Study of measurement method of high-energy neutrons for ADS

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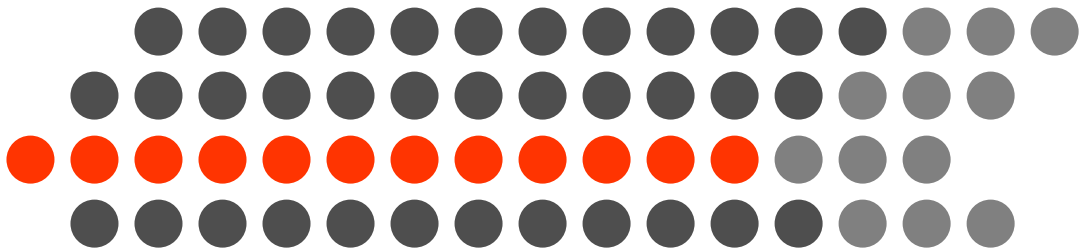


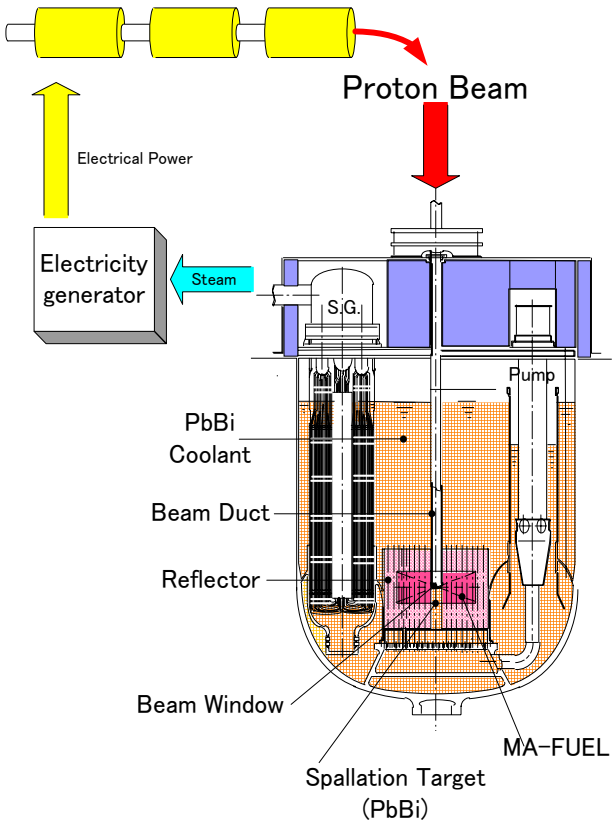
Background

- *Disposal problem of High level radioactive waste(HLW)*
  - HLW is released from a nuclear power plant
  - Deep geologic disposal is the basic policy for HLW in Japan
  - Nuclear transmutation has been studied to transmute HLW effectively

- *Development of Accelerator Driven System*
  - Japan advances ADS development projects as follows
    - FFAG KUCA at KURRI (in construction)
    - TEF –P and –T in J-PARC project (in plan) etc

ADS

- The ADS consists of a high intensity proton accelerator and a sub-critical reactor



- The proton energy of the ADS is 1.5GeV
- The proton beam current is from 20 to 30mA
- A target of the ADS is Pb-Bi
- When protons hit at the target, spallation neutrons with high-energy are generated

Fig.Pb-Bi cooling ADS that was proposed by JAEA

Spectrum of ADS

- Neutron spectrum for the ADS are classified into three components.
  - i. high energy neutron region above 10MeV
  - ii. fast neutron region from 0. 1 to 10MeV
  - iii. thermal neutron region below 0.1MeV

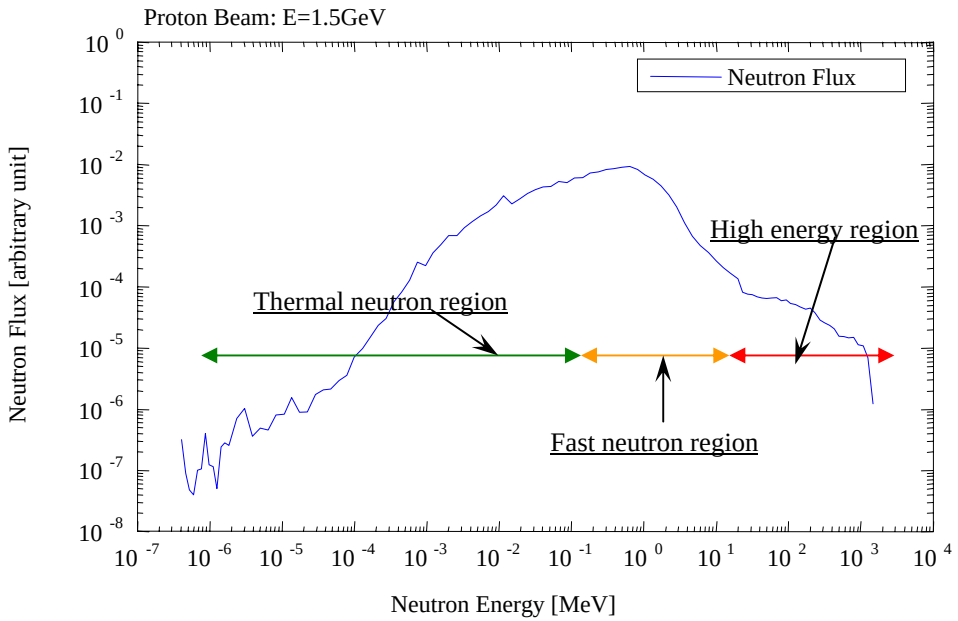


Fig. Typical spectrum in the ADS

- The spectrum is largely varied by changing the system conditions.
- For this reason, The system conditions of the ADS can be monitored by measuring the energy spectrum of those neutrons.
- However, there is no measurement method for the spectrum in ADS.

Aim of this study

- This study aims
  I. To develop the measurement method for high-energy neutrons in ADS
  II. To establish the measurement system for the whole energy spectrum in ADS

- The detectors for measuring the spectrum in ADS are:
  - A scintillation detector
  - A fission counter
  - A activation detector

- We selected an activation detector because:
  - It can measure the neutron spectrum with high energy resolution
  - It is useable in the strong γ field

I. Development of measurement method for high energy neutron spectrum

Development of measurement method for high energy neutron spectrum (1)

- Selection of foil
  - We propose the Bi activation detector for measuring high-energy neutrons.
    - Bi continuously occurs the (n,Xn) reactions successively from 10 to 100MeV with the same interval of 8MeV.
    - The activated nuclides have the suitable half-lives and the γ ray energies for the γ ray counting.
  - Bi is suitable to obtain the energy spectrum of high-energy neutrons.

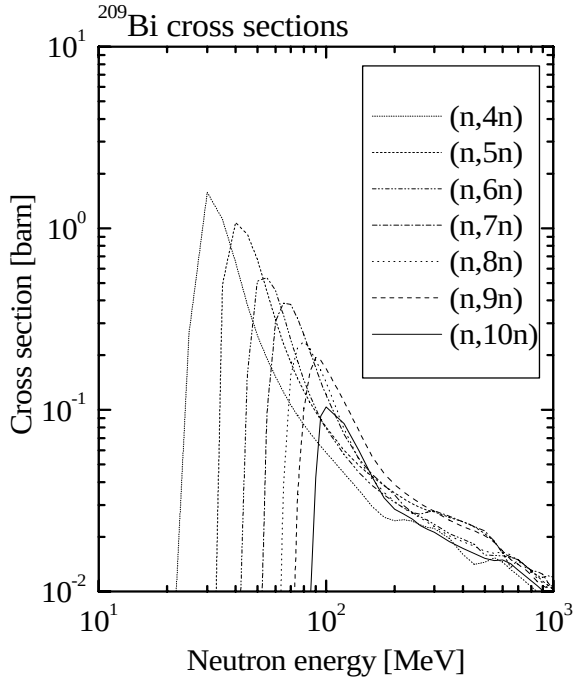


Fig.(n,Xn) threshold reaction cross section of Bi

Development of measurement method for high energy neutron spectrum (2)

- Verification experiment
  - The experiment of the Bi activation was made by using a Fixed Filed Alternating Gradient (FFAG) accelerator at High Energy Accelerator Research Organization (KEK)
  - FFAG accelerator
    - It is an accelerator combined advantages of a cyclotron and a synchrotron
    - Beam energy for the accelerator is 150MeV
  - In this experiment, the proton energy was not stable and the beam did not converge well. The beam energy could not be defined well.
    - It is supposed that the beam energy is between 70 and 80MeV

Development of measurement method for high energy neutron spectrum (3)

- Experimental setup
  - Setup of irradiation samples
    - W as a spallation target into which the proton beam is injected
    - Bi as an activation detector
  - Sample specification
    - Thickness and diameter for Bi and W were decided by the MCNPX calculation
    - Bi: the thickness is 3mm, the diameter is 5mm
    - W: the thickness is 9mm, the diameter is 5mm

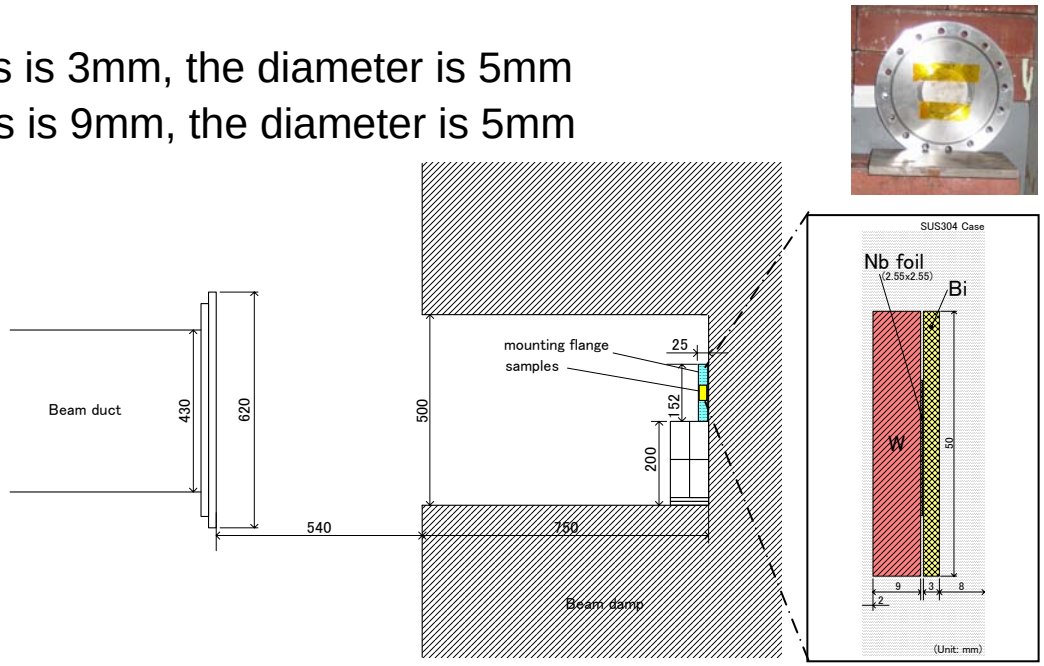


Fig. Experimental setup

- After activated, the sample was measured by used Ge detector.

Development of measurement method for high energy neutron spectrum (4)

Irradiation and measurement condition

- Irradiation time:
  - 3 hours
- Waiting time:
  - 5 hours
- Detection time:
  - 1.5 hours

reaction	threshold	CPS
(n,4n)	22.6MeV	2.30
(n,5n)	29.6MeV	0.25
(n,6n)	38.1MeV	3.76
(n,7n)	45.4MeV	0.31
(n,8n)	54.2MeV	0.32

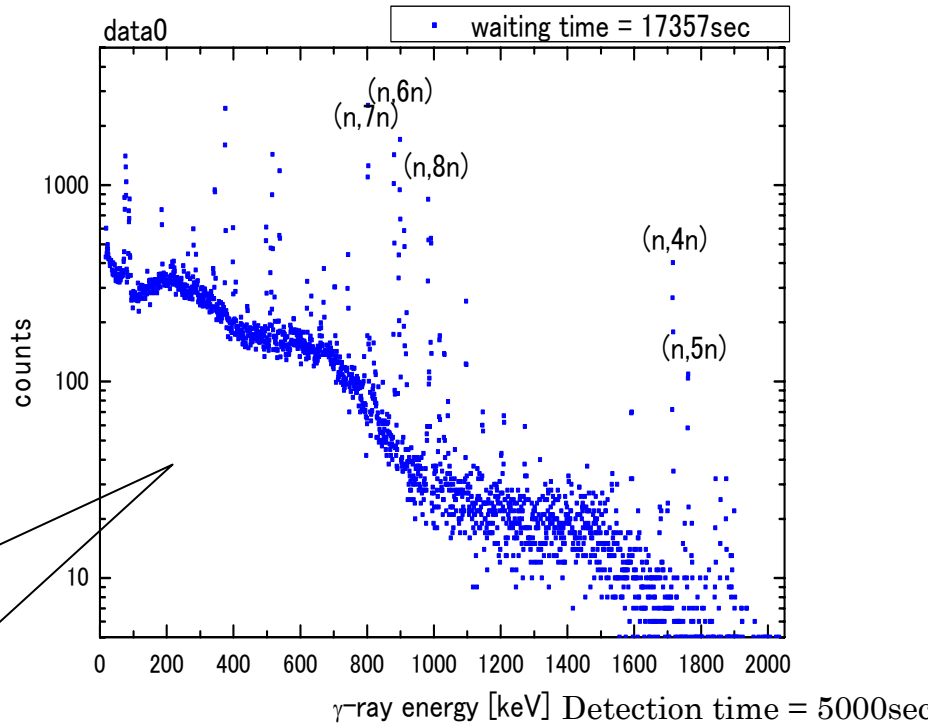


Fig. γ ray spectrum that was obtained in the experiment

Development of measurement method for high energy neutron spectrum (5)

- The neutron energy spectrum was derived by using the unfolding method from the measurement results.
- Experimental results were compared with calculated results.

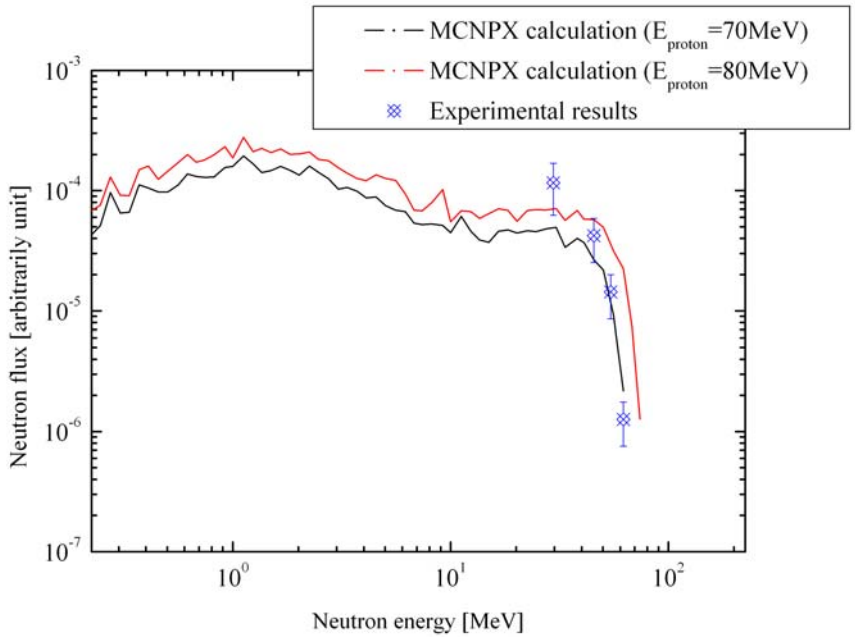


Fig. The experimental results by unfolding and the calculated values by MCNPX

- The experiment results are between the calculated values of 70 and 80MeV.
- Bi is available for measuring the high-energy neutron spectrum.
- More accurate experiment should be done to verify the Bi activation.

II. Establishment of measurement system for whole energy neutron spectrum

Establishment of measurement system for whole energy neutron spectrum (1)

- First, the measurement for thermal and fast neutrons is established.
- The experiment is performed by using the Kyoto University Critical Assembly(KUCA)

- The sub-critical core is driven with 14MeV
- Sub-criticality:
  - 1.2%dk/k
- Accelerator:
  - The accelerator was conventional Cockcroft-Walton accelerator with energy of 300KeV for producing D-T neutrons.
- Target:
  - Ttritium
- Sample setup:
  - The foils were set at the center of the core and near the target.

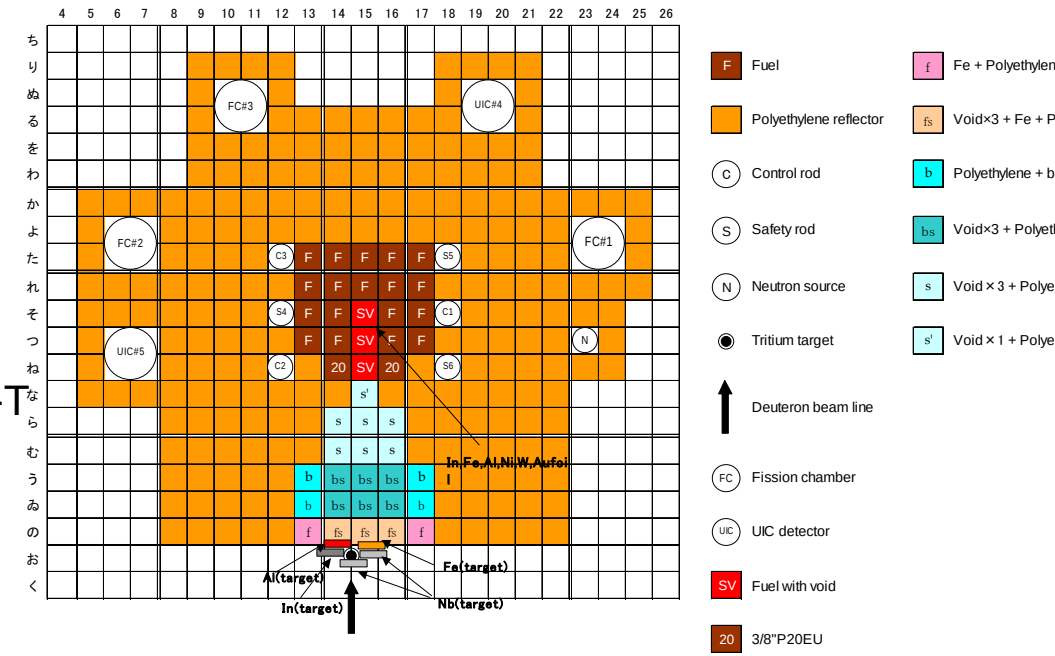


Fig. Experimental layout of the KUCA experiment

Establishment of measurement system for whole energy neutron spectrum (2)

- Foils employed in the experiment:
  - In, Ni, Fe, Al and Nb are adopted for measuring the fast neutrons with the energy threshold interval of 5MeV.
  - ^{197}Au was used for measuring the thermal neutrons .

Threshold reaction	Treshold(MeV)	half-life
^{115}In (n,n') ^{115m}In	0.5	4.5h
^{58}Ni (n,p) ^{58}Co	1.9	70.8d
^{56}Fe (n,p) ^{56}Mn	4.9	2.6h
^{27}Al (n,α) ^{24}Na	4.9	15h
^{93}Nb (n, 2n) ^{92m}Nb	9	10.15d
^{58}Ni (n,2n) ^{57}Ni	13	36h

Table. Parameter of foils

- Irradiation time:
  - 5hours
- γ counting:
  - The γ rays were detected by using a Ge detector.

Establishment of measurement system for whole energy neutron spectrum (3)

- Derivation of spectrum
  - The reaction rates for each foil were unfolded by SAND-II code.
  - The cross section was quoted from *JENDL Activation Cross Section File96.*

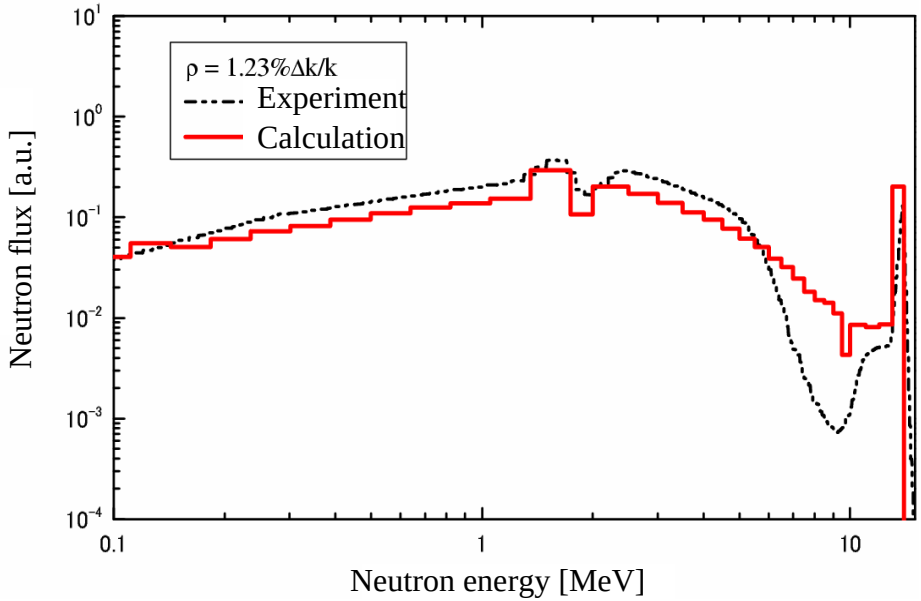


Fig. The derived spectrum

- The experimental result agreed with the calculated one by MCNP.
- The measurement method for the neutron spectrum in the thermal and fast region was established.

Establishment of measurement system for whole energy neutron spectrum (4)

- We designed a monitoring system for the ADS by JAEA.
- Monitoring system
  - Bi and In are employed for the whole energy spectrum at the ADS core.
  - The sample is
    i. placed to the appropriate position by a pneumatic tube,
    ii. irradiated for appropriate time,
    iii. withdrawn by the pneumatic tube,
    iv. set inside a Ge detector system with two Ge detectors and appropriate collimators,
    v. measured by the Ge detector.

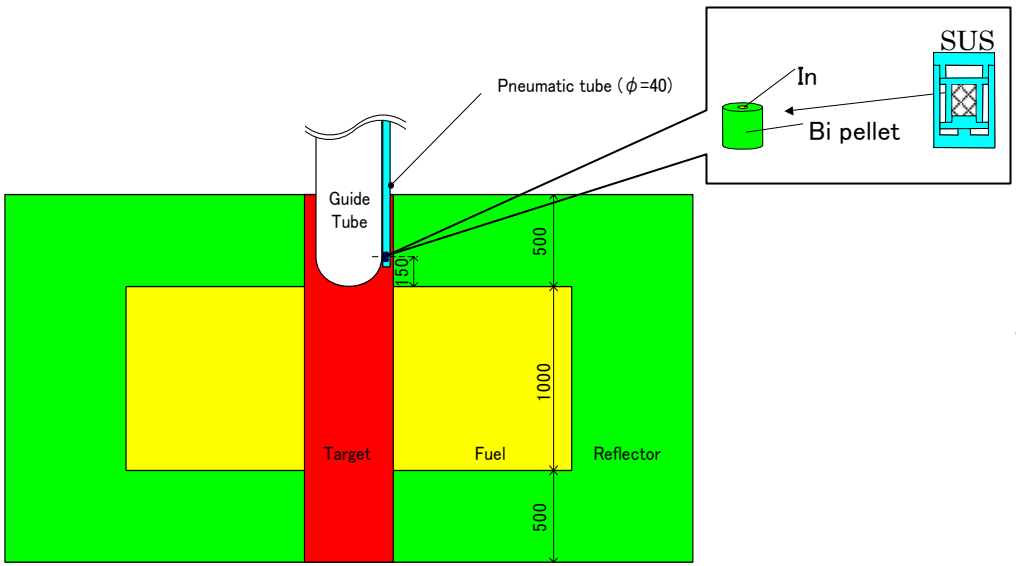


Fig. A typical system designed for the ADS

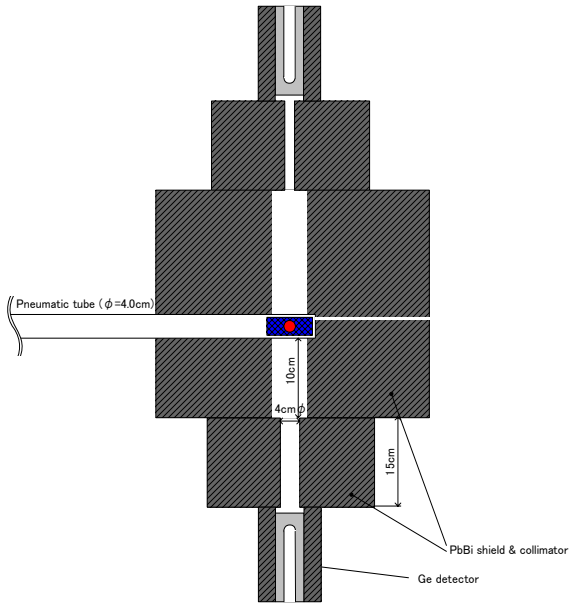


Fig. The measurement system for γ rays

Establishment of measurement system for whole energy neutron spectrum (5)

- *Sample*
  - In is for measuring the thermal neutrons by the In (n, g) reaction and the fast neutrons by the In (n, n') reaction.
  - The shapes and the masses of activation detectors were decided by MCNPX calculation as follows.

  - Bi:

  Mass: 12.25g, Shape: pellet, Size: 6.32mm × 10mm

  - In:

  Mass: 0.18275g, Shape: flat, Size: 5mm ×5mm ×1mm

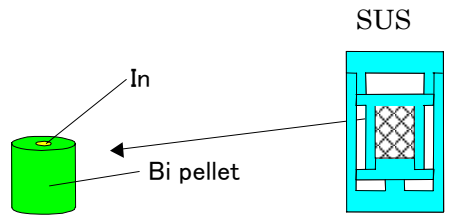


Fig. Sample using the system

- *Irradiation of sample*
  - Sample was irradiated for 3 hours.

Establishment of measurement system for whole energy neutron spectrum (6)

- System performance
  - This system was examined for measuring the whole neutron spectrum of the ADS core by using MCNPX and ENDF/B-IV.

Reaction	Threshold	Waiting Time	Detection Time	Peak Counts
Bi(n,10n)	70.89MeV	30min.	3hr.	105448
Bi(n,9n)	61.69MeV	30min.	3hr.	61883
Bi(n,8n)	54.24MeV	30min.	3hr.	571995
Bi(n,7n)	45.37MeV	6hr.	1day	76424
Bi(n,6n)	38.13MeV	30min.	3hr.	126098
Bi(n,5n)	29.62MeV	6hr.	1day	773
Bi(n,4n)	22.55MeV	6hr.	1day	12909
In(n,n')	Fast	12hr.	30min.	130843
In(n, γ)	Thermal	12hr.	30min.	99403

Table.The results when the irradiation time is set to 3hours and
Three types of the combination of the waiting time and the detection time are arranged

- Enough counts are obtained for every reaction of Bi(n,6n) to Bi(n, 10n) and In(n,γ) and (n,n').
- The spectrum at the center of ADS can be measured for the whole energy regions by using the system.

Conclusion and future task

Conclusion

I. The measurement method of the neutron spectrum of the high-energy neutrons was developed

II. The measurement system of the whole energy spectrum from thermal to high-energy neutrons existing in the ADS was established

Future task

- More accurate experiments will be performed to verify the Bi activation