EXFOR Activities in Korea

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Korea Atomic Energy Research Institute

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Organization

➤ **KNDC**

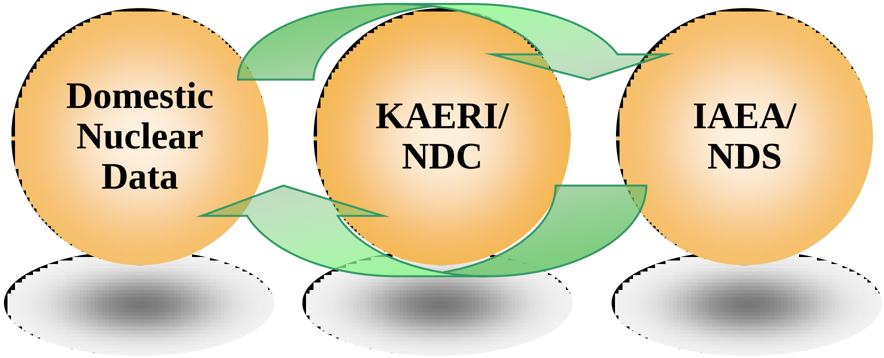
- Performs the measurement, evaluation, processing and validation of nuclear data which are requested by the various fields.
- 1 director, 11 permanent staffs (2 in evaluation, 1 in theory, 2 in processing and validation, 4 in measurements and application, 2 in atomic and molecular data), 1 PhD student, 1 post master's researcher and 1 secretary.
- Mission of KAERI/NDC is disseminating outcomes of international network as well as promoting domestic nuclear data activities and related applications.

Introduction

Compilation responsibility

Neutron data and CPND from Korea (coordinated by NDS)

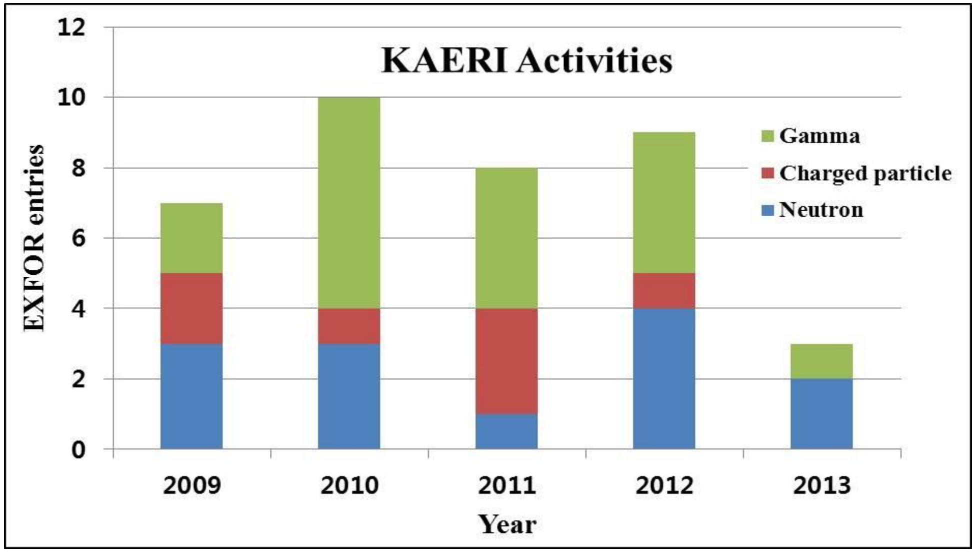
The beginning of EXFOR-DB construction from 2009

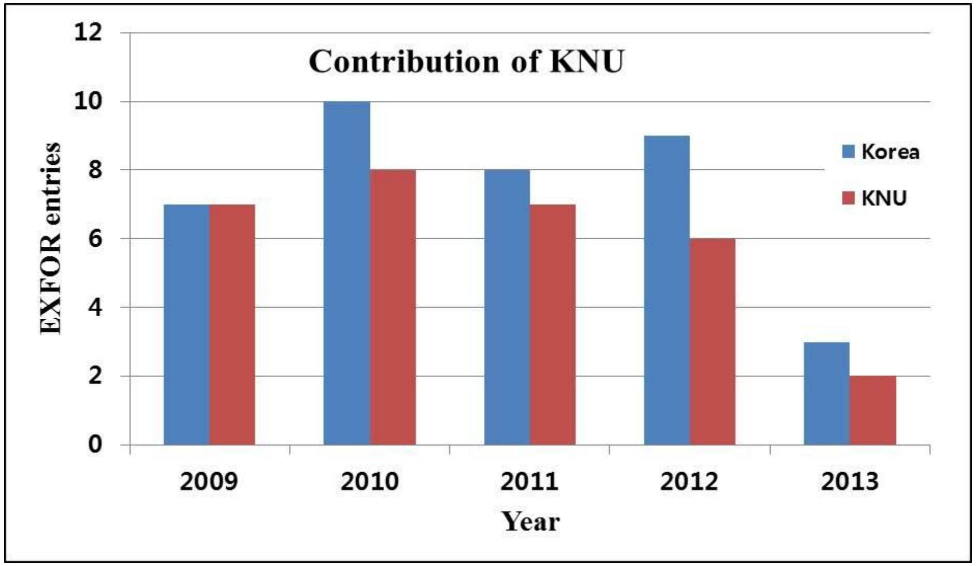


- **EXFOR Compilation Progress (since NRDC2013 meeting)**

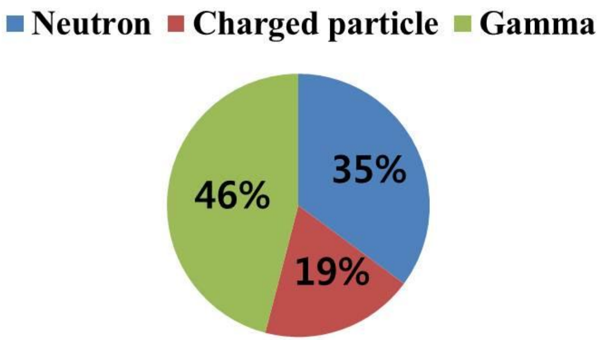
Entries	Count	Delay (Month)
Entered to EXFOR	3	5.5
Compiled (Prelim.)	1	
Reserved		
To be reserved	10	4.3

Status





Projectile



KNU's data

- **81%** contribution of produced EXFOR

Others

- Seoul National Univ. – 1
- KIGAM – 2
- Hallym Univ. – 1
- Sejong Univ. – 1
- KAERI – 1
- CIAE – 1

EXFOR Compilation

Compilation

Checking tool: http://www.jcprg.org/exfor/tool

Preliminary draft

```
ENTRY            30833   20130826
SUBENT        30833001   20130826
BIB                 12         39
TITLE      Measurement of thermal neutron cross section and
           resonance integral for the 170Er(n,g)171Er reaction by
           using a gold monitor
AUTHOR     (V.D.Nguyen, D.K.Pham, T.T.Kim, T.H.Nguyen, G.N.Kim,
            S.C.Yang, K.S.Kim, S.G.Shin, M.H.Cho, M.W.Lee)
INSTITUTE  (3VN IPH,3KORKNU,3KORPUE)
           (3KORKOR) Dongnam Institute of Radiological and Medical
            Science, Busan
REFERENCE  (J,NIM/B,310,10,2013)
FACILITY   (LINAC,3KORPUE) Pohang Neutron Facility
INC-SOURCE (PHOTO) Ta(g,n) photonuclear reaction
SAMPLE     Natural Erbium foil
            - Size: 10 x 100 mm
            - Purity: 99.9%
            - Thickness: 0.025 mm
            - Weight: 0.0354 g, 0.0378 g
           Natural Au foil
            - Siza: 10.0 x 10.0 mm
            - Purity: 99.95%
            - Thickness: 0.03 mm
            - Weight: 0.0489 g, 0.0463 g
            Natural In for the neutron flux monitoring
            - Size: 10.0 x 10.0 mm
            - Purity: 99.95%
            - Thickness: 0.05 mm
            - Weight: 0.0393 g, 0.0396 g, 0.0371 g, 0.0380 g,
                      0.0370 g, 0.0379 g
           The natural Ho and Au foils were irradiated with and
           without a Cd cover with a thickness of 0.5 mm.
METHOD     (ACTIV) Irradiated for 180 minute
           (GSPEC) Measuring time based on the activity and the
            half-life of each radioactive isotope
DETECTOR   (HPGE) To count gammas of reaction products 1.8 keV
            FWHM at 1332.5 keV peak of 60Co, efficiency of 20%
            relative to NaI(Tl) detector for the peak
REL-REF    (R,,E.Browne+,B,BROWNE,,2004) WWW Version 2.1
STATUS     (TABLE) Data from the Table 6
           (APRVD) Approved by G.N.Kim (2013-xx-xx)
HISTORY    (20130826C) S.C.Yang
ENDBIB              39          0
NOCOMMON             0          0
ENDSUBENT           42          0
SUBENT        30833002   20130826
BIB                  5         15
REACTION   (68-ER-170(N,G)68-ER-171,,SIG)
DECAY-DATA (68-ER-171,7.516HR,DG,295.90,0.289,
                                DG,308.31,0.644)
```

NDS-Comments

From: OTSUKA, Naohiko
Sent: Wednesday, 18 September 2013 14:58
To: 'scyang@kaeri.re.kr'
Subject: RE: Re: Fw: Nguyen Van Do+, J,NIM/B,310,10,2013 (EXFOR 30833)

Dear Yang-san,

thanks a lot for the new entry for the Er neutron capture. I am very glad to see that you compiled the necessary infor mation in very good shape! We are also happy that Prof. Van Do finally could find our question in his e-mail box.

I can see Prof. Van Do described answers in a very kind manner. Your description of ANALYSIS in 30833.003 is also very fine. I still do not understand the role of the In foils very well. Could you just ask him if the final data (Er thermal c ross section and resonance integral) depend on the In thermal cross section?

General comments:

1. A general problem we experienced in our previous compilation of a similar experiment is how to compile t wo statistical uncertainties (reaction sample and reference sample) because we have only one heading ERR-S for statistical uncertainty. Now we can use the correlation flag U to express the property instead of ERR-S. I added all remaining partial uncertainties from Table 5.
2. MONIT can be used only when the monitor value is proportional to the quantity to be determined (DATA). Eq.(2) shows that the thermal Er cross section is proportional to the thermal Au cross section, and we can u se MONIT for the 2nd subentry. However, the relation is more complicated for the resonance integral becaus e of Eq.(5). Therefore I modified MONIT1 etc. to ASSUM1 etc.

Because you have already done a lot of work, I would hesitate to do all these modifications, and I updated your entry as attached (30833_2013.08.26_NO.txt". The other attachment "revision.txt" is showing the major corrections done b y me by % character at the 11th column.

Other comments:

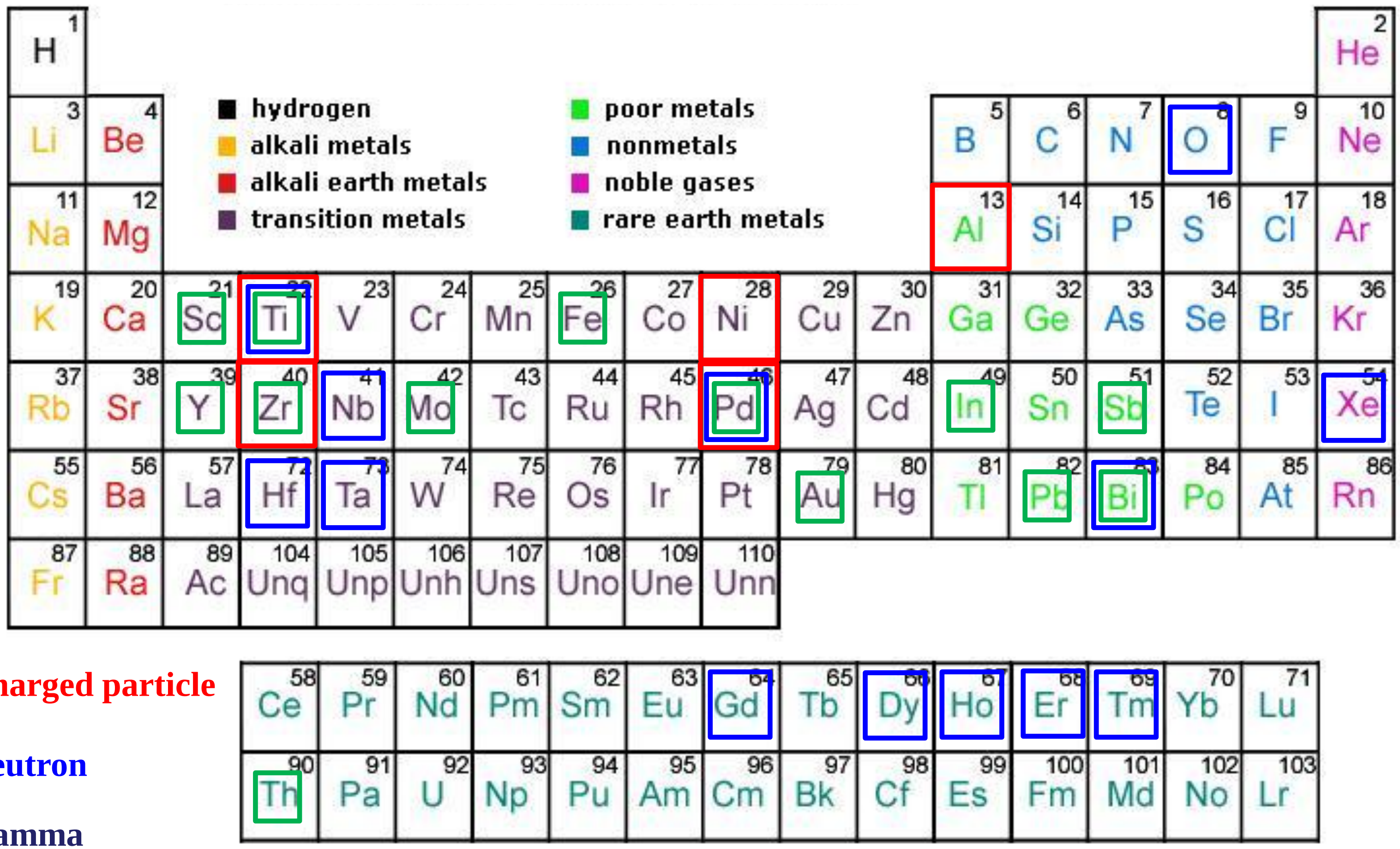
Erbium sample size: 10 x 100 mm? 10 x 10 mm?

Best regards,
Naohiko

EXFOR Compilation

Target element

Criteria: EXFOR entries listed since 2009



Charged particle

Neutron

Gamma

COVRES Code

- **Evaluates neutron c/s uncertainties in the resolved resonance region.**
  - **Improved from KERCEN**
  - **adopt transparent formalism (using MLBW or kernel approximation) based on resonance parameter uncertainties from the *Atlas of Neutron Resonances*.**
  - **Handles scattering radius uncertainty explicitly.**
  - **Produces MF33 instead of MF32.**

Resonance region

Error Propagation Equation

- **Uncertainty of average cross section**

$$<\delta\overline{\sigma}\delta\overline{\sigma}>=\sum_{i,r,i',r'}\frac{\partial\overline{\sigma}}{\partial p_{i,r}}<\delta p_{i,r}\delta p_{i',r'}>\frac{\partial\overline{\sigma}}{\partial p_{i',r'}},$$

where $<\delta p_{i,r}\delta p_{i',r'}>$ **is covariance of resonance parameters.**

- **Sensitivity**

$$\frac{\partial\overline{\sigma}}{\partial p_{i,r}}=\sum_{r'}\frac{\partial\overline{\sigma}_{r'}}{\partial p_{i,r}}=\frac{\partial\overline{\sigma}_{r}}{\partial p_{i,r}} \quad \text{where } i=\gamma,n$$

(kernel)

- **In COVRES, entire resonance energy region is divided into smaller regions called bin. Resonance-potential scattering, scattering-scattering, capture-capture and scattering-capture and bin-bin correlations are supplied as input.**

Resonance region
Sensitivity based on Multilevel Breit-Wigner

- **Sensitivity to a resonance parameter**
  - **for capture, scattering and fission**

$$\frac{\partial \bar{\sigma}_\gamma}{\partial \Gamma_i} = \frac{1}{\Delta E} \int_{E_1}^{E_2} \boxed{\frac{\partial \sigma_\gamma(E)}{\partial \Gamma_i}} dE,$$

$$\frac{\partial \bar{\sigma}_n}{\partial \Gamma_i} = \frac{1}{\Delta E} \int_{E_1}^{E_2} \boxed{\frac{\partial \sigma_n(E)}{\partial \Gamma_i}} dE,$$

$$\frac{\partial \bar{\sigma}_f}{\partial \Gamma_i} = \frac{1}{\Delta E} \int_{E_1}^{E_2} \boxed{\frac{\partial \sigma_f(E)}{\partial \Gamma_i}} dE,$$

→ analytically obtained

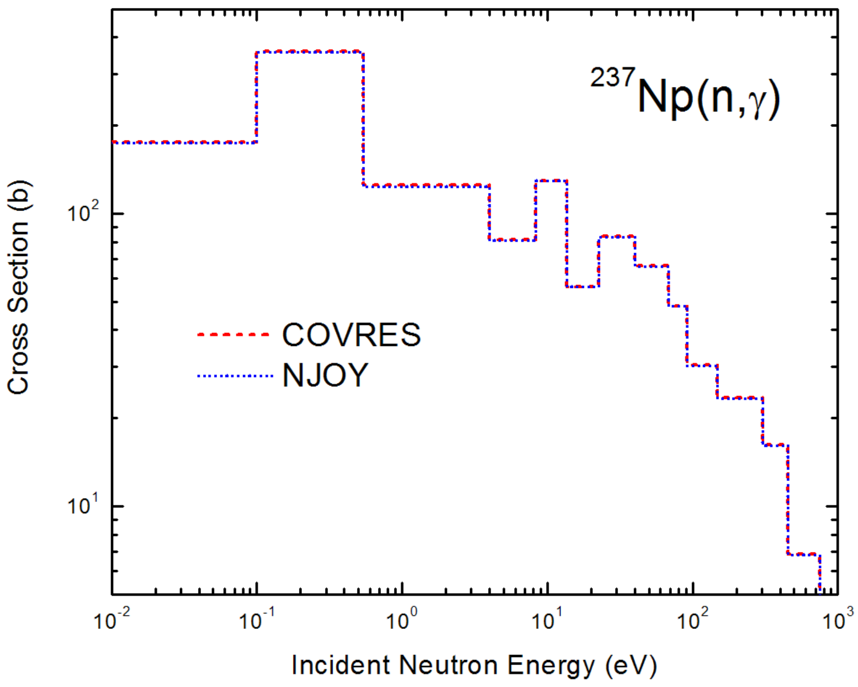
$\bar{\sigma}_i$: Average cross section in the arbitrary bin between E_1 and E_2 $\quad i = \gamma, n, f$

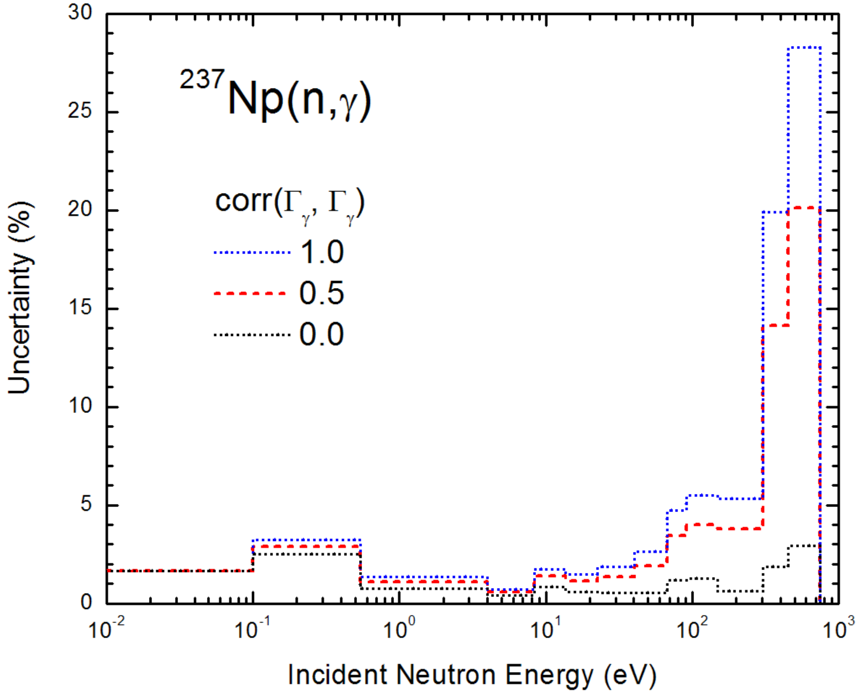
$\frac{\partial \bar{\sigma}_n}{\partial R'}$? by observing variation of average scattering cross section due to deviation of R’

$$\frac{\partial \bar{\sigma}_n}{\partial R'} \delta R' \approx \delta \bar{\sigma}_n (R' \to R' + \delta R')$$

Resonance region

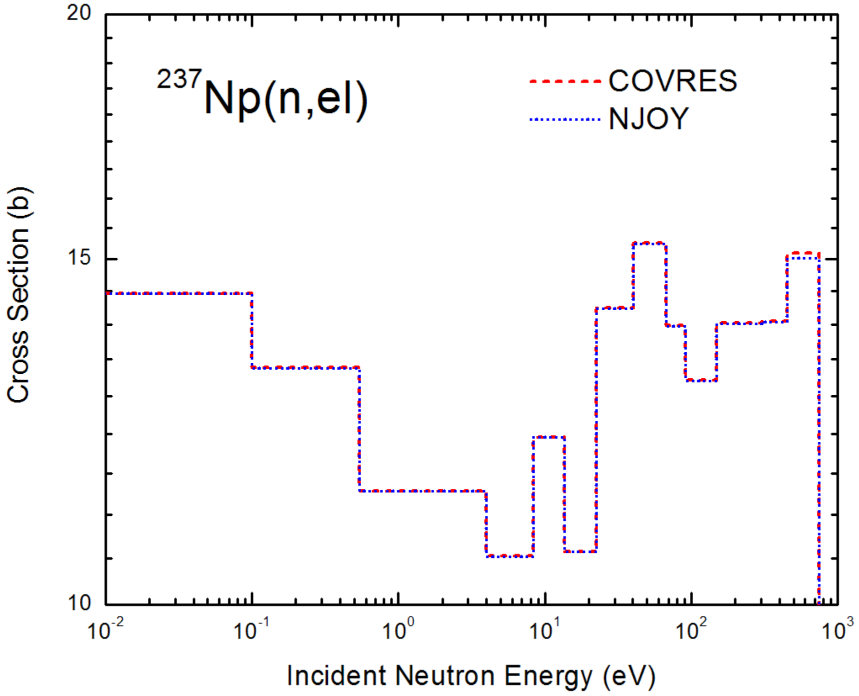
^{237}Np, capture

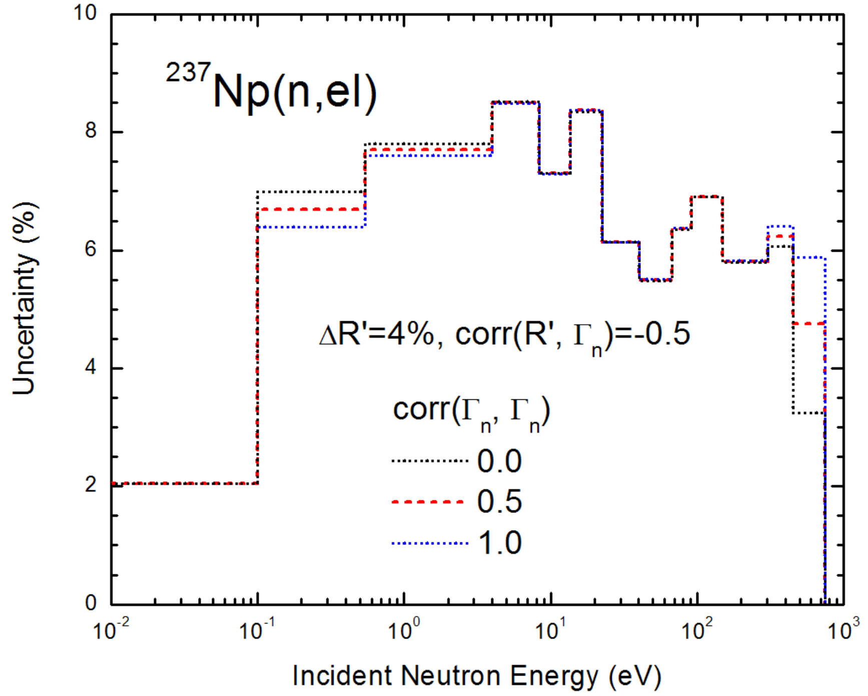




Resonance region

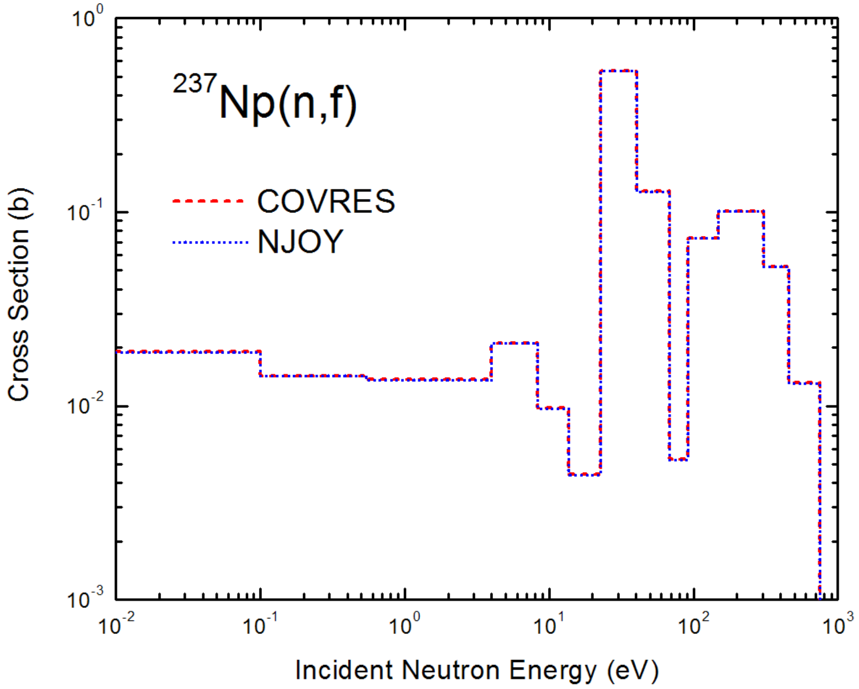
^{237}Np, scattering

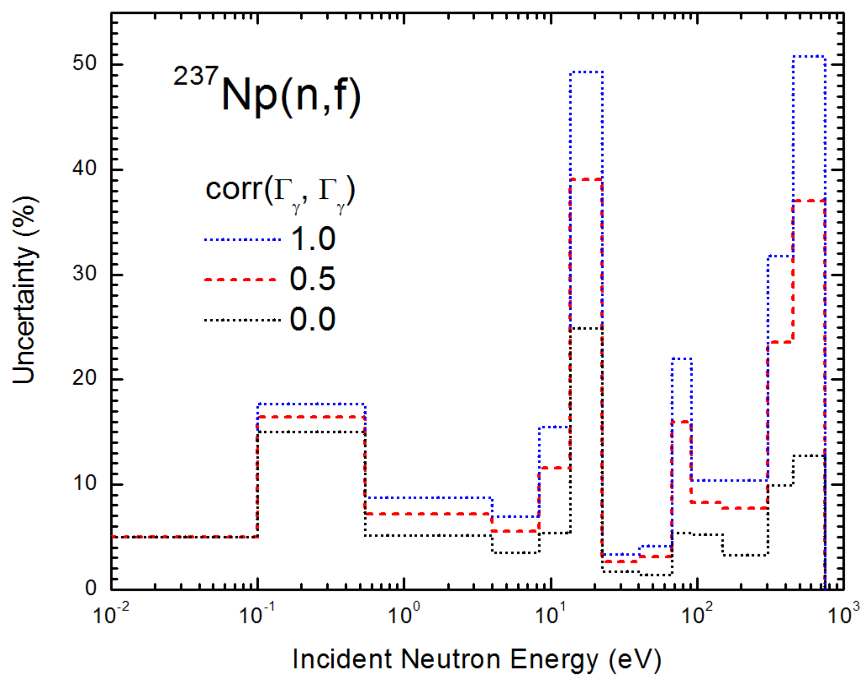




Resonance region

^{237}Np, fission

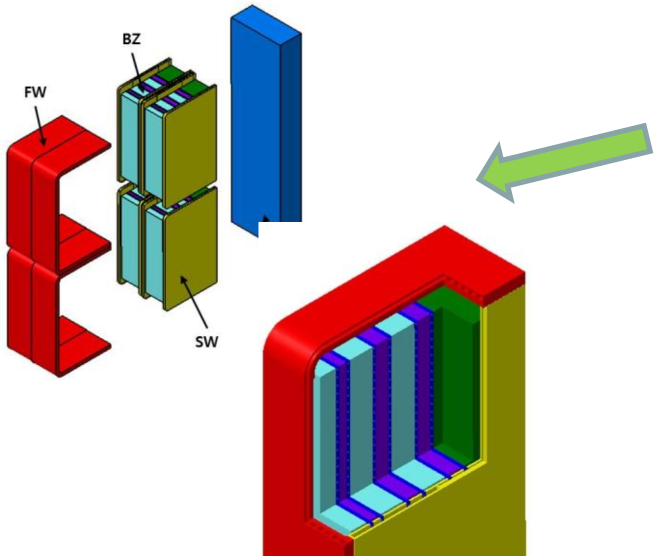




Ko HCCR TBM

- **A Mission of KAERI/NDC to Ko HCCR TBM**
  - **The neutronics analysis to obtain the optimal design parameters**
  - **Provision of the most reliable nuclear data**
    - **Recommendation of the evaluated nuclear data from the existing libraries**
    - **Production of the evaluated nuclear data**

HCCR TBM configuration



Projection view of HCCR TBM sub-module

Materials used in the Ko HCCR TBM

Material	Element
RAFM Steel* (Structural Material)	W, Ta, Fe, Cr, Zr, Mn, Mo, Nb, Cu, Ni, Co, V, Ti, S, P, Al, O, C, N, B, H
Li_4SiO_4 (Breeder)	Co, Fe, Ti, Ca, K, Si, Al, Na, O, Li-6, Li-7
Beryllium (Multiplier)	Fe, Si, Al, Mg, O, C, Be
SiC Coated Graphite (Reflector)	Pb, Zn, Cu, Ni, Co, Fe, Mn, Cr, V, Ti,Ca, K, Si, Al, Mg, Na, C, Li, B

*Reduced Activation Ferritic/Martensitic (RAFM)

Red :Done

Remaining: 2016

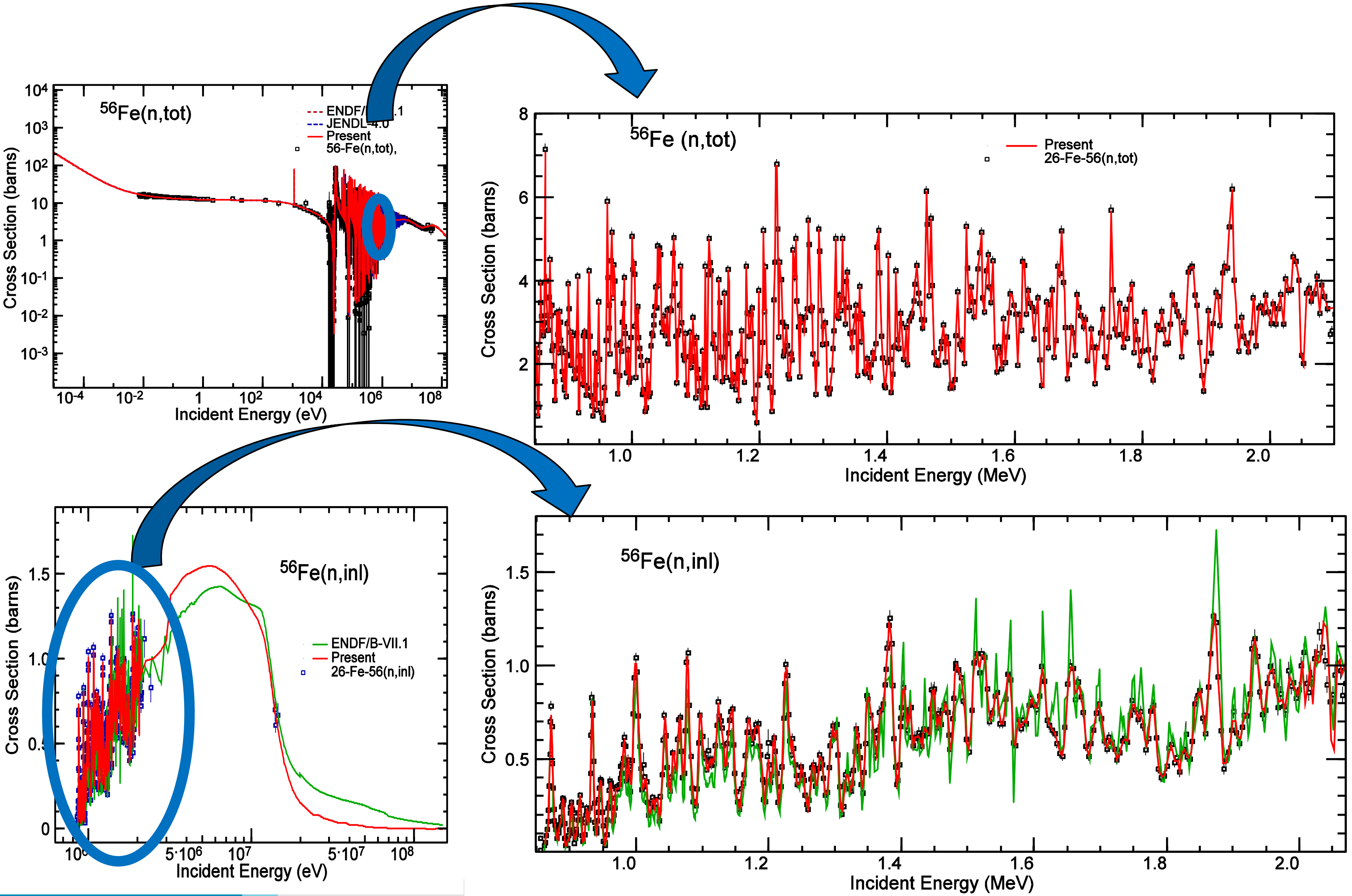
High energy region

Evaluation Procedure

- **Code**
  - **EMPIRE-3**
  - **Parallel computing to reduce a computing time due to covariance matrices and a thousand incident energies**
- **OMP adjustment**
  - **Tool for optimization of OMP developed by KAERI/NDC**
- **Models**
  - **Hauser-Feshbach with HRTW**
  - **DEGAS for gamma and PCROSS for others in pre-equilibrium**
  - **Empire specific level densities**
  - **Gamma strength function by plujiko(MLO1)**
- **Covariance**
  - **EMPIRE-KALMAN used**
  - **Sensitivity matrices by variations of model parameters around optimal value**
  - **Using uncertainties of measurements if available**

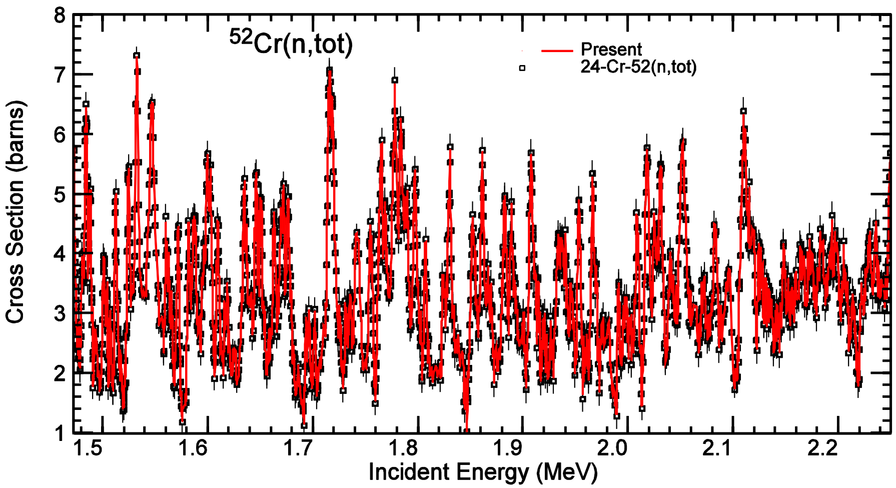
High energy region

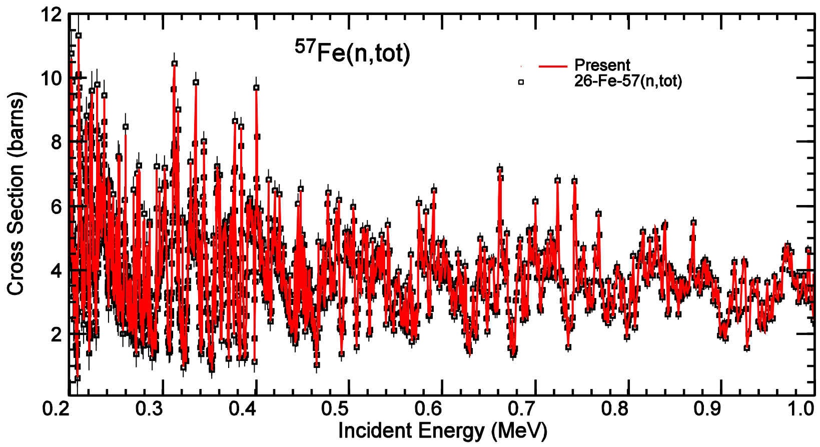
Reproductions of a resonance-like structure (1)

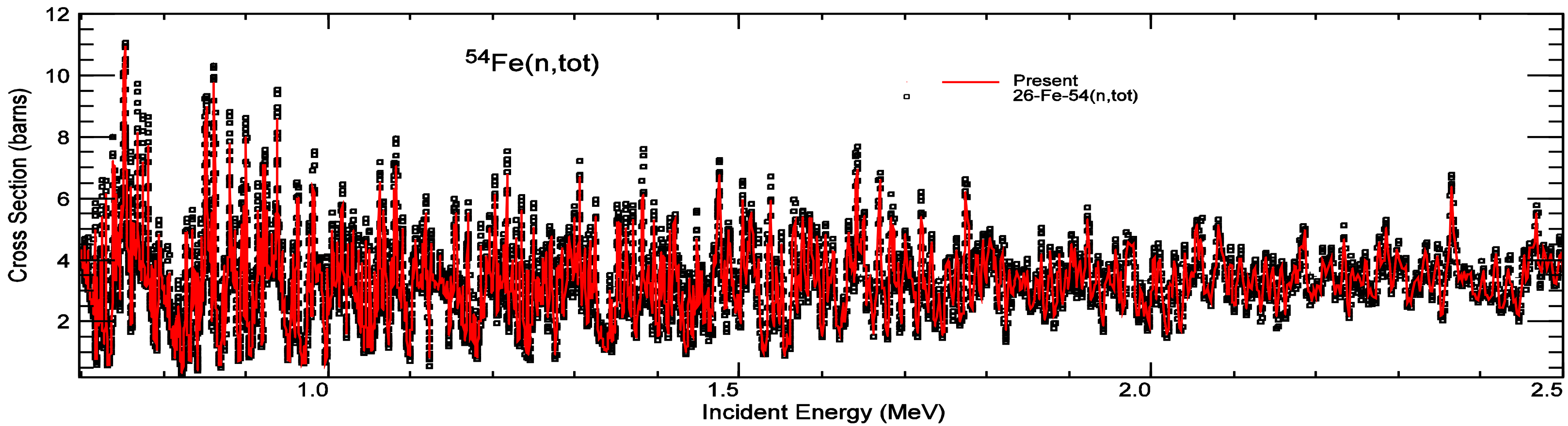


High energy region

Reproductions of a resonance-like structure

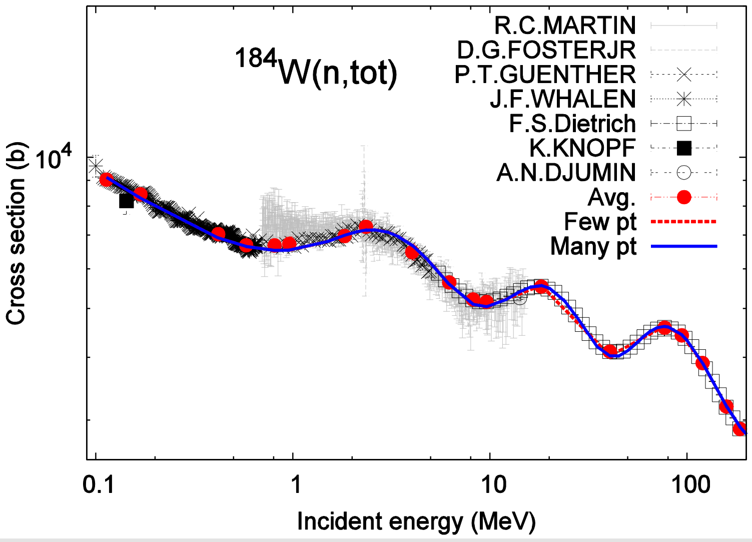


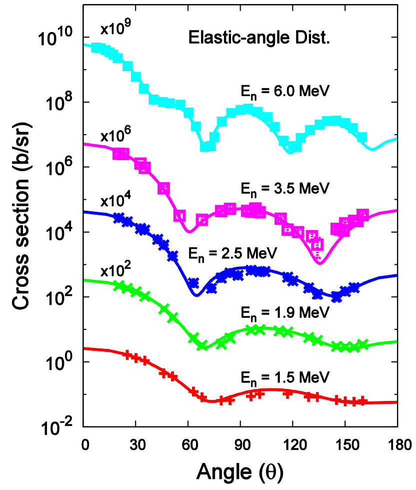




Procedure of OMP fitting

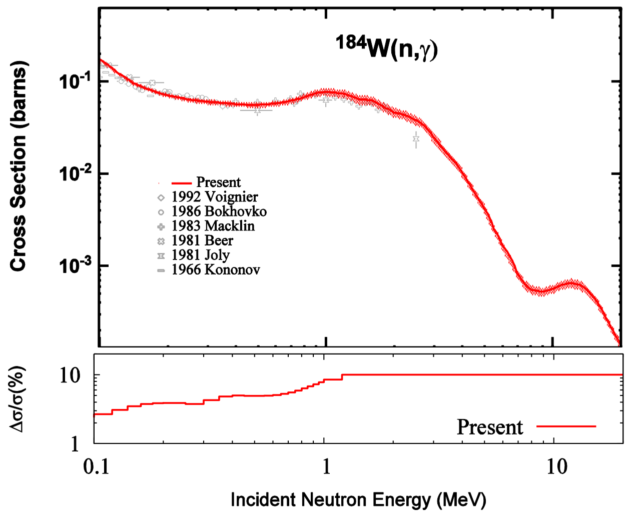
- **Preparation of experimental data**
  - **Total (non-elastic), elastic, elastic-angular distributions**
    - **Pseudo total(non-elastic) XS data for computational efficiency**
- **Preparation of reference OMP**
  - **Start from RIPL (global K-D OMP)**
  - **Determine Deformations and couple levels if deformed nuclei**
- **Run**
  - **Eye guide (I**
  - **Simulated A**
- **Optimum OM**

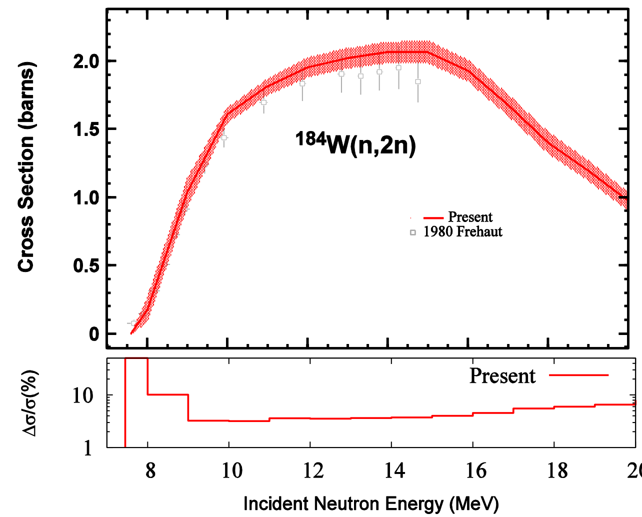


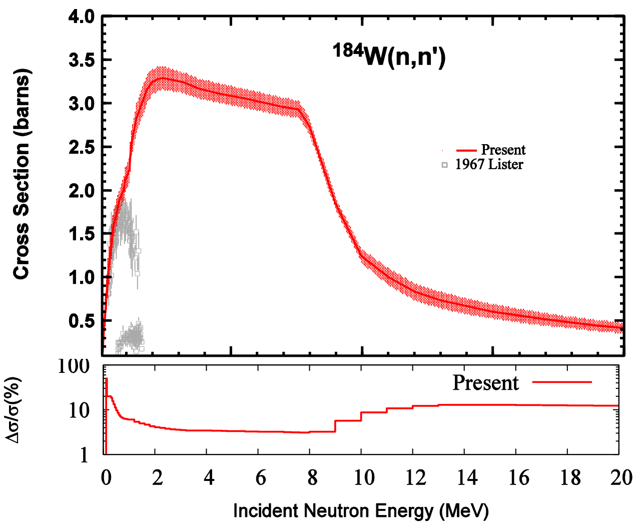


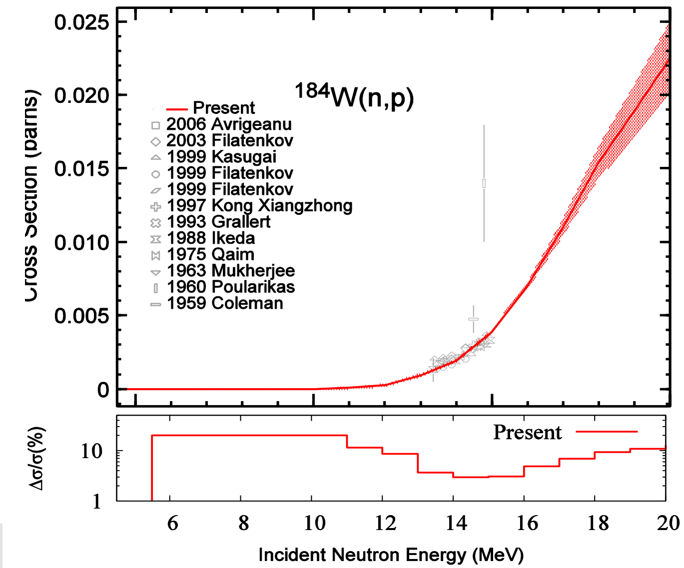
High energy region

Cross Section and Uncertainties of W



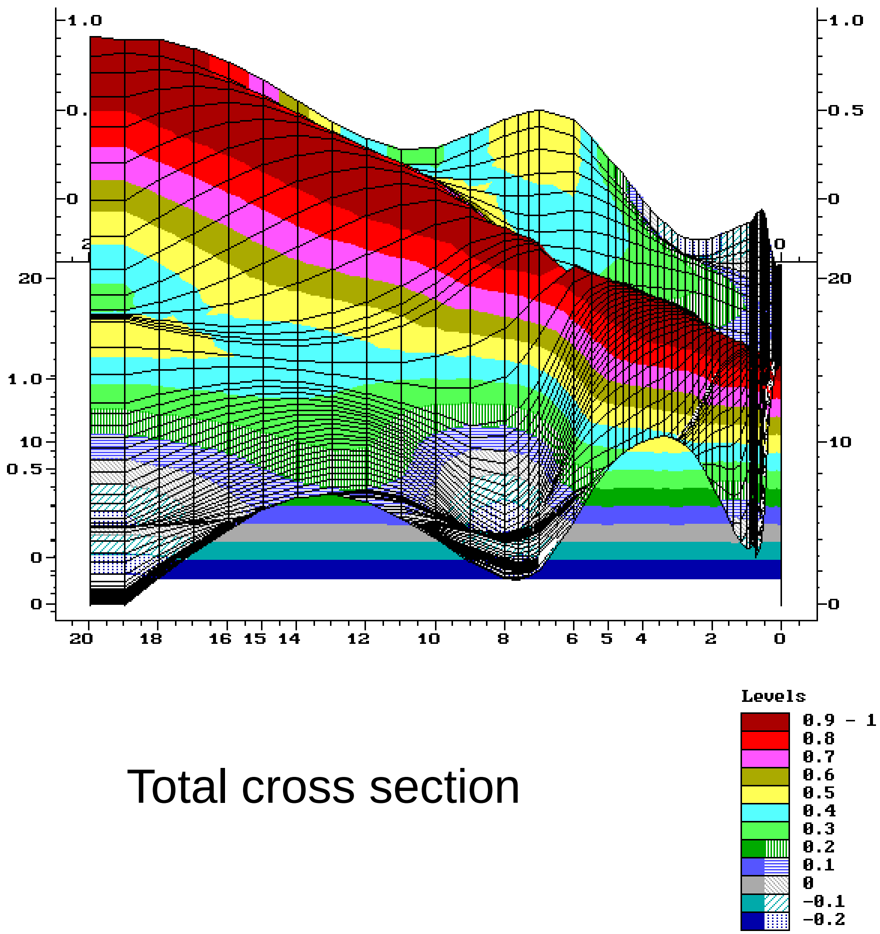




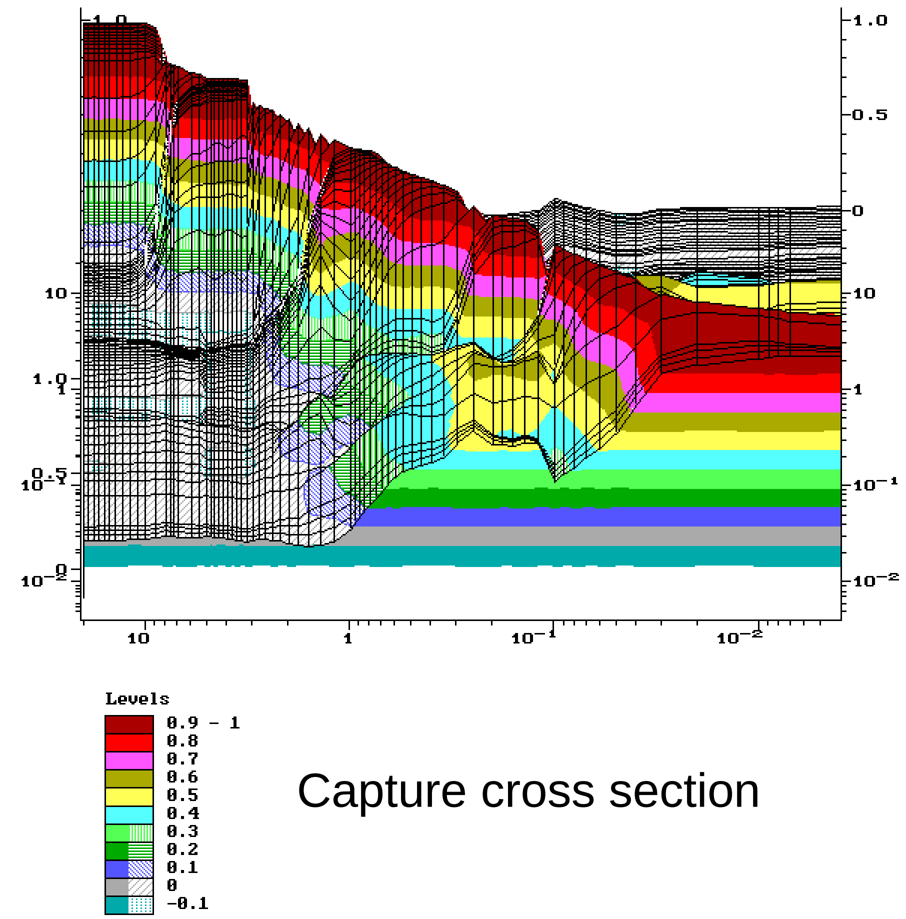


High energy region

Correlations of 184W



Total cross section

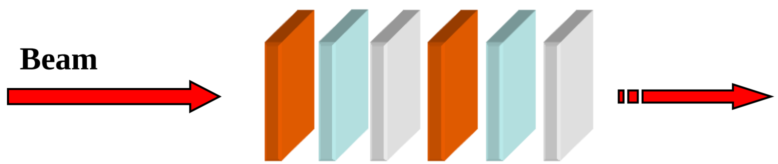


Capture cross section

Facilities in operation

➢ Charged particle (KIRAMS, Gyeong-ju, Jeong-eup)

Cross-section measurements using the Stacked-foil Activation Method



Er Cu Al Er Cu Al

◆ KIRAMS (Seoul)

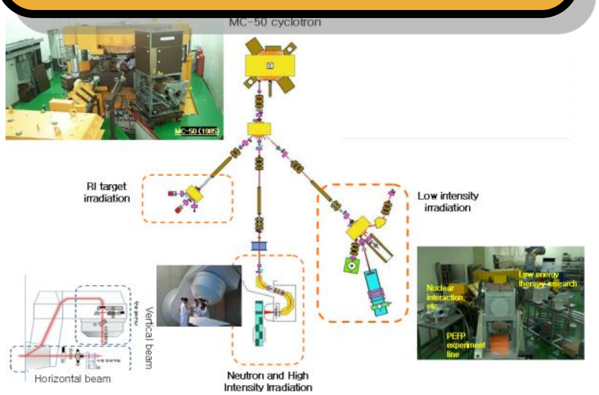
Energy: ~50 MeV
Current: <~100 nA
Projectile: p, d, α

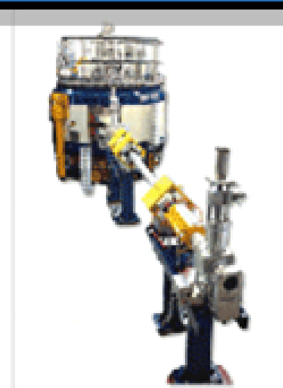
◆ Gyeong-ju

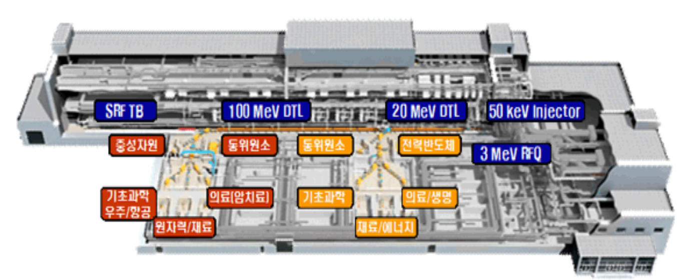
Energy: 100 MeV
Current: <~20 mA
Frequency: 350 MHz
Projectile: p

◆ Jeong-eup

Energy: 15~30 MeV
Current: <~350 μ A
Frequency: 65 MHz
Projectile: p







Facilities in operation

➢ Neutron (PAL, HANARO, KIRAMS, Jeong-eup, Gyeong-ju)

Measurement of Thermal (Fast) Neutron Cross-sections by TOF and activation method

◆ Thermal Neutron
- ✓ PAL (PNF)
- ✓ HANARO (Reactor)

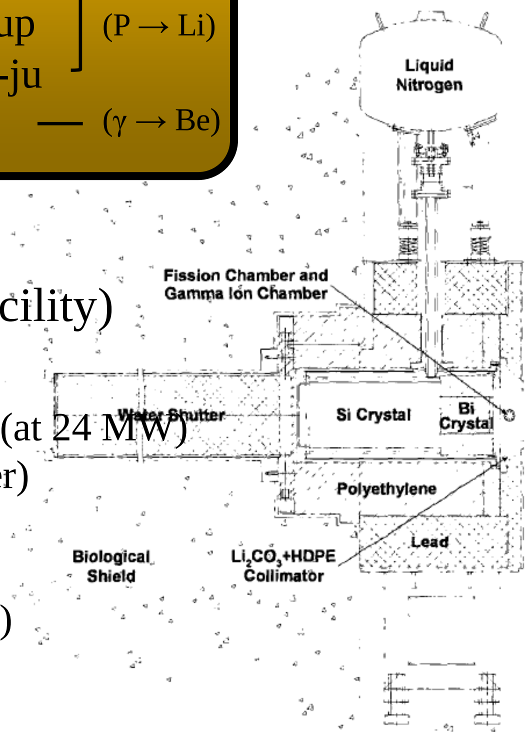
◆ Fast Neutron (plan)
- ✓ KIRAMS
- ✓ Jeong-eup
- ✓ Gyeong-ju
- (KIRAMS, Jeong-eup, Gyeong-ju: $(P \rightarrow Li)$)
- ✓ PAL — $(\gamma \rightarrow Be)$

➢ PAL

- Electron accelerator based TOF system
  - energy = 40 ~ 70 MeV
  - repetition rate = <30 Hz
  - pulse width = 1 ~ 2 μs
  - peak beam current = 30 ~ 60 mA
- Target (Ta) + water moderator

➢ HANARO (BNCT Facility)

- Thermal neutron
- Flux = ~1.19×10^{9} n/cm^{2}·s (at 24 MW)
- Si crystal (fast neutron filter)
  - length = 40 cm
  - diameter = 20 cm
- Bi crystal (gamma ray filter)
  - length = 15 cm
  - diameter = 10 cm



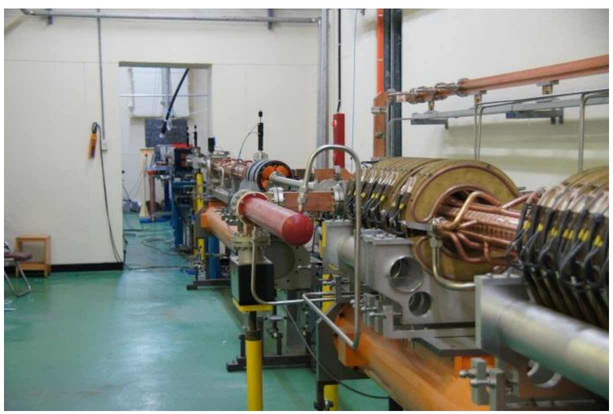
Facilities in operation

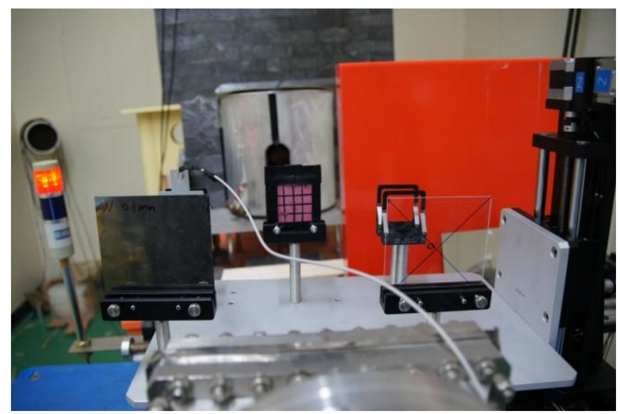
➢ Gamma (PAL)

Measurement of Photo-fission and Isomeric ratio by activation method

◆ Bremsstrahlung beam
  ✓ PAL (PNF)

- Electron energy : 40 ~ 70 MeV
- Target : thin W (100 mm × 100 mm × 0.1 mm)

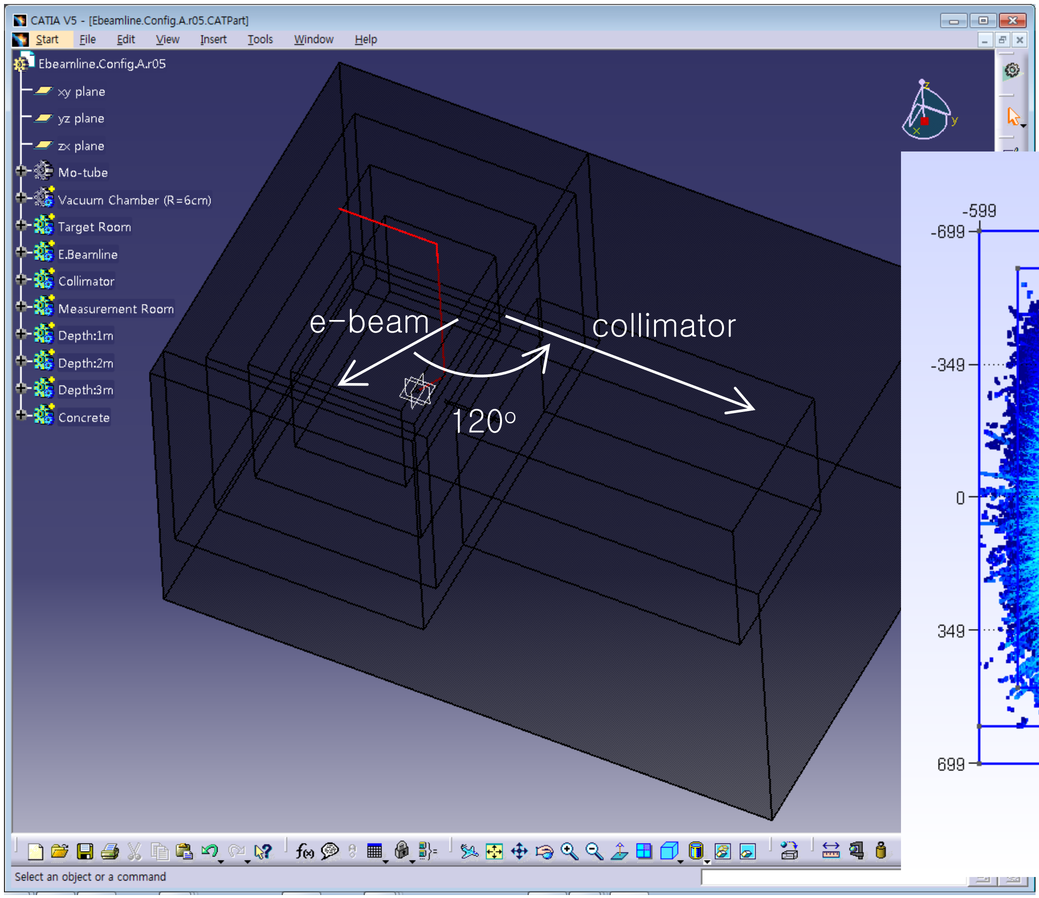


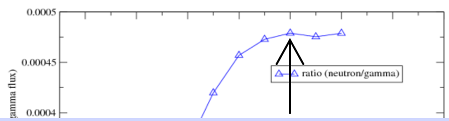


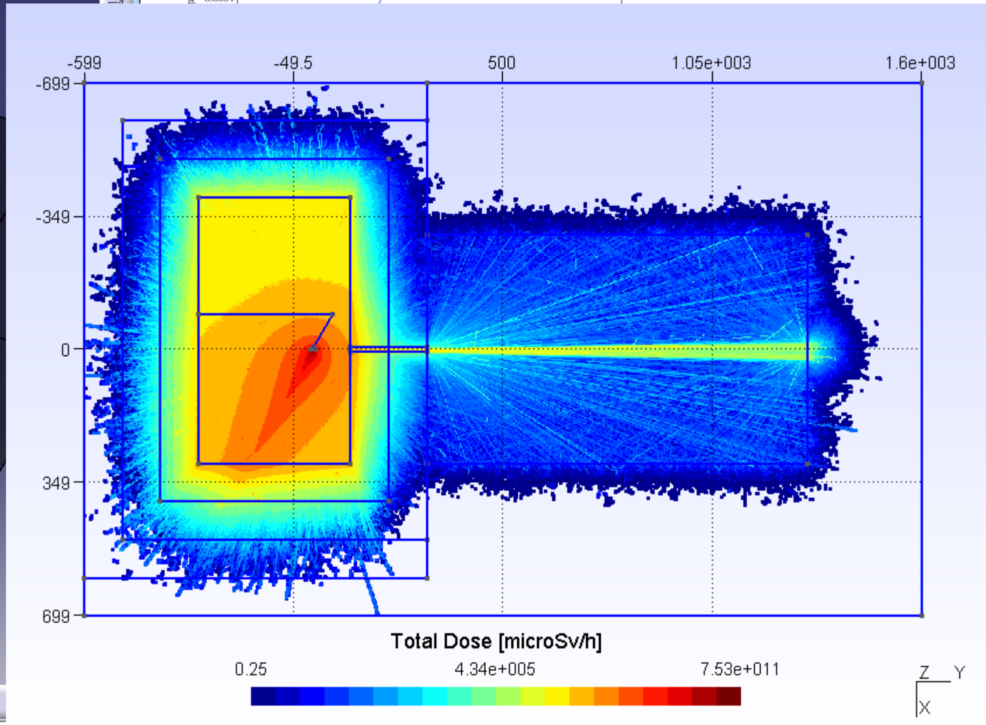
Facilities in design

KAERI e-linac-based n-TOF

- Angle between e-beam and collimator is 120° to minimize photon flash





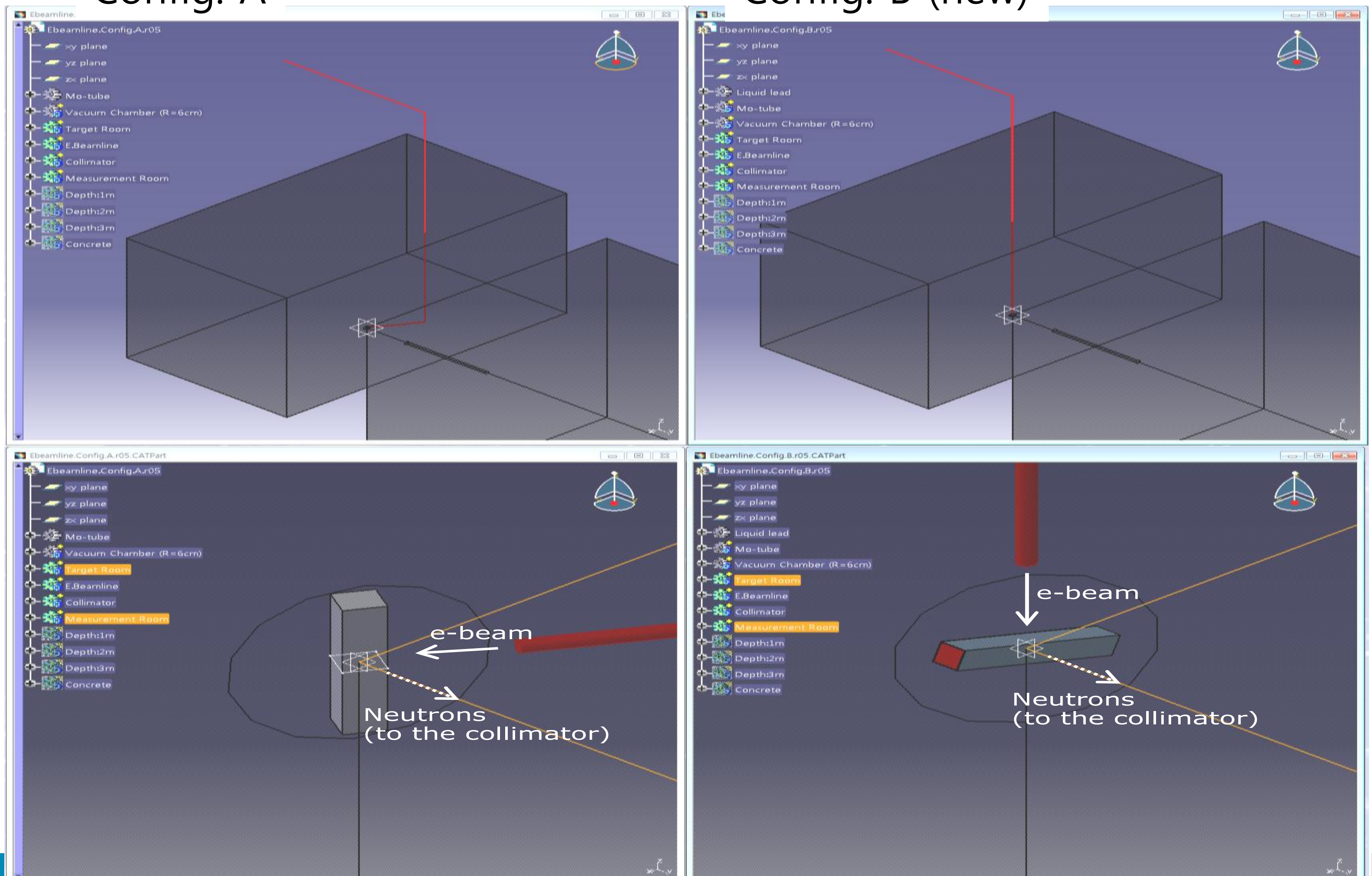


- two bendings of e-beam (90°, 90°)
- Construction difficulty → need new layout !

Facilities in design

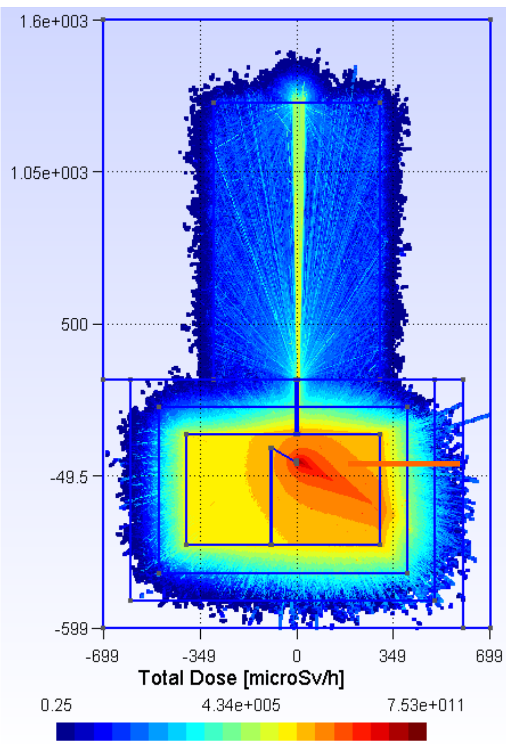
KAERI e-linac-based n-TOF

Config. A Config. B (new)

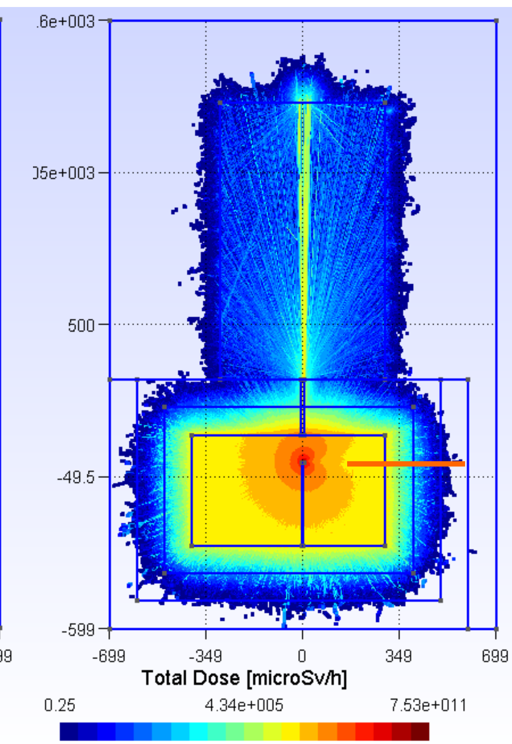


KAERI e-linac-based n-TOF

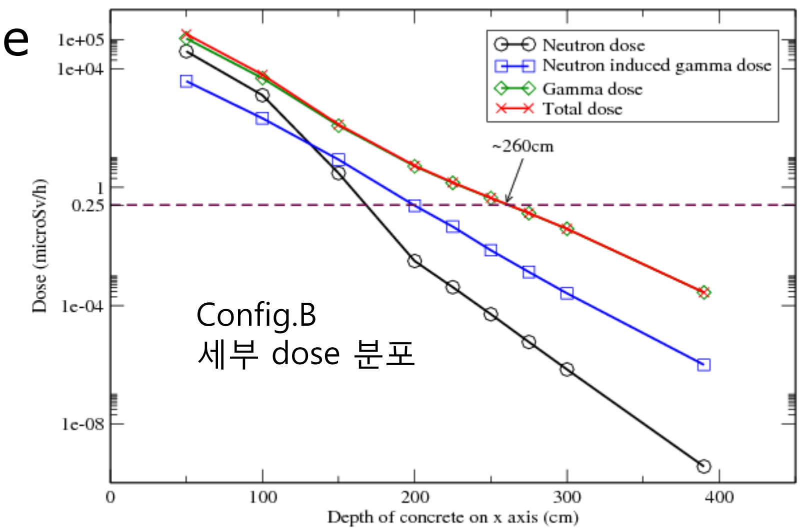
- Estimate shielding thickness on XY plane
  - Shielding thickness to meet 0.25μSv/h
    - Config.A: 340cm
    - Config.B: 260cm (-80cm)

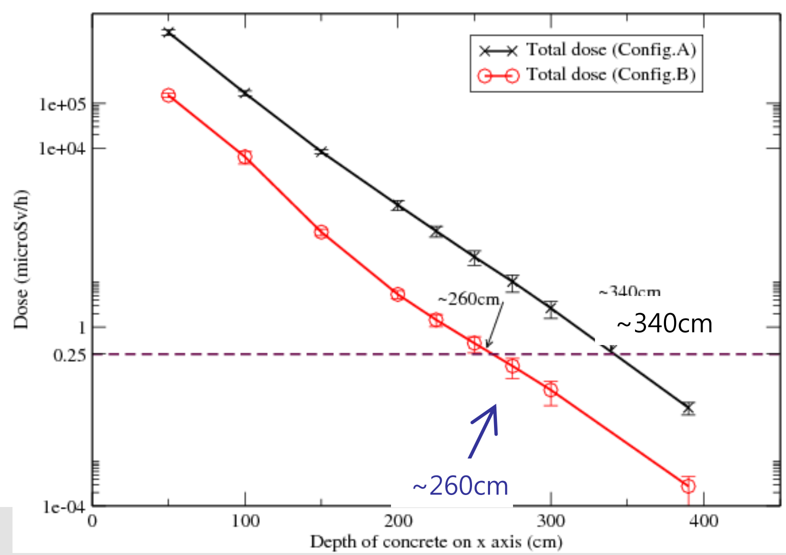


Config.A



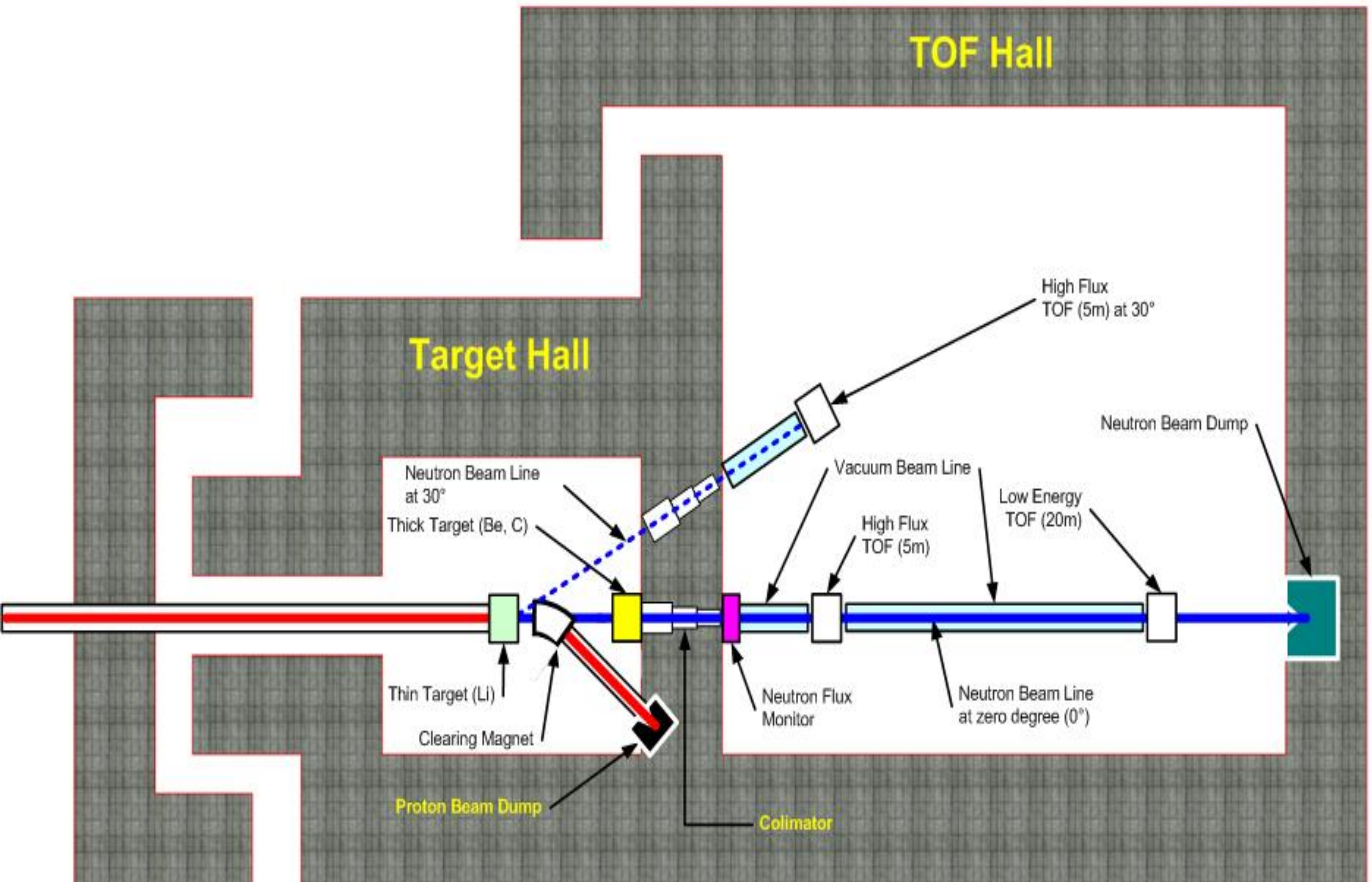
Config.B



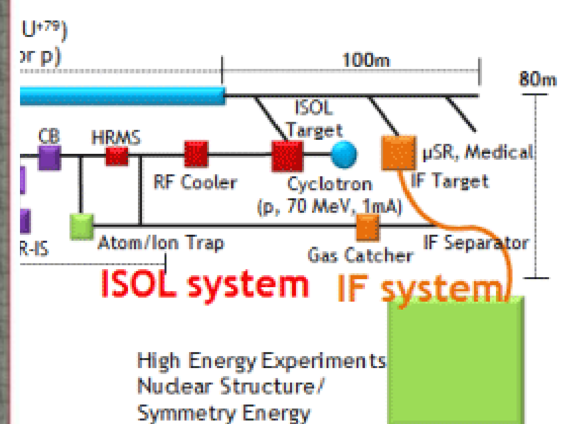


RAON Neutron Science Facility

53MeV deuteron; (d,n) reaction; white neutrons
88MeV protons; (p,n) reaction; mono-energetic neutrons

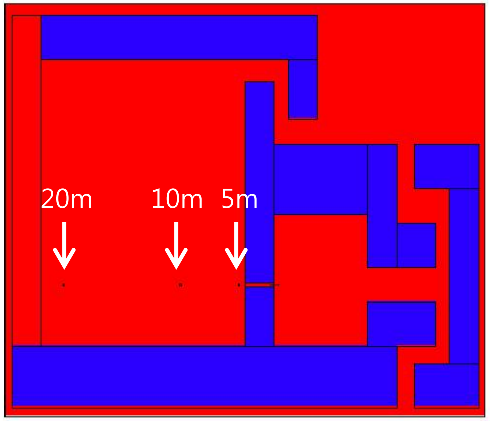


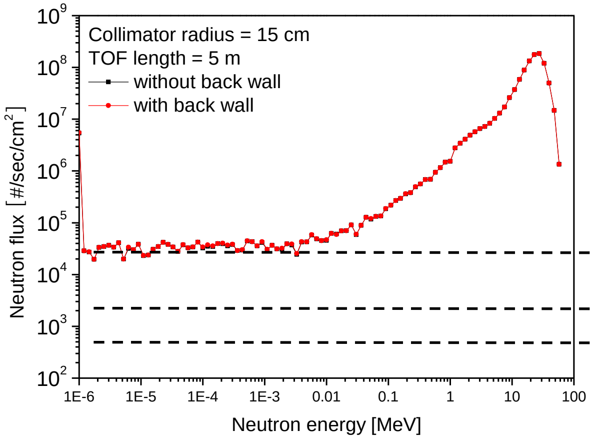
Linac		Post Acc.	Cyclotron
Xe^{+54}	U^{+79}	RI beam	proton
251	200	18.5	70
11	8.3	-	1000
400	400	-	70

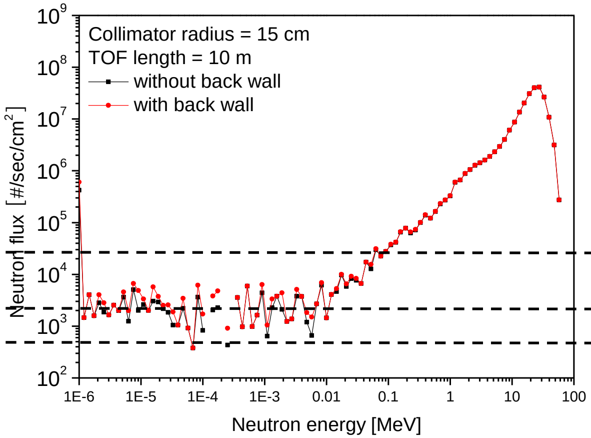


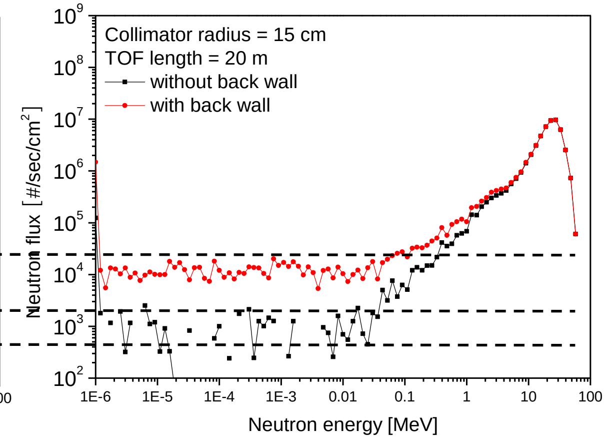
RAON Neutron Science Facility

- Estimate
  -Low energy tails of neutrons
  → beam window or filter suggested
  -Back-scatterd neutrons
  → design change in progress



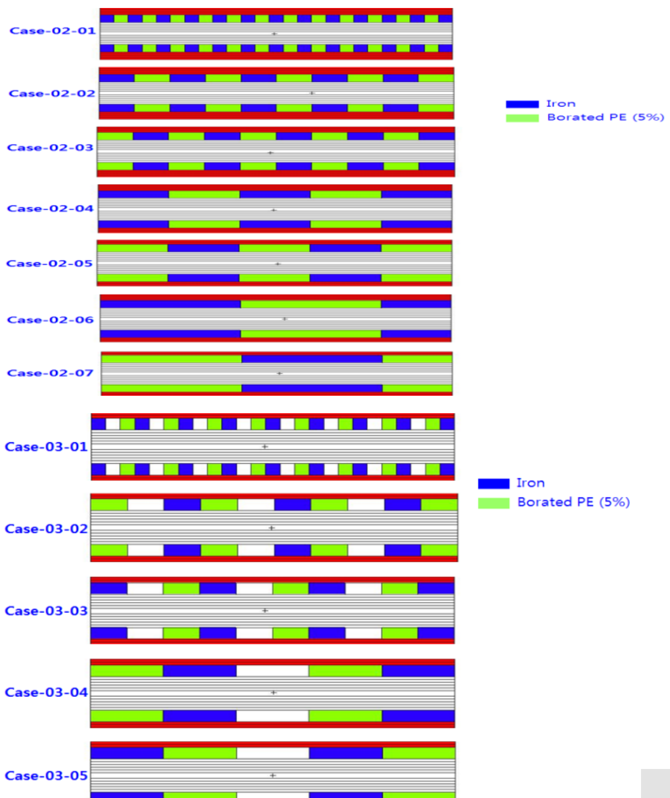


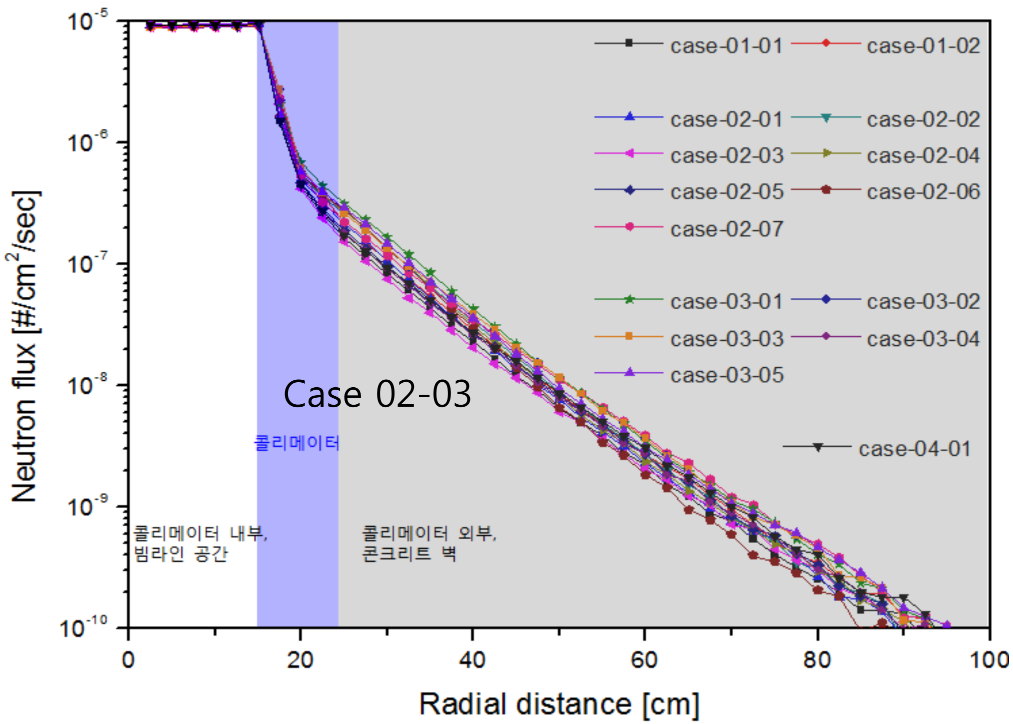




RAON Neutron Science Facility

- Collimator design study
  - Concrete, Iron, PE (5% Borated PE)
  - Iron: more neutrons with 0.01MeV<E<1MeV   - PE (5% borated): concrete-like
- Iron (fast neutrons) + 5% borated PE (low energy newtrons) suggested





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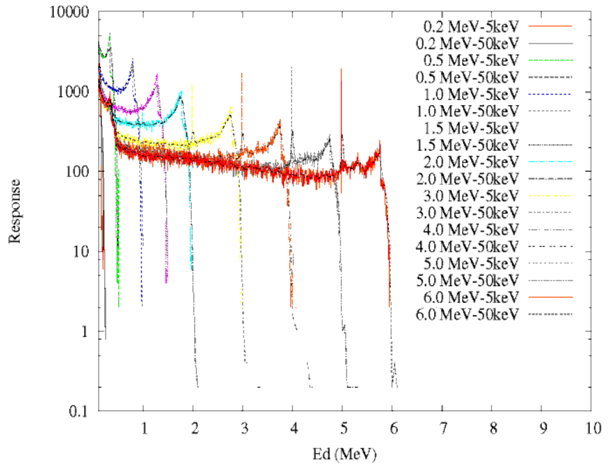
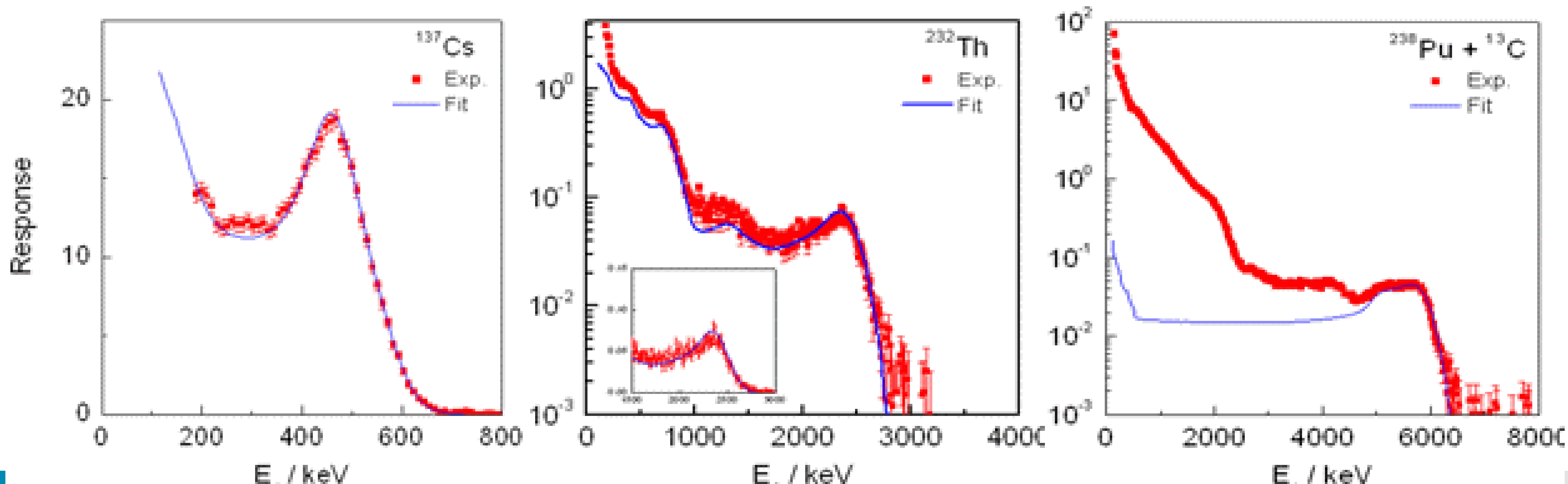
- C_6D_6 design (IRMM collaboration)

$$R(E_d, E_\gamma) = \int R_2(E_d, E_e) R_1(E_e, E_\gamma) dE_e$$





Facilities in design

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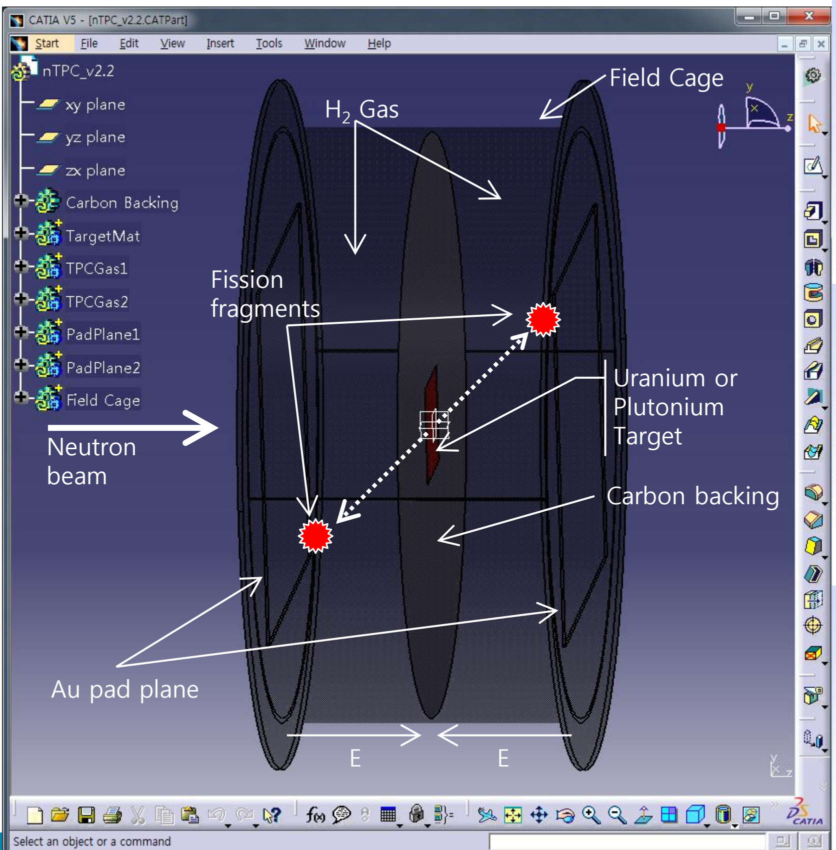
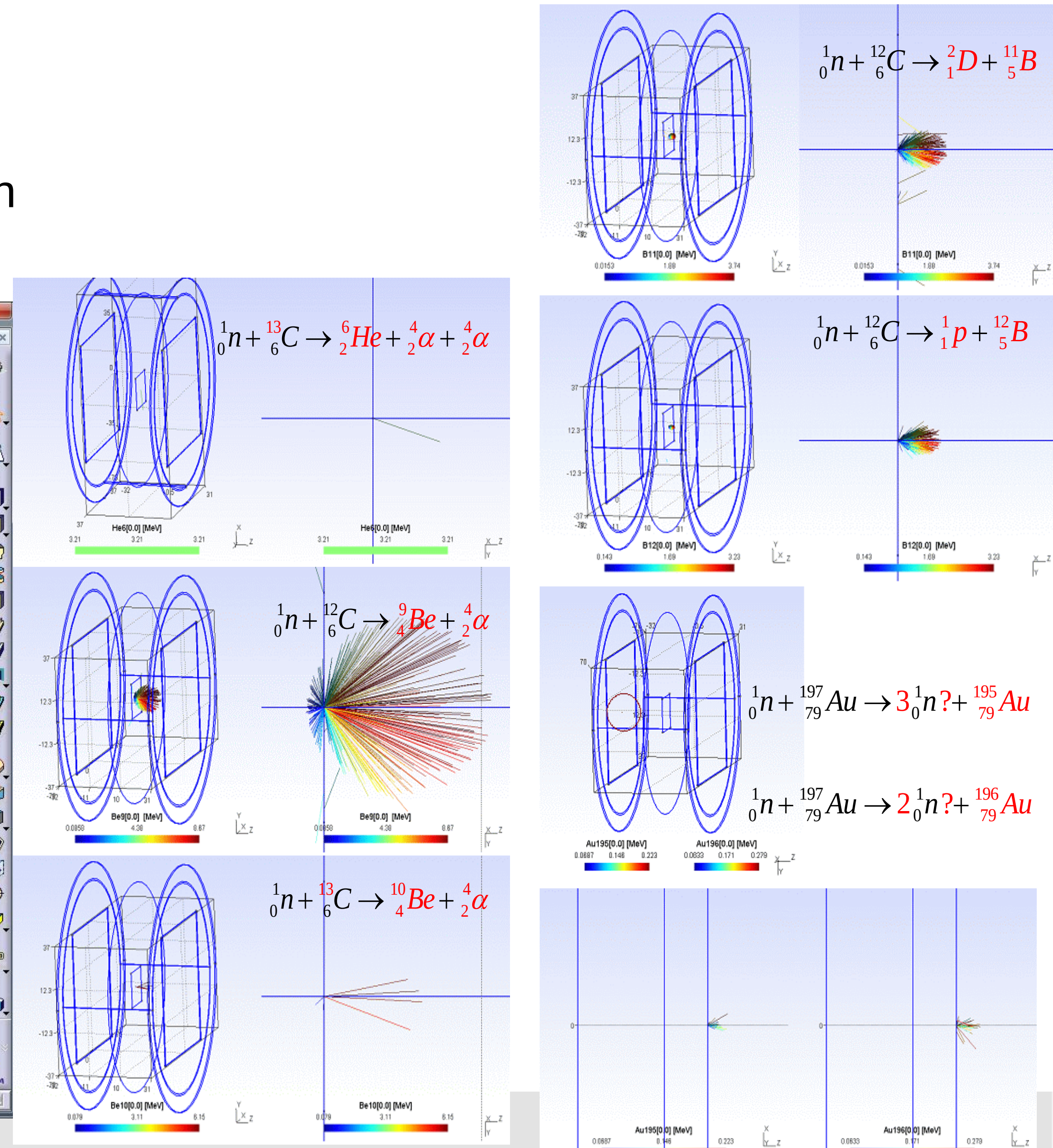
- TPC design: Geant4 simulation





Summary

- **EXFOR progress**
  - Compilation responsibility for domestic experiments
  - Since NRDC2013 meeting, EXFOR: 3, Compile: 1
- **EXFOR compilation procedure**
  - Cooperation with NDS
  - Checking through JCPRG website
- **The contribution of Kyungpook National Univ.**
  - A unique group of nuclear reaction experiment (81%)
- **Evauation activities**
- **Facilities in operation and in design**