Simulation program for multiwire-type two-dimensional neutron detector with individual readout

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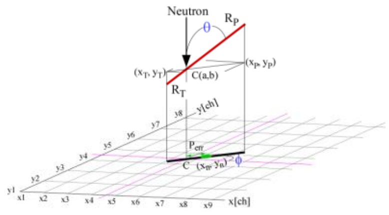
Introduction

In a high-intensity spallation neutron source at the Materials and Life Science Experimental Facility (MLF) at J-PARC, the neutron detectors have challenging performance standards; a response time of less than 1 μs, a spatial resolution of about 1 mm, a detection efficiency of more than 70% for thermal neutrons, a neutron/gamma-ray discrimination ratio of more than 10^6, a dynamic range of more than 10^6, and long-term stability for more than a few years are required for certain neutron scattering experiments. We are currently developing a multiwire-type two-dimensional neutron detector system with individual line readout method for use in such scattering experiments. The performance parameters of our system are strongly dependent on the gaseous mixture condition of ^3He and CF_4. In the present study, we developed a simulation program for our detector system to determine the gas condition. In addition, a small test system was fabricated to evaluate the simulation program.

Simulation method



C(a, b) [mm]: incident position

R_P and R_T: ranges of proton and triton

θ: angle between the z-axis (perpendicular to the multiwire element) and the track

ϕ: angle between the x-axis and the projected track on the surface of the multiwire element.

Schematic view of the simulation model

The end of the ranges of the proton (x_P, y_P) and triton (x_T, y_T)

(x_T, y_T) [mm] = $(a - R_T \sin\theta \cos\phi,\ b - R_T \sin\theta \sin\phi)$ (1)

(x_P, y_P) [mm] = $(a + R_P \sin\theta \cos\phi,\ b + R_P \sin\theta \sin\phi)$ (2)

Both ends of the projected track in the x- and y-axes, that is, the low and high channel in each axis: X_L, Y_L, X_H, and Y_H [ch]

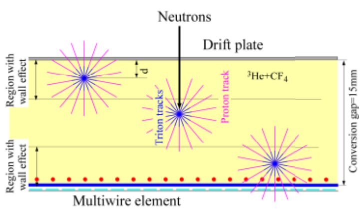
(X_L, Y_L) [ch] = $(round(x_T), round(y_T))$, (X_H, Y_H) [ch] = $(round(x_P), round(y_P))$

The incident position of the neutron is defined as the center of both ends.

(X_n, Y_n) [ch] = $(X_L + X_H, Y_L + Y_H)$, (x_n, y_n) [mm] = $(1/2)\, p\, (X_n, Y_n)$

where (X_n, Y_n) and (x_n, y_n) are the incident position of the neutron on the multiwire element as represented by the units of double number of channels and millimeter, respectively, and p is the pitch of the multiwire element [mm]. The errors of position detection P_{err} can be written as

P_{err} [mm] = $(x_n - a,\ y_n - b)$.



Schematic view of the wall effect

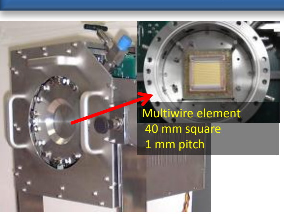
In the actual detector, the spatial resolution is also affected by wall effects as shown in the Figure. The range of the collision particle becomes shorter than R_p or R_t as defined in equations (1) and (2). For example, when the generated proton collides with the drift plate, equation (2) is changed to become

(x_P, y_P) [mm] = $(a + d \tan\theta \cos\phi,\ b + d \tan\theta \sin\phi)$ (2')

where d represents the distance from the drift plate to the point in the nuclear reaction.

By using the above calculations, a simulation program was developed. The program also calculates the detection efficiency of the system. In the program, the next values were entered; the conversion gap was 15 mm, and the pitches of each electrode were 1 mm. It was also assumed that the emitting probability for the secondary particles is isotropic over all angles, and that there are no fluctuations in signal height due to electronic noise.

Neutron experiments

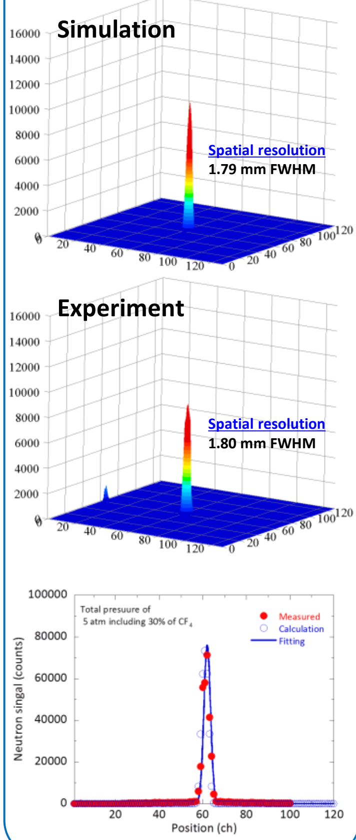


In order to evaluate the validity of the developed simulation program, neutron irradiation experiments for a small test system were performed using a collimated neutrons of JRR-3 at JAEA.

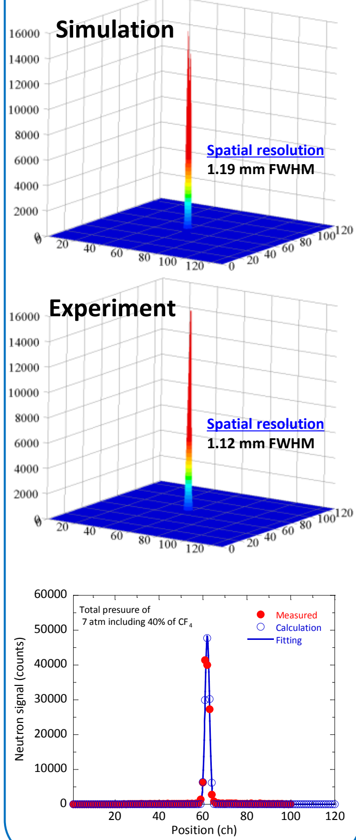
The small test consists of the multiwire element, a pressure vessel, amplifier-shaper-discriminator boards, position encoders with field programmable gate arrays, and a fast data acquisition device.

Simulation and experimental Results

5 atm 30% CF_4

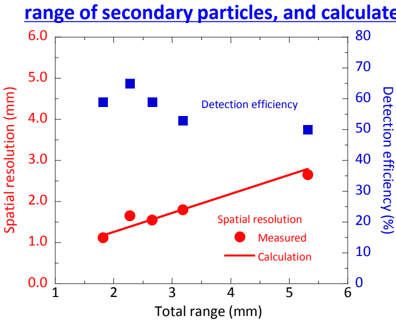


7 atm 40% CF_4



Gas condition		Simulation results			Experimental
Total (atm)	CF_4 (%)	Range of secondary particles (mm)	Detection efficiency (%)	Spatial resolution (mm FWHM)	Spatial resolution (mm FWHM)
4	20	5.32	50	2.80	2.65
5	30	3.19	53	1.79	1.80
6	30	2.66	59	1.56	1.55
7	30	2.28	65	1.37	1.65
7	40	1.82	59	1.19	1.12

Simulated and measured spatial resolution as functions of the total range of secondary particles, and calculated detection efficiencies.



The measured spatial resolutions agree well with the simulated results; thus, it was confirmed that the developed simulation program is valid for simulating an actual detector system.

Conclusions

A simulation program of the operation of a two-dimensional neutron detector system with individual readout was developed in order to determine the gas condition of the system. The simulation and experimental results demonstrate that the developed program works satisfactorily, and can thus be used in the future installation of our detector system at J-PARC/MLF in 2012.