

## Introduction

### Accelerator-based neutron source

- RFT-30 cyclotron at Advanced Radiation Technology Institute (ARTI) [1]
  - Beam specification: 30 MeV, 0-300  $\mu$ A proton beam
  - Target Material: 4 T Beryllium
- Application field [2]
  - Development of novel isotope labeled compounds
  - Research on the cross-section measurement
- Problem & solution
  - Neutron interactions with matter are highly energy-dependent
  - Necessity of the **neutron energy spectrum, not yet been characterized**
  - **NAA**: Efficient and reliable approach for neutron detection

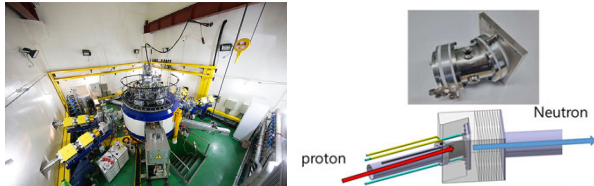


Figure 1. View of RFT-30 cyclotron at ARTI and Be target with moderator

### Multi-sample Neutron Activation Analysis (NAA)

- Sensitive, Non-destructive method with multi-element detection capability [3]
- Neutron flux and the energy distribution **can be known** if information is available:
  - Constituents of the **sample**
  - Response function of **activation reactions**
  - Measurement activities** of induced radionuclides

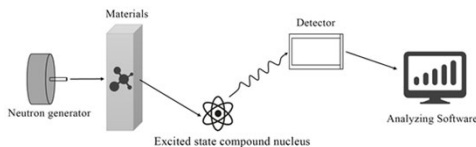


Figure 2. The principle of the neutron activation analysis technique [4]

## Methods

### Neutron Activation Experiment in RFT-30 cyclotron at ARTI

- Obtaining samples for activation experiment
  - Target of neutron energy spectrum: between **0-30 MeV**
    - 4 samples are selected : **Al, Co, Fe, Nb**
    - Size: 10  $\Phi$ , 5 mm thick cylinder
- Neutron irradiation
  - 30 MeV, 10  $\mu$ A proton beam operation 2 hrs on the beam line
- Sample Measurement
  - High-Purity Germanium (HPGe) detector
  - Activity of the foil were determined from **full-energy peak counts**

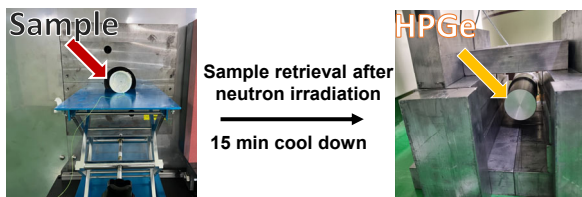


Figure 3. Samples placement for neutron irradiation in ARTI and HPGe detector

### Unfolding mechanism

- Validation check for neutron activation experiment
- Neutron spectrum unfolding was performed using **GRAVEL** [5]
  - 9 activation reaction, Total **661 points of Energy spectrum**
  - 4 T Be target irradiated by 30 MeV proton

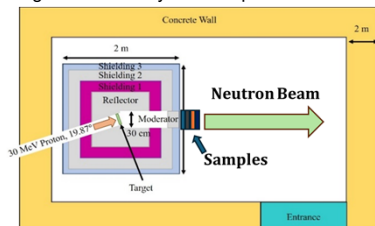


Figure 4. Geometry of MCNP 6.3 simulation [6]

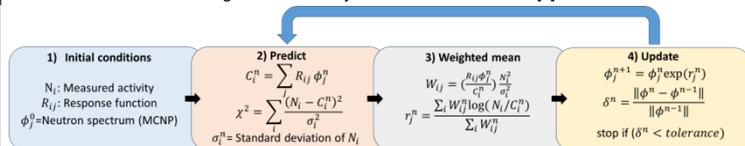


Figure 5. GRAVEL unfolding work flow diagram

## Results and discussions

### Sample measurement results

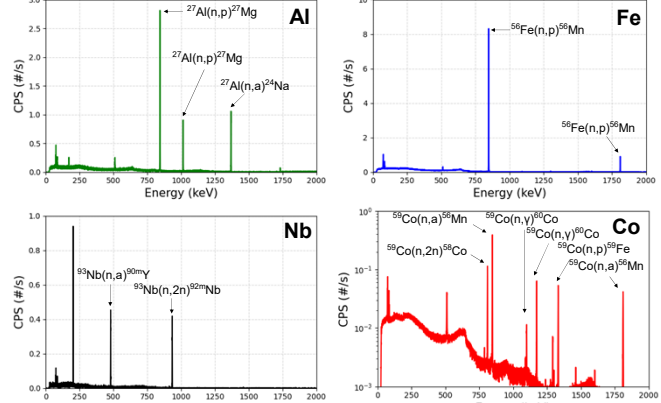


Figure 6. Gamma-ray spectra of neutron-activated samples

Table 1. Nuclear data of the Samples with measured Activity

Sample	Reaction	Threshold (MeV)	Half-life (s)	Peak (keV)	Activity
Al	$^{27}\text{Al}(n,p)^{27}\text{Mg}$	1.36E+00	5.67E+02	843, 1014	8.29E-21
	$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$	3.67E+00	5.40E+04	1368	7.47E-21
Fe	$^{56}\text{Fe}(n,p)^{56}\text{Mn}$	3.40E+00	9.28E+03	846, 1810	6.72E-21
	$^{56}\text{Fe}(n,\alpha)^{52}\text{Mn}$	0.00E+00	2.30E+05	479	2.95E-22
Nb	$^{93}\text{Nb}(n,\alpha)^{90m}\text{Y}$	0.00E+00	8.77E+05	934	2.86E-20
	$^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$	9.00E+00	8.77E+05	934	2.86E-20
Co	$^{58}\text{Co}(n,\alpha)^{56}\text{Co}$	0.00E+00	9.28E+03	1173, 1332	6.78E-19
	$^{58}\text{Co}(n,p)^{58}\text{Fe}$	1.20E+00	3.84E+06	1291	4.04E-21
	$^{58}\text{Co}(n,\alpha)^{56}\text{Mn}$	1.45E-03	9.28E+03	846, 1810	1.78E-21
	$^{58}\text{Co}(n,2n)^{57}\text{Co}$	1.10E+01	6.12E+06	811	2.94E-20

- Gamma activity from the samples are measured by the **Calibrated HPGe detector**

### Sample Response by Neutron Energy Group

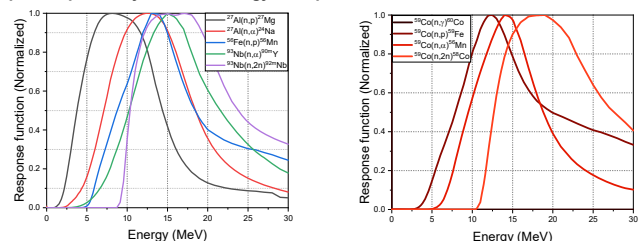


Figure 7. Sample response by 2017-TENDL for 661 neutron energy groups

### Neutron spectrum unfolding results and Activity Validation

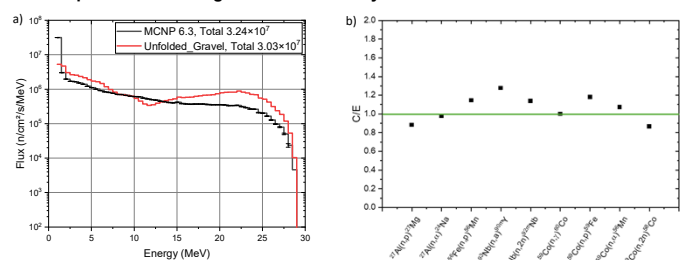


Figure 8. Comparison of a) Neutron energy spectrum between MCNP6.3 simulations and unfolding results b) measured activities and activities calculated from unfolded spectrum

- Flux obtained from the unfolding agrees with the MCNP6.3 result within **7%**
- The unfolded spectrum reproduces the measured activation observables within  **$\pm 27\%$**

## Conclusion

- Unfolding neutron spectrum was performed with **Al, Co, Fe, Nb** as activation foils
- Neutron energy spectrum has been obtained by applying **GRAVEL** unfolding method
- This study demonstrates the feasibility of reconstructing the neutron energy spectrum using a limited number of activation foils.

## Reference

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