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Effect of Portable Neutron Generator Operation Settings on Neutron Resonance Transmission Spectra

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***Abstract*— Portable neutron generators are an attractive option for on-site active neutron interrogation methods with applications for nuclear nonproliferation and nuclear safeguards. Newer models are easily transportable and can provide short pulses (~5 µs) of intense (~3e+08 n/s) fast neutron production. When operating a portable neutron generator for active interrogation applications, choice of beam current, acceleration voltage, and duty cycle can have a significant impact on the resulting neutron generation. This work characterizes the impact of different portable neutron generator operation settings on the total flux and shape of the neutron pulse and simulates their effect on resultant neutron transmission spectra. Experimental measurements of a P383 D-T generator demonstrated that increasing acceleration voltage can nearly double the total neutron flux without broadening the neutron pulse width, whereas increasing beam current can increase total neutron flux by over 50% with the trade-off of increased experimental pulse width. Synthetically generated neutron transmission spectra show that operation of the D-T generator at lower beam current and lower duty cycle can improve neutron energy resolution for neutron time-of-flight experiments.**

***Index Terms*— neutron generators, neutron resonances, nuclear fusion, nuclear safeguards**

I. INTRODUCTION

PORTABLE neutron generators are an attractive option for on-site active neutron interrogation methods with applications in nuclear nonproliferation and nuclear safeguards settings [1-3]. Newer models are easily transportable and are capable of providing short pulses—on the order of microseconds—of intense (~3e+08 n/s) fast neutron production [4]. One active interrogation technique, neutron resonance transmission analysis (NRTA) relies on sufficient neutron energy resolution via time-of-flight (TOF) techniques to resolve individual neutron resonances. Furthermore, the limited neutron flux of portable neutron generators relative to neutron beamline facilities increase the necessary measurement time to achieve neutron transmission spectra of a sufficient signal-to-noise ratio.

Portable neutron generators have several tunable parameters which affect the shape of the neutron pulse and the total neutron flux output. A trade-off exists between the shortness of the pulse and the total neutron flux. This work characterizes the neutron flux and pulse shape under differing generator operation settings and analyzes the impact on resulting neutron transmission spectra for fixed measurement times.

Fig. 1. Photo of the P383 D-T neutron generator.

II. EXPERIMENTAL METHODS

To determine the optimal operation settings to maximize neutron flux while maintaining sufficient resolution for NRTA applications, the neutron output of a Thermo Fisher P383 D-T portable neutron generator was characterized under differing beam current, acceleration voltage, and duty cycle. The P383 neutron generator is 16.5" in length and weighs 20 pounds. The generator has a maximum acceleration voltage of 130V, a maximum beam current of 70 µA, and a minimum nominal duty cycle of 5.0%. Certain combinations of operation settings would result in oscillations in the beam current and getter current of the generator, which could in some cases be avoided by slowly ramping up the beam current and acceleration voltage. The minimum achievable duty cycle was 3.1%.

Fast neutrons were detected using an EJ-309 organic scintillator at a bias voltage of 1750V, read out by a CAEN V1725 14-bit 250MS digitizer. Pulse shape discrimination was used to separate gamma rays from neutrons and fast neutrons were discerned using a cut on pulse energy. Time-of-flight spectra were calculated referenced to the TTL pulse source output from the P383 D-T generator.

To model the effects of the neutron pulse shape and total

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neutron flux, synthetic neutron transmission data were generated in Python using END/B-VII.0 neutron cross section data, theoretical neutron attenuation models, and empirically modeled neutron input spectra and background signal. All runs shown are normalized to a 30-minute run for 65uA, 130 kV acceleration voltage, and 5.0% duty cycle.

III. RESULTS

Figure 2 shows the time profile of the neutron pulse for increasing acceleration voltage from 100 kV to 130 kV given a beam current of 50 μA and a duty cycle of 3.1%. At higher voltages, the mean of the pulse shifts earlier in time but the width of the peak is unchanged. The integrated counts under the curve increased at a rate of 2500 counts/minute for each increase of 10kV, for a total increase by 75% from 100 kV to 130 kV.

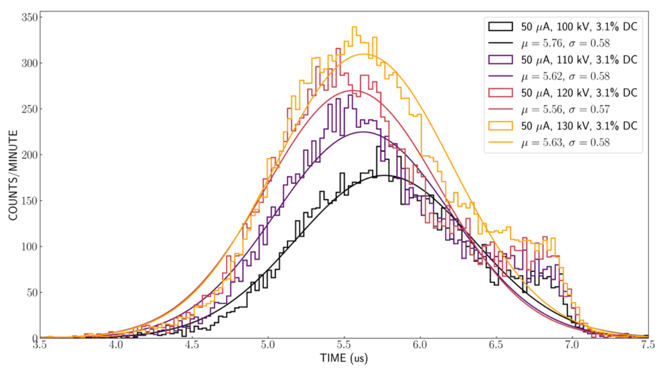

Fig. 2. Plot of increasing acceleration voltage from 100 kV to 130 kV with corresponding Gaussian fits.

Figure 3 shows the effect of increasing beam current over the range of 30 – 65 μA at the maximum acceleration voltage of 130 kV and a duty cycle of 5.0%. As the beam current increases, the peak of the neutron pulse shifts to earlier time with a reduced width, but is followed by an increasingly longer plateau of neutron production. The total neutron flux increases logarithmically at an average rate of 1700 counts/minute per 5 μA increase in beam current, for a total increase of 50% from 35 μA to 65 μA.

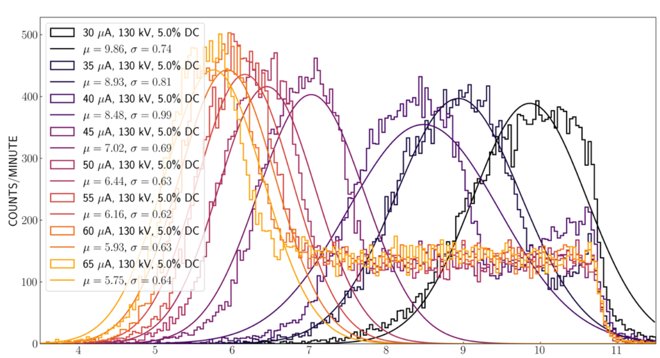

Fig. 3. Plot of increasing beam current from 30 to 65 μA with corresponding Gaussian fits.

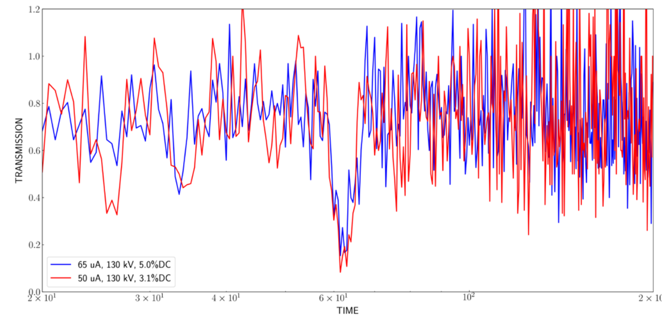

Fig. 4. Synthetic neutron transmission spectra based on D-T operation at 5% duty cycle and higher current (blue) and a 3.1% duty cycle and lower current (red). Note the increased noise and improved resolution of the lower duty cycle signal.

Synthetically generated neutron transmission spectra based on the experimental observed pulse shapes and fluxes for a 1.0 cm thick depleted uranium target is shown in Figure 4. The 5.0% duty cycle (blue) was chosen to maximize neutron flux whereas the 3.1% duty cycle case (red) was chosen to maximize resolution. The 3.1% duty cycle spectrum is noisier than that of the 5.0% duty cycle, but also has deeper resonant dips at lower times-of-flight (*i.e.* higher energies.) However, the rightmost resonant dip (corresponding to the 6.7 eV U-238 resonance) is similar for the two spectra.

IV. CONCLUSION

When operating a portable neutron generator for active neutron interrogation applications, choice of beam current, acceleration voltage, and duty cycle can have a significant impact on the resulting signal. Increasing acceleration voltage can nearly double the total neutron flux without modification to the measured pulse width, whereas increasing beam current can increase total neutron flux by over 50% with the trade-off of increased experimental pulse width.

In applications prioritizing total neutron flux, such as neutron transmission imaging, choosing operation settings to maximize flux may result in a shorter measurement time needed, whereas for applications prioritizing accurate isotopic quantification, such as neutron TOF experiments, the trade-off of lower flux for improved neutron energy resolution may be preferred.

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