Nuclear Data Activities in Korea

AASPP Workshop, the 1st Asian nuclear reaction database development workshop

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Chronology of Nuclear Data Activities in Korea

- 1997 : First start nuclear data R&D
- 2000 : measured Mono-energy neutron cross sections (PNF)
- 2001 : Contribute 124 photonuclear cross sections to IAEA
- 2006 : Contribute 32 FP neutron cross sections to ENDF/B-VII
- **2008 : Became one of the key R&Ds in KAERI: stable budget**
- **2010: ND2010 in Jeju island (4.26-4.30, 2010, 濟州島)**

- **As of 2010:**
  - -Participate in international nuclear data network
  - -Coordinate domestic network in measurements, evaluation & validation
  - -Supply nuclear data libraries (evaluated, processed and validated) to advanced fuel cycle, future nuclear system, fusion, accelerator, etc

Nuclear Data Network

IAEA, OECD, BNL, EU, JAEA , CIAE etc

International Network

Nuclear Data Measurements

Nuclear Data Evaluation

Processing/ Validation

Supply to nuclear R&D

- SFR, AFC, ADS
- Fusion
- Accelerator
- Space etc

Domestic Nuclear Data Network

(Pohang PNF)
•eV pulseneutron
•Neutron resonance
•Photonuclear reaction

(KAERI photo-ntn)
•keV pulse neutron
•TREE

(KIGAM VDG)
•MeV pulse neutron
•Wide-range standard ntn

(KoRIA)
•Fast neutron data

Nuclear Data Activities as of 2010

- **Resonance:** KERCEN code in development
- **Above Resonance:** Evaluation and Covariances for ^{237}Np, ^{240}Pu and Cm isotopes

- **Pohang Neutron Facility** (eV neutrons)
- **KIGAM Neutron Facility** (standard neutron fields up to ~MeV)

- **KAERI Neutron TOF Facility** on e-LINAC (above 100 KeV)
- **Nuclear Data Measurements at KoRIA** (up to tens of MeV)

KERCEN code in development (with BNL)

- Evaluates neutron c/s covariances in the resolved resonance region.
  - Uses a transparent formalism based on resonance parameter uncertainties from the *Atlas of Neutron Resonances*.
  - Handles scattering radius uncertainty explicitly.
- Produces MF33 bypassing MF32 processing issues.

KERCEN input

R, dR	scattering radius and its uncertainty
Gg_i,dGg_i	average gamma width and its uncertainty for *i*th partial wave
CorrRP	correlation between resonance and potential scattering
CorrNN	correlation between neutron widths in the same bin
CorrGG	correlation between gamma widths in the same bin
CorrNGS	correlation between neutron and gamma widths of single resonance
CorrNNB	correlation between scattering c/s in different bins
CorrGGB	correlation between capture c/s in different bins

KERCEN formulae

- Sensitivity

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

- Uncertainty of average cross section

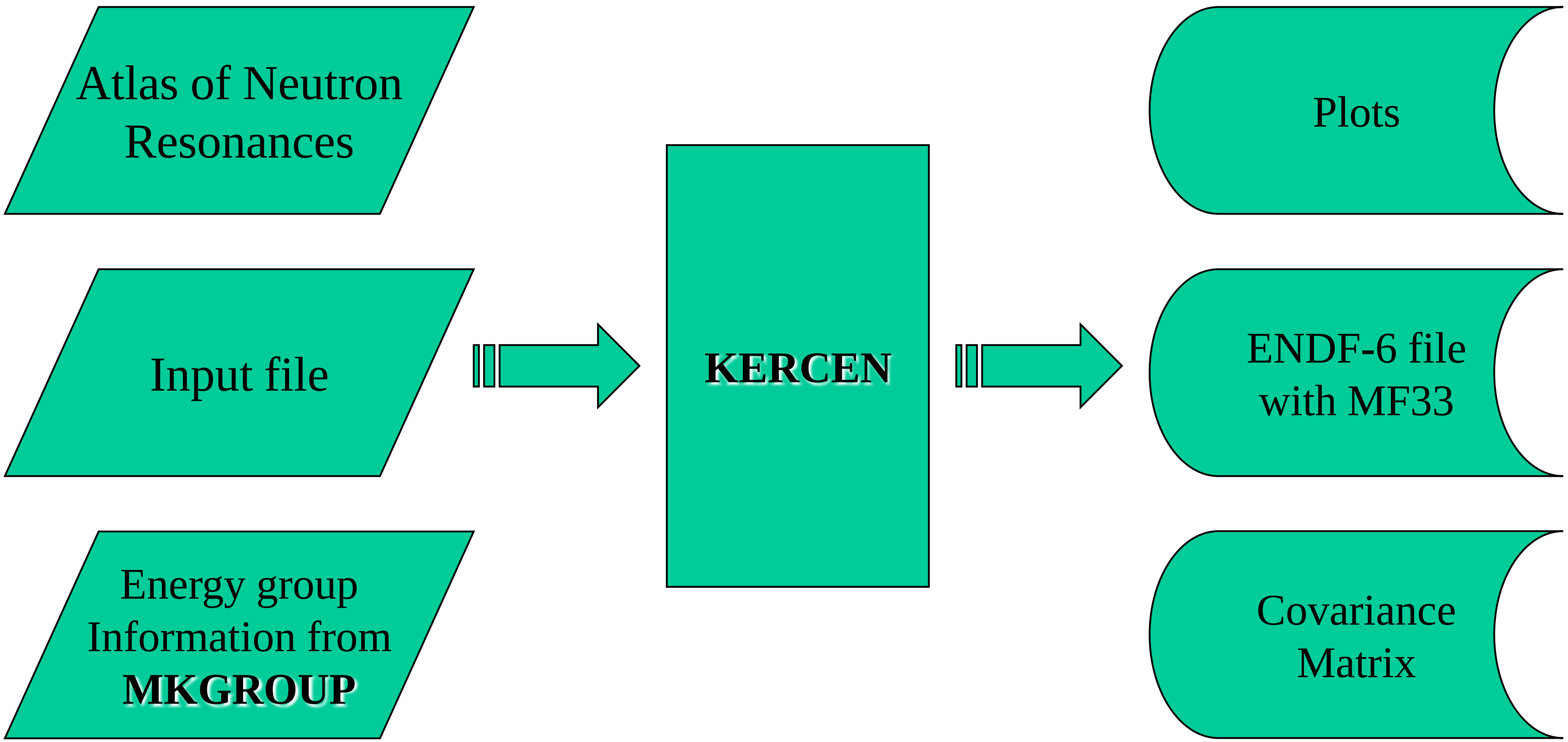
$$< \delta\overline{\sigma}\delta\overline{\sigma} >= \sum_{i,r,i',r'} \frac{\partial\overline{\sigma}}{\partial p_{i,r}} < \delta p_{i,r}\delta p_{i',r'} > \frac{\partial\overline{\sigma}}{\partial p_{i',r'}},$$

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

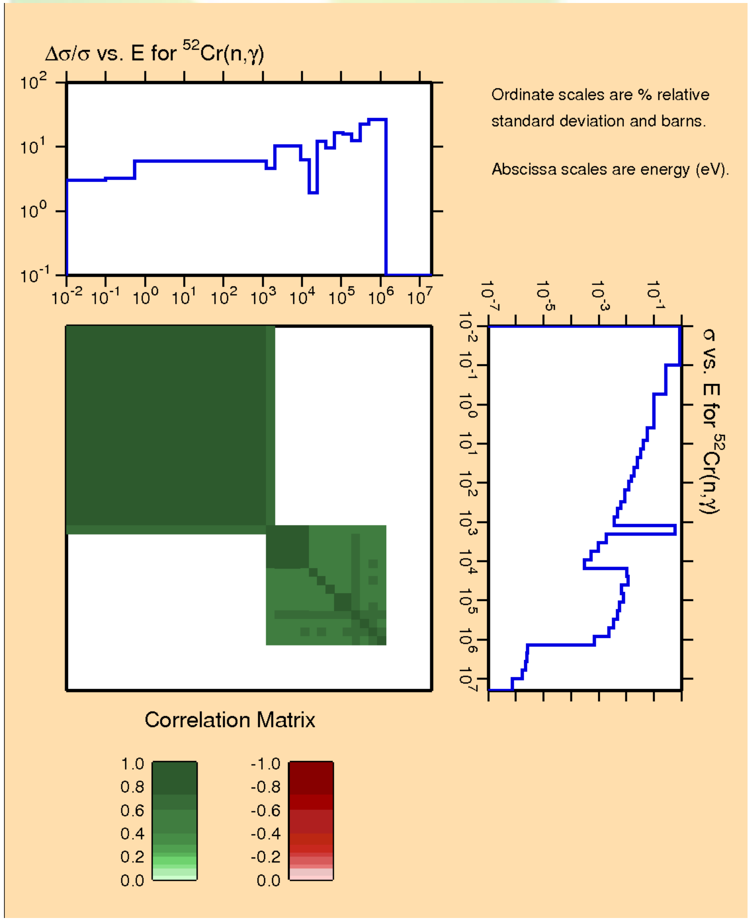
- In KERCEN, entire resonance energy region is divided into smaller regions called bin. Resonance-potential scattering, scattering-scattering, capture-capture and scattering-capture and bin-bin correlations are supplied as input.

- ^{50,52,53}Cr, ^{55}Mn, ^{54,56,57}Fe, ^{58,60}Ni

KERCEN procedure

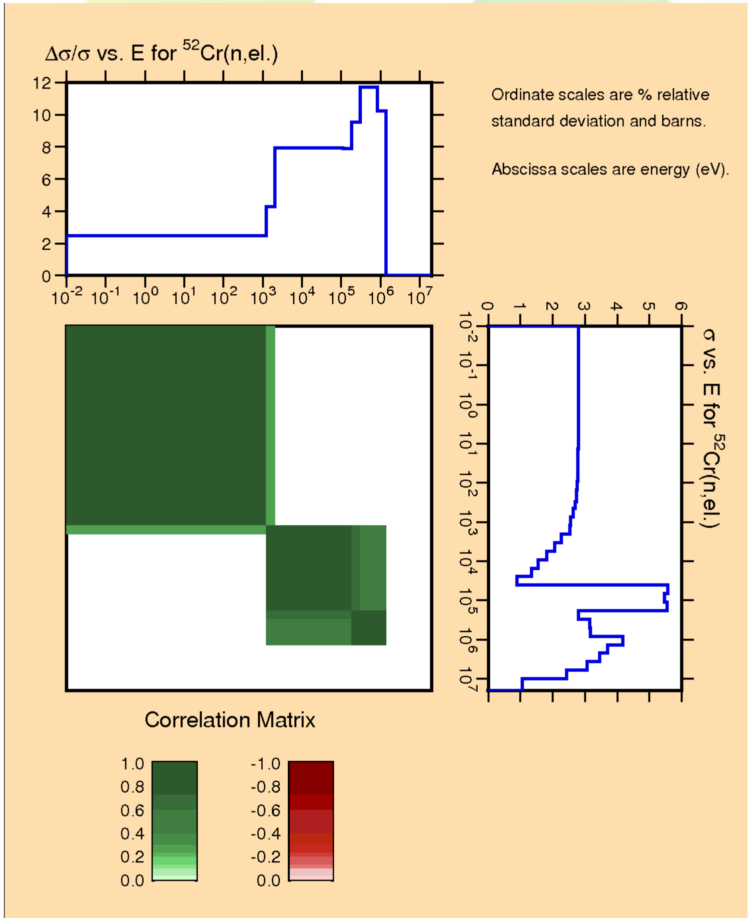


KERCEN outputs (1)



Capture c/s covariances for ^{52}Cr

$\mathrm{corr}(\Gamma_\gamma, \Gamma_\gamma)$: 0.5



Scattering c/s covariances for ^{52}Cr

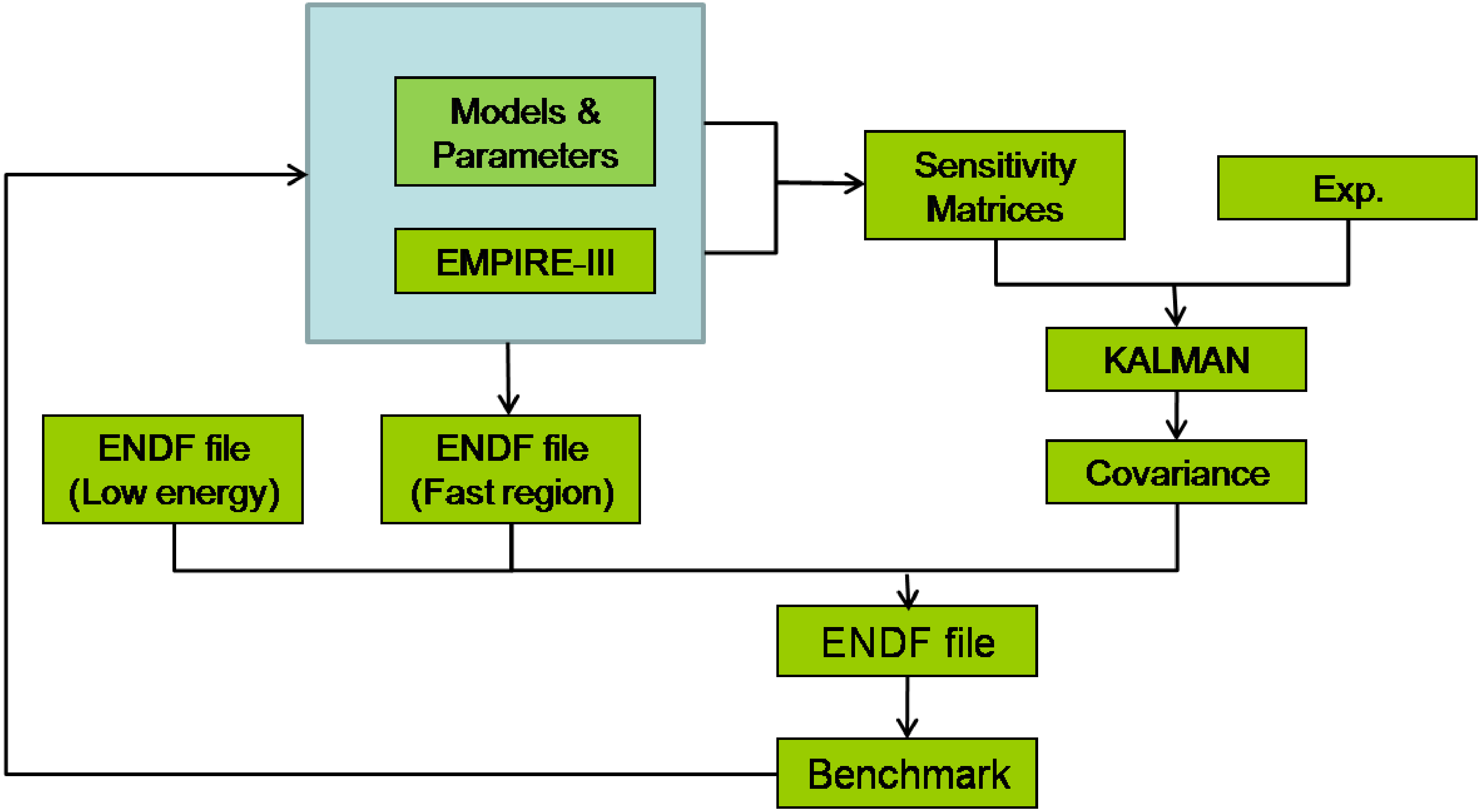
$\mathrm{corr}(\Gamma_n, \Gamma_n)$: 0.5

$\mathrm{corr}(R', \Gamma_n)$: -0.5

Evaluation of ^{237}Np, ^{240}Pu and Cm isotopes

- To improved the evaluated nuclear data with uncertainties of Minor Actinides for
  - Advance Fuel Cycle (AFC), Safeguards, Fast System etc
- A KAERI-ORNL collaborative work under International Nuclear Energy Research Initiative (I-NERI) program
  - Selected priority: ^{237}Np, ^{240}Pu, and $^{240\text{-}250}$Cm
  - ORNL: RR and URR
  - KAERI: Fast region

Evaluation & Covariance Procedure



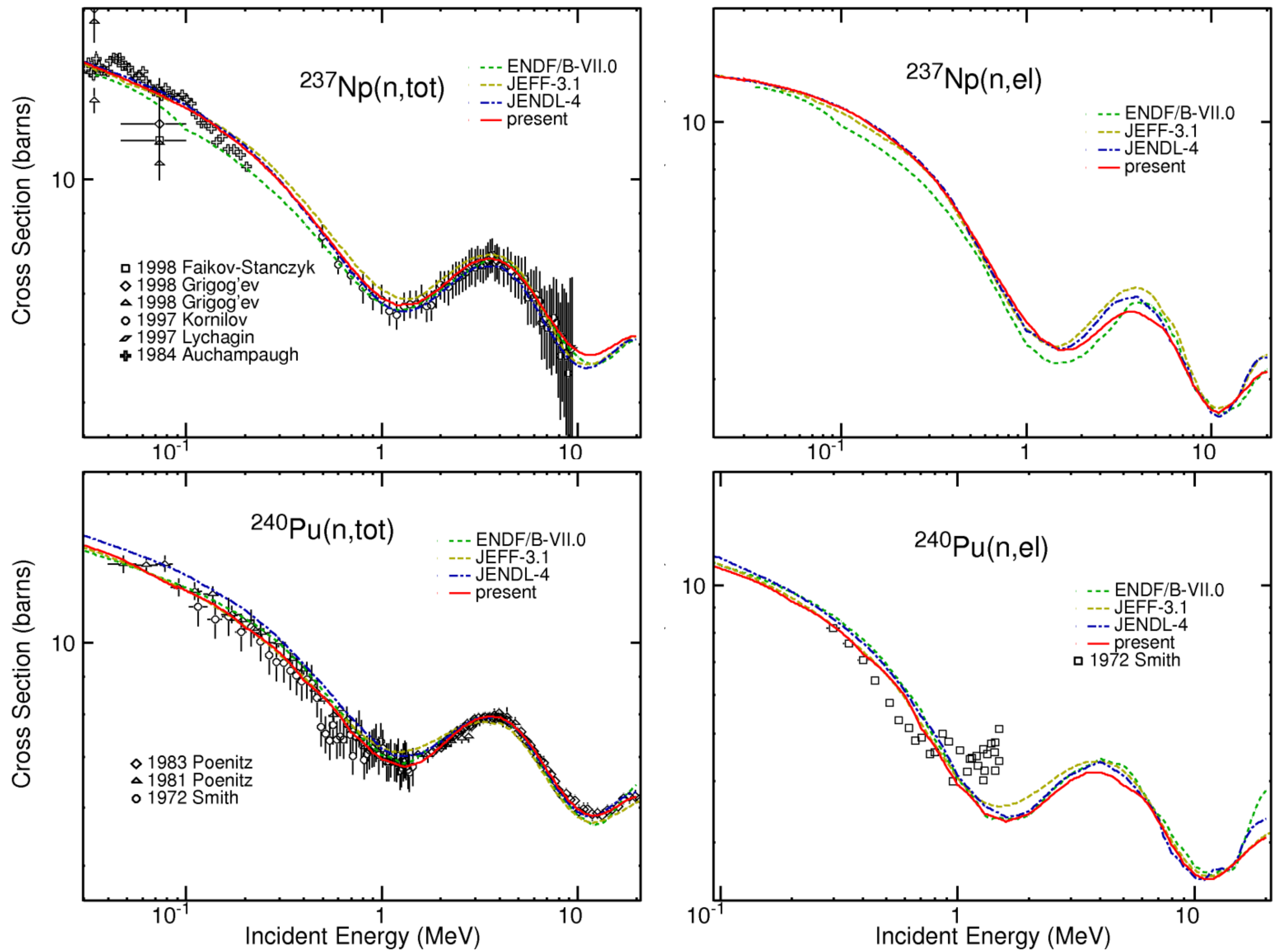
EMPIRE-3 calculation

- ✓ OMP
  - ➢ An isospin-dependent coupled-channels optical model potential containing the dispersive term (DCCOMP) suggested by Capote et al.. (RIPL # 2408)
- ✓ Hauser-Feshbach with width-fluctuation corrections
- ✓ DEGAS for gamma and PCROSS for others in pre-equilibrium
- ✓ Empire specific level densities
- ✓ Gamma strength function by plujiko(MLO1)
- ✓ Double-humped fission barrier
  - ➢ OMPs for fission suggested are modified in order to reproduce fission cross section

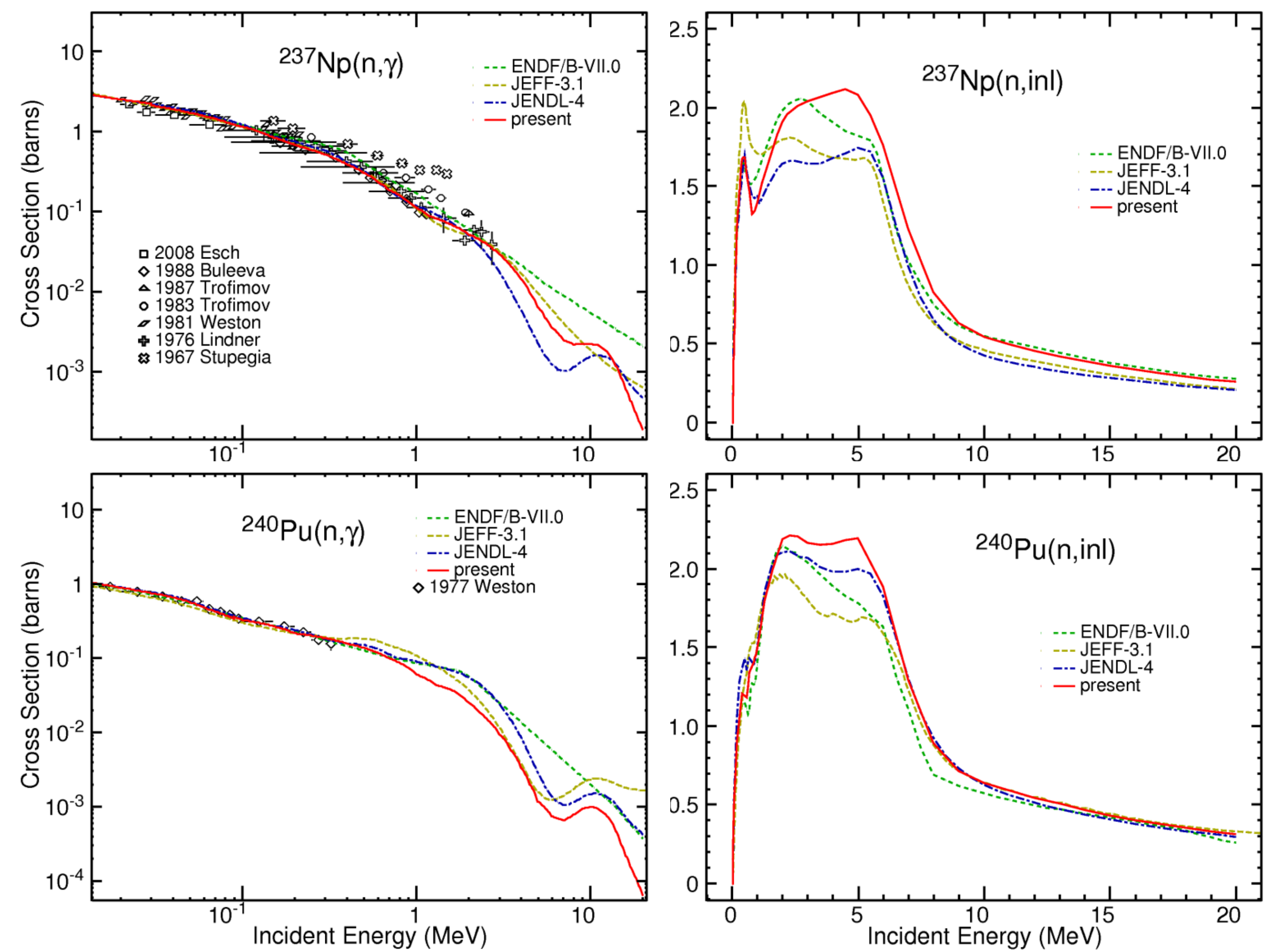
Covariances

- ✓ EMPIRE-KALMAN
- ✓ Covariances
  - ➢ Sensitivity matrices from variations of model parameters in the EMPIRE-III calculation
  - ➢ Using the measurements if available
  - ➢ Using pseudo data with 10% uncertainty for the cross section of model calculation if no measurement is available
- ✓ Completed file
  - ➢ Present list of covariance data generated:
    - MT=1,2,4,16,17,18,22,24,(51-91),102,103,107
  - ➢ MF=32 from ORNL for (^{237}Np, ^{240}Pu, ^{244}Cm)
  - ➢ Getting from JENDL-4 (nu-bar, fission neutron spectra, MT=151, MF=31)

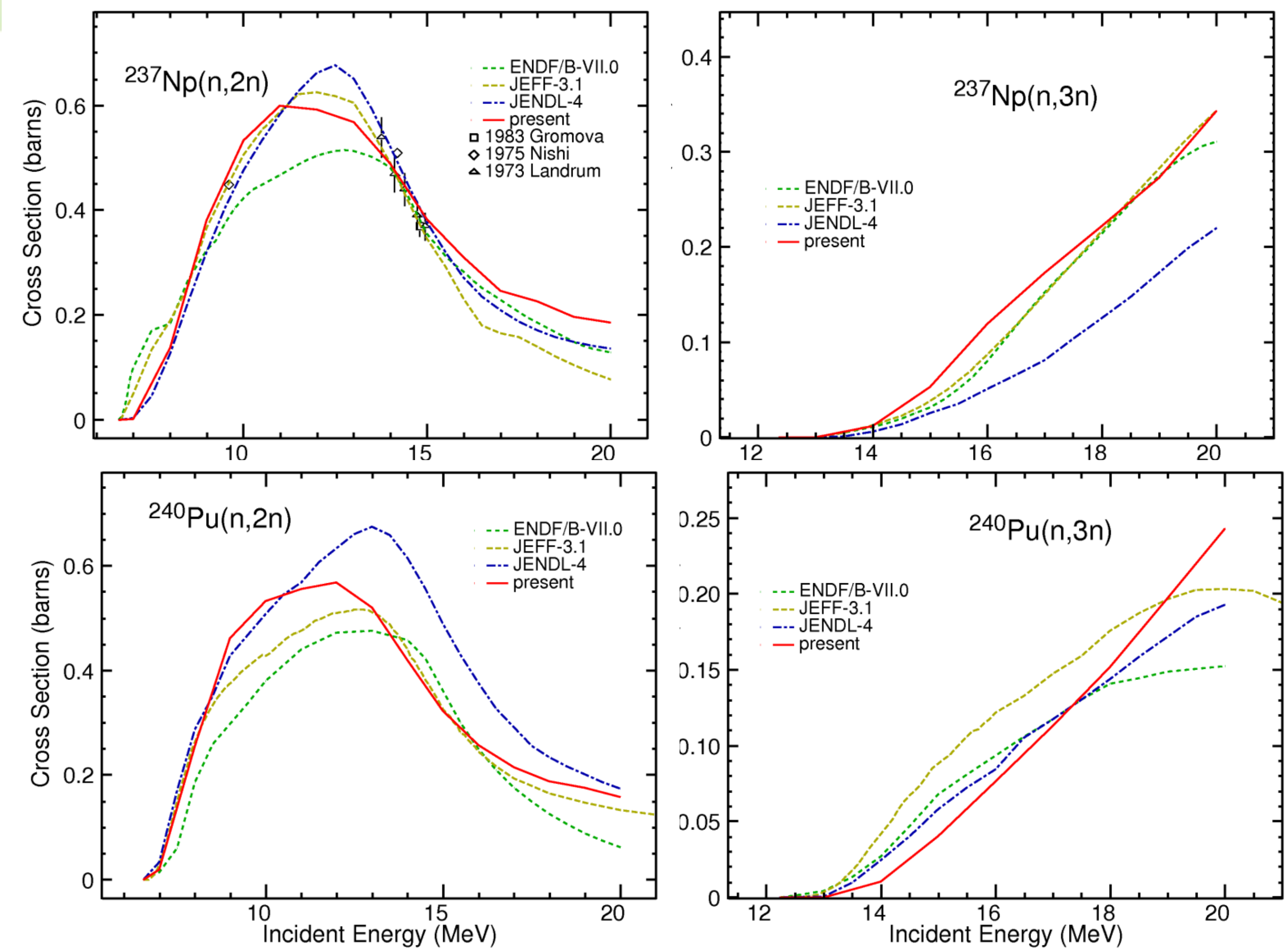
Cross section



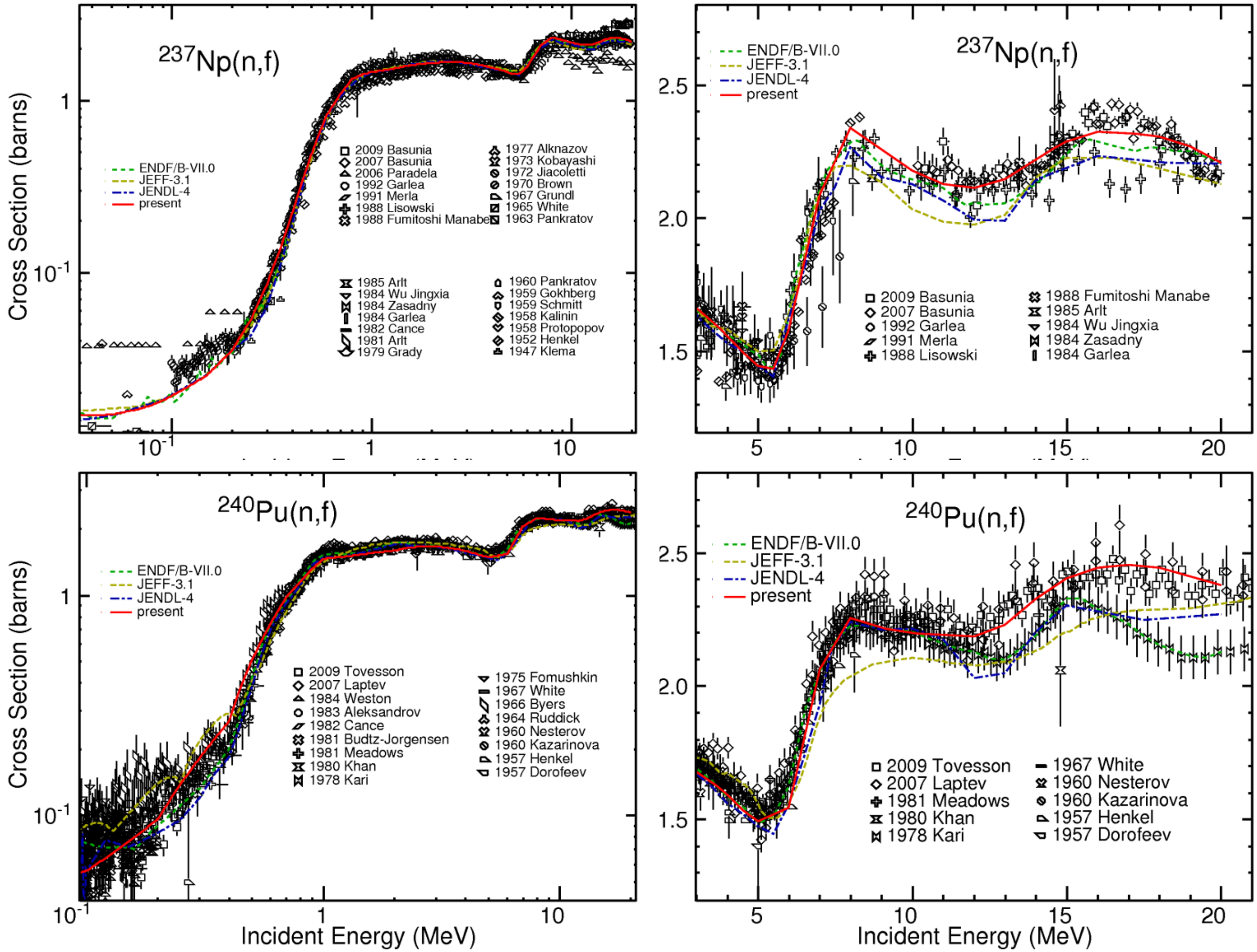
Cross section



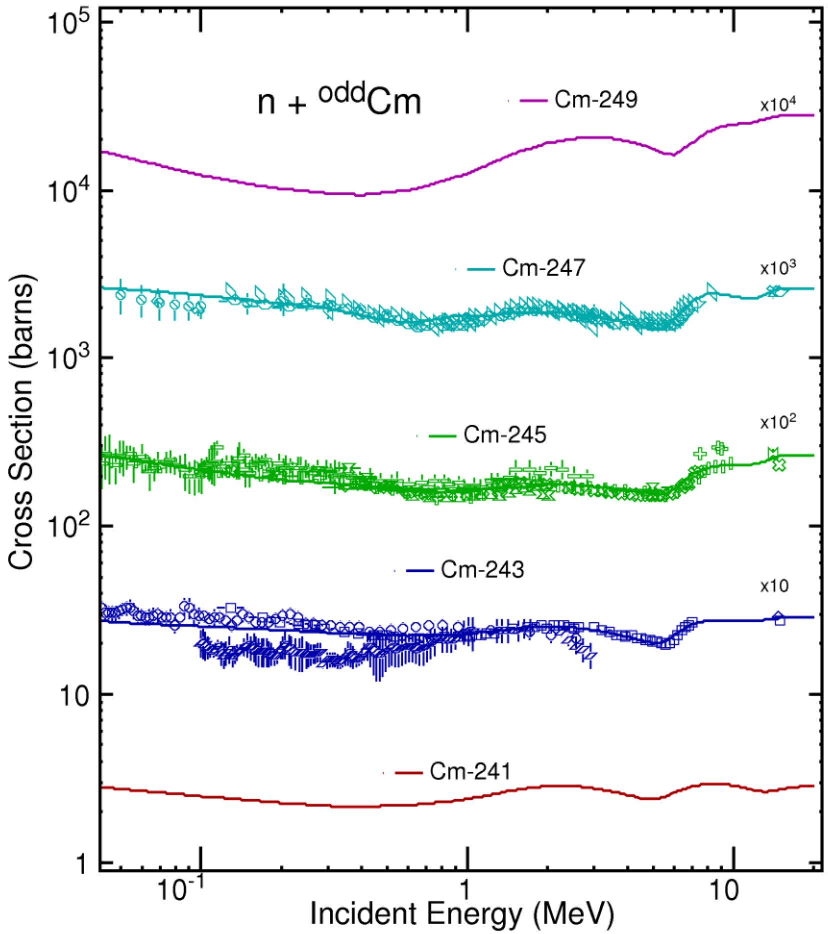
Cross section

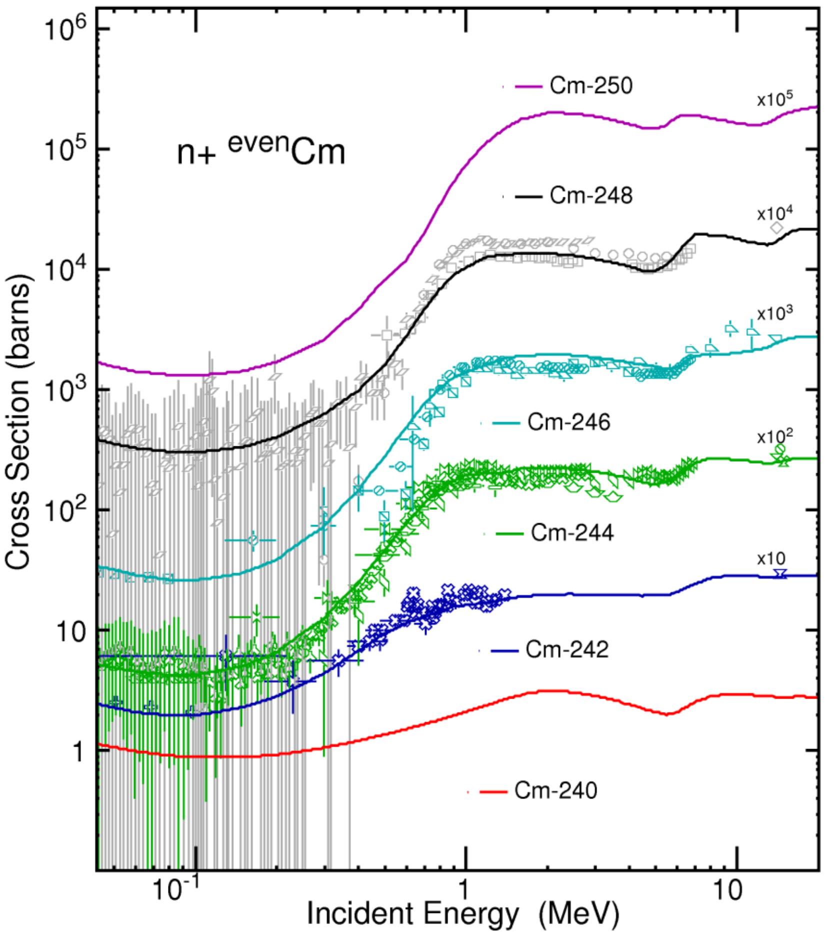


Cross section

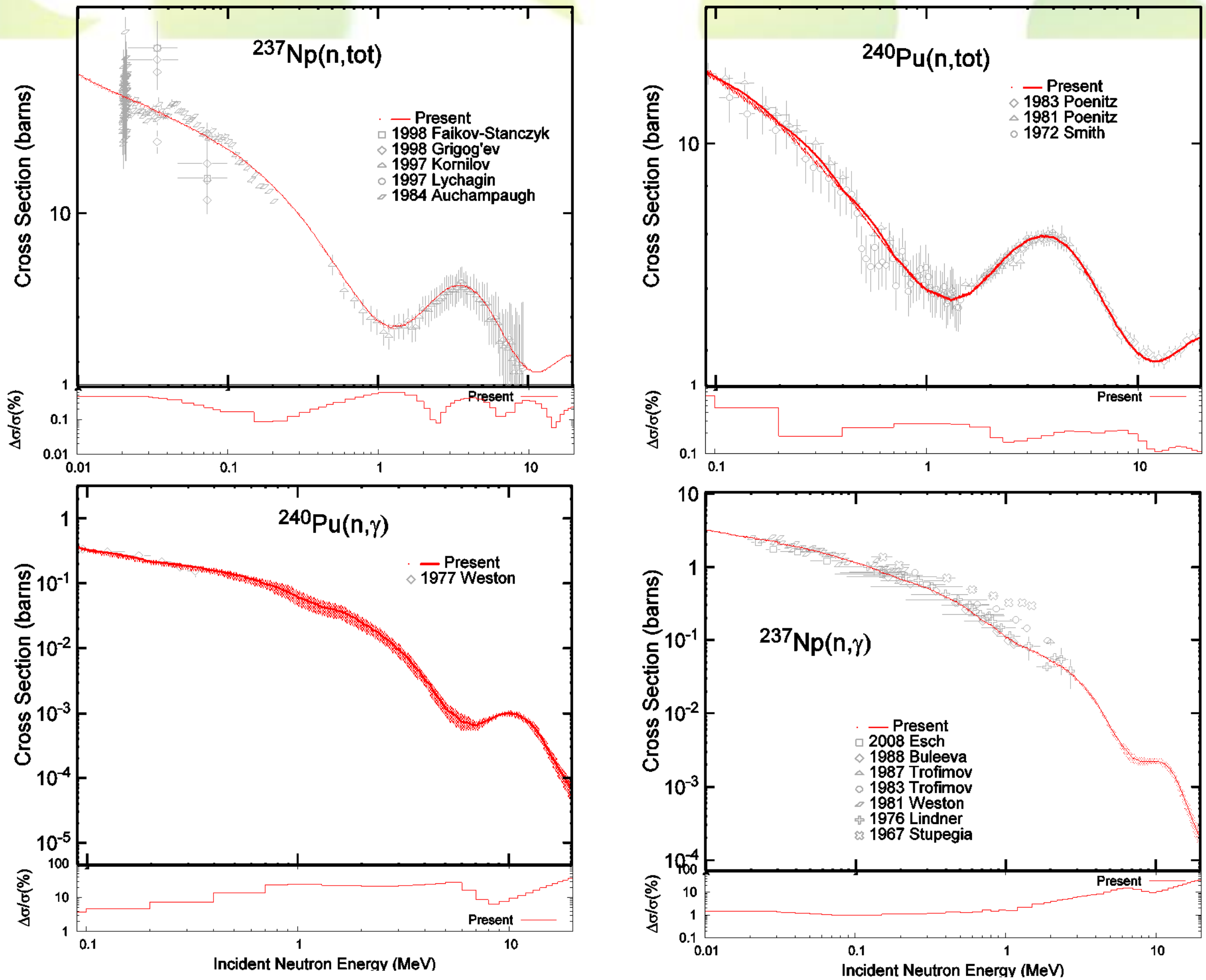


Cross section

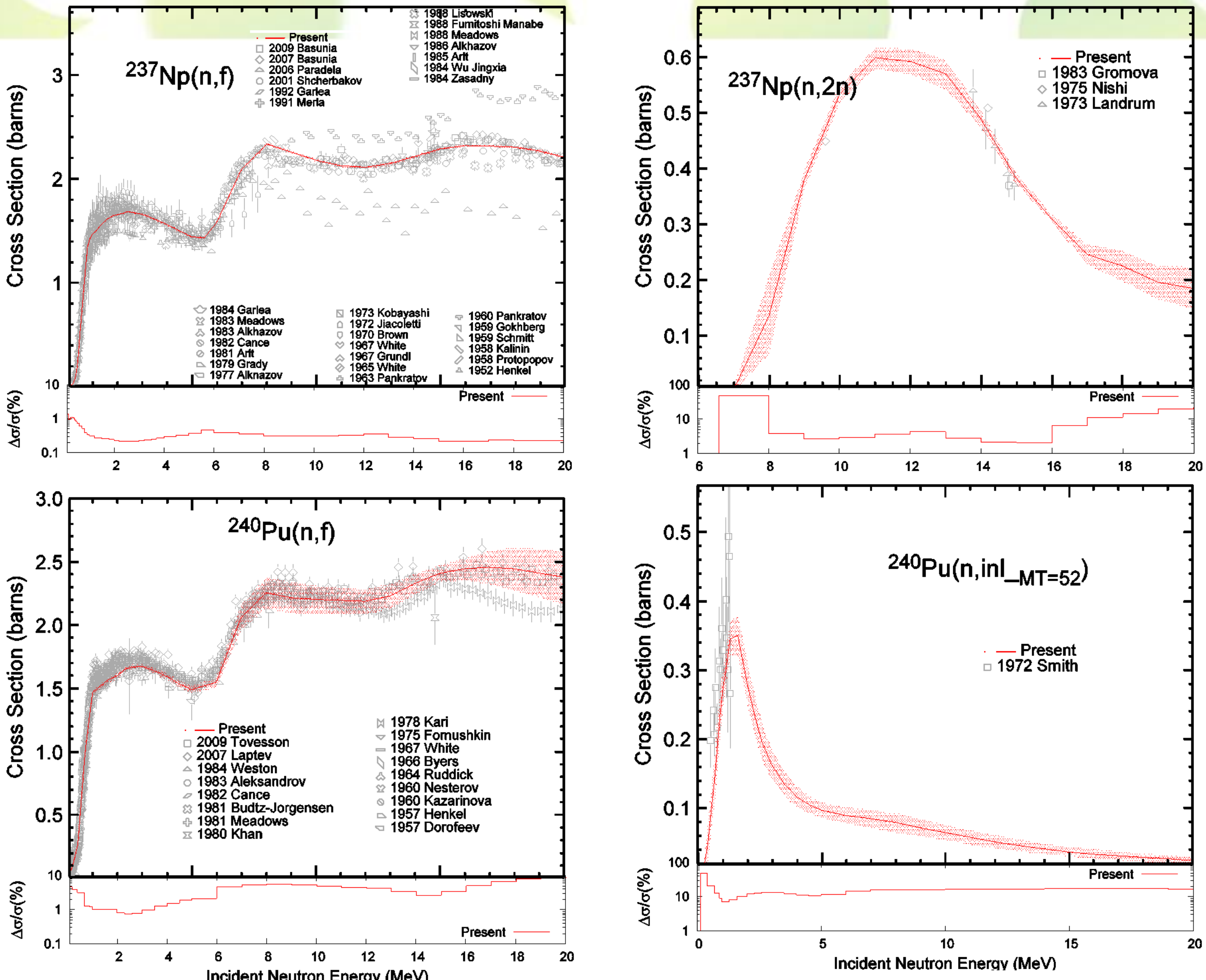




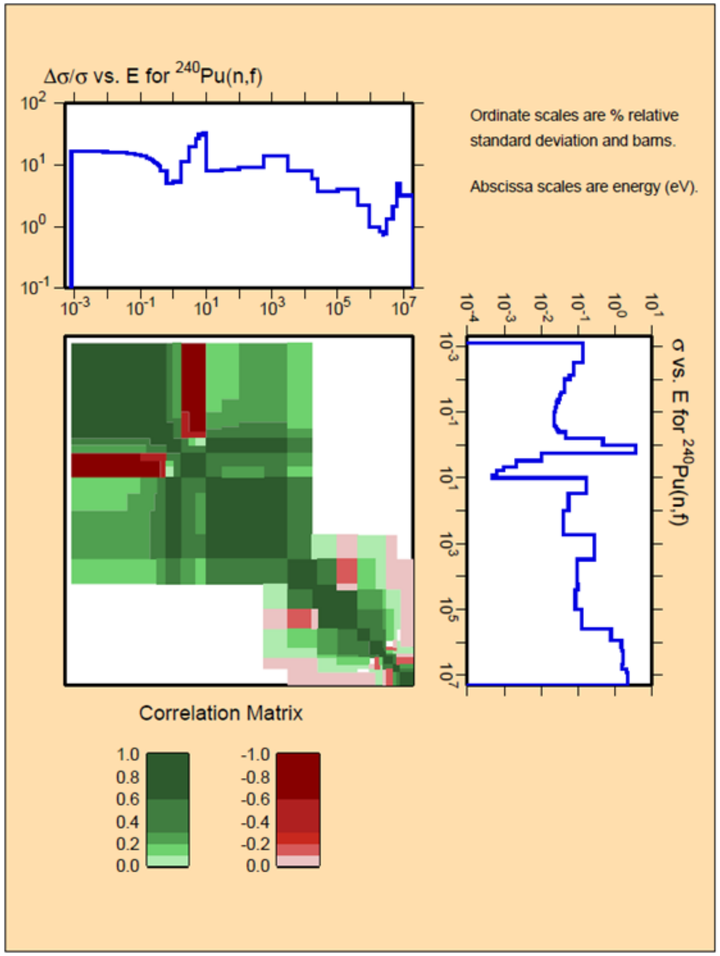
Uncertainties for cross sections with measurement

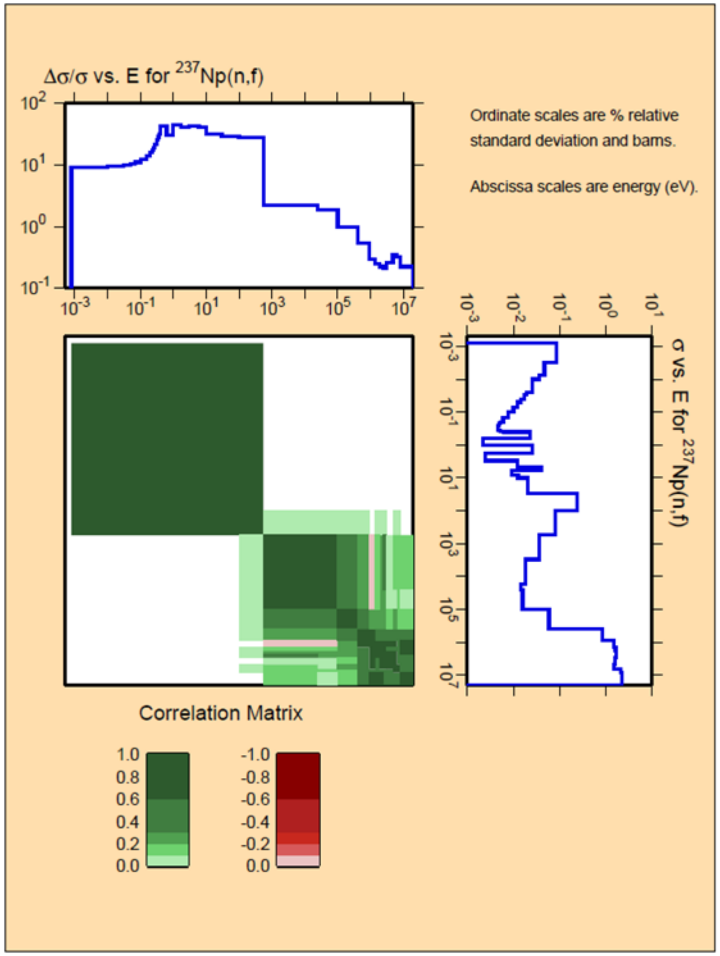


Uncertainties for cross sections with measurement



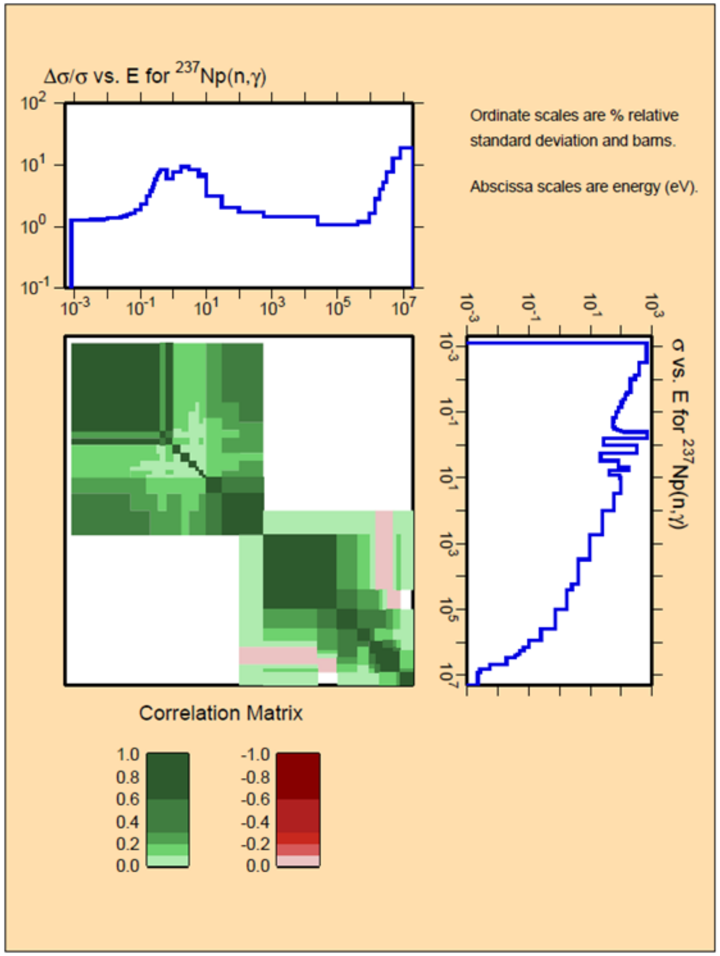
Correlation

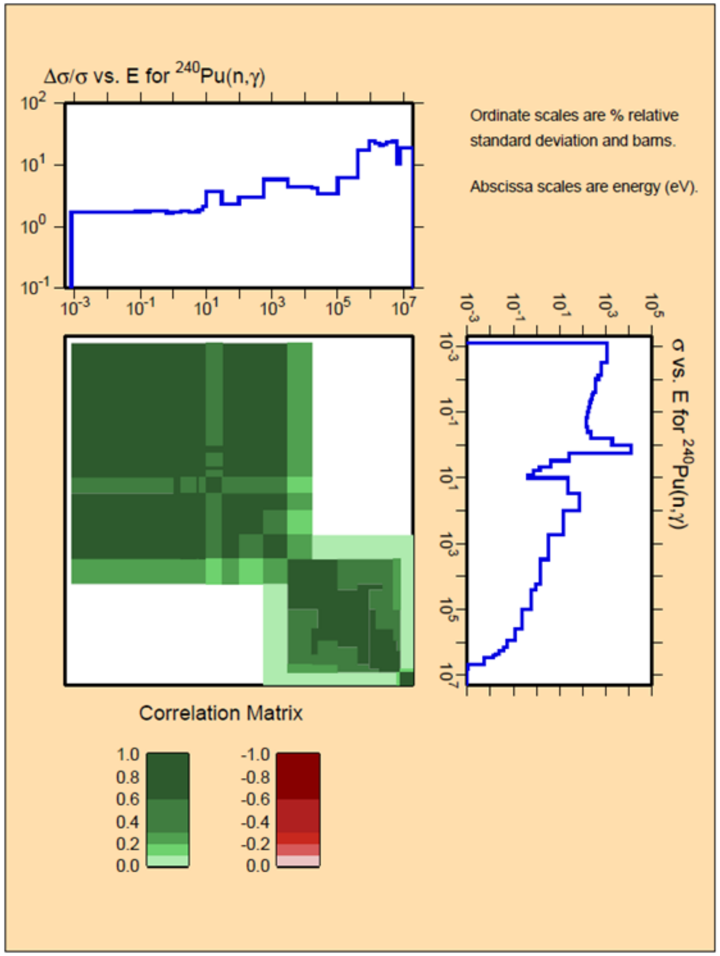




Covariance data of (n,f) for ^{237}Np and ^{240}Pu

Correlation

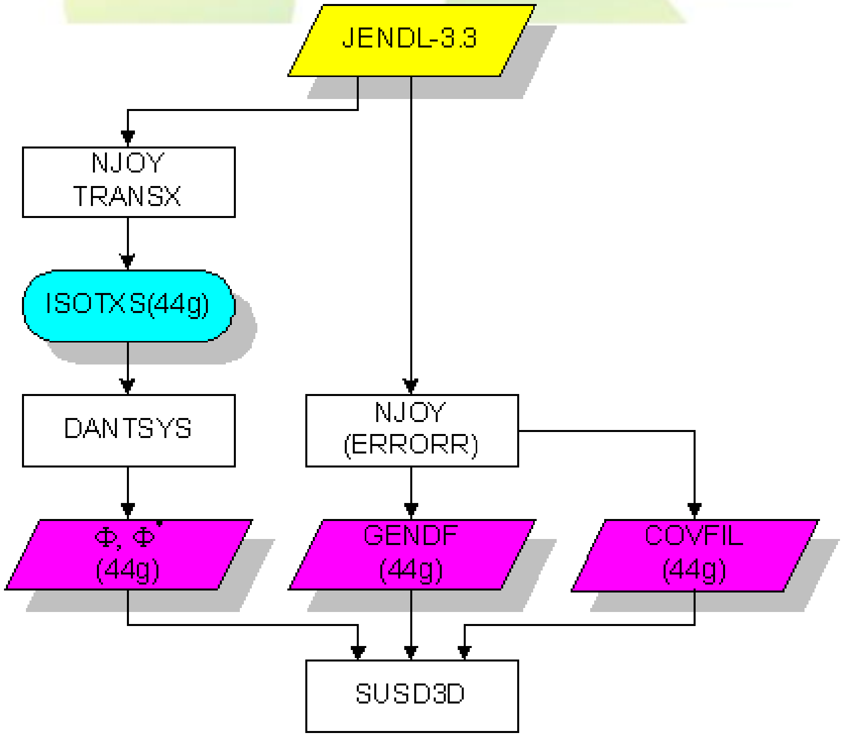




Covariance data of (n,g) for ^{237}Np and ^{240}Pu

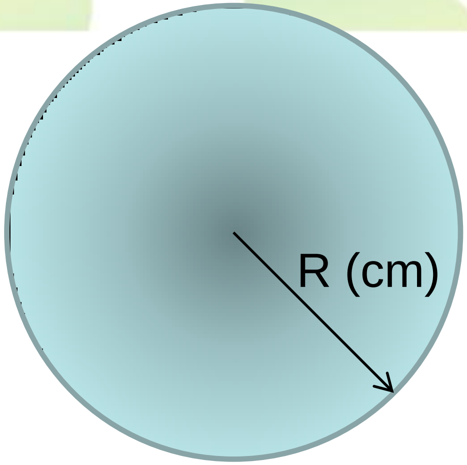
Sensitivity and Uncertainty Analysis of k_{eff}

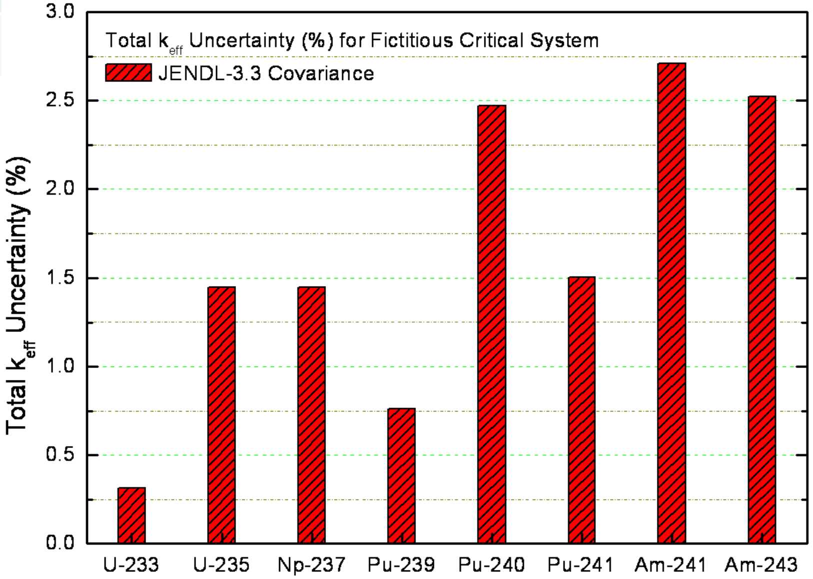
- Data preparation
  - NJOY99/TRANSX
  - Reference data: JENDL-3.3
  - Energy group: SCALE 44-group
- Forward/adjoint flux distribution
  - DANTSYS
  - P_3-S_{16} approximation
- S&U analysis of k_{eff}
  - SUSD3D
  - Total fission (MT=18) and total ν (MT=452 or MT=455+456) covariance data
  - **Covariance data: JENDL-3.3, Low-fidelity, New covariance data**



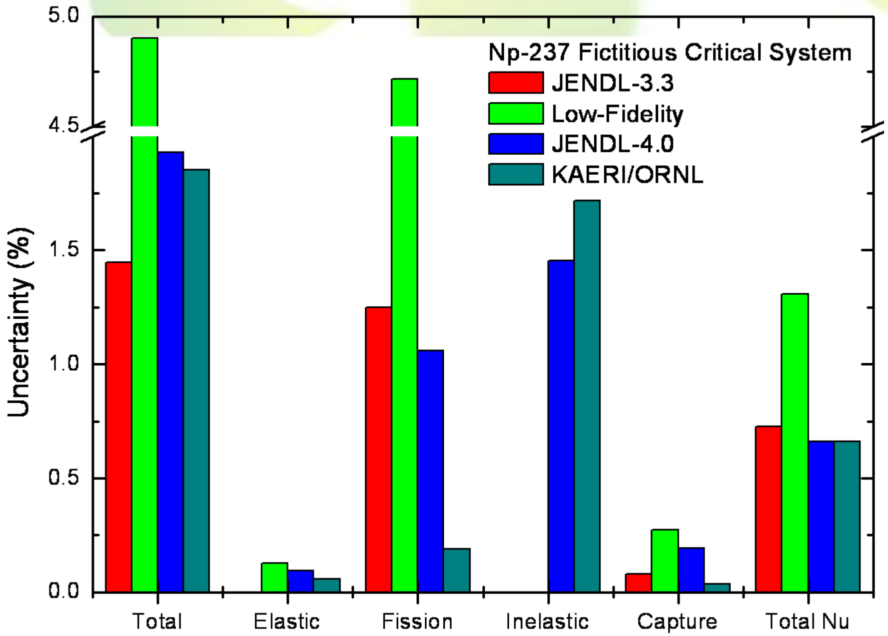
Fictitious critical system searched by JENDL-3.3-based DANTSYS calculation

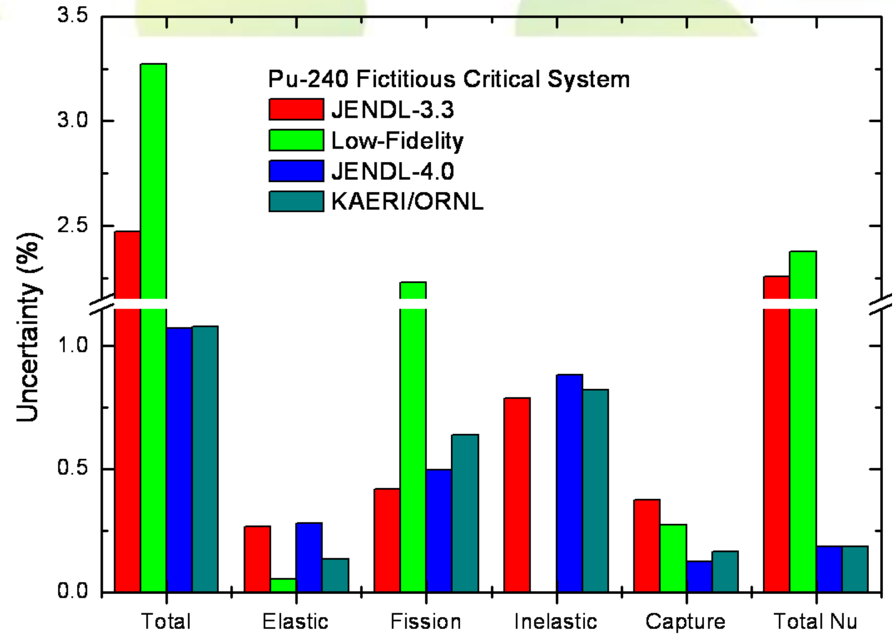
No.	Actinide	Critical Radius (cm)
1	92-U-233	5.72
2	92-U-235	8.25
3	93-Np-237	9.20
4	94-Pu-239	4.95
5	94-Pu-240	7.24
6	94-Pu-241	5.20
7	95-Am-241	11.33
8	95-Am-243	15.54





- ✓ Total uncertainties: ~2.5% for ^{240}Pu-, ^{241}Am-, and ^{243}Am-fictitious cores due to large uncertainties in
  - ✓ total nu covariance data
  - ✓ total fission covariance data
  - ✓ capture covariance data





✓ Large total k_{eff} uncertainty for Lo-Fi ^{237}Np:

→caused by large fission data.

✓ KAERI/ORNL covariance brings about nearly the same total k_{eff} uncertainty estimation as JENDL-4.0.

- ✓ underestimate total fission
- ✓ overestimate inelastic scattering

✓ Large total k_{eff} uncertainty fo Lo-Fi ^{240}Pu

→ caused by large fission and total nu data.

✓ Total uncertainty with KAERI/ORNL covariance is comparable to those with JENDL-4.0.

- ✓ slight increase of total fission

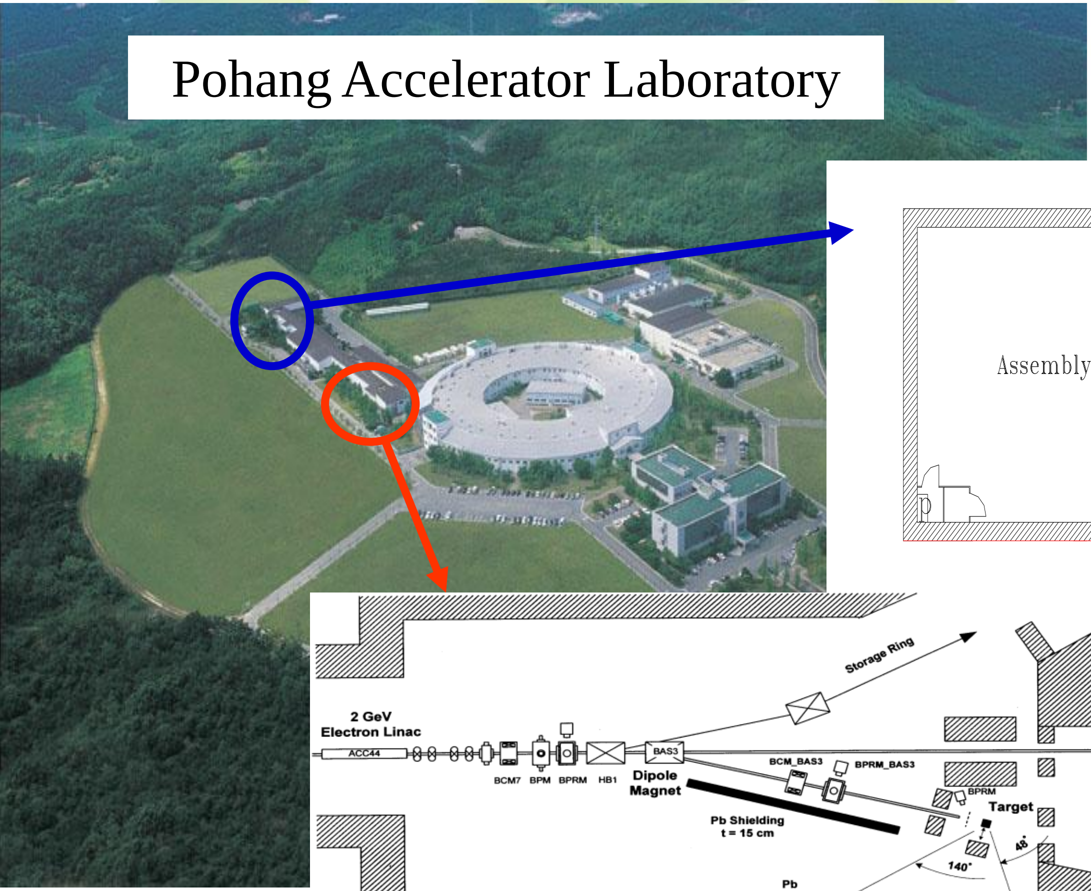
SUMMARY :Nuclear Data Evaluation and Covariances for ^{237}Np, ^{240}Pu and Cm isotopes:

- We produced neutron cross section files of ^{237}Np, ^{240}Pu and $^{240-250}$Cm for AFC applications and safeguards.
- Covariance matrices of cross sections were generated by the EMPIRE-KALMAN module considering sensitivity matrices from model calculations and the uncertainty of experimental data
- Fictitious system was constructed and used for validation of our covariances

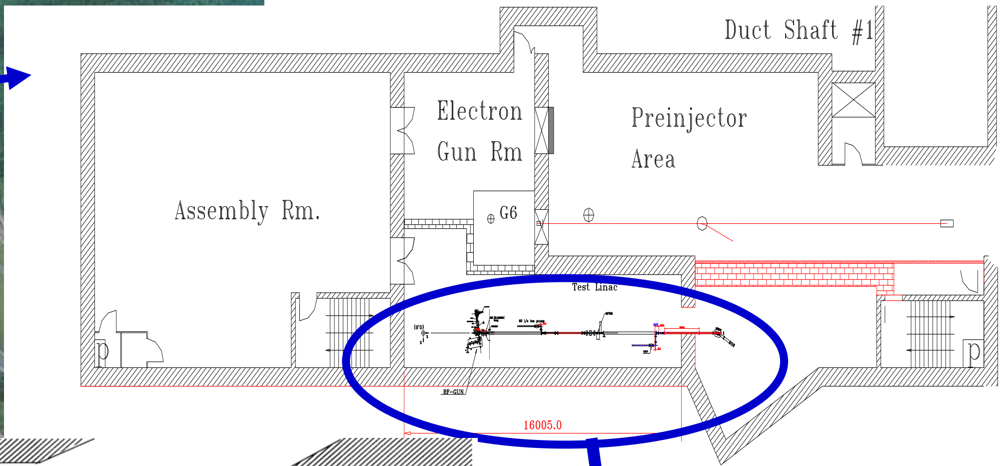
- Further works
  - Covariance files for **all curium** will be produced
  - **Covariances for angular distributions** and average nu-bar will be added.

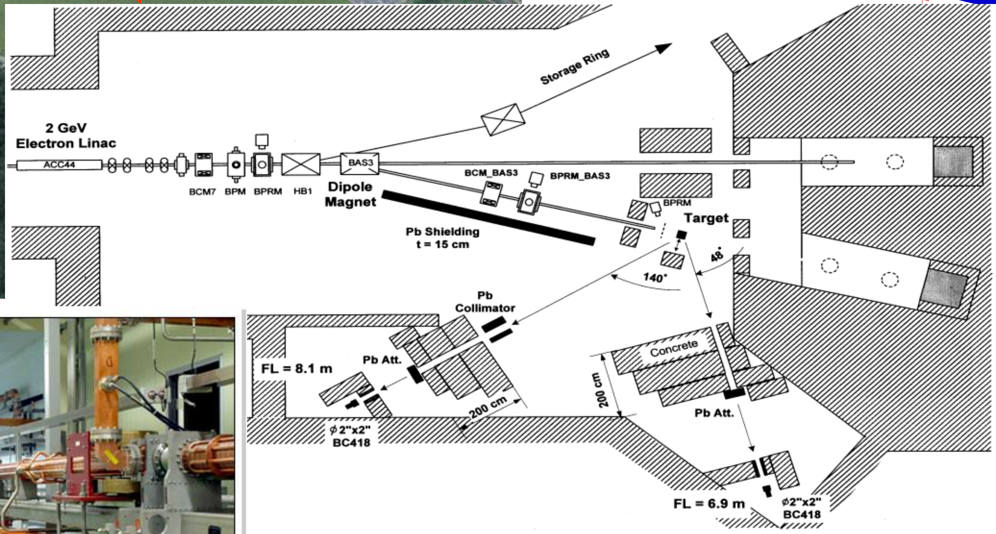
Pohang neutron facility

Pohang Neutron Facility



Pohang Neutron Facility based on 100-MeV e-linac





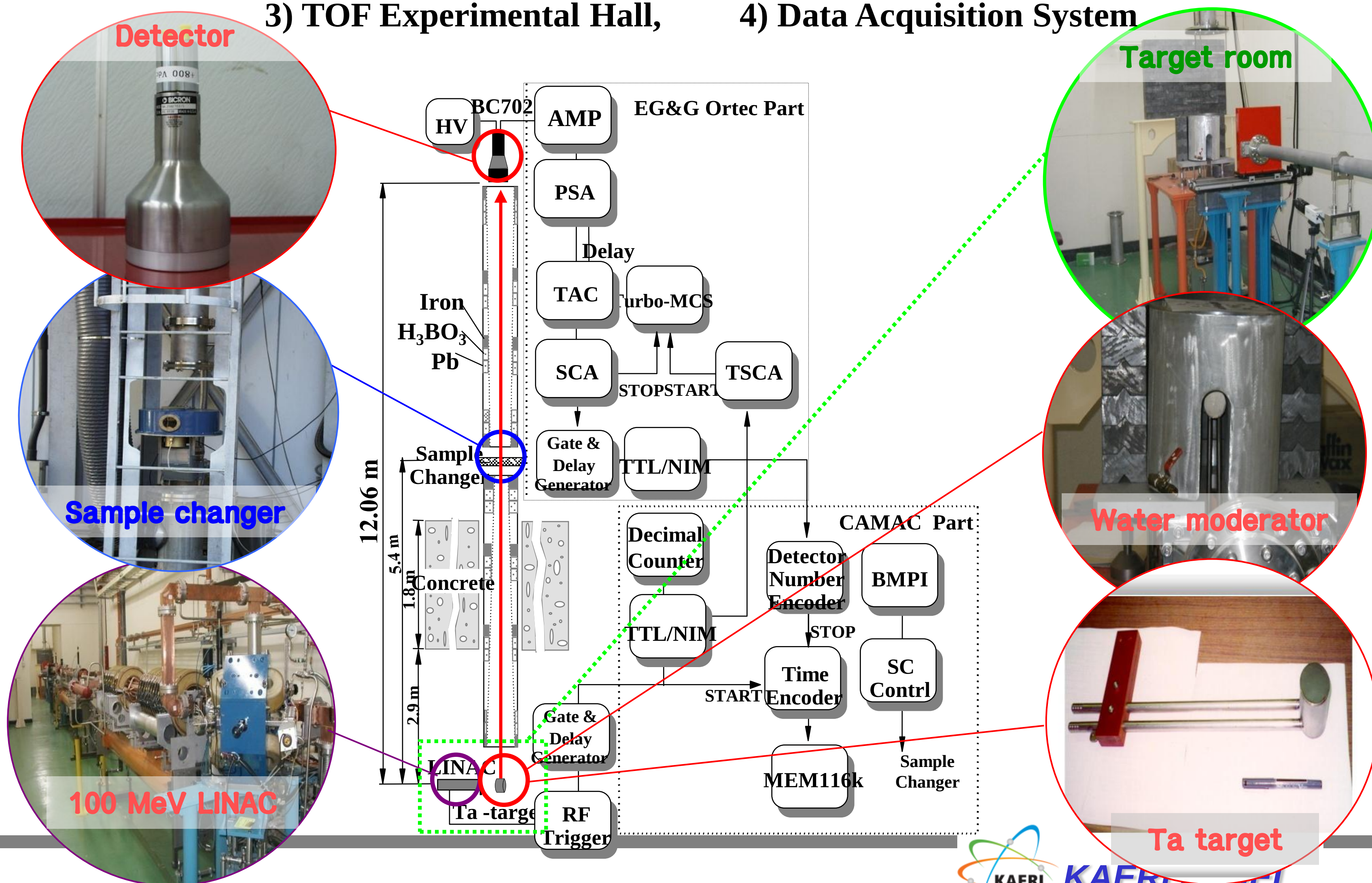
Pohang High Energy Radiation Facility with 2.5 GeV e-linac

Neutron Total Cross Section Measurement using n_TOF

- **Pohang Pulsed Neutron Facility (PNF)**

  1) Electron Linear Accelerator, 2) Target System

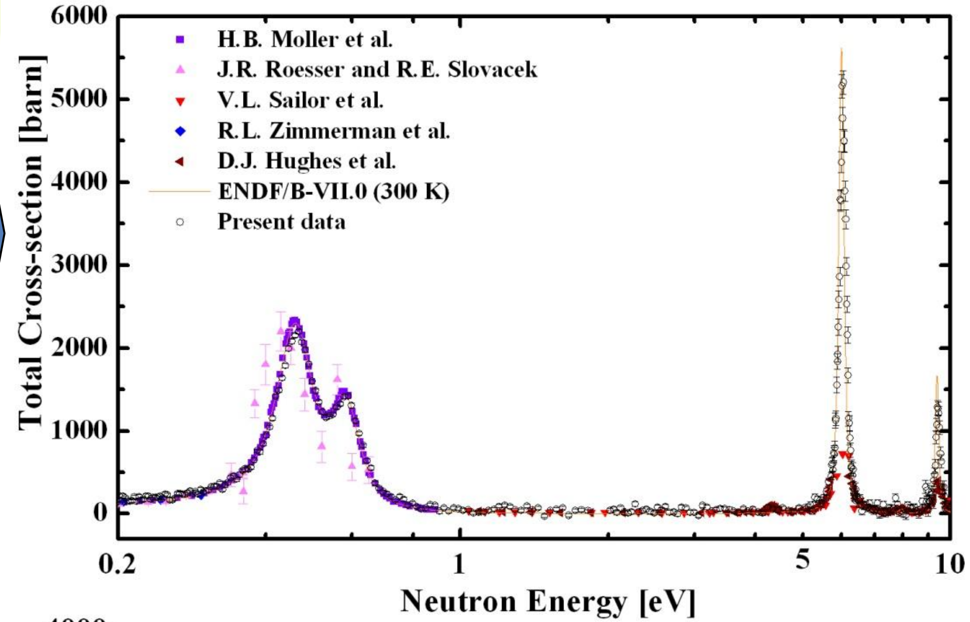
  3) TOF Experimental Hall, 4) Data Acquisition System

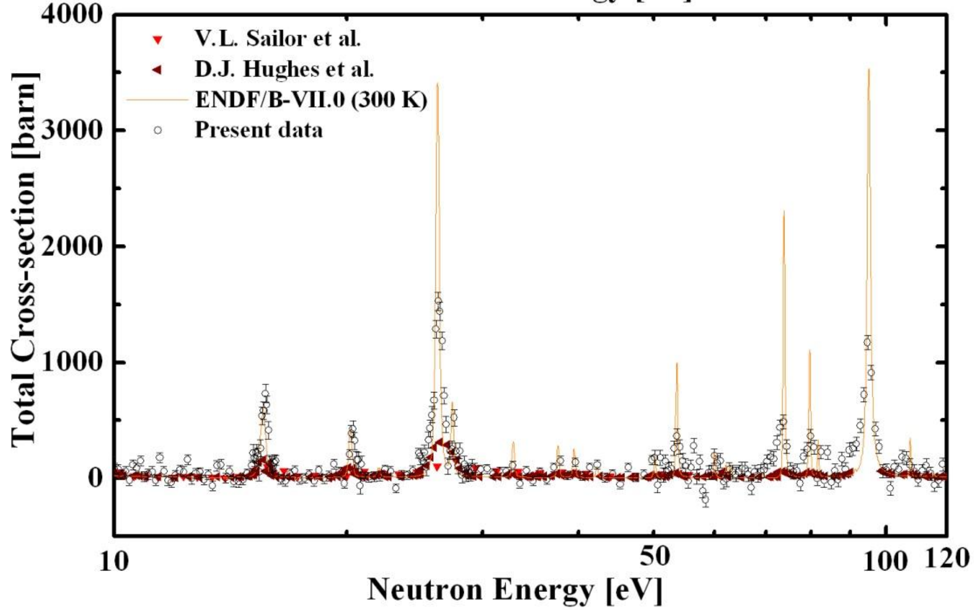


Neutron Total Cross Sections

Recent Publications

- Measurements of neutron total cross-sections and resonance parameters of erbium at the Pohang Neutron Facility, Nucl. Instr. Meth. B 268 (2010) 106-113.
- Measurement of neutron cross sections and resonance parameters of ^{169}Tm below 100 eV, Chinese Phys. C 34 (2010) 1-5.





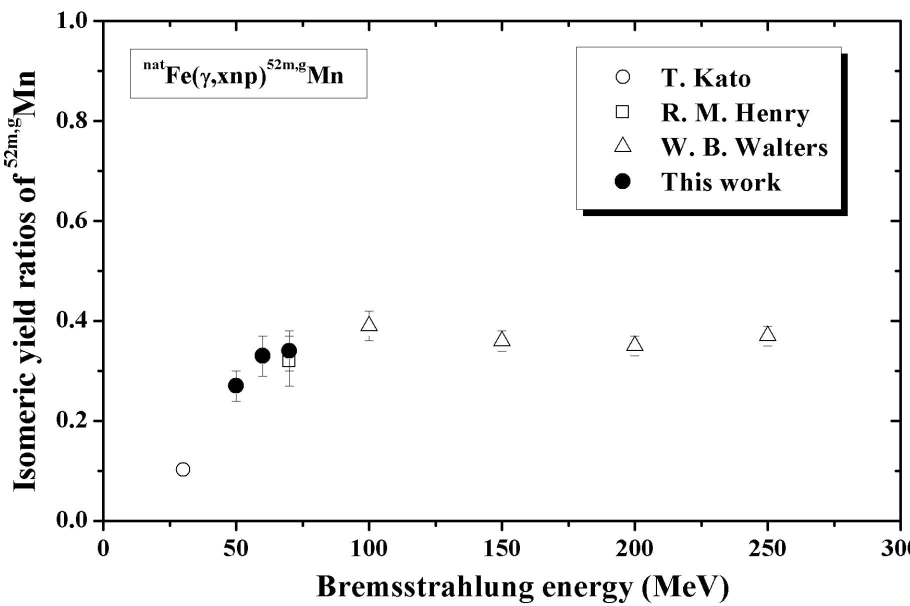
In progress

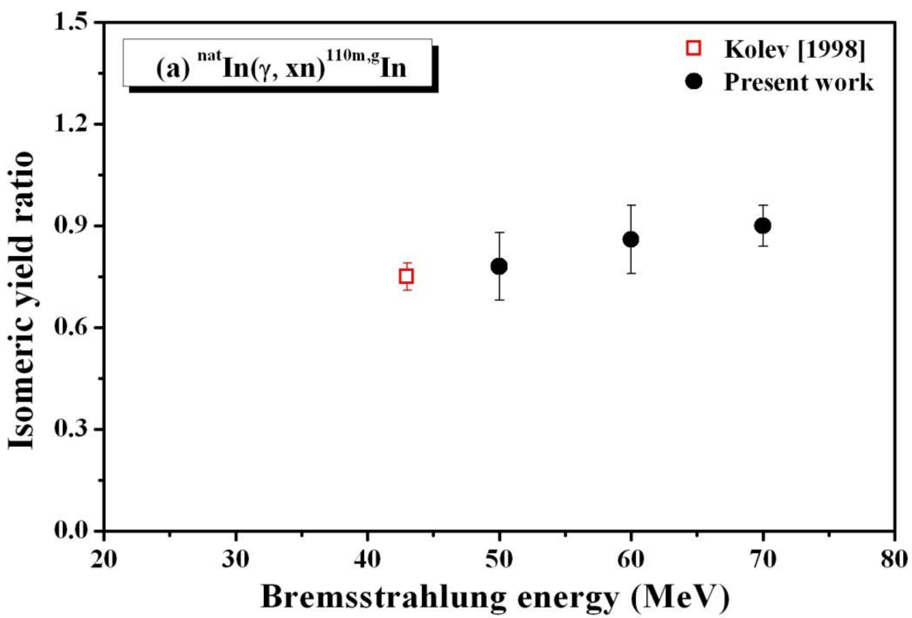
- Measurements of neutron total cross-sections and resonance parameters of Dy at the Pohang Neutron Facility

Photonuclear reactions with Bremsstrahlung

Recent publications

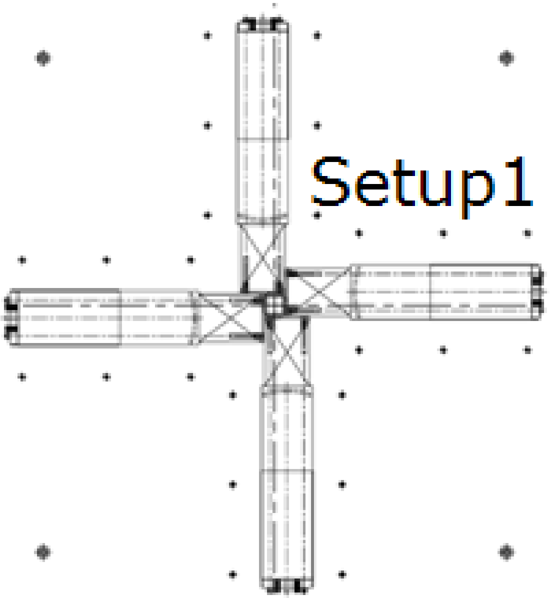
- Measurement of isomeric yield ratios in ^{nat}In and ^{nat}Sn with 50, 60, and 70 MeV bremsstrahlung photons, Nucl. Instr. Meth. B 268 (2010) 13-19.
- Isomeric yield ratios in the photoproduction of $^{52m,g}Mn$ from natural iron using 50-, 60-, 70-MeV, and 2.5-GeV bremsstrahlung, J. Radioanal Nucl. Chem. 283 (2010) 683-690.
- Measurement of isomeric-yield ratios for the $^{197}Au(\gamma,n)^{196m,g}Au$ reactions induced by bremsstrahlung, J. Radioanal Nucl. Chem. 283 (2010) 519-525.
- Mass–yield distributions of fission products from photo-fission of ^{nat}Pb induced by 50–70 MeV bremsstrahlung, J. Radioanal Nucl. Chem. 283 (2010) 439-445.

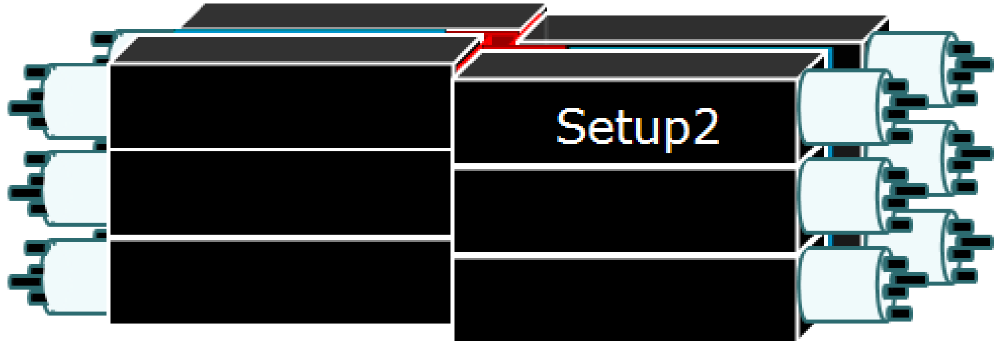




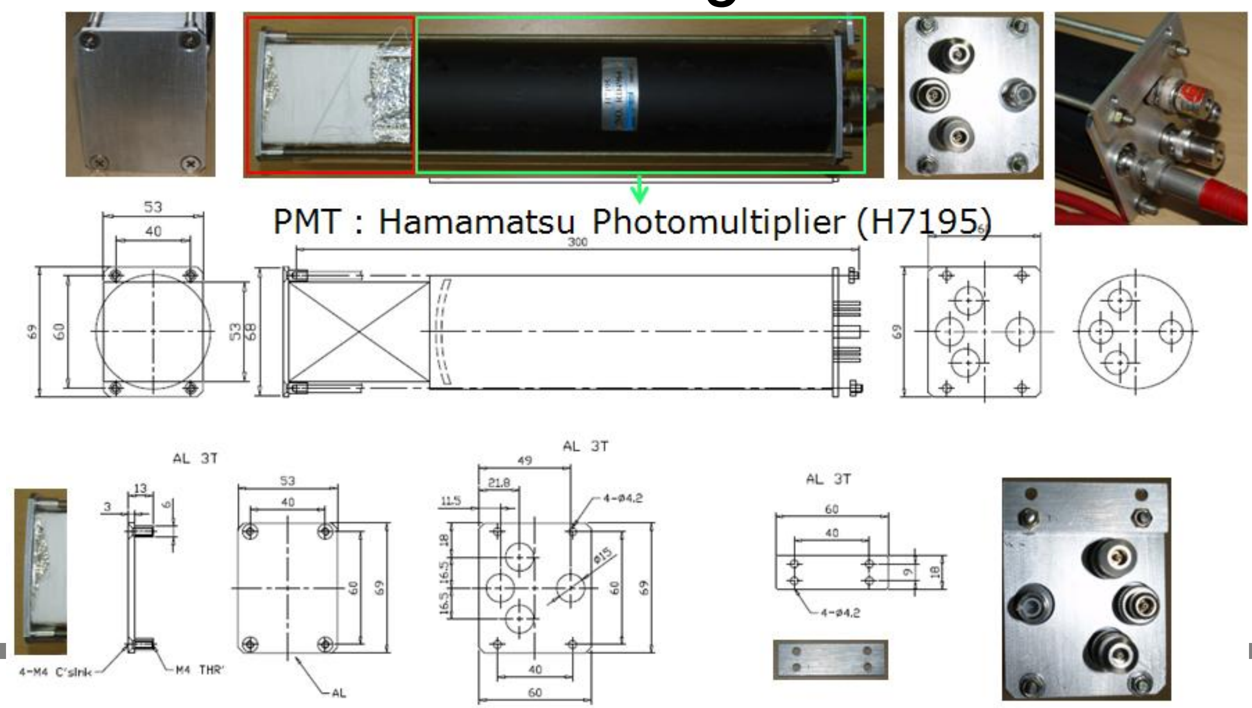
Development of Detector System for Capture C.S

- Layout of detectors: setup1: 98.25%, setup2: 98.21%

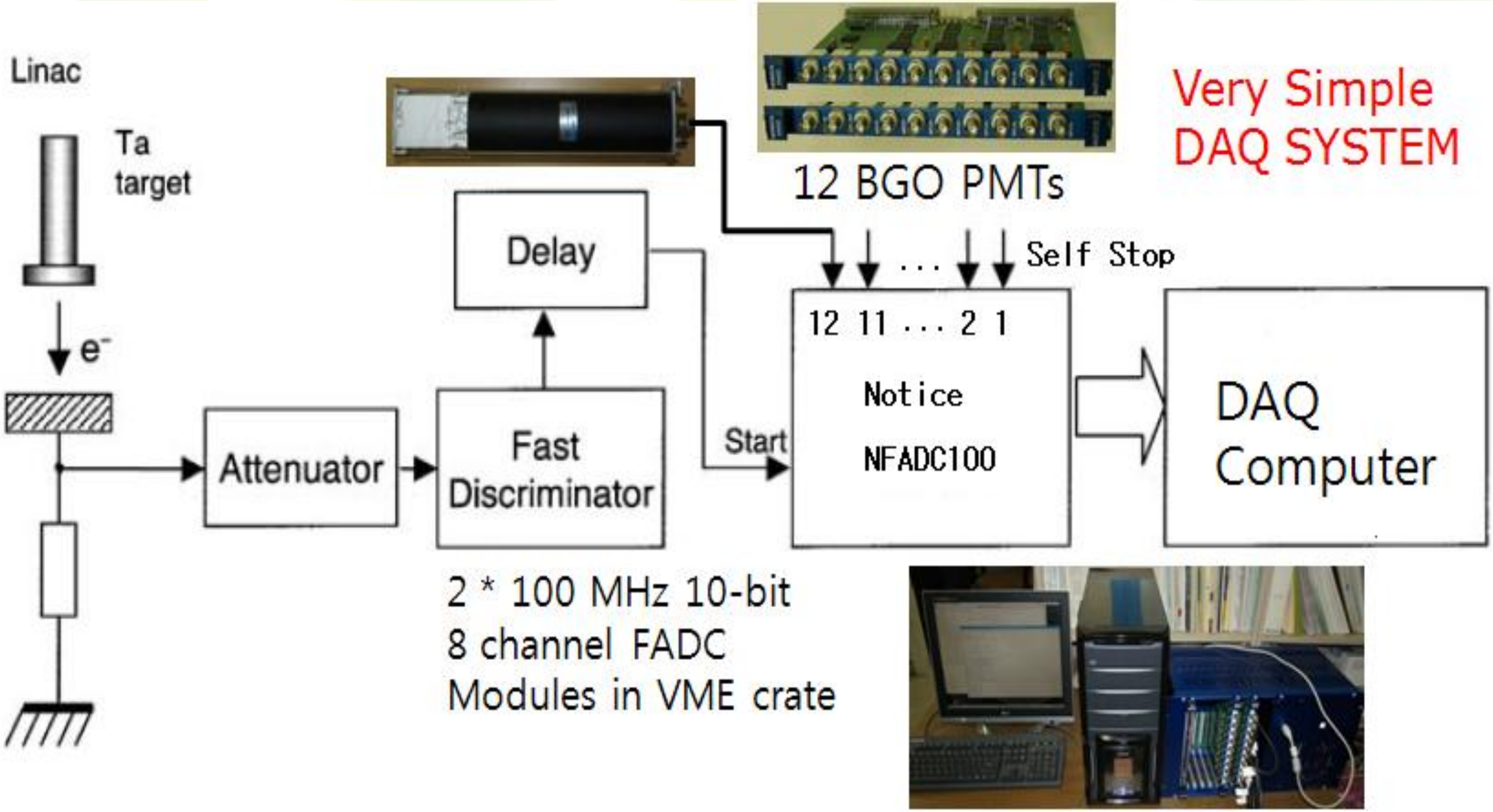




- Assembling



Data Acquisition System of TOF with FADC

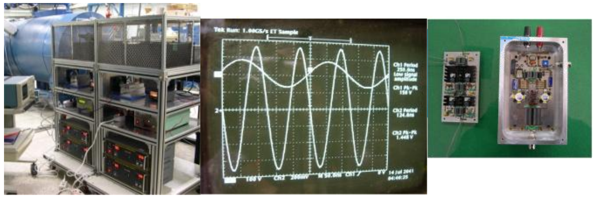


- Widen neutron energy range: 0.1 – 수백 eV → 0.01 eV – keV
- will be used for neutron capture cross section measurement

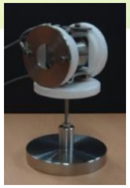
KIGAM neutron facility

Neutron facility

RF
amplifier

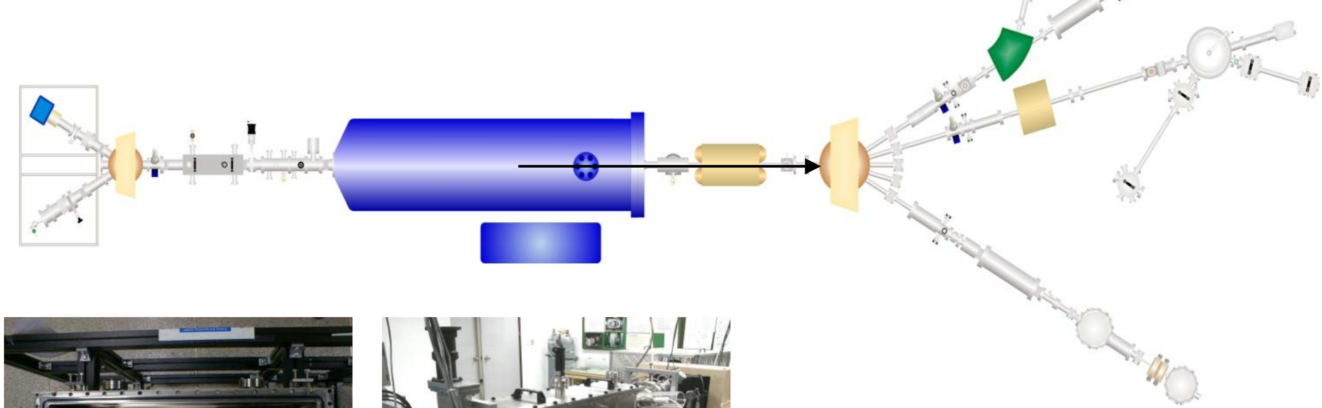


Time-pick-up
module

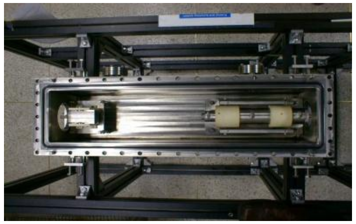


TOF system

Neutron beam line



SNCIS

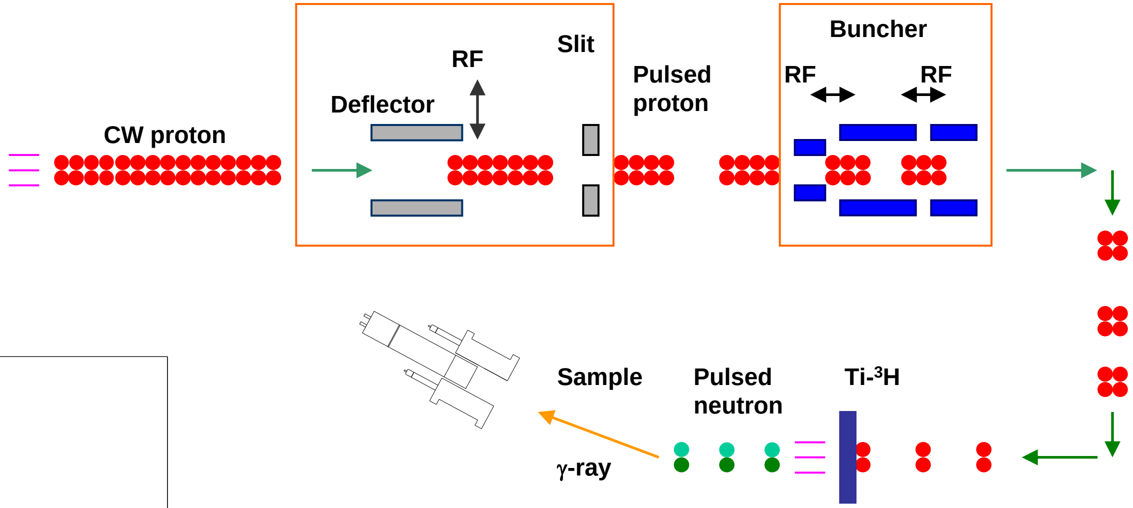


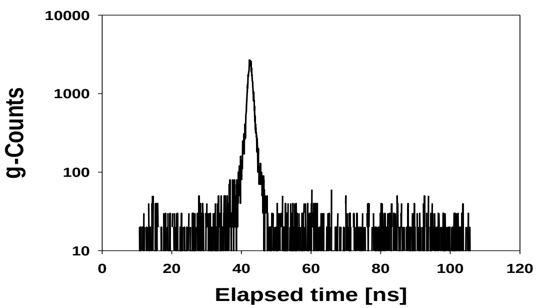
Beam pulsing system

-KIGAM 1.7 MV tandem accelerator
-Beam bunching system (self-made)

Beam pulsing system by RF field and double bunching system

1) Beam size : 8 mm below
2) Bunching beam width : 1 ~ 2 ns
3) Bunching yield : <10 %
4) Bunch repetition rate : 8 MHz





Check of bunching beam width by (p,γ) reaction

KIGAM neutron source for nuclear data production

2007 : ^{3}T(p,n) reaction : ~ 2 MeV ,

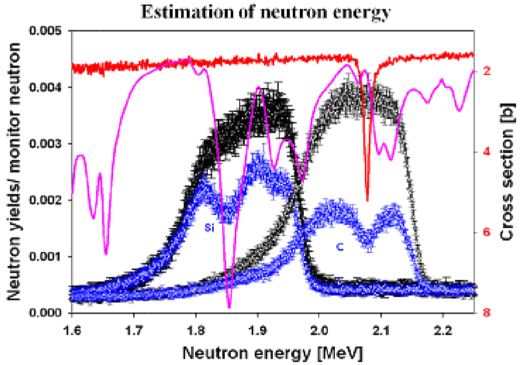
2008 : ^{7}Li(p,n) reaction 500 keV ~ 1.2 MeV,

2009 : D-D reaction 3.5 MeV ~ 6.2 MeV,

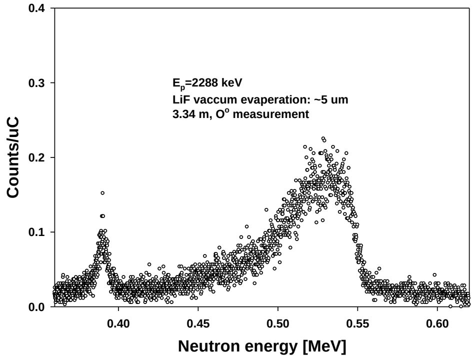
2010 : D-Li reaction 17 MeV

influence : 10^6~10^7 neutrons /sec at 0°

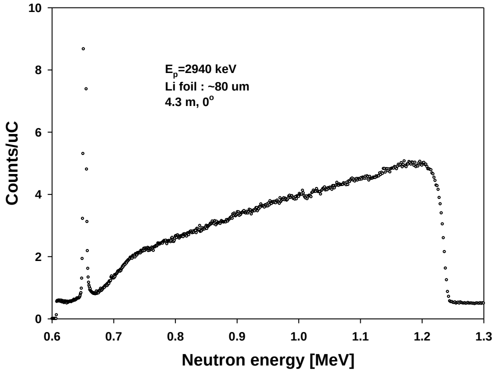
^{3}T(p,n) on Thin target :
2.15 MeV neutron with energy spread of 180 keV

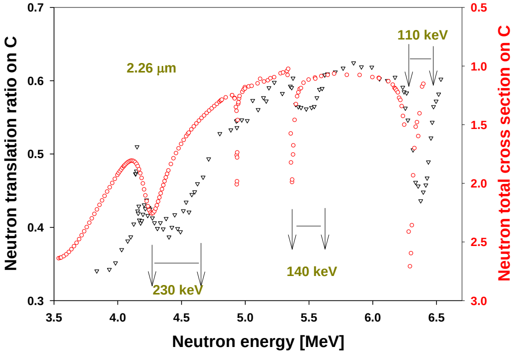


^{7}Li(p,n) on Thin target :
0.5 MeV neutron with energy spread of 50 keV



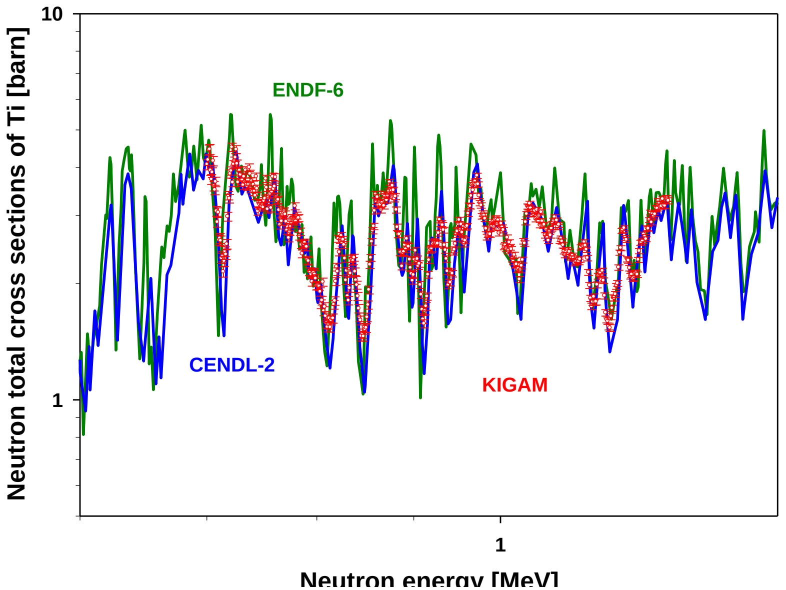
^{7}Li(p,n) on Thick target :
1.2 MeV neutron with energy spread of 500 keV

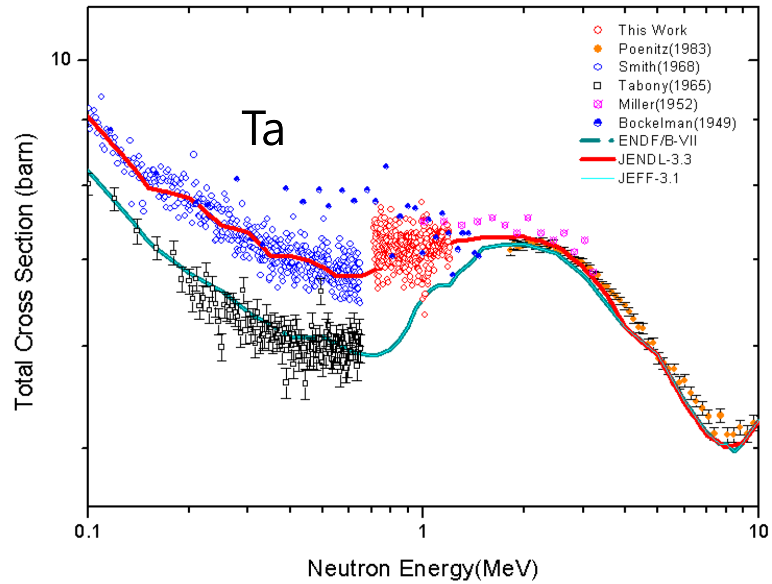


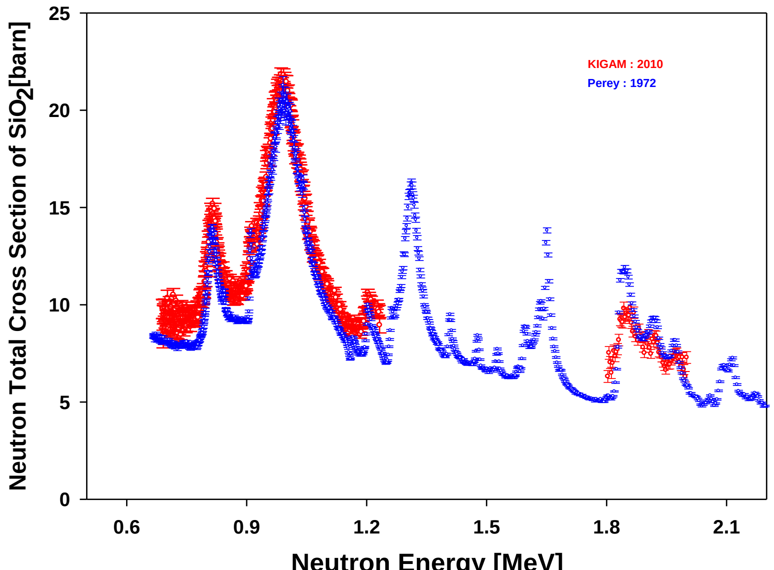


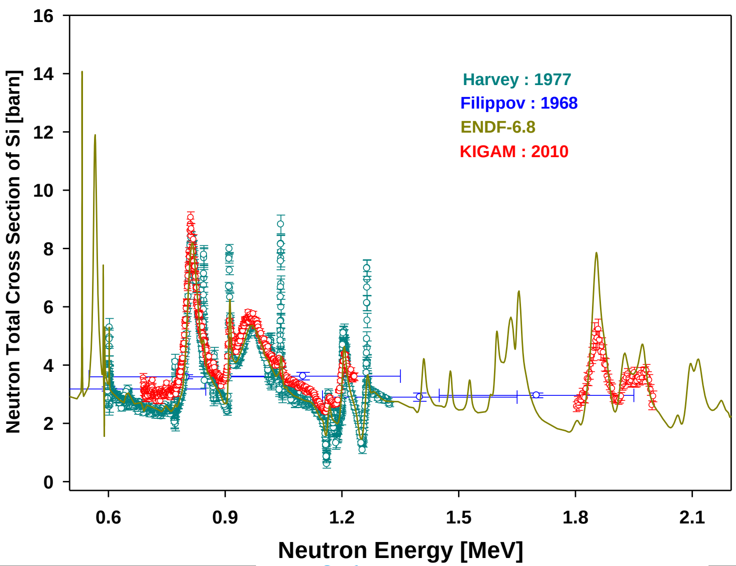
^{2}D(d,n) on Thin target :
3.5~6.2 MeV neutron with energy spread of <~230 keV

Nuclear data by KIGAM facility



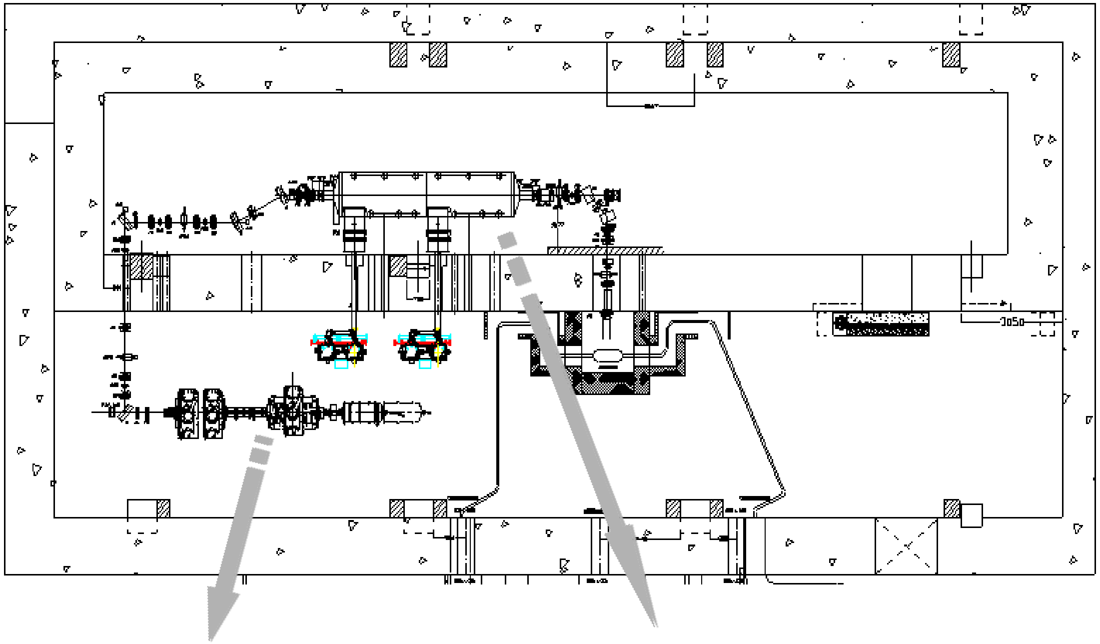






KAERI neutron facility (in design)

KAERI Electron Accelerator

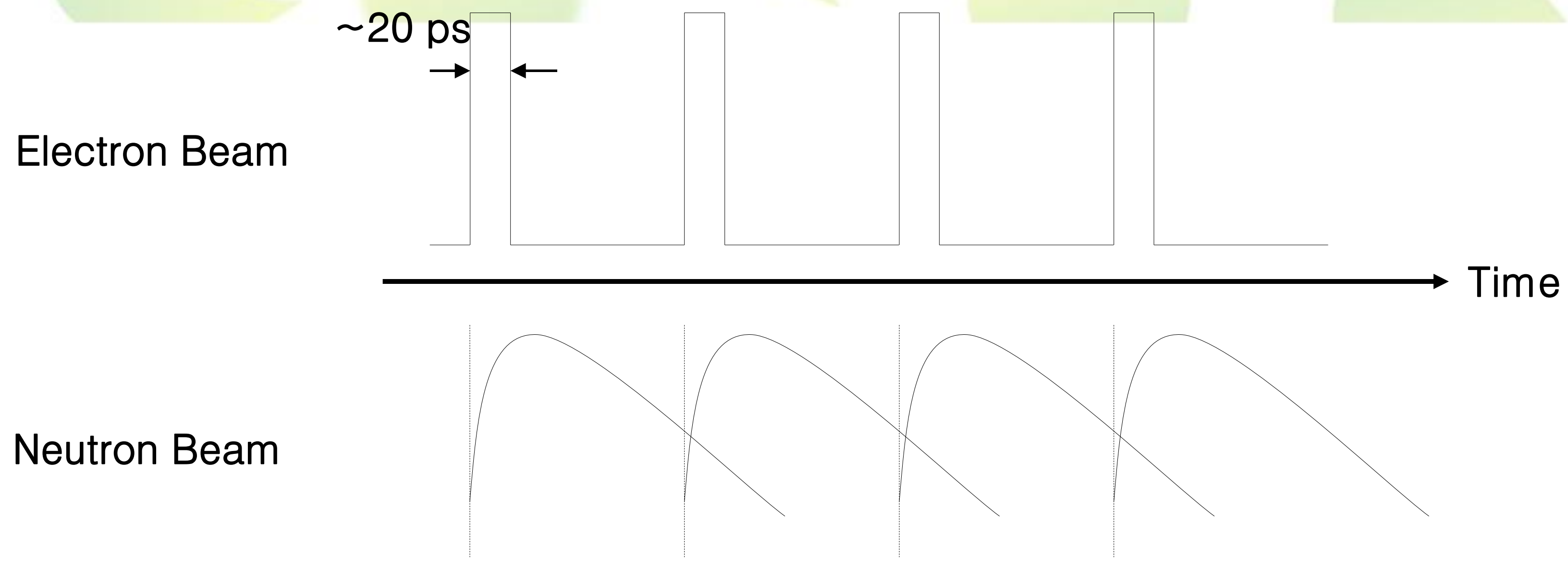


- Beam applications
  - Development of materials
  - Environment
  - Irradiation Test

- Accelerator Specifications

Energy	17 MeV
RF Power	Max. 100 kW
Pulse Width	~ 20 ps
Pulse Current	~ 20 A
Pulse Frequency	Max. 2 MHz
Beam Power	Max. 14 kW

Pulse Beam Characteristics for Neutron TOF



- Thermal neutron : frequency of a few hundreds Hz → beam power of a few W
- Fast neutron (20 keV< E <10 MeV) : frequency of 0.5 MHz → beam power of 4 kW)
- Things to work out in using fast neutrons

  1) Energy resolution

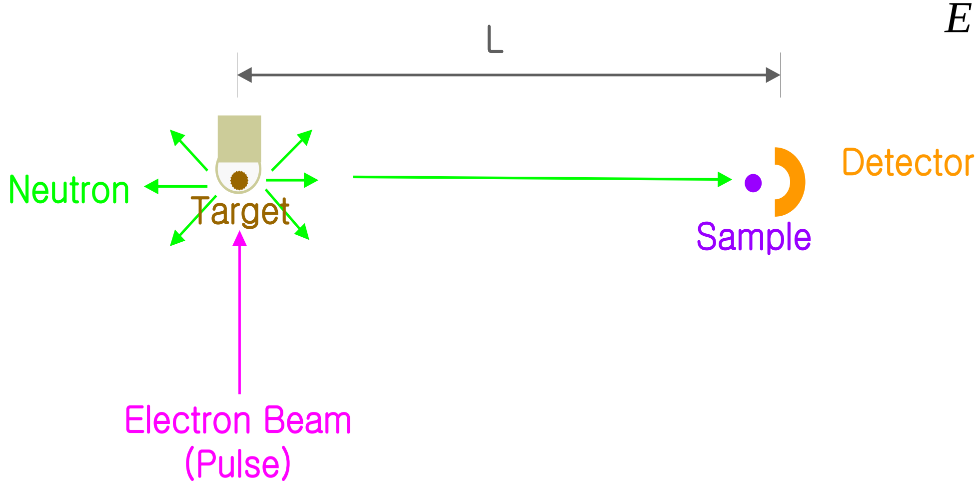
  2) Pulse overlapping

  3) Target cooling

Neutron Energy Resolution

- Neutron energy E is measured by flight time t (flight length L)

$$E(eV) = \left(72.3 \times \frac{L(m)}{t(\mu \sec)}\right)^2$$



$$\frac{\Delta E}{E} = 2\frac{\Delta t}{t} = 0.02766\left(\frac{\Delta t(\mu \sec)}{L(m)}\right)\sqrt{E(eV)}$$

$$\Delta t = \sqrt{\Delta t_1^2 + \Delta t_2^2 + \Delta t_3^2}$$

Δt_1 : Electron Beam Pulse Width
Δt_2 : Target Scattering
Δt_3 : Detector & DAQ

- Better energy resolution : Decreasing Δt or increasing L
- Increasing L $\rightarrow$ Decreasing neutron flux, therefore try to decrease Δt
- Energy resolution < 1% at L=5~10 m, E=1 MeV

  $\rightarrow$ Δt should be less than 1 ns

Neutron Source Target Requirements

- $\Delta t = \sqrt{\Delta t_1^2 + \Delta t_2^2 + \Delta t_3^2}$ (Δt_1 = 20 psec, Δt_3 : a few hundreds psec is possible)
- To make Δt_2 a few hundreds psec

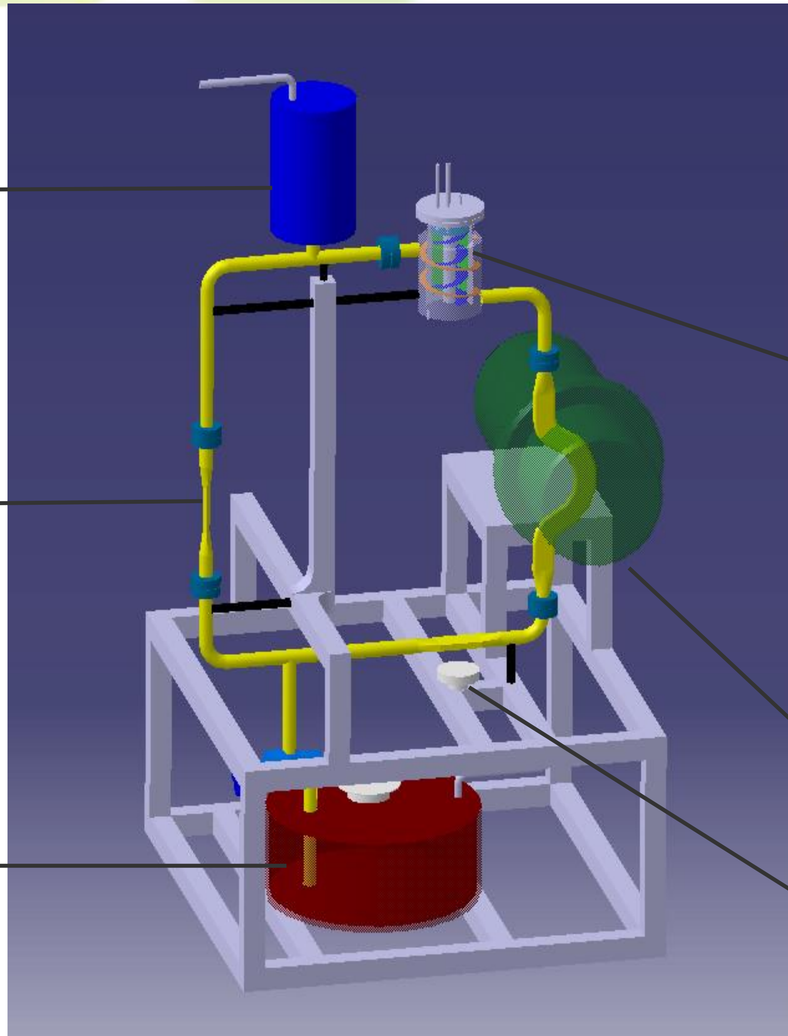
  → Beam diameter (~5 mm), beam penetration depth (~ 1 cm)
- Heat deposition rate (~20 kw/cm^3)
- **Liquid metal target** is required for the effective cooling of target
- Possible liquid target material : Pb, Pb-Bi, Hg

  → Pb is better considering toxic problems
- Reference Liquid Pb target : FZD (Forschungzentrum Dresden-Rossendorf)

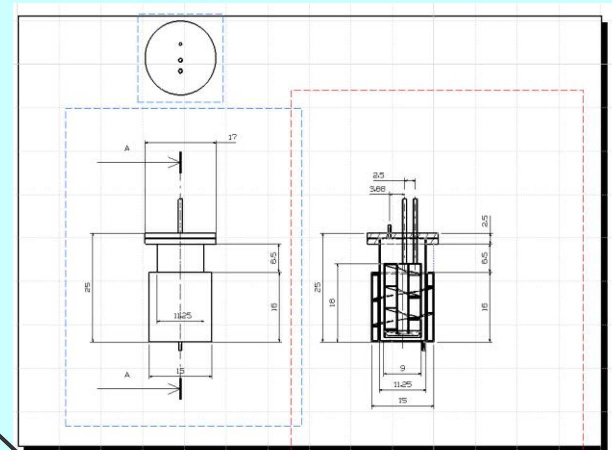
  → KAERI is developing a similar target

Neutron Source Target

- Developed by FZD
  (Height : ~ 2 m, Weight : ~ 500 kg)
- Liquid Pb target : Small volume is possible



Heat Exchanger



Neutron Production Simulation by MCNPX

- MCNPX 2.5.0 was used to simulate neutron production
- Pb target has a rectangular shape : Width 2cm

  → Pb is surrounded by Mo of which thickness is 0.5 mm
- Electron beam was assumed to be uniform with a diameter of 1 cm
- Electron beam energy was varied from 17 MeV to 65 MeV
- Target depth was varied from 0.2 cm to 1.8 cm

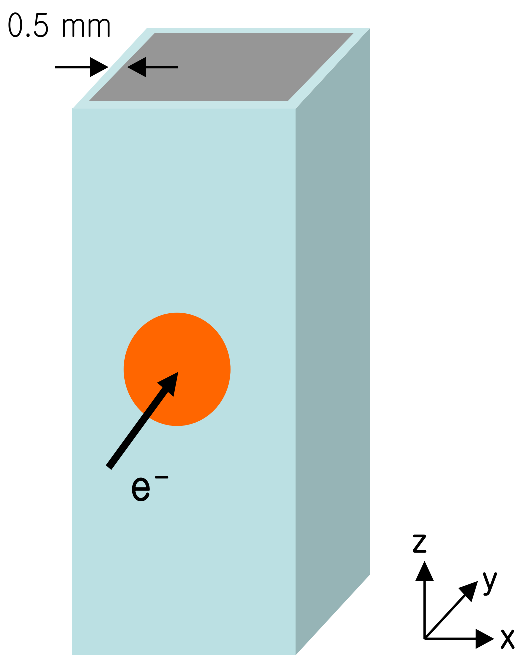
- Simulation was performed to study:

  → Neutron production rate and energy spectrum

  → Photon production rate and energy spectrum

  → Heat deposition in the target

Neutron and Gamma Production (1)

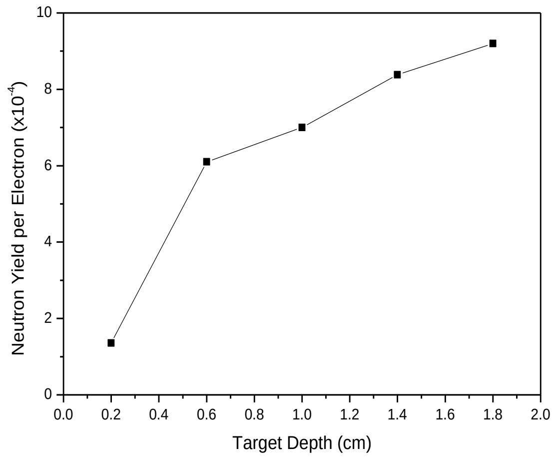


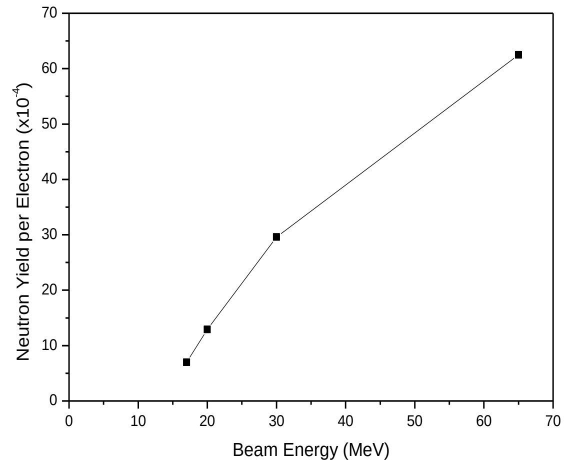
Pb Target	2 cm x 1 cm x 2 cm
Mo Tube	Thickness 0.05 cm
Beam Shape	Diameter 1 cm
Beam Power	17 MeV, 1.4 kW

Neutron Yield	$3.5 \times 10^{11}\ s^{-1}$
Gamma Yield	$1.2 \times 10^{15}\ s^{-1}$
Neutron Flux (5 m in x–direction)	$1.1 \times 10^{5}\ cm^{-2}s^{-1}$
Gamma Flux (5m in x–direction)	$2.2 \times 10^{8}\ cm^{-2}s^{-1}$
Gamma Flux (5m in y–direction)	$7.1 \times 10^{9}\ cm^{-2}s^{-1}$

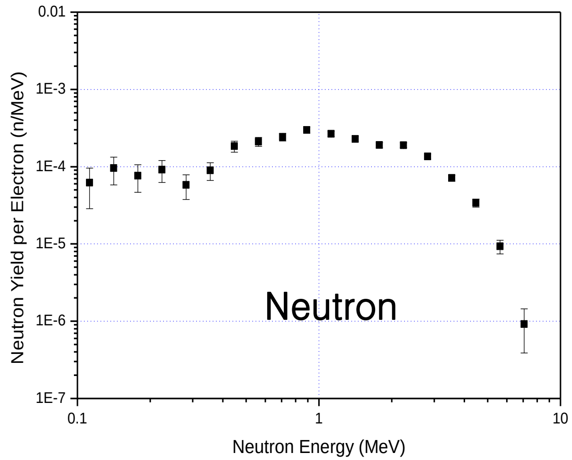
Neutron and Gamma Production (2)

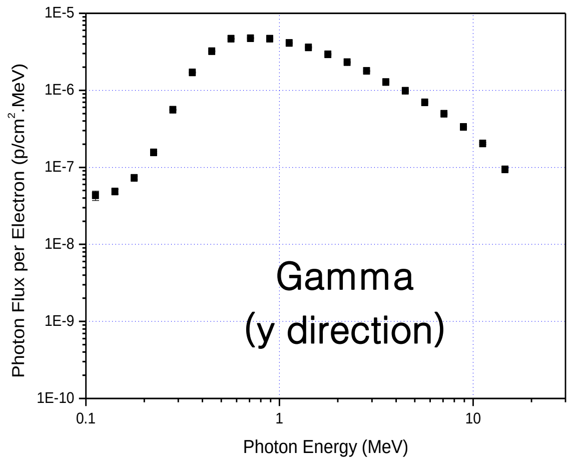
- Neutron production vs Target Depth/Beam Energy

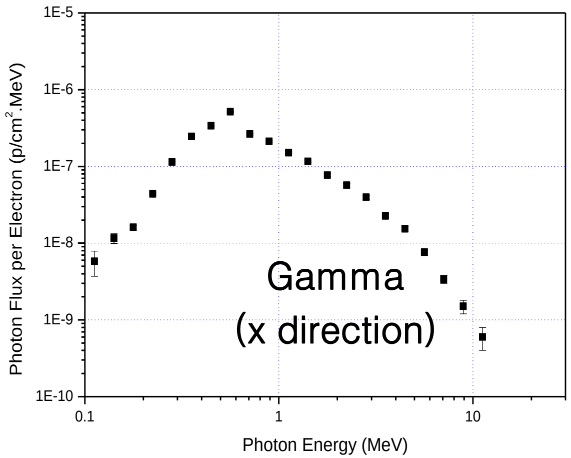




- Energy spectrum

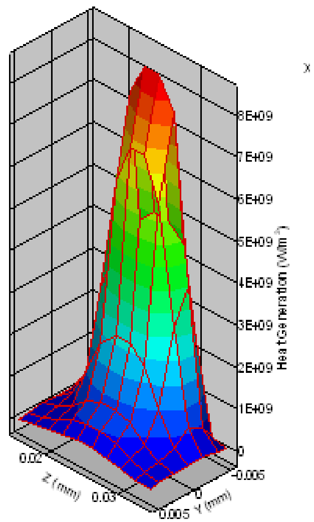


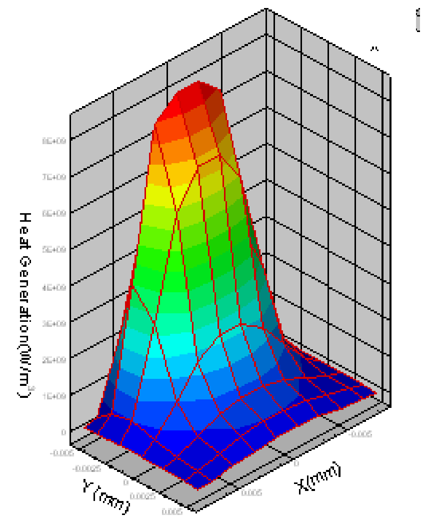




Thermal-hydraulic Analysis of Target (1)

- Heat Calculation : MCNPX, 17 MeV, 4 kW, Beam Diameter=1 cm

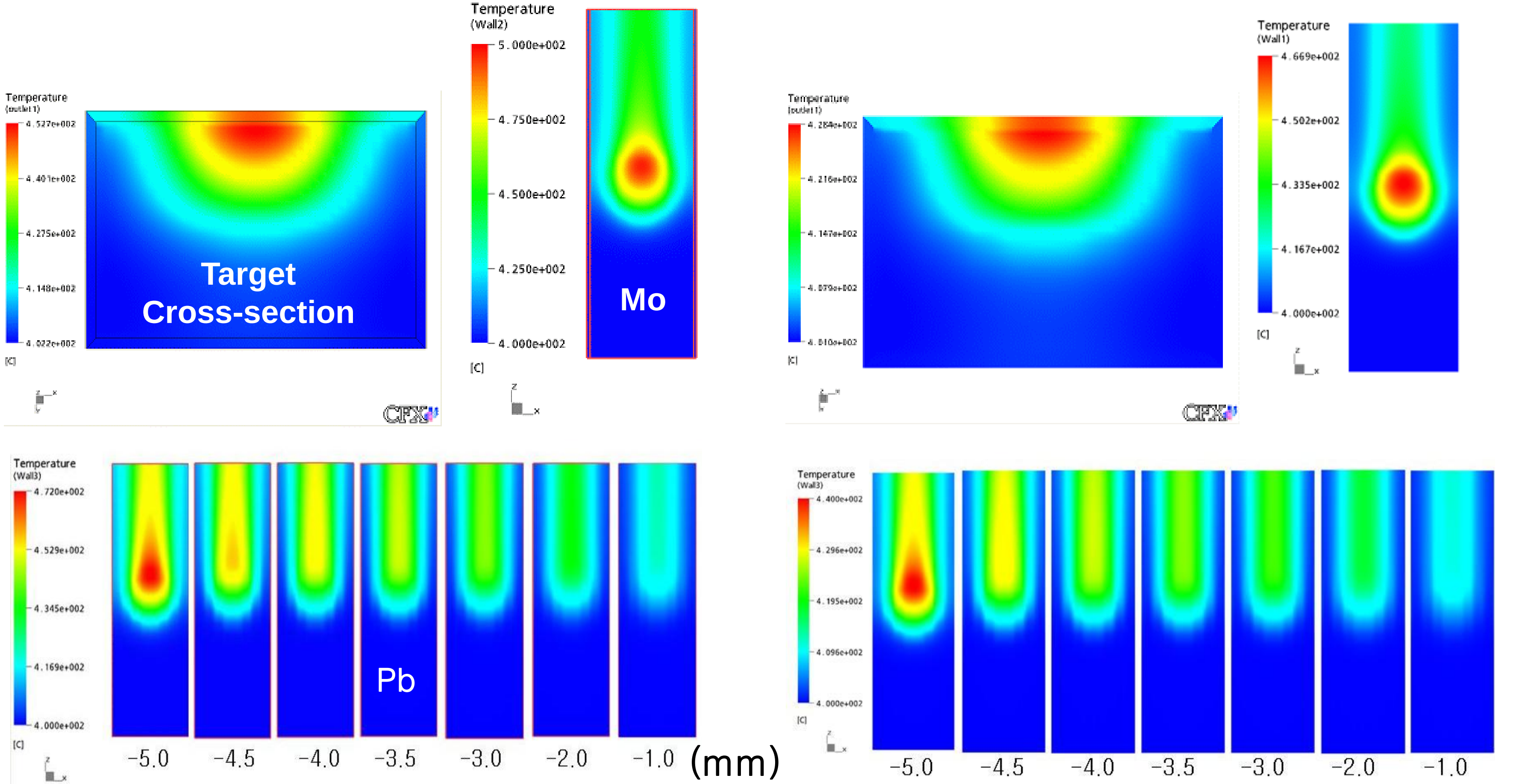




- Heat Thermal–Hydraulic Analysis : CFX, Inlet T=400°C, Inlet V=1–2 m/s

Velocity	Max. Mo Temp.	Max. Pb Temp.	Avg. Outlet Temp.
1 m/s	500°C	472°C	414°C
2 m/s	467°C	440°C	407°C

Thermal-hydraulic Analysis of Target (2)

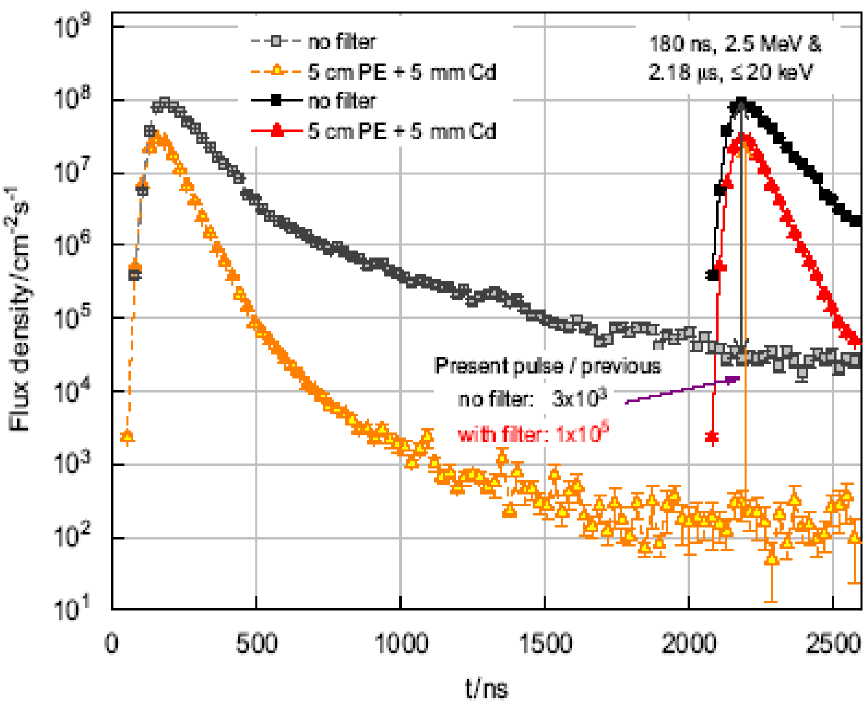


Velocity 1 m/s

Velocity 2 m/s

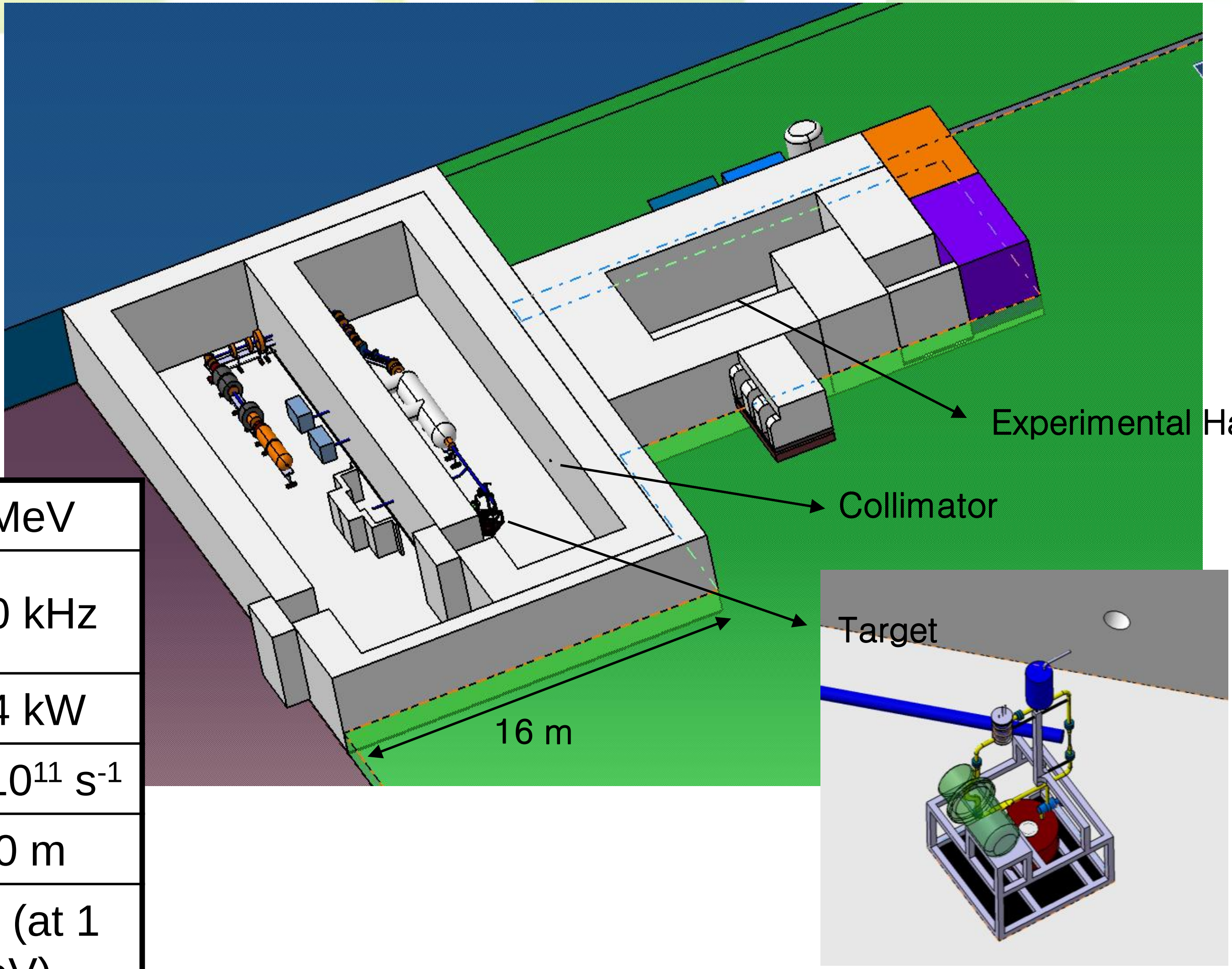
Neutron Pulse Overlapping

- Nuetron pulse overlapping problem can be improved by using PE and Cd slabs in the collimator
- 0.5 MHz frequency (E>20 keV) case : Signal–to–background ratio becomes 10^5



* Reference : FZD Pb Liquid Target neutron TOF System

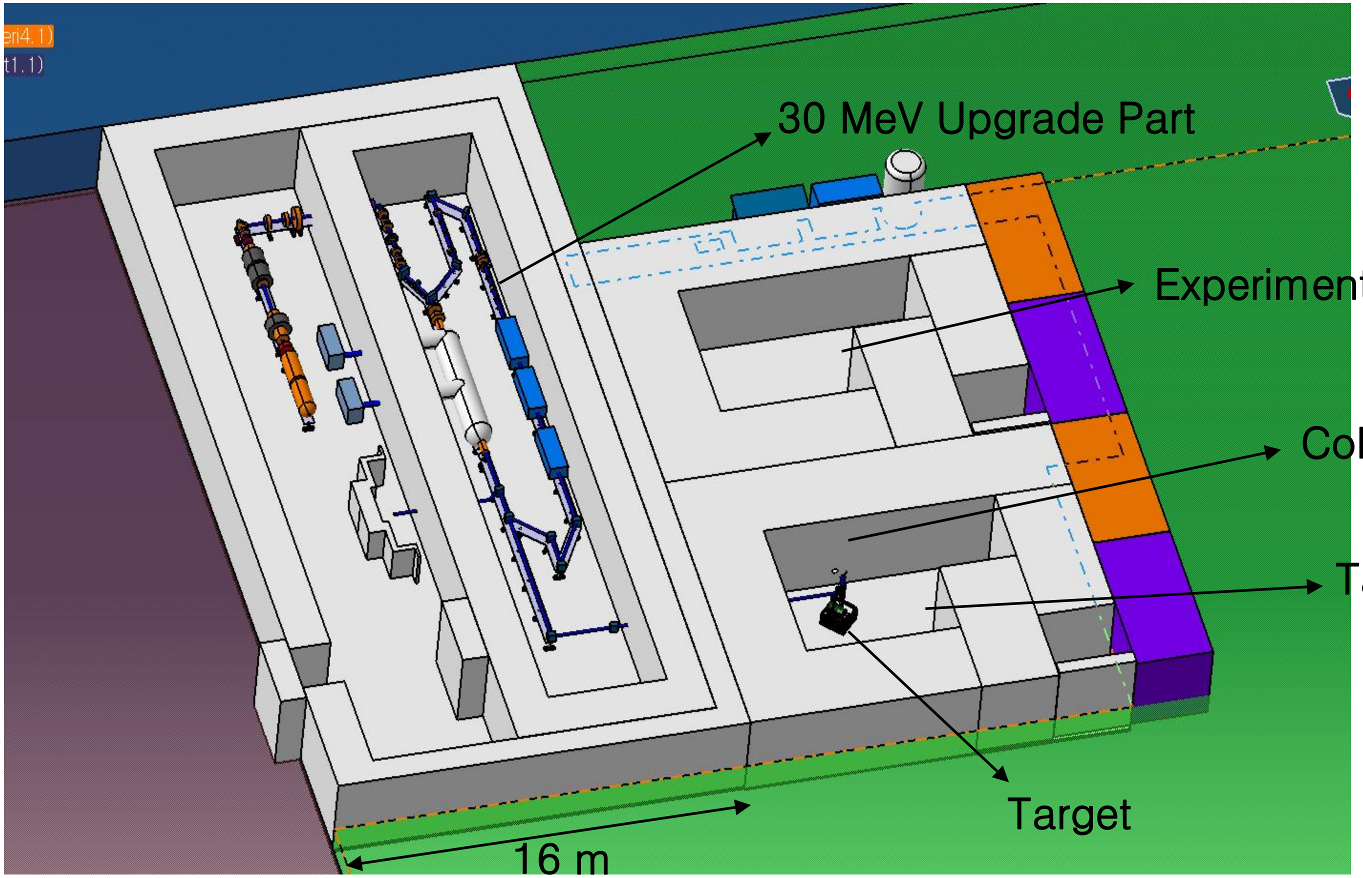
KAERI TOF Neutron System : Plan for Stage 1



Energy	17 MeV
Pulse Frequency	~ 200 kHz
Beam Power	~ 1.4 kW
Neutron Yield	3.5 x 10^{11} s^{-1}
Flight Length	~ 10 m
Energy Resolution	< 1% (at 1 MeV)

KAERI TOF Neutron System : Plan for Phase 2

- Electron energy 30 MeV with increased current, target located in a separate target room
- Collimator is located between target room and experimental room



Summary: Design of Neutron Production Target for KAERI TOF Facility

- KAERI electron accelerator can be used for neutron data measurements

  → Energy 17 MeV, max. beam power 14 kW, pulse beam width 20 ps
- High heat deposition rate (~20 kw/cm^3) → Liquid Pb target
- KAERI is developing a liquid Pb target with the cooperation of FZD
- Simulation study was performed to investigate neutron production by MCNPX
- Thermal-hydraulic calculation was performed by CFX
- Frequency 0.5 MHz → Neutron energy > 20 keV
- Phase 1 : Electron energy 17 MeV, target is located in the accelerator room
- Phase 2 : Electron energy 30 MeV with increased current, target is located in a separate target room

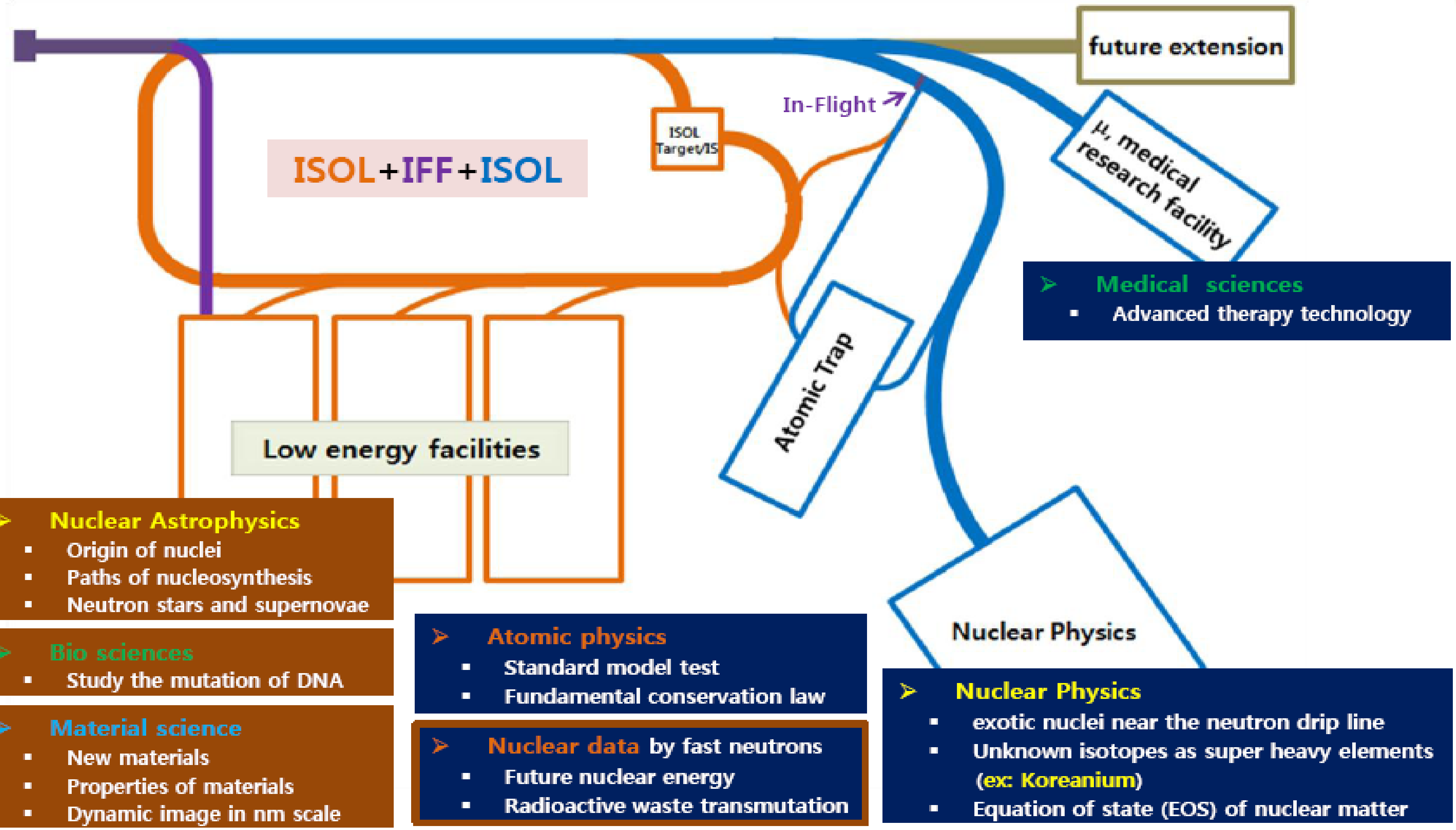
Nuclear Data Activities Relevant to ADS (2)

- Nuclear Data Evaluation and Covariances for ^{237}Np, ^{240}Pu and Cm isotopes
- Design of Neutron Production Target for KAERI TOF Facility
- **Nuclear Data Measurements at KoRIA**

Nuclear Data Measurements at KoRIA (Conceptual Design)

Korea Rare Isotope Accelerator (KoRIA)

Researches of basic and applied science with stable and unstable isotopes



- Medical sciences
  - Advanced therapy technology

- Nuclear Astrophysics
  - Origin of nuclei
  - Paths of nucleosynthesis
  - Neutron stars and supernovae

- Bio sciences
  - Study the mutation of DNA

- Material science
  - New materials
  - Properties of materials
  - Dynamic image in nm scale

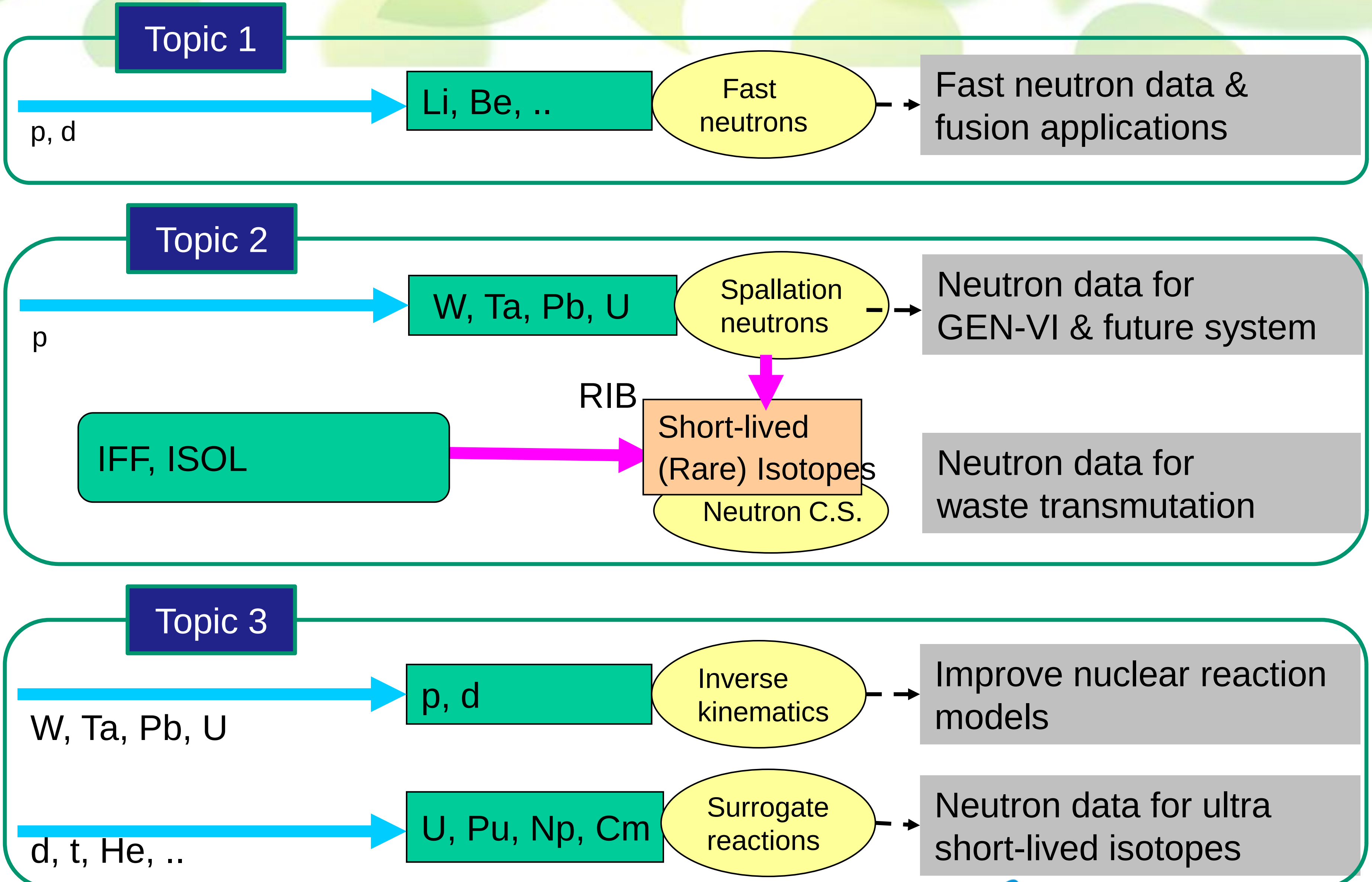
- Atomic physics
  - Standard model test
  - Fundamental conservation law

- Nuclear data by fast neutrons
  - Future nuclear energy
  - Radioactive waste transmutation

- Nuclear Physics
  - exotic nuclei near the neutron drip line
  - Unknown isotopes as super heavy elements (ex: Koreanium)
  - Equation of state (EOS) of nuclear matter

Prepared by prof. S.W. Hong & prof. Y.K. Kim of KoRIA project

Nuclear Data Research Topics in KoRIA



Beam Requirements for Research Topics

- Topic 1 : Cyclotron beam
  - **p (70 MeV, 1 mA), d (35 MeV, 300 μA)** for fast neutron production
    (p→(Mono-energy neutron production, d→Broad spectrum neutron production)
  - CW and pulse beams
  - Pulse beam : pulse width 1ns, repetition rate 1 kHz-1 MHz

- Topic 2 : Linac beam (400 kW)
  - **p (600 MeV, 0.66 mA) for spallation** neutron production
  - Pulse beams (Basic repetition rate 70 MHz)
  - Pulse beam : pulse width 1ns, repetition rate 100-500 kHz
    (Average current is proportional to repetition rate)

- Topic 3 : Linac beam
  - **Inverse kinematics**
    - Actinide ion beam (2-10 MeV/u), spallation target material beam (a few hundreds MeV)
  - **Surrogate reaction**
    - 20-60 MeV p ,d, t, He-3, He-4

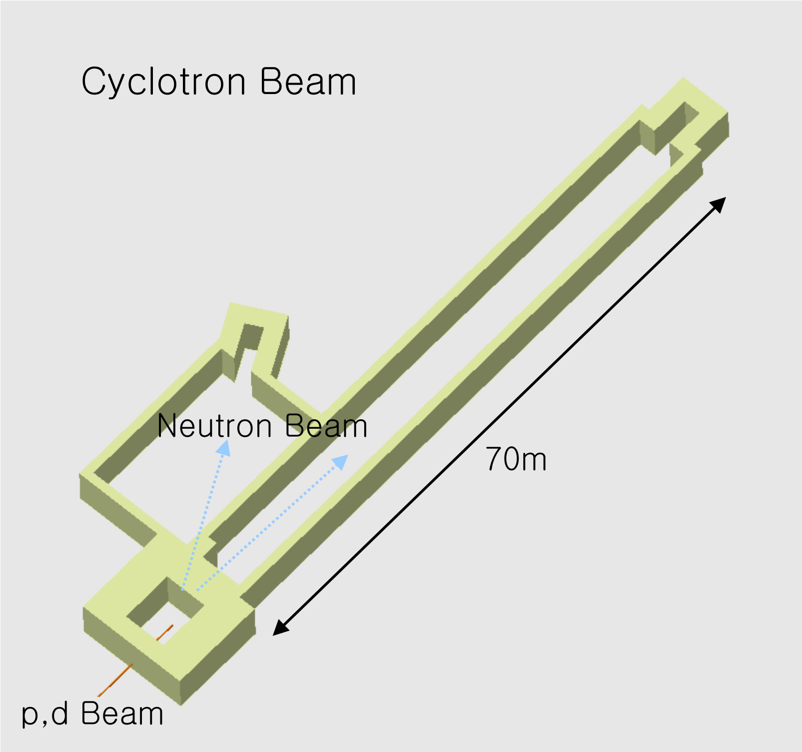
Experimental Program with TOF at KoRIA

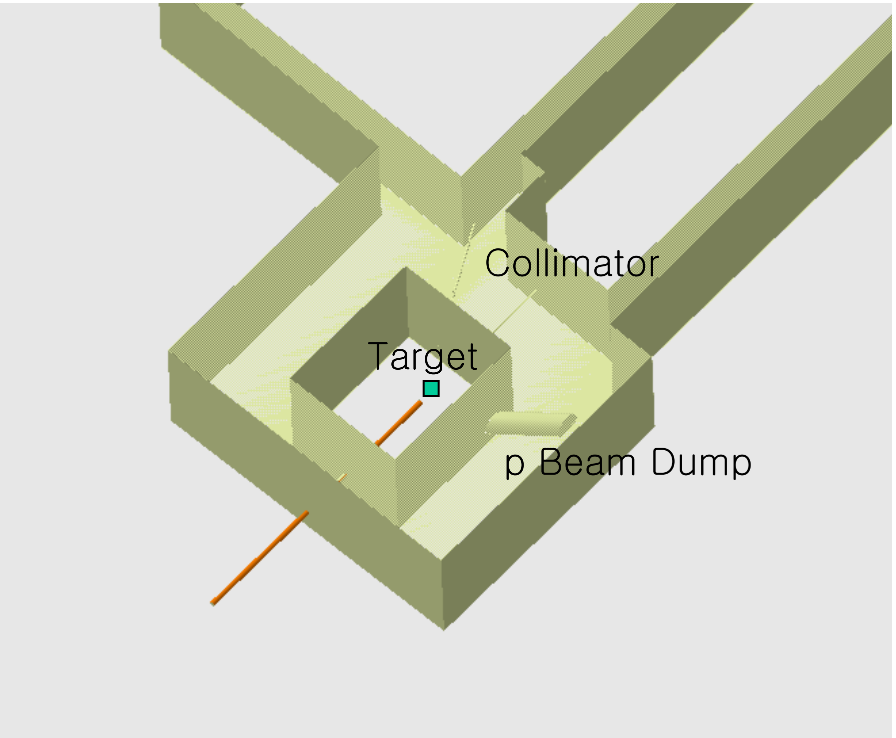
Capture measurements	
Mo, Ru, Pd stable isotopes	Calculation of r-process residuals Isotopic patterns in SiC grains
Fe, Ni, Zn, Se, Zr stable isotopes	S-process nucleosynthesis in massive stars Accurate nuclear data needs for structural materials
A~150	S-process branching points Long-lived fission products
^{233,234,236}U, ^{231,233}Pa, ^{232}Th	Th/U nuclear fuel cycle
^{234,235,236}U	Standards, conventional U/Pu fuel cycle
^{239,240,242}Pu, ^{241,243}Am, ^{245}Cm	Incineration of minor actinides

Fission measurements	
^{237}Np, ^{231}Pa, ^{240,241,242}Pu, ^{241,243}Am, ^{244,245}Cm	Fission cross-section data for minor actinides
^{235}U(n,f)	New ^{235}U(n,f) cross-section standard
^{232}Th, ^{233,234,235,236,238}U	Th/U fuel cycle and transmutation
Various nuclides	Fission fragments angular and mass distribution
^{234}U(n,f)	Study of vibrational resonances at the fission barrier

Experimental Hall and Beam Line for Topic 1

- **Experimental hall for the measurements of fast neutron reaction data**
  - Cyclotron beam is used to produce fast neutrons
  - Beam line : p/d beam line + neutron production target + collimator/duct
  - d+thick Li/Be/C target : Two neutron beam lines for TOF method (0^o, 30^o)
  - p+thin Li target : Proton deflecting magnet and beam dump
  - TOF resolution at 70 m : 10 MeV neutron $\Delta E/E$=0.2% (assuming detector Δt=1 ns)

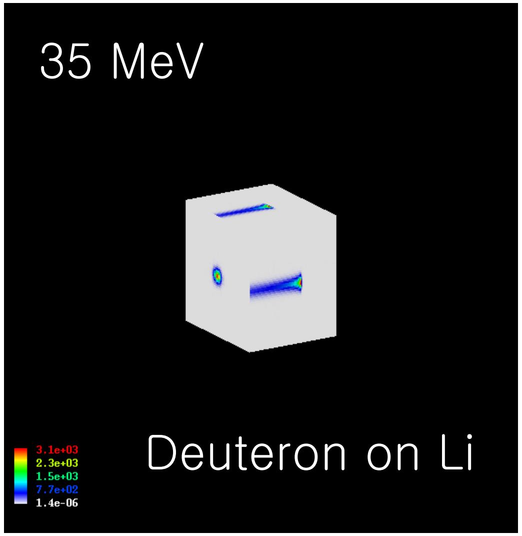


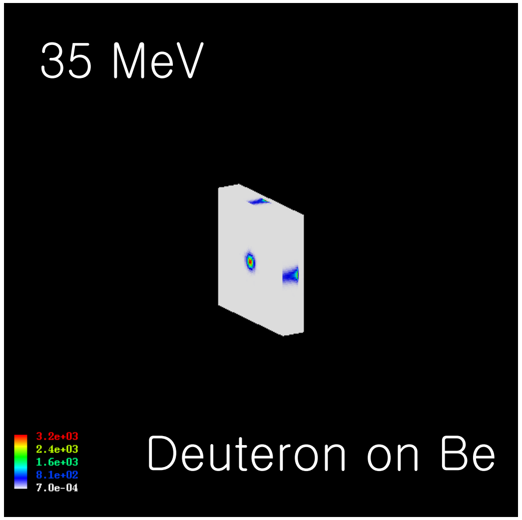


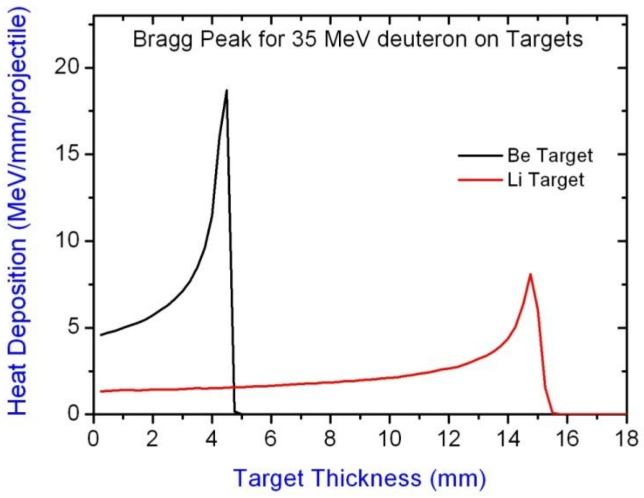
Fast Neutron Production of Thick Target

- **Conceptual design of thick target**
  - Broad spectrum fast neutron production : Thick target of C, Be, Li (d beam)
  - Beam power 1-2 kW : Water-cooled Cu backing Be target
  - High beam power : Rotating Be/C or liquid Li target similar to IFMIF target

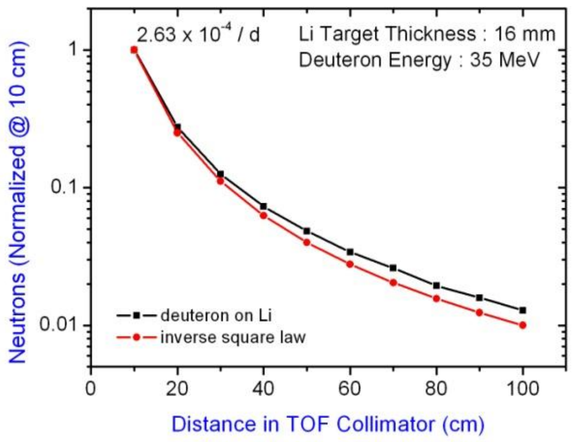
- **Heat deposition calculation**
  - Beam diameter 3 mm, target 4 cm x 4 cm, 35 MeV d beam, C/Be/Li target.
  - Heat deposition result → Input of CFX, ANSYS for cooling calculation

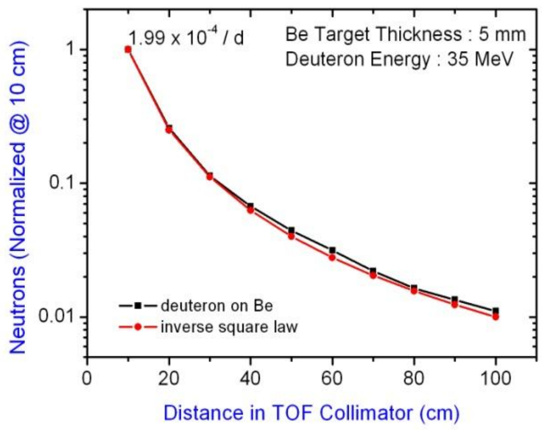






Estimation of TOF Neutron Output (@35 MeV)





Simulation results with 1 m TOF collimator tube (2 cm diameter) :

-At the end of the collimator, the neutron passage is **~10^{-6} n/deuteron**.

-We estimate **~10^{-10} n/deuteron at 100 m** from the inverse square law.

-35 MeV deuteronson a lithium target can produce

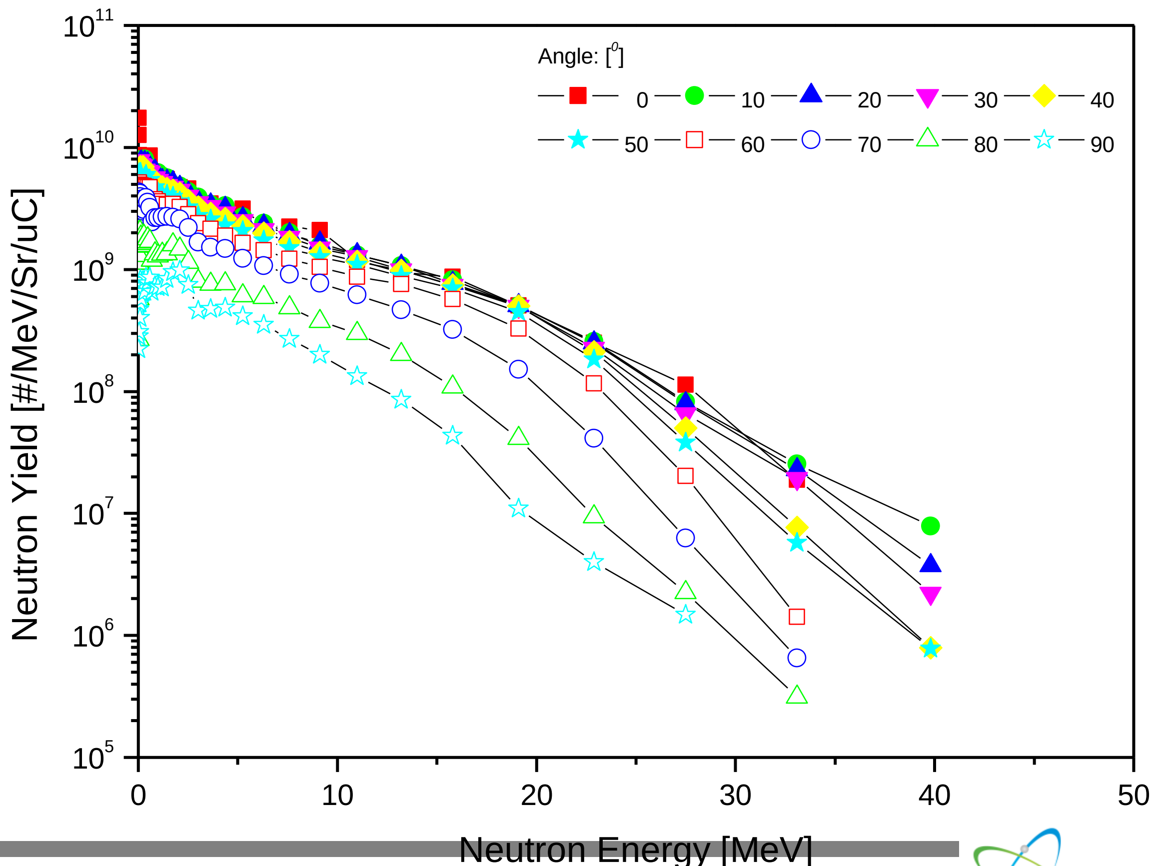
fast neutrons of the energy up to ~30 MeV.

-**0.1 mA** of the deuteron beam will guarantee

- **>10^4 n/s at the end of the 100 m TOF line.**

Neutron Spectrum of Thick Target

- Neutron spectrum calculated for thick target for 35 MeV d beam
  - Spectrum of neutrons produced at Be target (PHITS code)
  - Target thickness : 1 cm



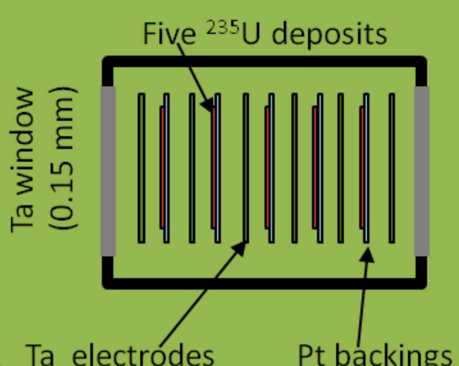
Detection System for Producing Nuclear Data

- **Design approach**
  - Investigation of international detection system (CERN, GELINA etc.)
  - design of flux monitor, total cross section detection system, capture cross section detection system, inelastic cross section detection system and fission cross section detection system

- **Neutron flux measurement system :**
  1) (n,f) detector : use of U-235, efficiency of 0.854
  2) Micro-Megas system : use of B-10 and U-235 for measurement of neutron beam shape
  3) Silicon Monitor : use of ^{6}Li (n,α) reaction

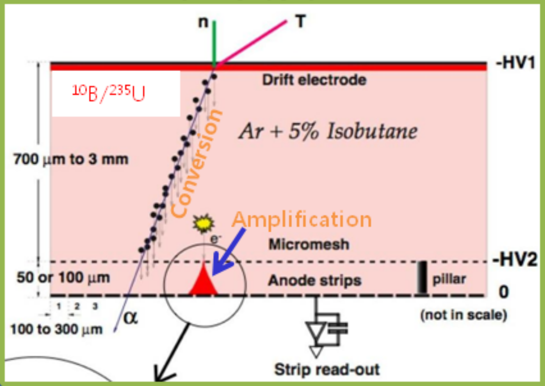
PTB (n,f) detector

Uranium mass (201.4 mg) and detection efficiency (0.954) known within 0.5%.



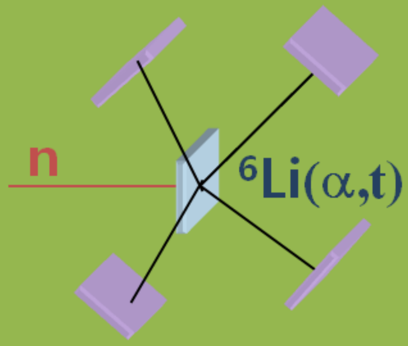
MicroMegas (MGAS)

Transparent detector for charged particles equipped with ^{10}B and ^{235}U converters.



Silicon Monitor (SiMon)

Four silicon detectors looking at a 200 μg/cm^2 ^{6}Li foil. Well known efficiency below ~1-10 keV.



Measurement System for Nuclear Data at KoRIA

A. **Total cross section :**

1) 25m and 70m flight length and plastic detector : time resolution < 10^{-3}

B. **Capture cross section :**

1) 12 C_6D_6 detector and use of weighting technique,

2) 40 or 160 BaF_2 ball detector (assuming)

C. **Elastic cross section** : plastic detector and TOF system

D. **Inelastic cross section** : (n,n'γ) reaction : 4 HP Ge detector and TOF system

E. **Fission cross section** : use of Fission ionization Chamber

F. **Neutron flux monitor** : Fission ionization chamber

* **Use of coincidence measurement system** of capture cross section and total cross section

* **Construction of 5 parameter detecting system** :

TOF signal,

Capture cross section TOF signal,

Pulse height signal, Elastic scattering TOF signal or Fission particle signal,

neutron flux signal.

Nuclear Data Activities: SUMMARY

- KERCEN code in development for resonance region
- Evaluation and covariance for ^{237}Np, ^{240}Pu and Cm isotopes :
  - KAERI-ORNL collaboration
  - Advance Fuel Cycle (AFC), Safeguards, Fast System etc

- Pohang Neutron Facility (eV)
- KIGAM Neutron Facility (a few MeV)

- Design of Neutron Production Target for KAERI TOF Facility
  - Fast neutrons with energy greater than ~ 100 keV

- Nuclear Data Measurements at KoRIA
  - Fast neutron data for fusion, GEN-VI and ADS
  - Charged particles for Inverse kinematics and surrogate reactions (needed in ADS and Transmutation)