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Characterization of Neutron Energy Spectrum at KIRAMS MC- 50 Cyclotron Using Genetic Algorithm

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1. Introduction

The complex neutron spectra arising from nuclear reactors, isotopic sources or particle accelerators are vital roles related to tasks including the application of neutron irradiation. In particular, fast neutron offers substantially improved the characteristics of semiconductor devices based on irradiation effects.

The well-established unfolding techniques have been widely used for many years to determination neutron spectra with adopting the interactive recursion method [1], least-squares fitting techniques [2], and Tikhonov's regularisation method [3]. These unfolding methods are frameworks to develop the unfolding codes as SAND, STAY'SL, LOUHI-83, etc., which require an initial spectrum to staring up the unfolding procedure of an unknown spectrum. The accuracy and exactness of the resulting spectrum primarily depend on the subjectively chosen guess spectrum. To overcome this drawback, the other approach for unfolding of neutron spectra using a Genetic Algorithm (GA) search process has been implemented to unfold the neutron spectra from a particle accelerator source.

The experiment of improving the switch speed of IGBT devices have done based on the generated fast neutron irradiation proving by the MC-50 cyclotron at KIRAMS (Republic of KOREA). The fast neutron spectrum at the irradiated position was necessarily required for the experiments as well as estimations of the radiation damage of fast neutron on the IGBT devices. The guess neutron spectrum must be provided when using the SAND or STAY'SL codes to unfold the neutron energy spectrum of MC-50 cyclotron, but the Monte Carlo codes have some problems to simulate the neutron spectra with energy excess 20 MeV due to lacking the cross-section data libraries.

In this study, the characterization of the fast neutron was unfolded by using the GA technique which does not require an initial spectrum.

2. Methods and Results

The 35 MeV proton beam at 20 μA from the MC-50 cyclotron bombarded a thin beryllium target to generate an intense beam of fast neutron via the spallation process. The fast neutrons emitting from the target were collimated by a graphite collimator of length about 3.75 cm (Fig. 1). The irradiation position was set on the horizontal plane, which was at a distance of 165 cm from the end of the collimator.

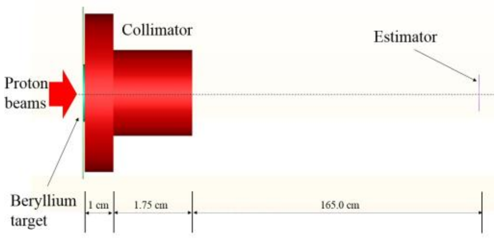

Fig. 1. Schematic diagram of the experimental setup of MC-50 cyclotron facility in KIRAMS

The activation detectors, which were its size as small enough to ensure a uniform neutron field at the irradiation position, were used to measure the reaction rates. Difference foil materials can measure neutron in different energies and the corresponding reaction rates of the experiments are shown in Table 1 using an HPGe spectroscopy.

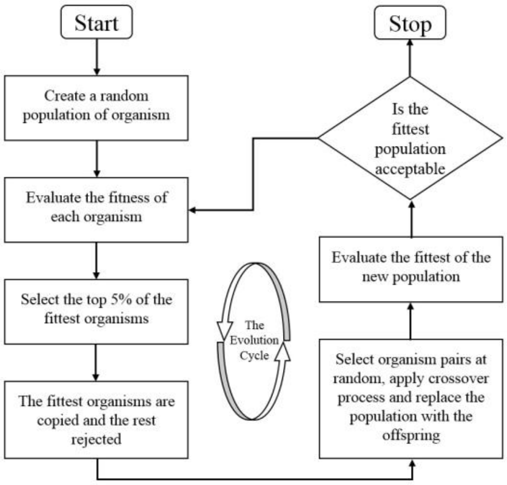

Fig. 2. Flowchart showing the principle of Genetic Algorithm.

A GA search mechanism belongs to the artificial intelligence family, which mimics the Darwinian Evolution-Paradigm and applied to solve various complex mathematical problems [4]. The basic principle behind GA deals with improving the results of certain closed-loop operations by successively incorporation the transitional results to achieve a better solution (Fig. 2).

Table. 1. Characteristic parameters of each foil and corresponding reaction rates.

Nuclear reaction	Mass (mg)	Abundance (%)	Gamma energy (keV)	Reaction rate (s^{-1})
Ti^{46}(n, p)Sc^{46}	141.9	8	1120.51	4.89445x10^{-17}
Ti^{47}(n, p)Sc^{47}	141.9	7.3	159.4	2.59738 x10^{-20}
Ti^{48}(n, p)Sc^{48}	141.9	73.8	1037.5	1.84629 x10^{-18}
Cu^{63}(n, γ)Cu^{64}	0.284	69.17	511.1	1.53757 x10^{-16}
Co^{59}(n, γ)Co^{60}	61.2	100	1332.5	1.55328 x10^{-16}
Co^{59}(n, p)Fe^{59}	61.2	100	1291.56	3.75284 x10^{-18}
Co^{59}(n, 2n)Co^{58}	61.2	100	810.76	3.58215 x10^{-17}
Fe^{56}(n, p)Mn^{56}	132	91.72	846.76	4.06643 x10^{-18}
Mg^{24}(n, p)Na^{24}	28.3	78.99	1368.6	1.10228 x10^{-17}
Ni^{58}(n, p)Co^{58}	28.3	68.077	810.76	2.83952 x10^{-17}
Ni^{58}(n, 2n)Ni^{57}	28.3	68.077	127.19	1.96465 x10^{-18}
Zn^{64}(n, p)Cu^{64}	231.3	48.6	511	1.2262 x10^{-17}
In^{115}(n, γ)In^{116m}	248.3	95.7	1293.54	6.18555 x10^{-16}
In^{115}(n, n')In^{115m}	248.3	95.7	336.24	1.68522 x10^{-17}
Sc^{45}(n, γ)Sc^{46}	50.7	100	1120.51	7.98723 x10^{-17}
Na^{23}(n, γ)Na^{24}	478.4	100	1368.55	6.99989 x10^{-19}
Dy^{164}(n, γ)Dy^{165}	30.3	28.2	361.67	1.08802 x10^{-14}
Ag^{109}(n, γ)Ag^{110m}	171.9	48.161	65.775	1.1246 x10^{-18}
Au^{197}(n, γ)Au^{198}	223.17	100	411.8	3.11699 x10^{-16}

An unknown neutron spectrum is unfolded by solving the Fedholm integral equation which is presented below in the discrete form (Eq. 1).

$$C_i = \sum_{j=1}^{n} R_{ij}\phi_j \qquad (1)$$

In the Eq. 1, C_i is a single nuclear reaction rate (s^{-1}) of foil i, ϕ_j is a neutron fluence rate ($cm^{-2}s^{-1}$) of the j^{th} group, R_{ij} is the response of the i^{th} foil for the neutron belong to the j^{th} group. The solution of the Eq. 1 using the GA technique was summarized as follows: by manipulating each component using a GA the neutron fluence vector ϕ_j in Eq. 1 is globally optimized and the corresponding detector output of each detector (C_i) is explicitly calculated until the criteria in Eq. 2 are met.

The implications of the Eq. 1 are: (a) the calculated pulse count of each detector shall be equal to the measured pulse count and (b) the fluence shall have only positive, no-zero elements. The fluence ϕ_j represents the unfolded neutron spectrum (the optimal solution of Eq. 1) when the conditions in Eq. 2 are satisfied.

$$\begin{aligned} &(a): \left| \left(C_{meas(n)} / C_{calc(n)} \right) \right|_{n=1}^{n=i} \sim 1 \\ &(b): \left| \phi_m \right|_{m=1}^{m=j} > 0 \end{aligned} \qquad (2)$$

The GA-based neutron spectrum unfolding tool was developed based on the GA toolbox in MATLAB [5] with an initial organism population of 100 and the crossover and mutation rates as 0.5 and 0.06, respectively. To reduce the time–consuming calculating, the Maxwellian spectrum was introduced to start up the spectral unfolding process without effect to the final result.

In Fig. 3, the neutron spectrum unfolded using the GA tool is shown with the same spectrum unfolded with the STAY’SL PNNL code [6].

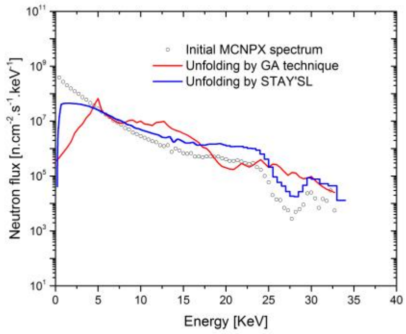

Fig. 3. Neutron energy spectrum of the spallation-neutron target unfolded with GA technique and STAY’SL code.

3. Conclusions

The GA is a robust problem-solving tool and it can unfold the neutron spectrum successfully without requiring a specific starting parameter as the initial neutron spectrum. This paper validated and demonstrated the GA technique to become a competitive method in unfolding neutron spectra.

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