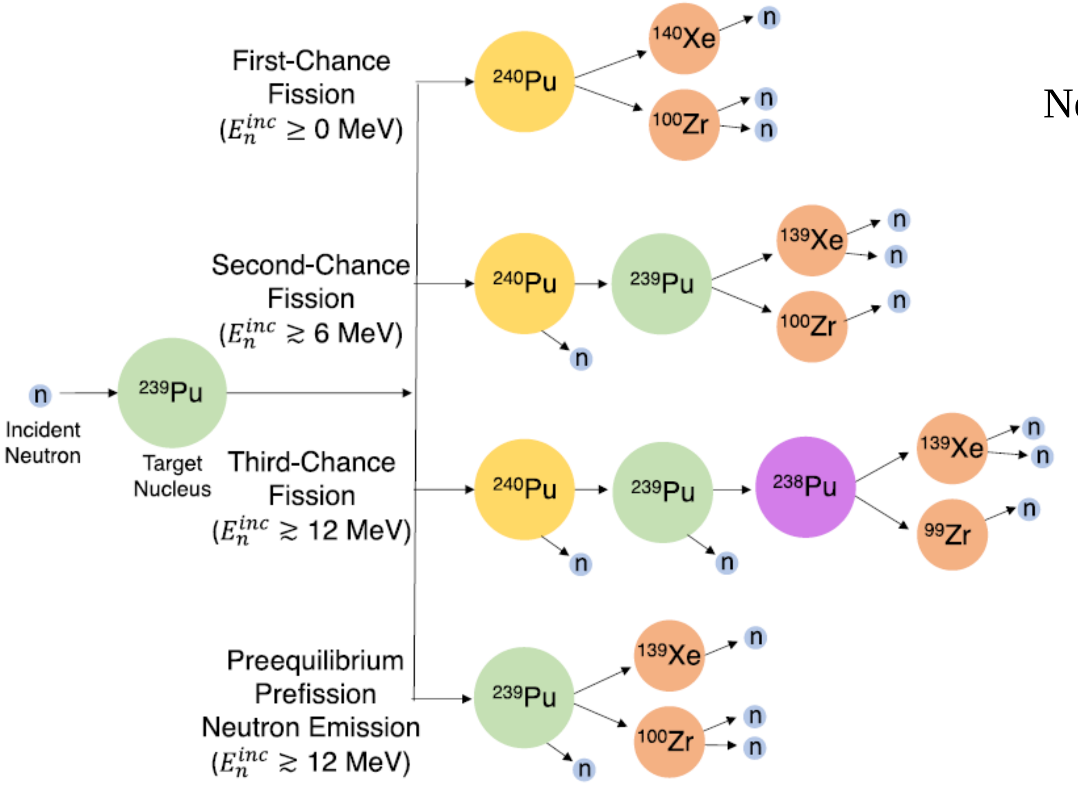




~ counts / neutrons at tens of MeV

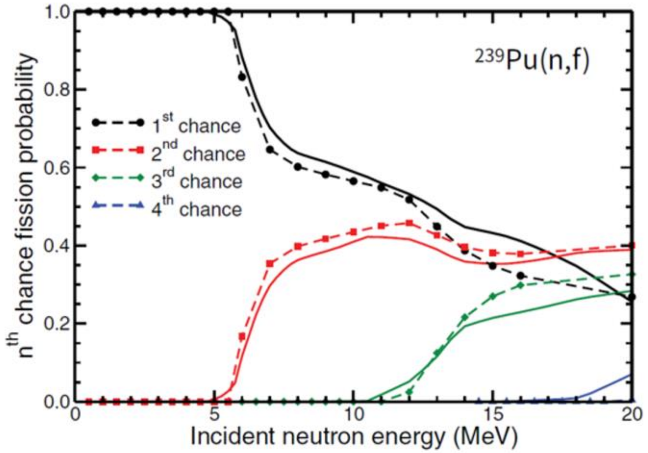
고에너지 중성자 핵데이터 필요성 (Multi-chance fission)

Multi-chance fission

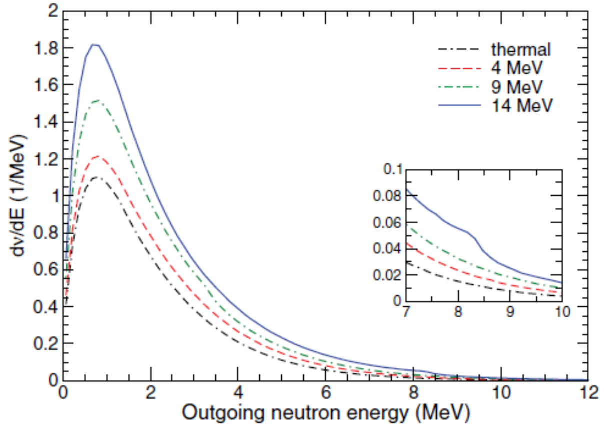


FREYA model with multi-chance fission and pre-equilibrium neutron emission

Neutron-induced fission cross section of ^{239}Pu



Prompt Fission Neutron Spectrum



NDPS 실험주제

- 무거운 원소들의 핵분열 반응 단면적 측정
  - Pb, Bi, Th 또는 악티나이드 (Np, Am, Cm, etc) → LOI
- 준중성자에 의한 활성화에너지 (n, xn) 반응 측정
  - ^{59}Co(n,xn), ^{93}Nb(n,xn), ^{197}Au(n,xn), ^{209}Bi(n,xn)
- **Activation experiments induced by light or heavy ions**
- **Surrogate reactions for (d, pγ) and fission fragment measurement**

핵분열 단면적 측정

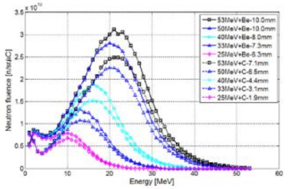
Nuclear Data Production System

Experimental Fission cross section

$$\sigma_f = \frac{R}{I} = \frac{\#\ of\ fission\ reactions}{\#\ of\ particles \cdot \#\ of\ nucleus/area}$$

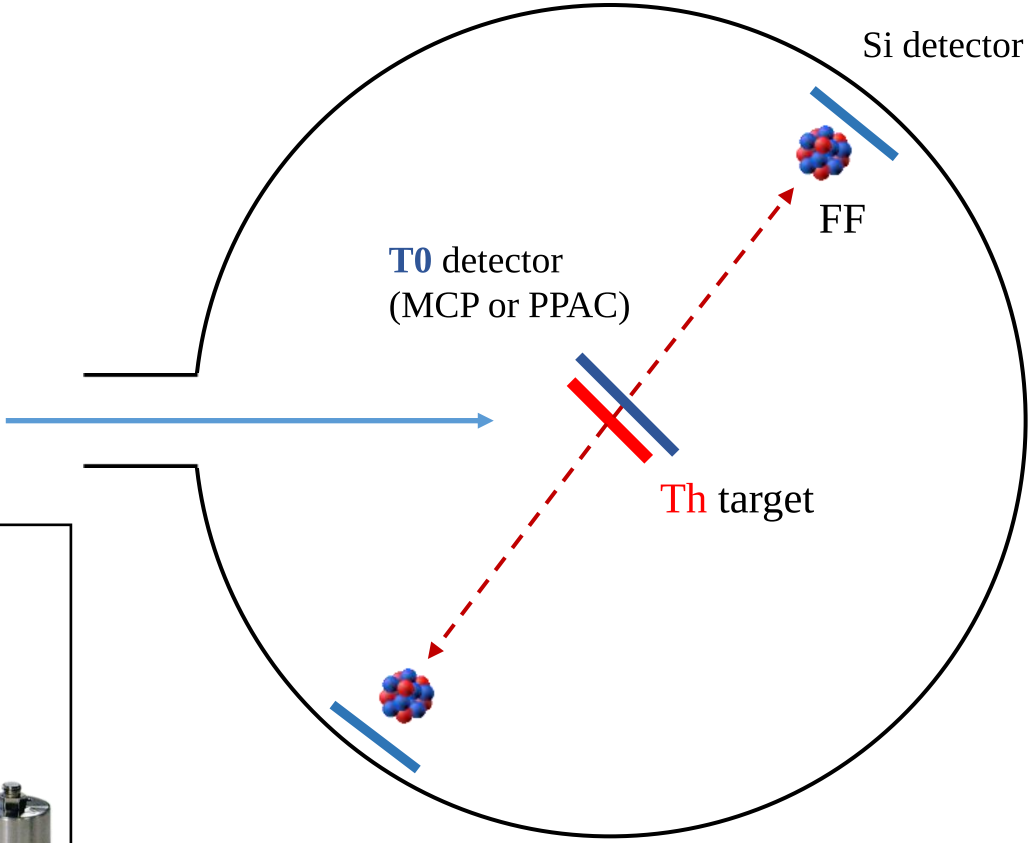
R = number of fission reactions per target nucleus

I = number of incident particles per unit area



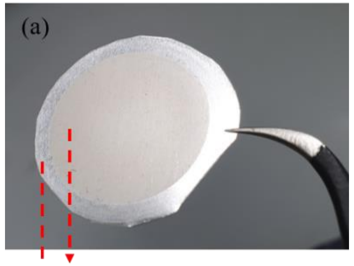
neutron

Fission chamber



Expected counts -> Simulation

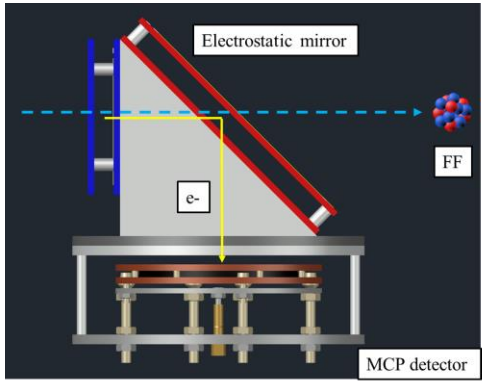
Th target



Th target (22 mm Dia.)

Al backing(0.2 mmT)

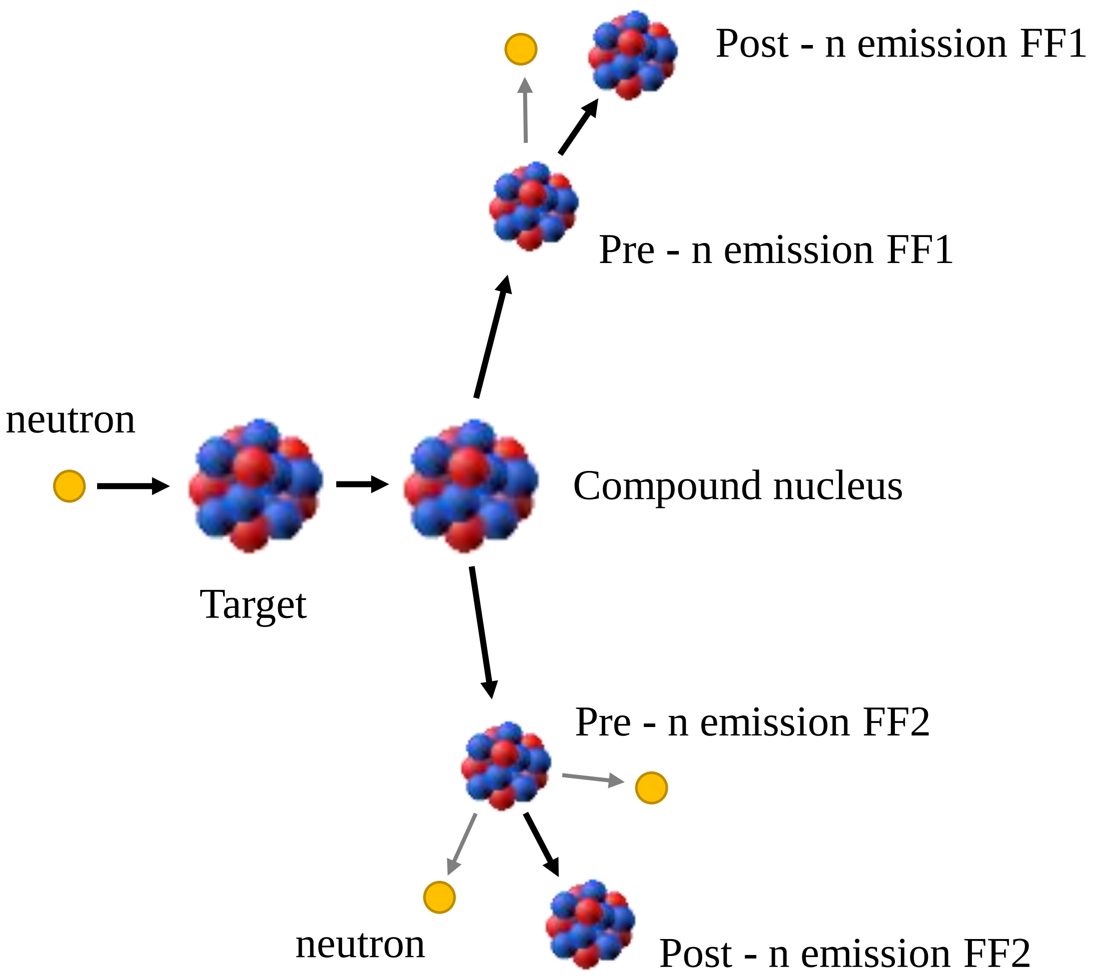
MCP detector



Si detector

Pre-neutron emission fission fragments

Experimentally, E^{post} and v^{post} are measured



Measurement of energy and velocity of both products

Product masses are readily obtained

$$m_{1,2}^{post} = \frac{2 \cdot E_{1,2}^{post}}{\left(v_{1,2}^{post}\right)^2}$$

Assuming that, on average, velocities are unchanged by neutron emission, pre neutron-emission masses are obtained (momentum conservation)

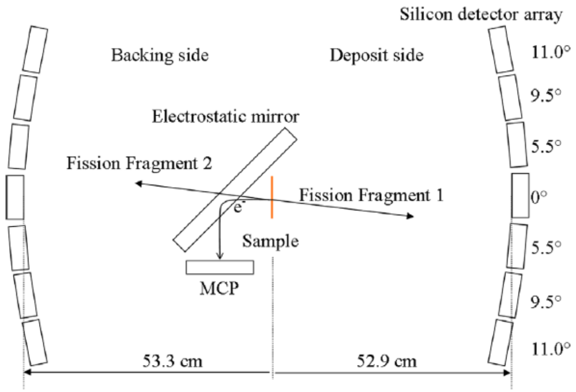
$$m_{1,2}^{pre} = m_{CN} \cdot \frac{v_{2,1}^{pre}}{v_1^{pre} + v_2^{pre}}$$

Energy of FF before neutron emission

$$E_{1,2}^{pre} = \frac{1}{2} m_{1,2}^{pre} \left(v_{1,2}^{post}\right)^2$$

Pre-neutron emission fission fragments

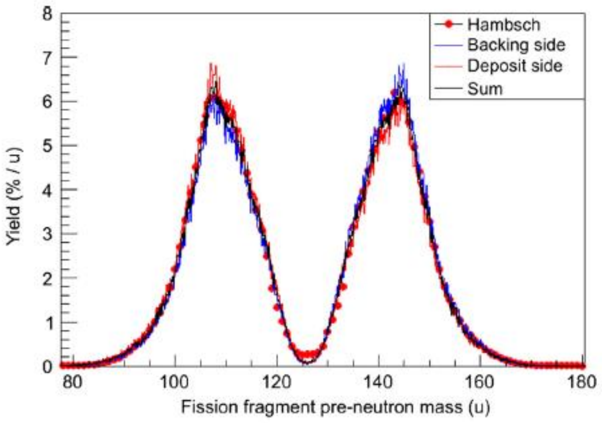
The Fission-fragment Spectrometer **VERDI**



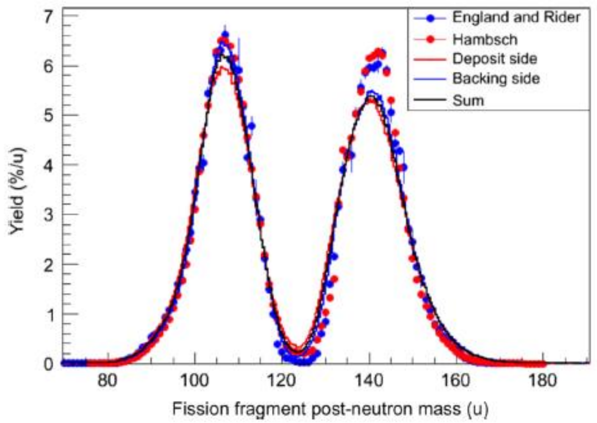
- Energy (E)
  - 2 arrays of 16 Si detectors
  - Each detector 450 mm²
- Time-of-Flight (v)
  - **Start**: Electrons emitted from target detected by Micro Channel Plate (MCP)
  - **Stop**: Si detector

- Maximum solid angle coverage (0.5% of 4π) at relatively short flight path (50 cm)
- Energy (0.5%) and timing (150 ps) resolution
- Energy losses only in target backing and silicon detector dead layer

Pre-neutron



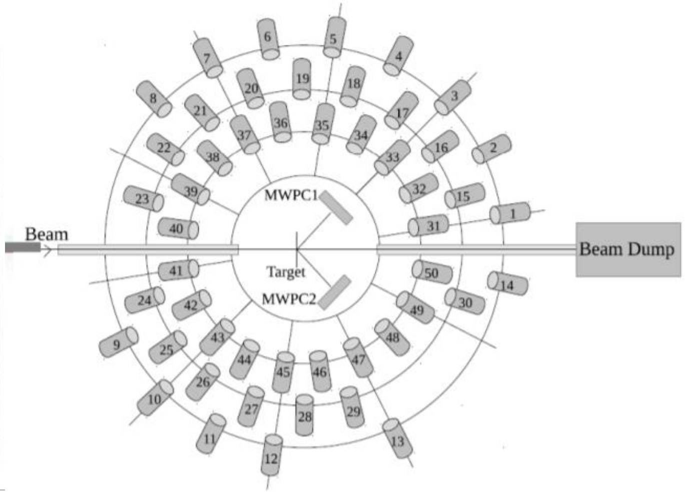
Post-neutron



Neutron multiplicity measurement

National Array of Neutron Detectors (**NAND**)

NAND Array at IUAC, New Delhi



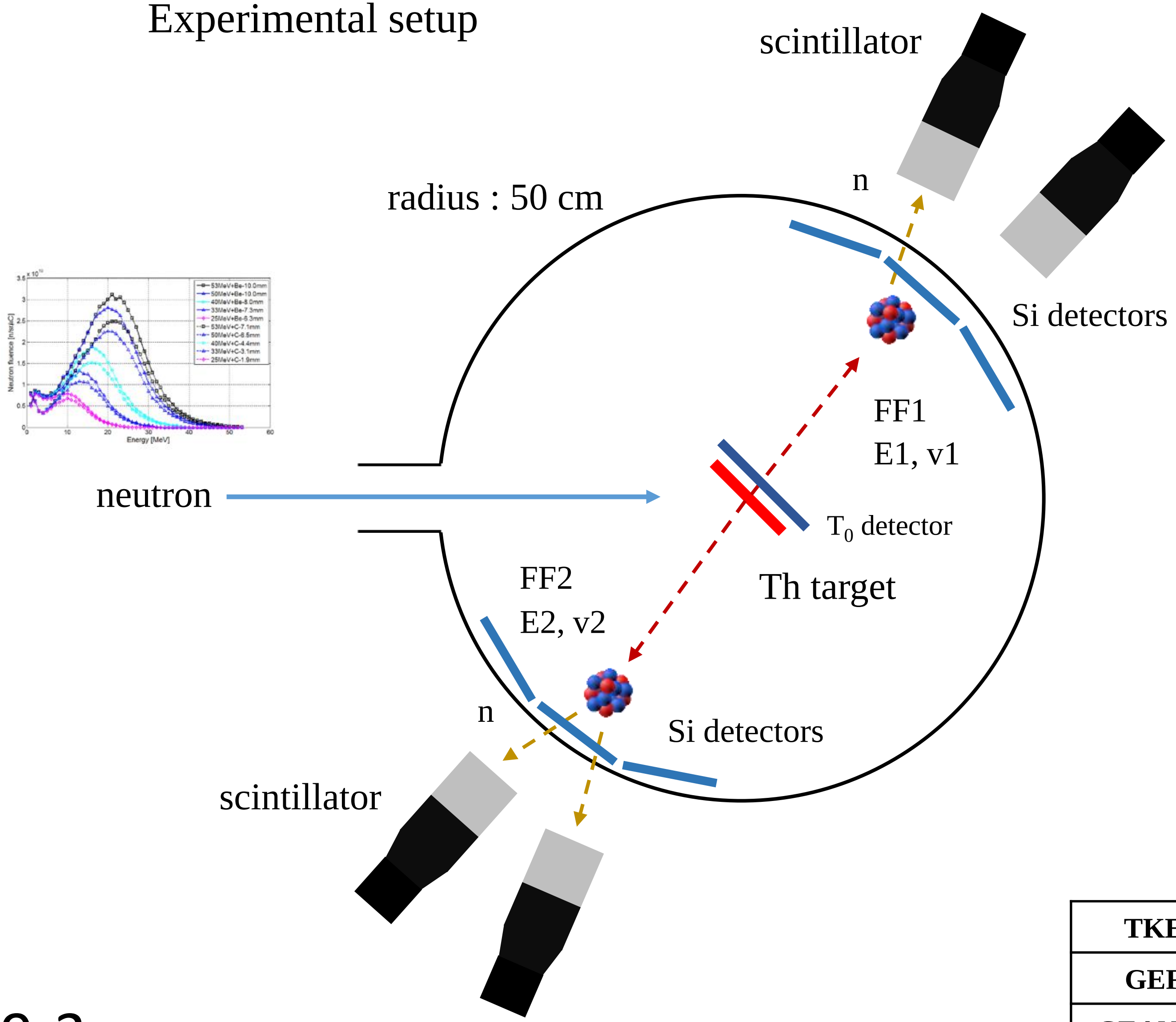
50 BC501 Organic Liquid Scintillators

Fission fragments were detected by a pair of large area multi-wire proportional counters (MWPCs) (12.7 cm × 7.62 cm) kept at the fission fragment folding angle at distances of 18.5 and 17.0 cm from the target position.

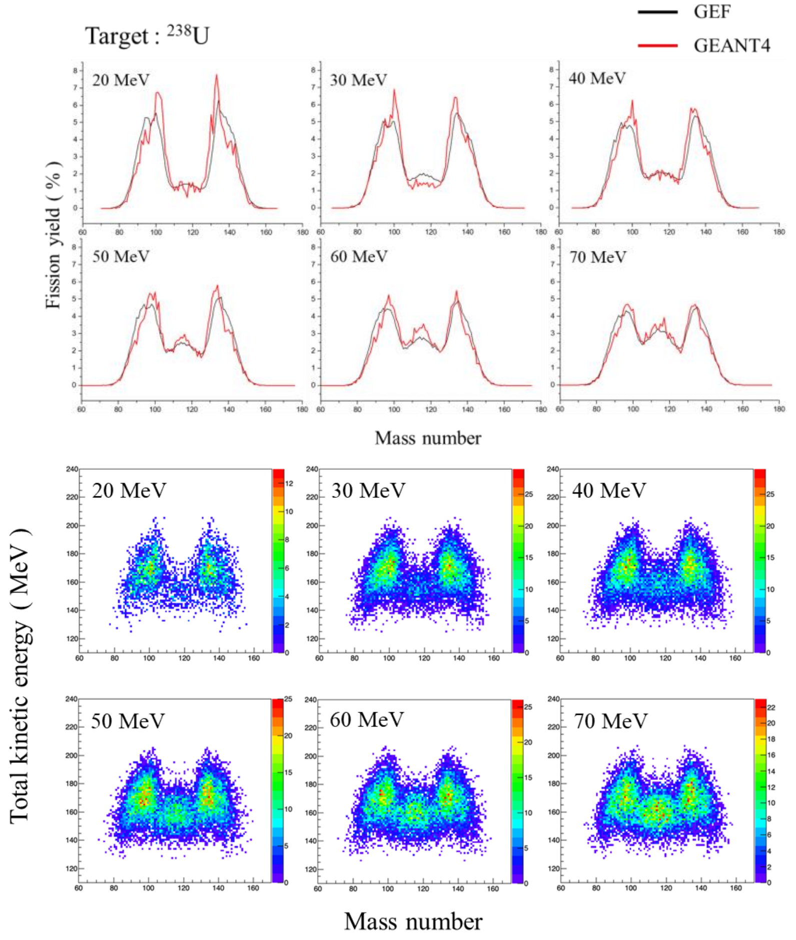
NDPS에서의 2E-2V 방법

Nuclear Data Production System

Experimental setup

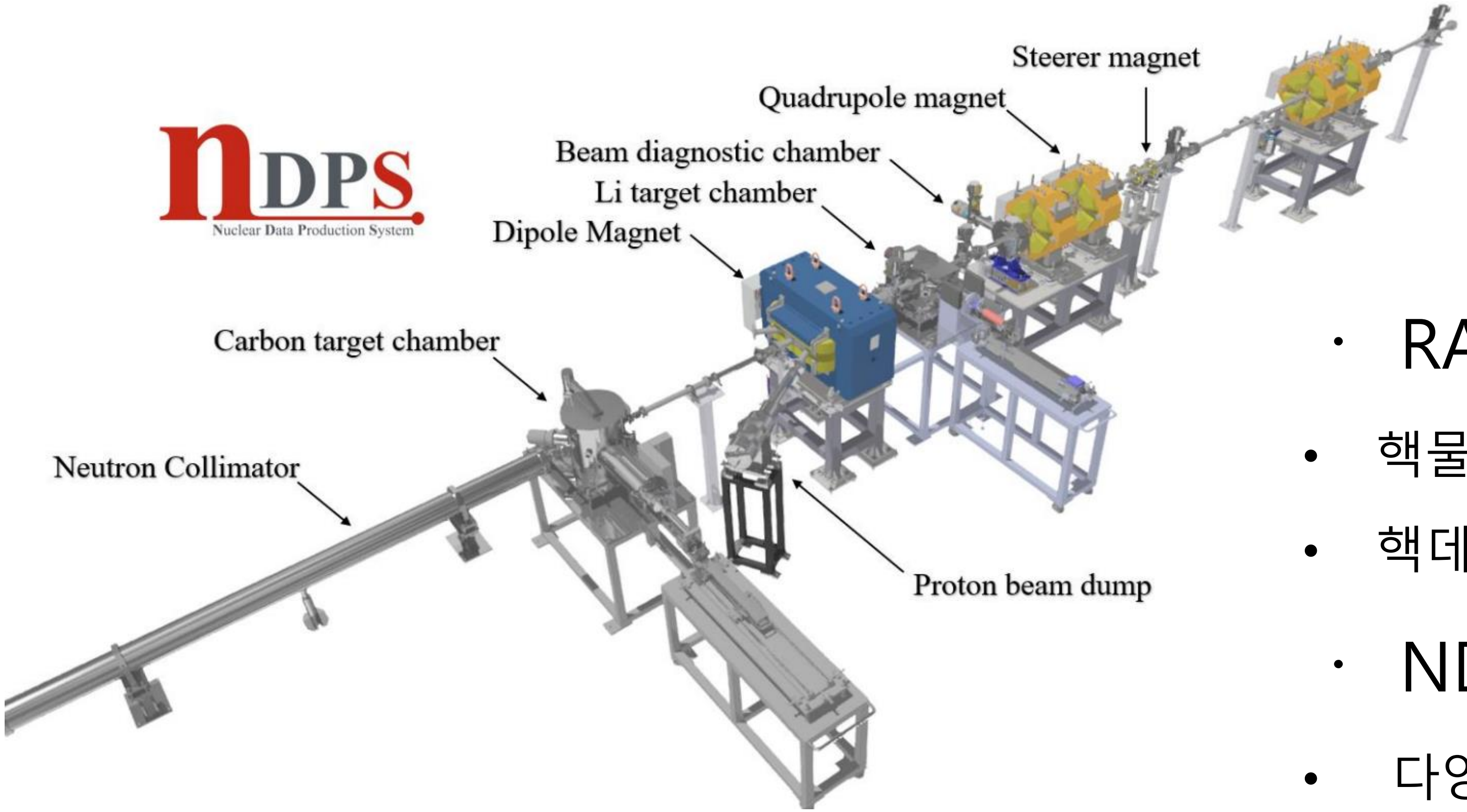


Mass distribution & TKE by using GEANT4 simulation



TKE	20 MeV	30 MeV	40 MeV	50 MeV	60 MeV	70 MeV
GEF	166.6 MeV	165.8 MeV	165.7 MeV	165.4 MeV	165.1 MeV	164.4 MeV
GEANT4	165.9 MeV	165.7 MeV	165.6 MeV	165.7 MeV	165.4 MeV	165.1 MeV

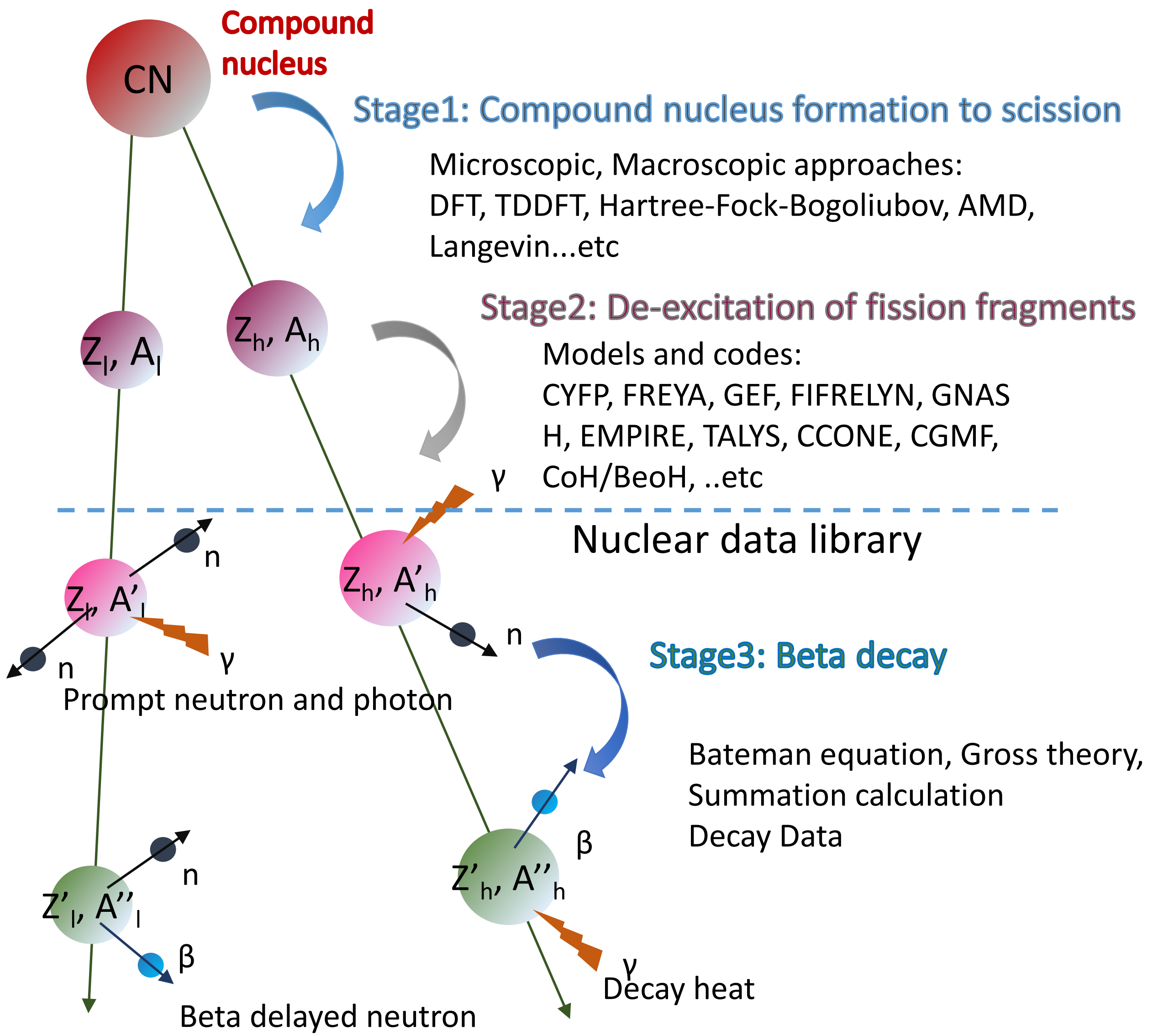
Summary

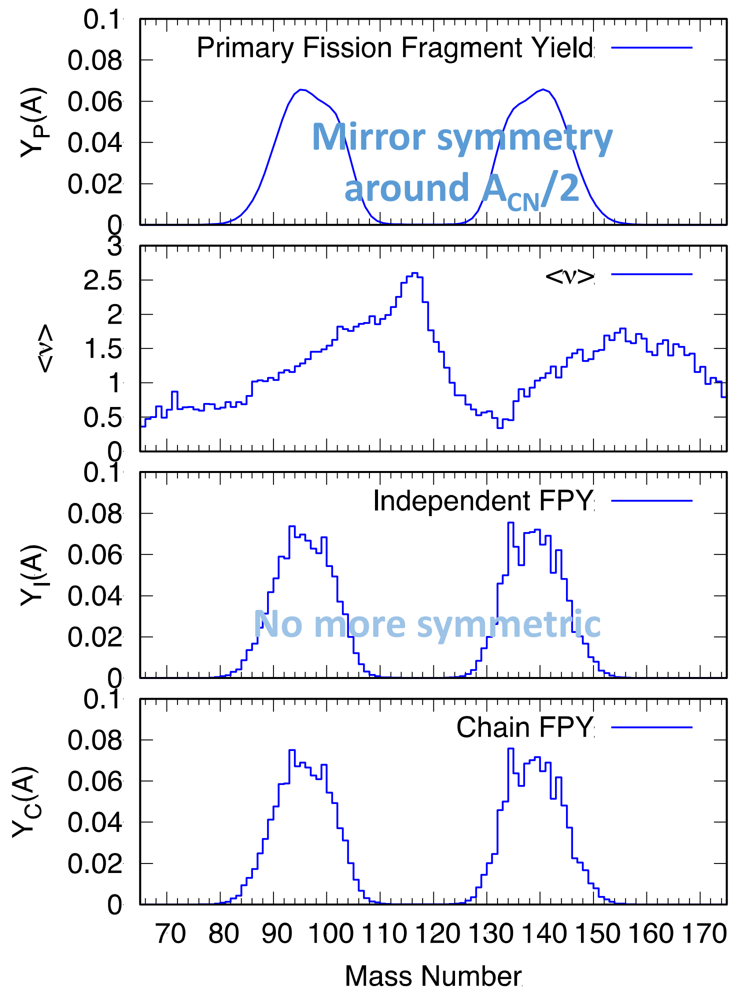


- RAON
- 핵물리
- 핵데이터, 핵물질 등 다양한 응용분야
- NDPS: 2024 작동시작
- 다양한 주제
- 초기 실험들에 대한 다양한 토의 진행중

Backup

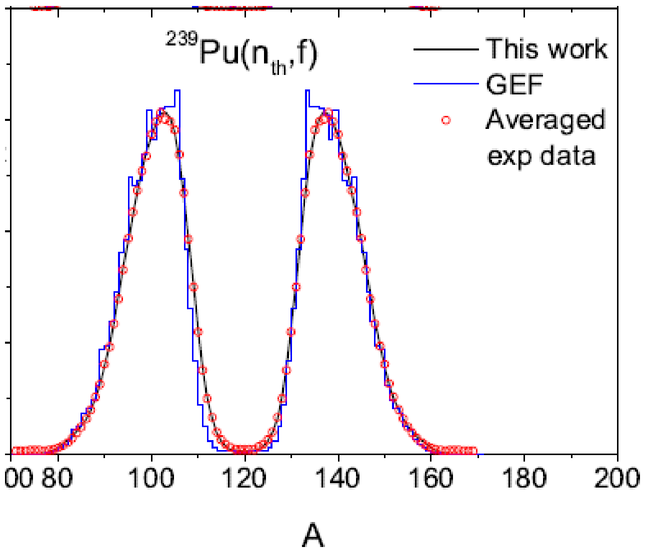
Nuclear fission and decay processes

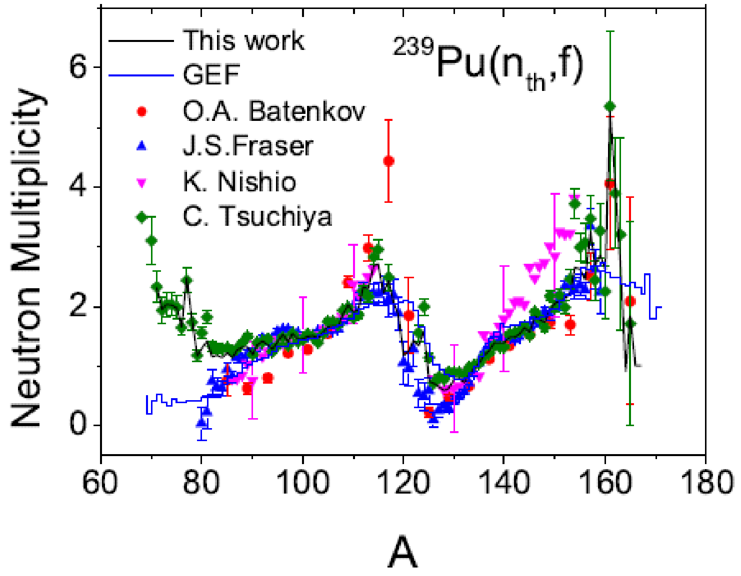


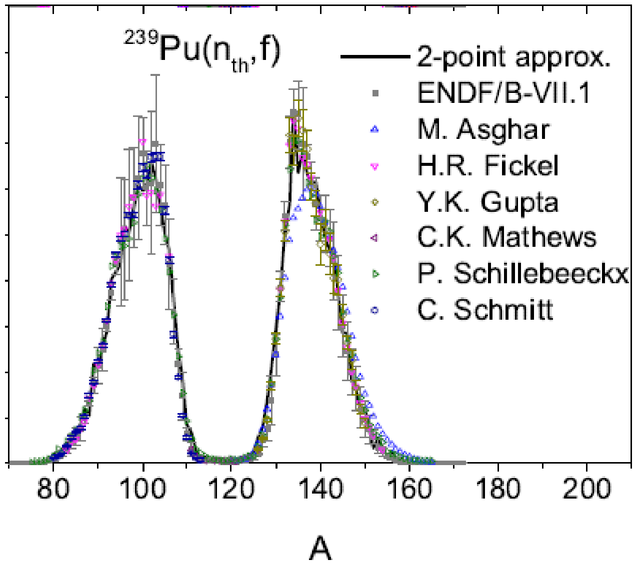


From Pre- to Post-neutron emission Fission Fragment Yield

Pre-neutron emission Yield ⇨ Neutron multiplicity ⇨ Post-neutron emission Yield

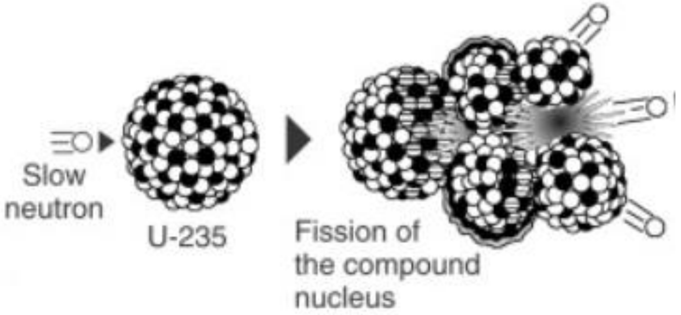






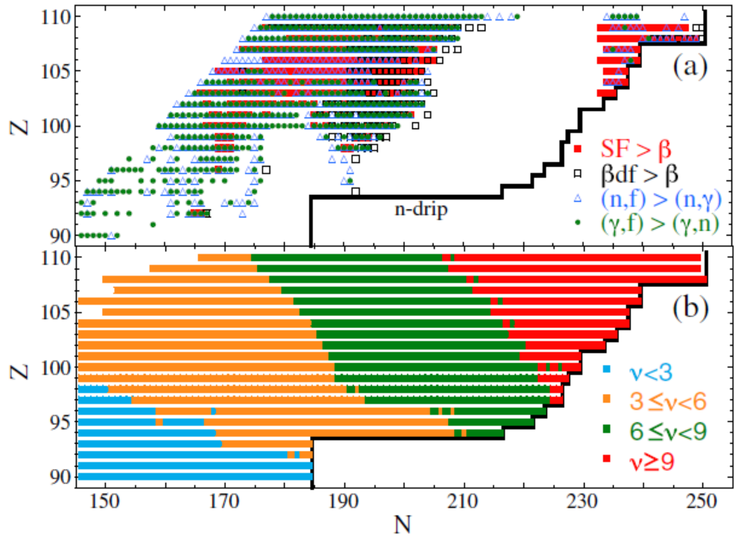
Jonghwa Lee, Tae-Sun Park, SWH

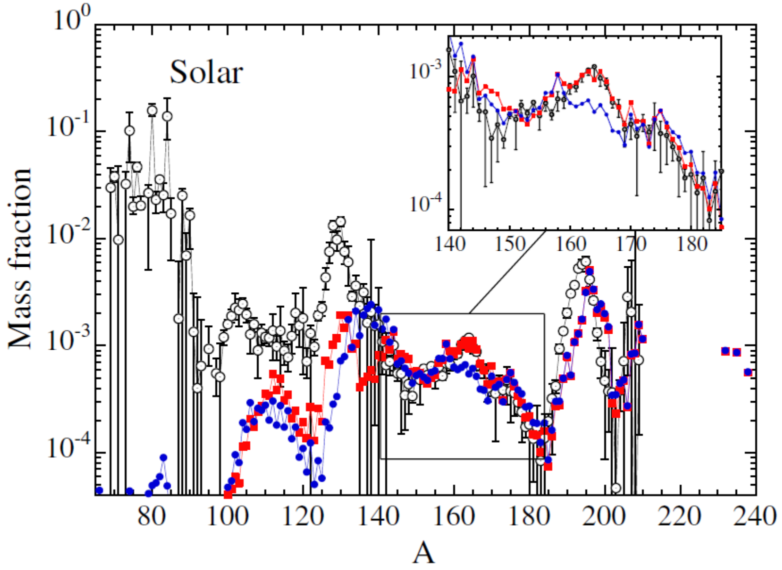
Calculation of post-neutron fission fragment mass distribution by using pre-neutron FPY and neutron multiplicity data



Importance of fission for r-process

abundance of elements and importance of measuring the fission fragment distribution





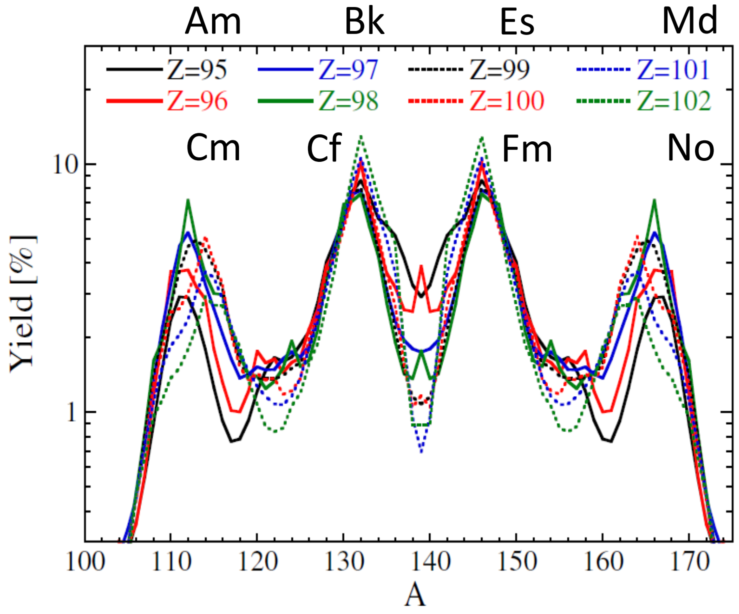


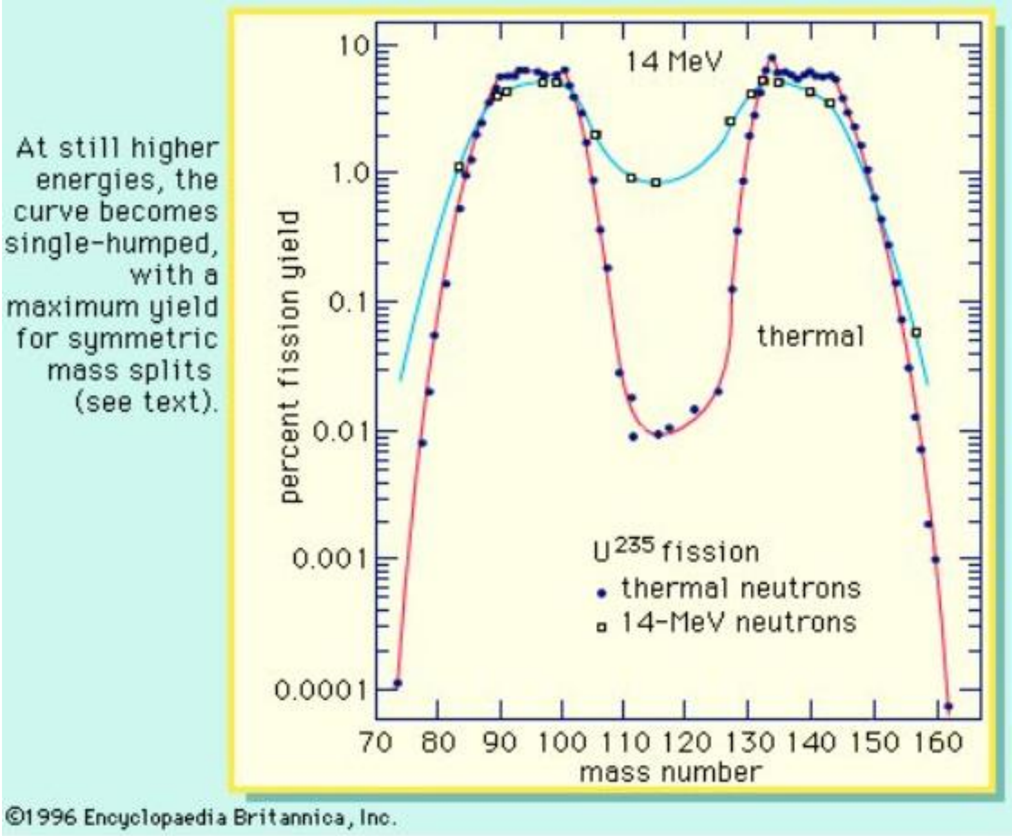
FIG. 2 (color online). FFDs from the SPY model for eight $A = 278$ isobars.

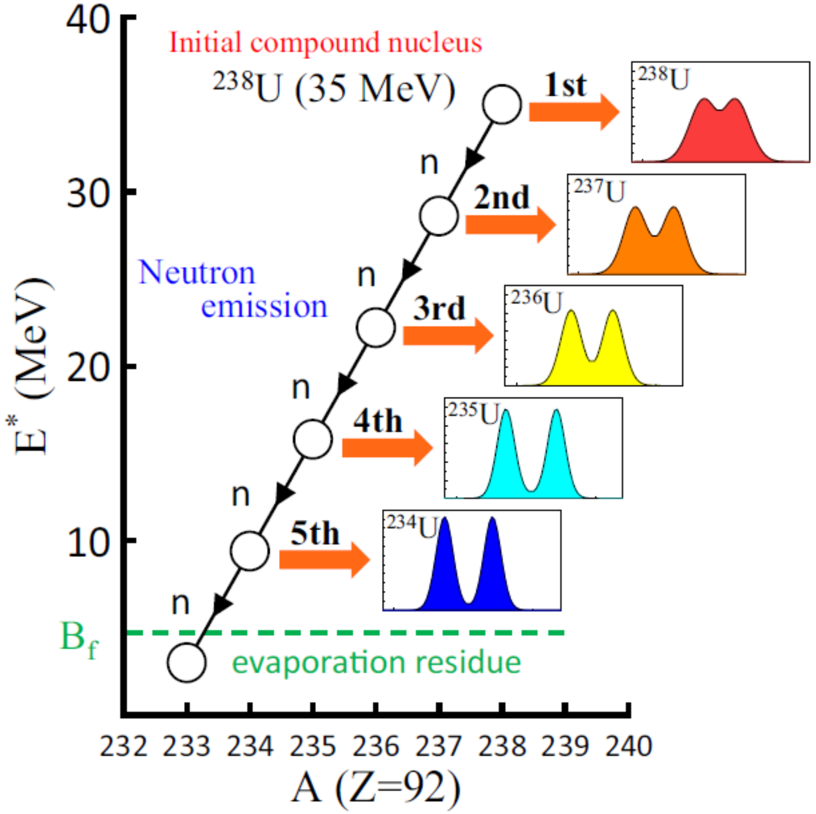
설명 문구?

S. Goriely et al PRL, 111 242502 (2013)

Challenges in fission experiments

- Precise measurement of fission fragment yields over a large range!
- Thousands of isotopes to identify!
- Measurement of neutrons.
- Dynamics of fission with the neutron energies
- Distribution of kinetic energies





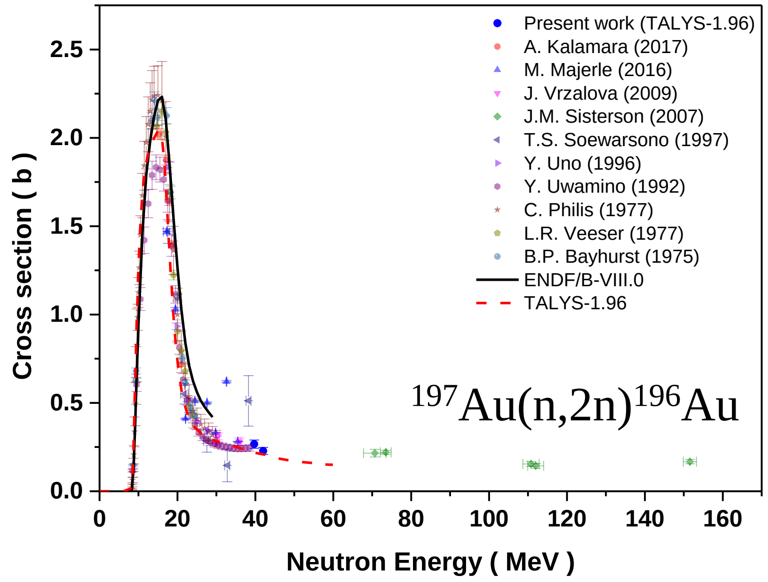
Neutron Activation Analysis (NAA)

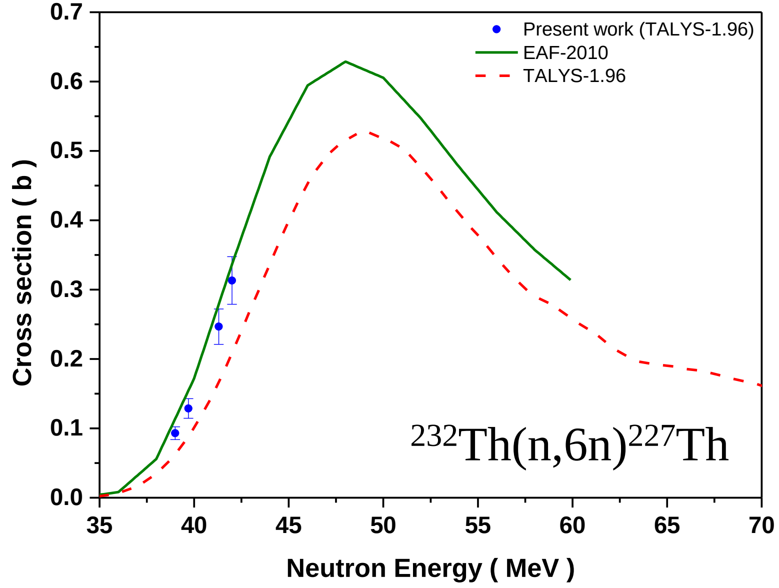
- **NAA** for monitoring neutron flux at NDPS
  - ^{197}Au(n,2n) is recommended for neutron dosimetry
    → IAEA Report (2007)
  - ^{197}Au(n,xn), ^{209}Bi(n,xn) … reactions could be used as neutron monitoring reactions

- **NAA** for Accelerator-Driven System
  - Ta, Bi, Pb → spallation target, cooling material of ADS
  - Th-U fuel cycle
  - Neutron-induced reaction for structural material
  - (n,xn) reaction has important role in ADS

Experimental reaction cross section

$$\sigma = \frac{A\,\lambda\,(RT/CT)}{N_T\,\varepsilon\,I_\gamma\,\emptyset\,(1-e^{-\lambda t})\,e^{-\lambda T}\,(1-e^{-\lambda RT})}$$





L.R. Greenwood and A.L. Nichols, "Review the requirements to improve and extend the IRDF library (International reactor dosimetry file (IRDF-2002))", IAEA Report, INDC(NDS) – 0507, (2007).

Summary

- RAON will provide great research opportunities not only in nuclear physics, but also in applied sciences such as nuclear data, material, and bio-medical sciences.
- NDPS is under construction for setting up experimental equipments for TOF.
- NDPS will be prepared for use in 2023.
- Candidates of early stage experiments are under discussion.
- Please join the collaboration groups to make the best use of the facility.

NDPS 그룹

nDPS Nuclear Data Production System

- 국내 연구자
  - 중이온가속기연구소: 이상진
  - 희귀핵연구단: 김융희
  - 성균관대학교: Vivec CHAVAN, 문달호, 홍승우
  - 경북대학교: 김귀년
  - 울산과기원: 정모세
  - 한국원자력연구원: 송태영, 양성철, 양승대, 이영욱, 이승현, 이창희, 허민구
- 국제공동연구 기관 및 연구자
  - 중이온가속기연구소: 이상진
  - 일본 큐슈 대학교: Nobuhiro SHINGO, Yukinobu WATANAVE
  - GELINA, JRC: Peter SHCILLEBEECKX
  - 일본 공업대학: Satoshi CHIBA
  - JAEA: Katsuhisa NISHIO

NDPS 성과

번호	논문명	학술지명	주저자명
1	A simulation study and its experimental validation for the detection of neutrons with a continuous energy spectrum by using a MICROMEGAS Detector	Journal of Korean Physical Society	Cheolmin Ham
2	Analysis on the stop bamd of fourth-order resonance in high-intensity linear accelerators	Physics of Plasmas	Yoo Lim Cheon
3	Effects of transient nonthermal particles on the big bang nucleosynthesis	International Journal of Modern Physics	Tae-Sun Park
4	Mass Distribution of the Fission Products of Products of Plutonium Isotopes as Calculated by Using a Semi-empirical Model	Journal of the Korean Physical Society	Jounghwa LEE
5	Shape coexistence in isotopes from Oxygen to Calcium	Journal of Korean Physical Society	Eun Jin In
6	Subtraction Method for an Effective Quasi-monoenergetic Neutron Beam by Using Continuous Energy Spectra	Journal of Korean Physical Society	Eun Jin In
7	The effects of alpha irradiation on the optical reflectivity of composite polymers	Radiation Physics and Chemistry	Vivek Chavan
8	Calculation of fission product yields for uranium isotopes by using a semi-empirical model	EUROPEAN PHYSICAL JOURNAL A	Jounghwa Lee
9	Measurement of cross sections for the formation of Rh-100g in Pd-nat(p,x)Rh-100m,Rh-g reactions up to 42.61MeV	JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY	Van Do Nguyen
10	Mass yield distributions in the Th-232(n, f) reaction with fast neutrons	PHYSICAL REVIEW C	H. Naik
11	Measurement of half-lives for Y-87m,Y-g and Au-196m,Au-g,Au-194 produced from the photon and neutron induced reactions of Y-89 and Au-197	JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY	Wooyoung Jang
12	Isomeric yield ratio of Au-196m,Au- g in the Au-197(n, 2n) reaction with fast neutron based on the Be-9(p, n) reaction	EUROPEAN PHYSICAL JOURNAL A	Wooyoung Jang
13	Photo-neutron reaction cross-sections of Co-59 in the bremsstrahlung end-point energies of 65 and 75 MeV	EUROPEAN PHYSICAL JOURNAL A	H. Naik
14	Measurement of activation cross-sections of Dy-na(t)(p,x) reactions up to 45 MeV	NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B-BEAM INTERACTIONS WITH MATERIALS AND ATOMS	M. Shahid
15	Measurement of the thermal neutron cross section and resonance integral of the 187Re(n,γ)188Re reaction	The European Physical Journal Plus	T. H. Nguyen
16	Measurement of natNi(γ, xn)57,56Ni and natNi(γ, pxn)58−55Co reaction cross sections in bremsstrahlung with end-point energies of 65 and 75 MeV	Journal of Radioanalytical and Nuclear Chemistry	H. Naik
17	Excitation functions and thick target yields of the natZr(p,x)95ZrnatZr(p,x)95Zr , 95mNb95mNb , 95gNb95gNb reactions	EUROPEAN PHYSICAL JOURNAL A	Van Do Nguyen
18	Production cross-sections of Mo-isotopes induced by fast neutrons based on the 9Be(p, n) reaction	The European Physical Journal Plus	H. Naik
19	Measurements of ^{nat}natCd(γ, x) reaction cross sections and isomer ratio of ^{115m,g}115m,gCd with the bremsstrahlung end-point energies of 50 and 60 MeV *	*Chin.Phys.C*	M. Nadeem
20	Measurement of 59Co(n, x) reaction cross sections with the fast neutrons based on the 9Be(p, n) reaction	*Chin.Phys.C*	M. Zaman
21	Measurement of cross sections of Zr-isotopes with the fast neutrons based on the ^99Be(p, n) reaction	EUROPEAN PHYSICAL JOURNAL A	H. Naik

NDPS 성과

번호	논문명	발표자	발표학회
1	Measurements of secondary neutrons from the collision of 800 MeV/u Si on C	함철민	한국물리학회 봄 학술논문 발표회 및 제 95회 정기총회
2	Neutron TOF Experiments for transmission and Capture of Neutrons on Rh in the Resonance Region	Vivek	2019 international conference on Nuclearr data for Science and technology
3	Neutron Production Double-differential Cross sections on Carbon bombarded by 800MeV/u	함철민	2019 international conference on Nuclearr data for Science and technology
4	Measurements of gamma-ray intensities from the decay of 187W in the reaction 186W(n,g)187W	함철민	2019 international conference on Nuclearr data for Science and technology
5	RAON-Rare isotope Accelerator complex for ON-line experiments	홍승우	762nd ASRC Seminar
6	Calculation of fission fragment mass distributions by using a semi-empirical method	홍승우	13th APCTP-BLTP JINR joint workshop/Modern Problems in Nuclear and Elementary Particle Physics
7	Applications of RAON	홍승우	Fourth Int Workshop on Technology and Components for Accelerator Driven Systems
8	RAON: Rare isotope Accelerator complex for ON-line experiments	홍승우	14th Asia-Pacific Physics Conference(APPC 2019)
9	Neutron Production Double-differential cross section from Carbon and Niobium targets bombarded with 290 MeV/u 136Xe ions	문달호	2019 Nuclear Data Symposium, Kyushu University
10	Construction status and future plan for RAON and its nuclear data production system	정모세	2019 Nuclear Data Symposium, Kyushu University
11	Overview of Thorium ADS	홍승우	한국원자력학회 온라인 춘계학술발표회
13	ADS Accelerator: Linac option	정모세	Korea Nuclear Society Workshop
12	The detection system of Nuclear Data Production System	문달호	2020년 한국물리학회 가을 학술논문발표회
13	고해상도 TOF (Time of Flight) 중성자 실험을 위한 단일 번치 빔 생성 방법 연구	문석호	2020년 한국물리학회 가을 학술논문발표회
14	Status of construction of NDPS facility	홍승우	한국물리학회 2021년 봄 학술논문발표회
15	Neutron detection system status of Nuclear Data Production System	문달호	한국물리학회 2021년 가을 학술논문발표회
16	Fission experiments at the NDPS	홍승우	한국물리학회 2021년 가을 학술논문발표회
17	Measurement of the cross sections for the 209Bi(n,4n)206Bi and 232Th(n,6n)227Th reactions by using monoenergetic neutrons generated by the 9Be(p,n)9B reaction	문달호	한국물리학회 2022년 봄 학술논문발표회
18	Monoenergetic neutrons from the 9Be(p,n)9B reaction induced by 35, 40 and 45 MeV protons	Vivek	한국물리학회 2022년 봄 학술논문발표회
19	Nuclear Data Production System of RAON	홍승우	15th International Conference on Nuclear Data for Science and Technology
20	Neutron monitoring detector system for Nuclear Data Production System of RAON	문달호	15th International Conference on Nuclear Data for Science and Technology
21	Neutron production double differential cross section from Carbon, Niobium and Bismuth targets bombarded by 290 MeV/u 136Xe ions	문달호	15th International Conference on Nuclear Data for Science and Technology
22	Monoenergetic neutrons from the 9Be(p,n)9B reaction induced by 35, 40 and 45 MeV protons	Vivek	15th International Conference on Nuclear Data for Science and Technology
23	Measurementof(n,xn)crosssectionsfortheTa,Au,Bi,andThbyusingmonoenergeticneutronsgeneratedbythe9Be(p,n)9Breaction	문달호	The 15th Asia Pacific Physics Conference
24	Monoenergetic neutrons from the 9Be(p,n)9B reaction induced by 35, 40 and 45 MeV protons	Vivek	The 15th Asia Pacific Physics Conference
25	Measurement of natHf(a,x) cross sections from E= 29 to 45 MeV	C. T. Nguyen	The 15th Asia Pacific Physics Conference
26	Preliminary beam experiment results of single bunch selection at RAON facility	문석호	19th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS2022)
27	Measurement of (n,xn) cross sections for the Ta, Au, Bi, and Th using monoenergetic neutrons	문달호	한국물리학회 2022년 가을 학술논문발표회