

# 고선속 중성자 선원 발생 기술개발 현황


## [핵물질 분석관련]

2016. 10. 26

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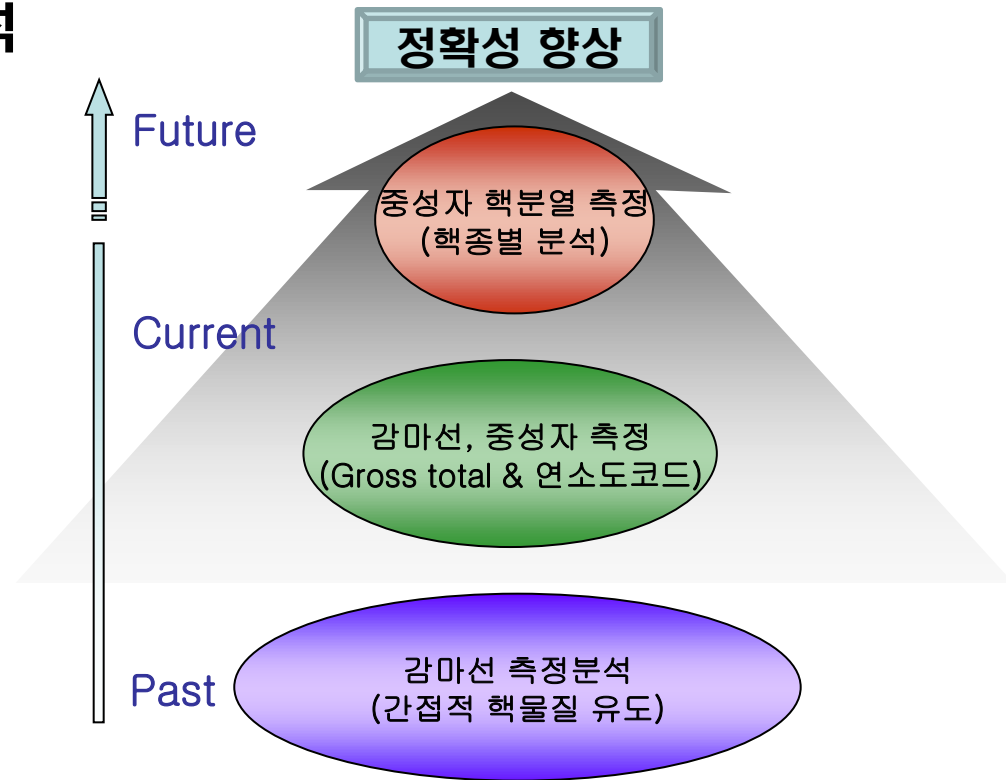


한국원자력연구원  
Korea Atomic Energy Research Institute

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- I. 중성자 선원 필요성
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  - V. 결론

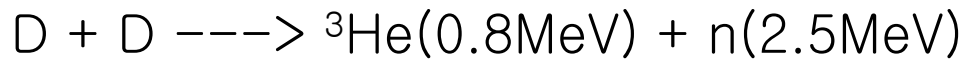
# 필요성

- 핵물질 분석
  - 핵연료 핵물질 분석
  - 사용후핵연료 핵물질 분석
- 원자력 재료 연구
  - 재료 hardening
  - 재료 물성 및 수명
- 방사선 측정
- 동위원소 생산
- 방사성 폐기물 처리
  - 장반감기 핵물질 소멸
- 물질 구조 분석
  - 라디오그래피
  - 토모그래피
- 미임계 원자로

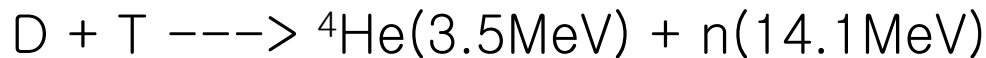


# 중성자 발생장치

- D-D 반응:  $\sim 10^9$  n/sec



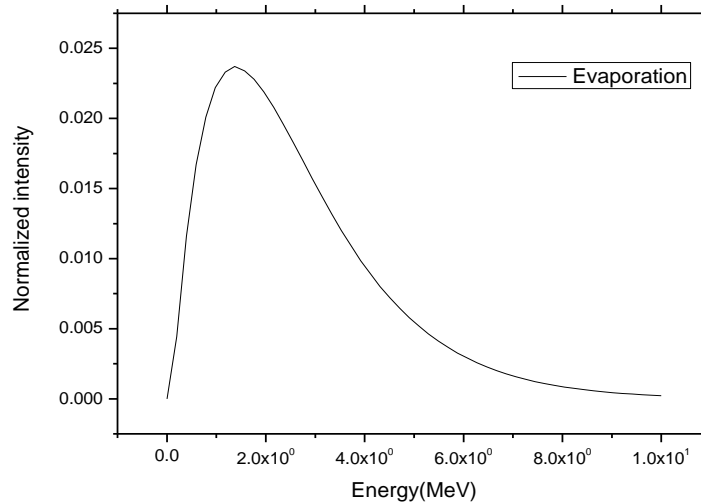
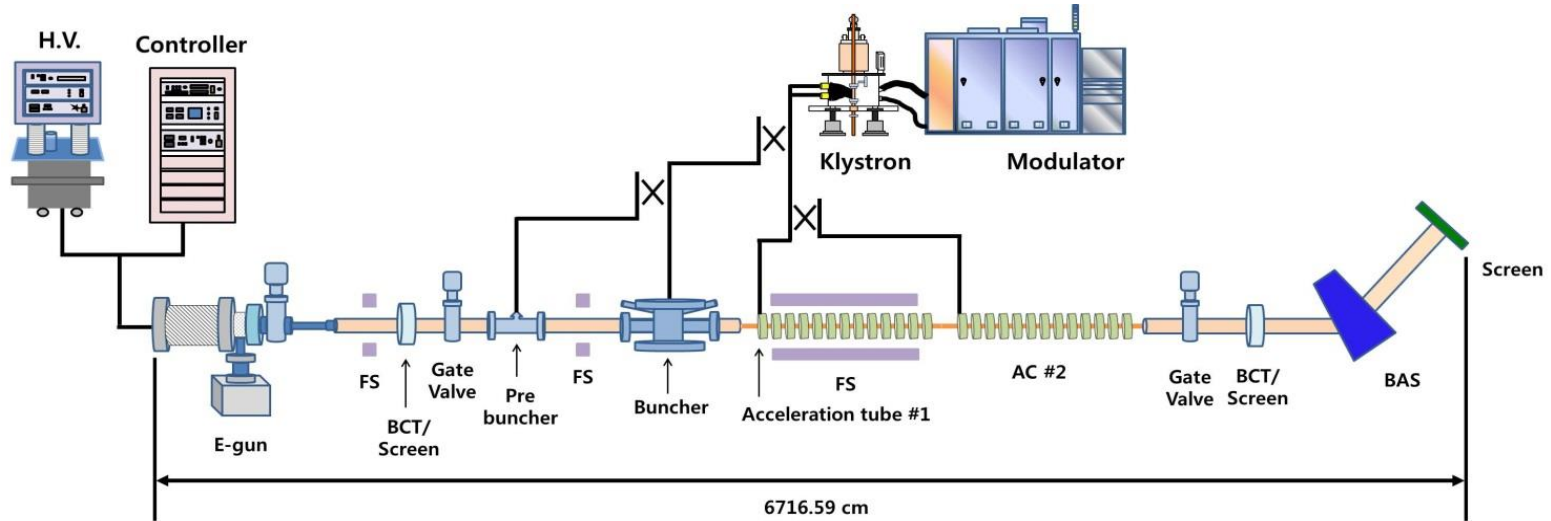
- D-T 반응:  $\sim 10^{11}$  n/sec



- 가속기 이용

	RPI	MIT	ORELA
Energy	60MeV	50MeV	140MeV
Target	Ta	U	D2O
Power	1kw	1kw	84kw
n/sec	E12	E12	E14
length	9m	8m	30m

# 발생장치 (e-LINAC System)

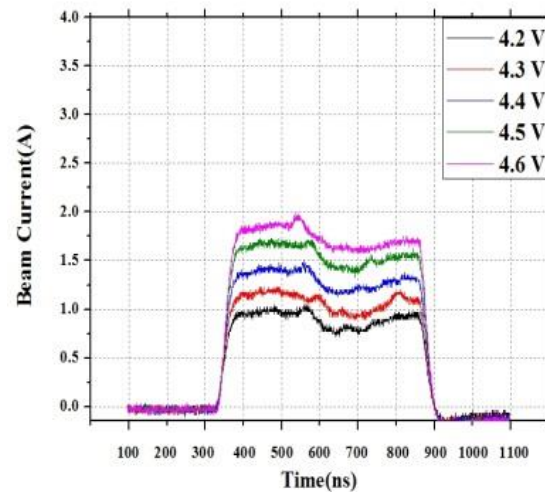


30MeV electron  $\rightarrow \sim 10^{12}$  n's/sec

# 전자발생 [e-Gun]

## 파라메터 선정

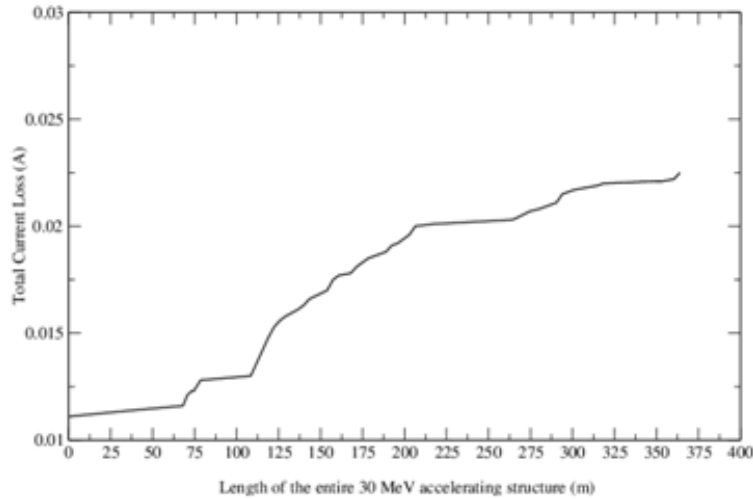
Cathode Voltage (V)	Bias Voltage (V)	Pulse		Beam Current (A)
		Width (ns)	Amplitude (eV)	
4.2	50	500	-140	~ 1.01
4.3	50	500	-150	~ 1.21
4.4	50	500	-160	~ 1.46
4.5	50	500	-180	~ 1.7
4.6	50	500	-190	~ 1.9



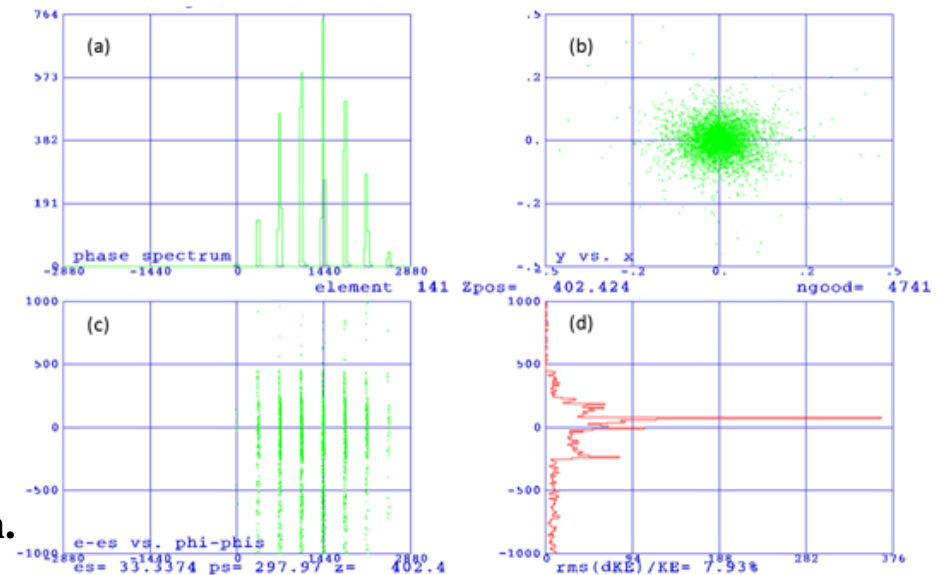
Current shape.



# 전자빔 모사



**Fig. Beam loss at different accelerator position.**



- (a) Phase spectrum
- (b) Electron beam
- (c) Energy spectrum
- (d) Energy spread

- 500mA incident at accelerator tube
- beam loss: 0.02A at 300cm length (~ 4%)

- Beam cross sectional size: < 4mm
- Beam energy spread: 7.9%

# 표적 특성

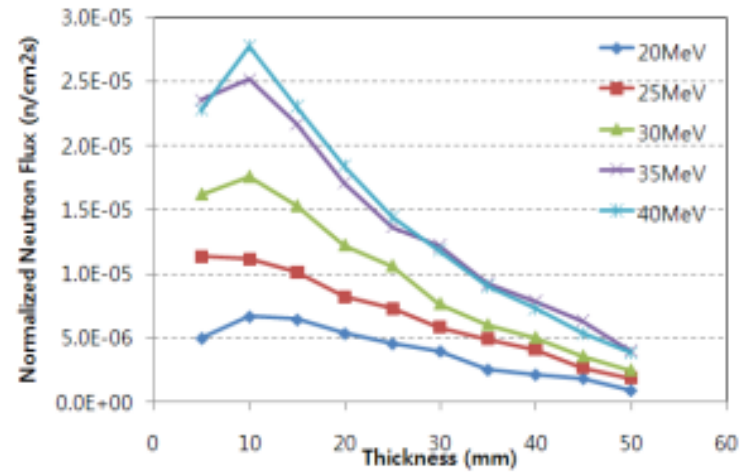
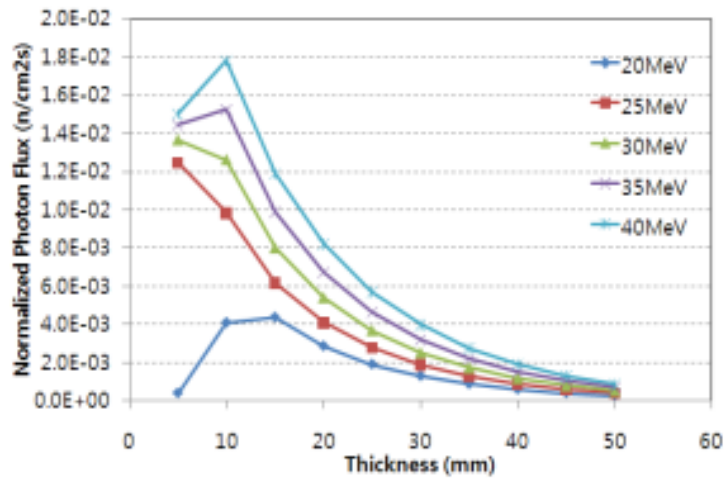


그림. 두께에 따른 중성자 속 변화.

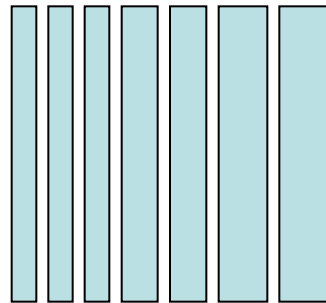


Plate 1

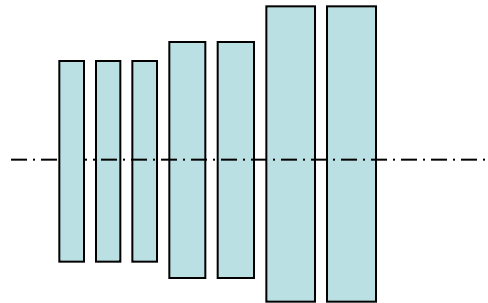
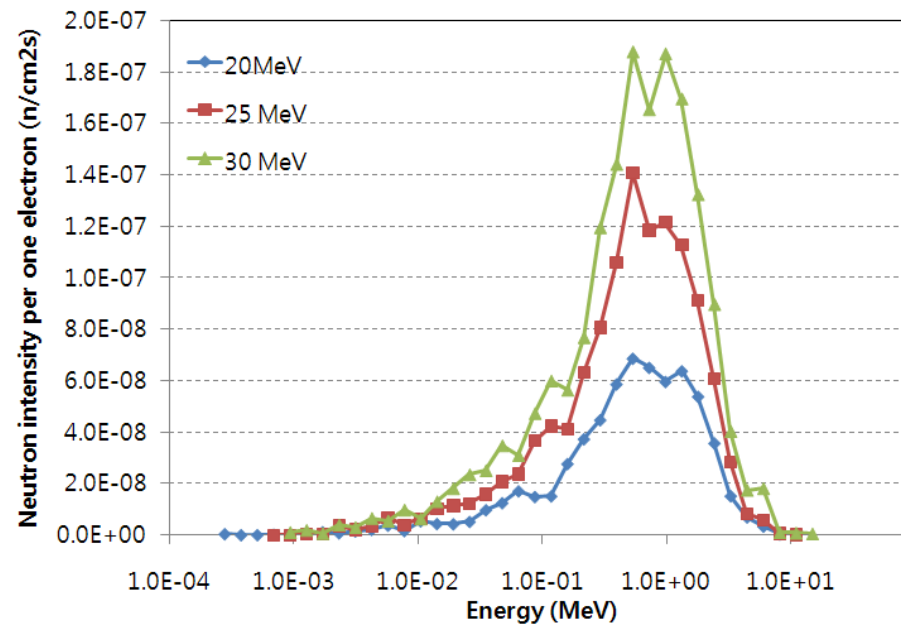


Plate 2

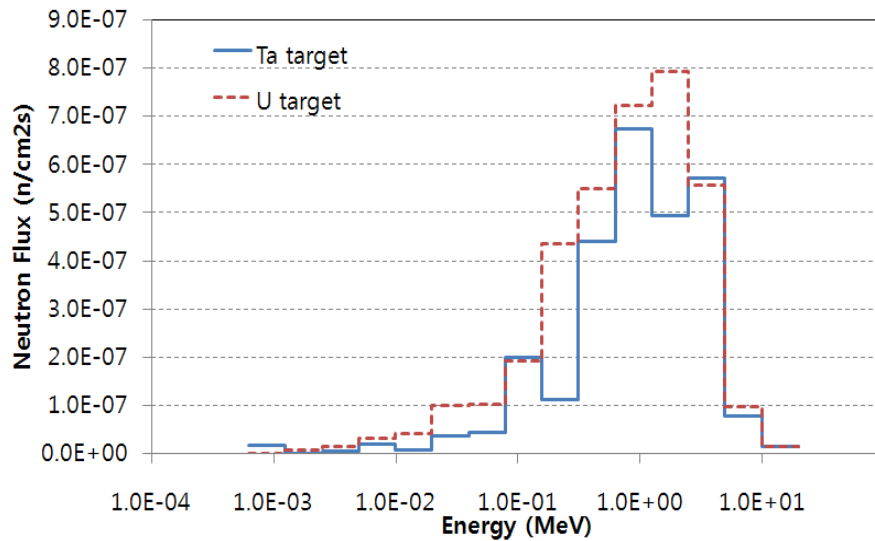




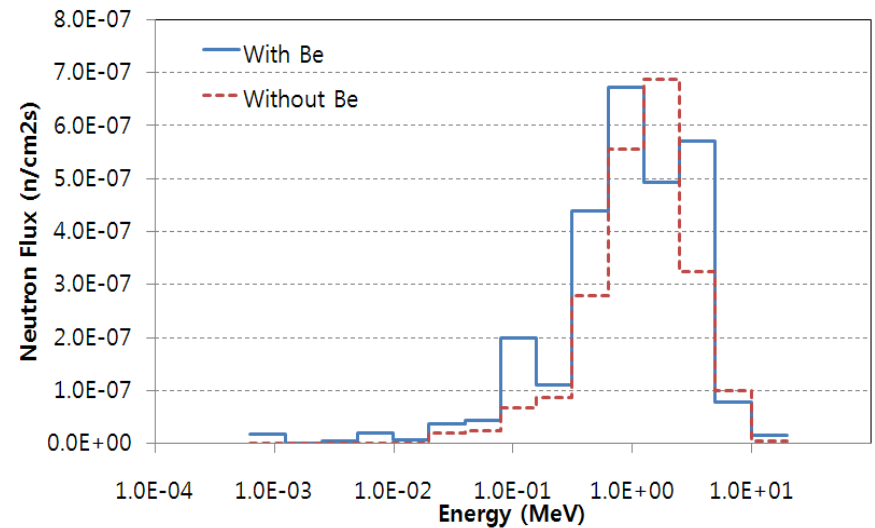
# 중성자 스펙트럼



# 중성자 스펙트럼

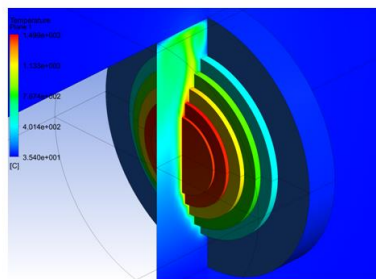
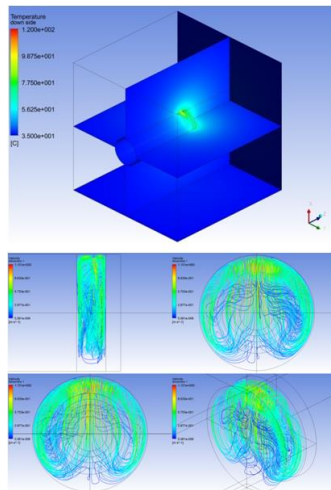


40~50% increase in U target



10~20% increase with Be

# 열발생

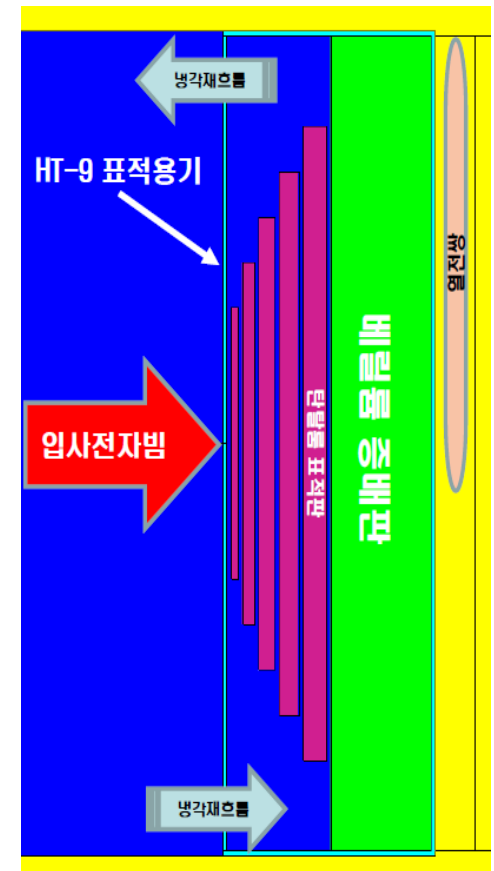


Location	T <sub>avg</sub>	T <sub>melting</sub>
Target 1	1438 °C	2996 °C
Target 2	1469 °C	
Target 3	1200 °C	
Target 4	830 °C	
Target 5	441 °C	
Be	76 °C	1273 °C
Pb block	38 °C	327.5 °C

층	weight(g)	Heat (W/g)	Heat (W)
Cell 1 (Ta)	93.9	0.986	92.6
Cell 2 (Ta)	250.3	1.077	269.6
Cell 3 (Ta)	521.5	0.498	259.7
Cell 4 (Ta)	938.7	0.213	199.9
Cell 5 (Ta)	1533.2	0.0958	146.9
Be	1453.0	0.0143	20.8

# 냉각재 영향

Coolant	Neutron (#/cm <sup>2</sup> s)		Electron (#/cm <sup>2</sup> s)		Photon (#/cm <sup>2</sup> s)	
	average	standard deviation	average	Standard deviation	average	Standard deviation
Air	9.26E-03	6.39E-04	2.66E-01	1.30E-03	3.34E+00	7.67E-03
He	9.39E-03	6.27E-04	2.63E-01	1.29E-03	3.33E+00	7.32E-03
Water	9.89E-03	6.67E-04	2.66E-01	1.30E-03	3.34E+00	7.68E-03



# 중성자 수율



Coolant	Neutron [# /cm <sup>2</sup> s]		Electron [# /cm <sup>2</sup> s]		Photon [# /cm <sup>2</sup> s]	
	average	error	average	error	average	error
Alr	9.26E-03	6.39E-04	2.66E-01	1.30E-03	3.34E+00	7.67E-03
He	9.39E-03	6.27E-04	2.63E-01	1.29E-03	3.33E+00	7.32E-03

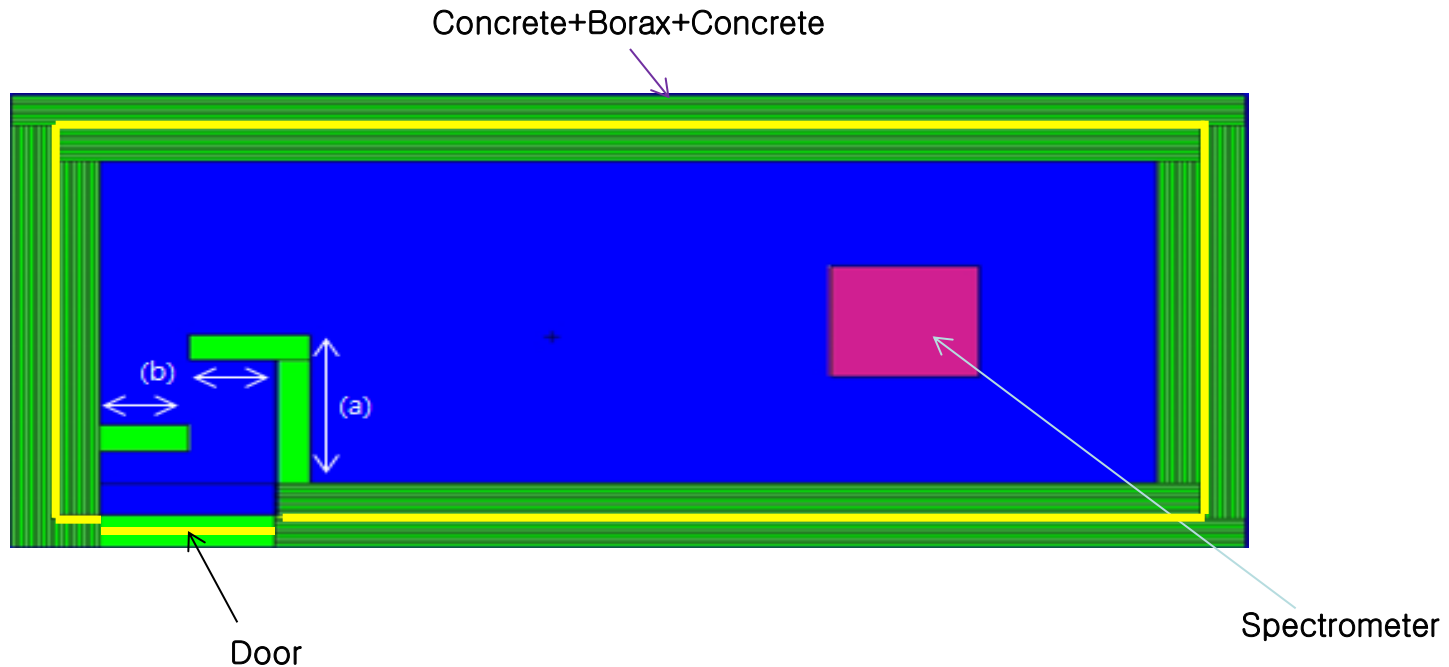
Energy (MeV)	Neutron production per one electron (n/cm <sup>2</sup> s)	Converted Neutron Intensity (n's/sec)
15	1.90E-07	2.68E+11
20	6.42E-07	9.07E+11
25	1.18E-06	1.67E+12
30	1.70E-06	2.40E+12
35	2.14E-06	3.02E+12
40	2.77E-06	3.91E+12



- Spontaneous fission from spent fuel
- $(\alpha, n)$  from spent fuel
- Gammas from spent fuel
- Gammas from Target
- Intense source neutrons from target
- Gammas from induced fissile fission
- Fast neutron by induced fission

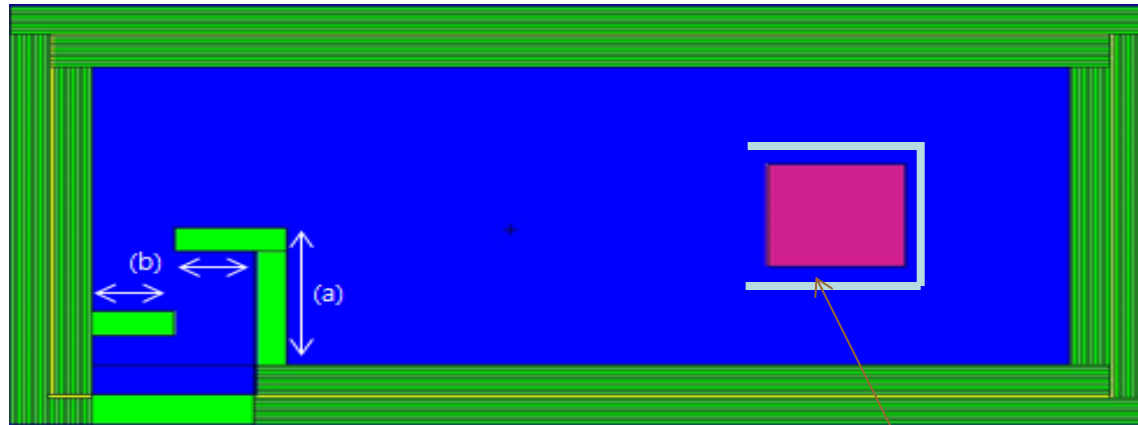
➤ Intense & complex radiation field

# 차폐



- Concrete : 138cm
- Combination : 55-5-45 cm
- Inside wall (a, b) : 30cm
- Borax : 5cm
- Door : 20-5-15 cm

# 차폐 [covering 영향]



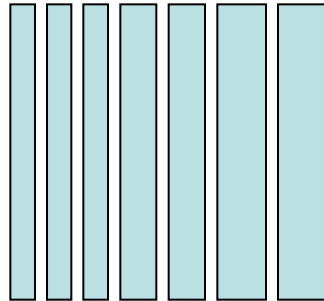
Covering

Material and Thickness	Dose rate[ $\mu$ Sv/h]		
	Left wall	Right wall	Top wall
No covering	4.48E-02	3.49E-02	4.18E-02
HDPE-Borax (5 cm)	1.32E-02	1.11E-02	1.08E-02

Covering: 3cm borax  
(70% dose rate down →  
20% wall thickness down)

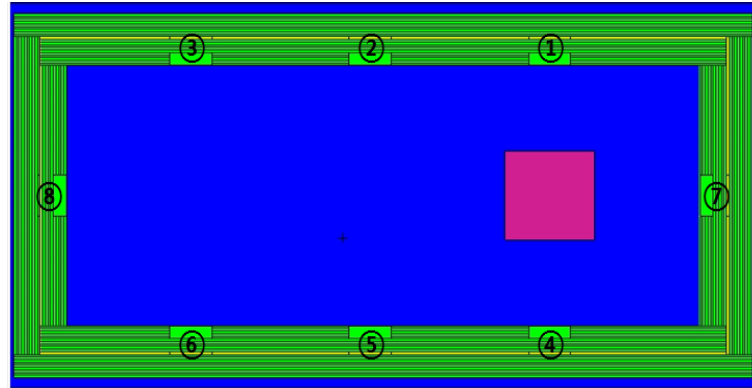


# 방사화평가 (표적)



Material	Cooling time						
	1s	30m	1hr	3hr	1day	7 day	90day
	Total activity (Ci)						
Ta	3.05E+09	2.92E+09	2.80E+09	2.36E+09	3.96E+08	1.91E+03	1.11E-03

# 방사화평가 (콘크리트)



Concrete Position	Total activity(Ci) for Irradiation time					
	1 sec	1 hour	2 hours	5 hours	7 hours	10 hours
1	7.04E-05	1.33E-03	1.33E-03	1.35E-03	1.35E-03	1.36E-03
2	2.57E-05	4.86E-04	4.88E-04	4.92E-04	4.95E-04	4.98E-04
3	1.30E-05	2.46E-04	2.47E-04	2.49E-04	2.50E-04	2.52E-04
4	7.05E-05	1.33E-03	1.34E-03	1.35E-03	1.35E-03	1.36E-03
5	2.57E-05	4.86E-04	4.88E-04	4.92E-04	4.95E-04	4.98E-04
6	1.30E-05	2.46E-04	2.47E-04	2.49E-04	2.51E-04	2.52E-04
7	6.43E-05	1.21E-03	1.22E-03	1.23E-03	1.24E-03	1.25E-03
8	1.50E-05	2.84E-04	2.85E-04	2.87E-04	2.89E-04	2.91E-04



# 중성자 선원 이용 핵물질 분석

# SF 핵물질 측정분석 필요성

- **사용후핵연료 저장소의 최적화 설계**

[It will increase Safety, Effectiveness in management of spent fuel]



- **핵연료주기를 통한 핵물질 재활용**

[It will increase Safety, Economics in recycle]



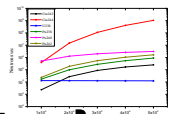
- **국가적인 핵물질 관리 통제**

[It will contribute to next generation safeguards]



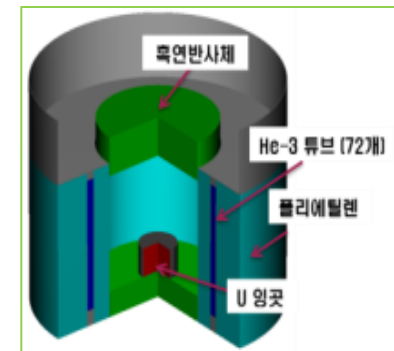
- **연소도 코드의 정확도 향상**

[It provides the correction for fissile material generation]



# 핵물질 측정방법

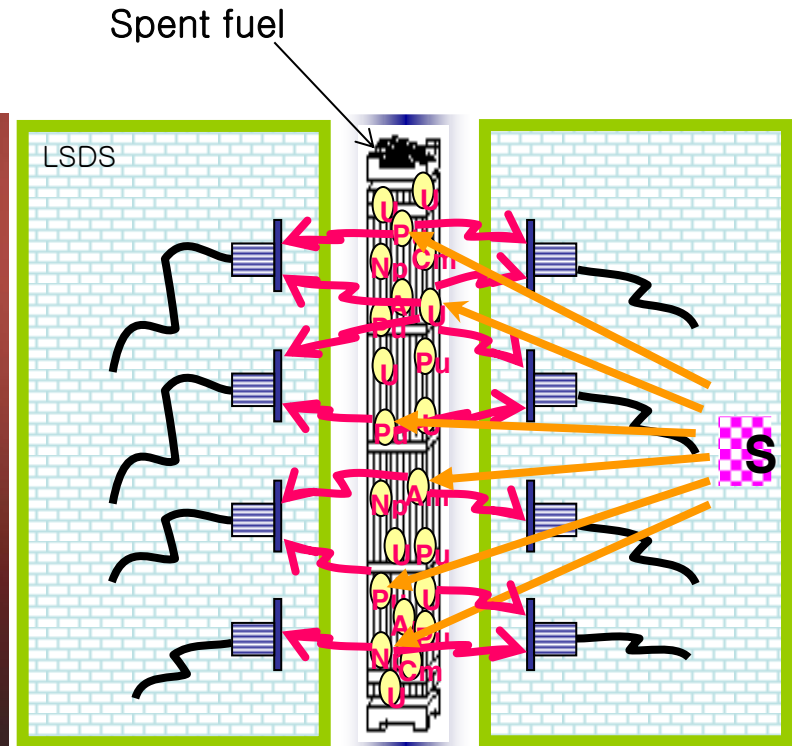
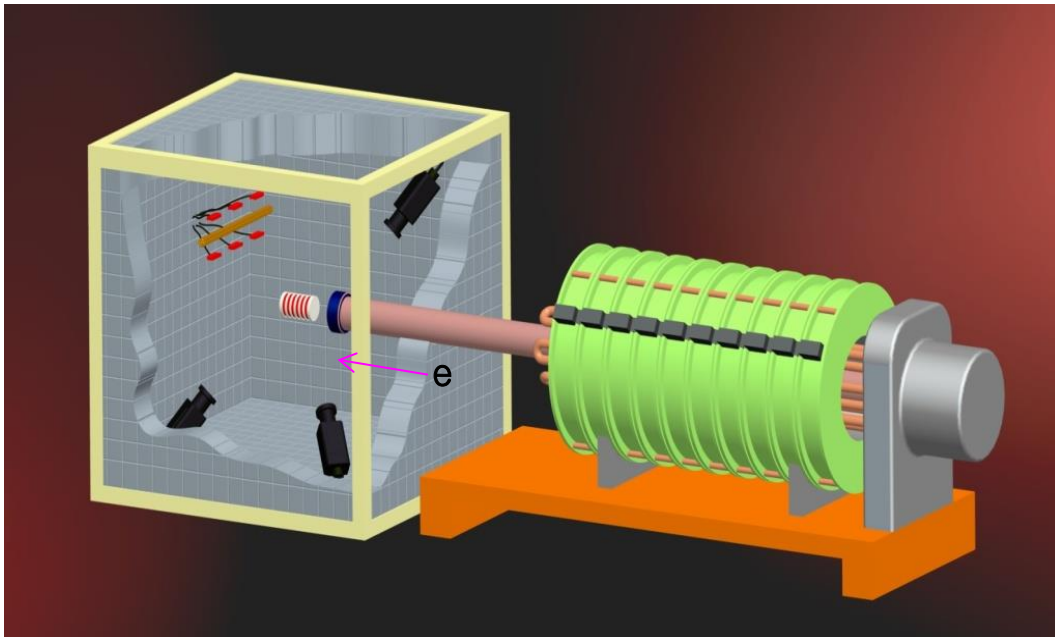
- **감마선 측정**
  - 연소도(Cs, Nd), 핵물질 추정
- **Delayed Neutron 측정 (LANL)**
  - delayed 중성자 수는 fissile 함량과 관련함
  - U235의 signal이 Pu239보다 2.6배 활용
  - 동위원소 비 필요
- **SMOPY (프랑스)**
  - 중성자 감마선 측정 (SF 유무 판단)
- **Cm244 방출 중성자 측정 (LANL)**
  - 연소도 코드 도움필요
- **LSDS (KAERI)**



# LSDS 특성

- ✓ **Direct** Fissile Assay(U235, Pu239, Pu241)
- ✓ **Isotopic** Fissile Assay (not total fissile)
- ✓ **No need** burnup code
- ✓ **No influence** from Radiation Background
- ✓ **Near Real Time** Fissile Assay
- ✓ Fissile assay in spent fuel and recycled fuel

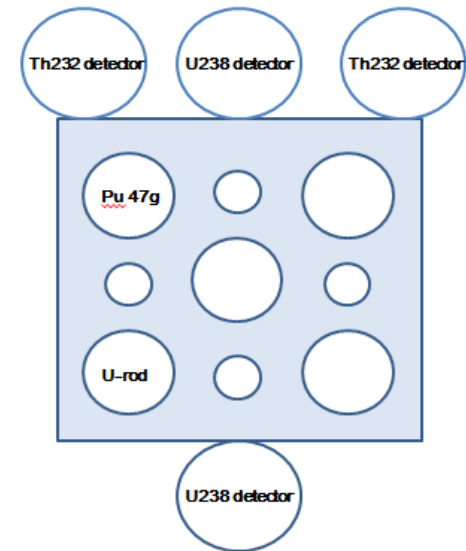
# LSDS 시스템



LSDS(Lead Slowing Down Spectrometer)

# 핵종별 함량분석 (Experiment)

- U235 4.8%(36g), Pu239 47g at RPI



Nuclide	U235	Pu239	Pu241
Content(g)	36.82	46.26	-1.20
Error	1.77E-5	7.45E-6	3.02E-6





- 중성자 선원은 다양한 분야 활용
  - 특히 직접적인 핵물질 분석에서는 필수
  - 원자력 재료분야
  - 동위원소 생산
  - 물질분석
- 핵물질 함량분석용 중성자 선원개발
  - 전자가속기
  - 표적
- 전자 가속기 활용
  - E11~E13 n/sec
  - 경제성, 효율성, 관리, 크기
- 고선속 고에너지 경우 차폐시설이 필요

Thank you

