

**302b** of cube **302** includes an exit window **306a** for emissions resulting from interactions between target neutron absorber. In one embodiment of the present invention, exit window **306a** is about 29 mm in diameter. Exemplary materials of exit window **306a** include  $MgF_2$ ,  $CaF_2$ ,  $Al_2O_3$ ,  $SiO_2$ , and the like.

[0048] Detector **104** is positioned inside a detector housing **324** such that the interaction region between neutron beam entering cube **302** and target neutron absorbers **318** is within the field of view of the detector **104**. In one embodiment of the present invention, detector **104** is a photomultiplier tube (PMT). Detector housing **324** is mounted above top face **302b** of cube **302**. Exemplary detectors for detecting emitted radiation include Hamamatsu solar-blind R6835 photomultiplier tube in a modified model 658 end-on housing from McPherson Instruments, Inc. The R6835 has a  $MgF_2$  window and a CsI photocathode. Reaction cell **300** includes a compartment **320**, positioned between detector **104** and exit window **306a** for housing a filter **316**. Filter **316** is used to form a coarse spectrometer to analyze the wavelength of the emitted radiation from cube **302** passing through exit window **306a**. Exemplary filters that may be used to form a coarse spectrometer include  $Al_2O_3$ ,  $CaF_2$ ,  $SiO_2$  filters, and the like. Compartment **320** is operated at a low pressure to prevent gas mixtures exiting cube **302** from coming into contact with the detector **104**, which could render detector **104** inoperative over time. Gas handling system **108** maintains compartment **320** at a low pressure using a vacuum pump connected to compartment **320** at manifold **322**.

[0049] Under normal operation of an embodiment of the present invention using solid-phase neutron absorbers, gas handling system **108** will evacuate all gases from reaction cell **300**. Further, reaction cell **300** is heated to remove water and contaminant from cell walls, neutron absorber, and substrate. In one embodiment of the present invention, reaction cell **300** is heated for at least 10 h at 70° C. while being evacuated. Evacuation and heating of reaction cell **300** creates a base pressure within reaction cell **300**. In one embodiment of the present invention, evacuation and heating of reaction cell **300** creates a base pressure of about  $3 \times 10^{-8}$  kPa. Noble gases are introduced into cube **302** through manifold **310** using gas handling system **108**. In one embodiment of the present invention, noble gases introduced into interaction region include ultrahigh purity Ar, Kr, and Xe. In some embodiments of the present invention, a gas filter is connected between manifold **310** and cube **302** to remove trace contaminants from gas sources. Exemplary filters that can be used to remove trace contaminants from gas include Microtorr MC1-902-F filter, and the like.

[0050] A beam of neutrons enters reaction cell **300** through entry window **304a** attached to metal-seal flange port **304** on front face **302a** of cube **302**. In one embodiment of the present invention, neutron beam entering reaction cell **300** through entry window **304a** has a diameter of about 4 mm and a neutron beam fluence rate of about  $(2.61 \pm 0.37) \times 10^5 s^{-1} cm^{-2}$ . Beam lines having such properties include the NG6-A beam line at NCNR. Neutrons entering cube **302** react with high neutron absorption cross-section nuclei in the solid-phase **318** resulting in decay of the resulting compound nucleus into energetic particles. The energetic particles escape the solid material and undergo collisions with noble gas atoms within cube **302** to form excimers. Excimers formed within cube **302** radiatively decay with the emission of FUV radiation. Unreacted neutrons exit from cube **302** through exit window **308e**. FUV emissions pass through exit window **306a** and spectral

filter **316** into compartment **320**. FUV emissions pass through compartment **320** into detector housing **324** where FUV emissions are detected by detector **104**. Detector **104** is generally operated in photon-counting mode with its output connected to processor **106**. In photon-counting mode, detector **106** counts the number of FUV photons emitted from cube **318**. In one embodiment of the present invention, processor **106** is a preamplifier followed by a spectroscopy amplifier whose output drives the input of a multichannel analyzer.

[0051] In one embodiment of the present invention, detector **104** can be calibrated using the radiation from a synchrotron over the wavelength region 125 to 210 nm. Calibration results for detector **104** can be convolved with the emission spectrum of each excimer to determine an effective efficiency of detector **104** for each of noble gases used. Processor **106** calculates the total number of photons generated using photon flux detected by detector **104**. Correcting the calculated total for background, window transmission, solid angle, and using known cross section of the reaction within reaction cell and the neutron flux, the number of photons produced for each reacted neutron can be calculated using the equations (1)-(3):

$$\text{Number of neutrons reacted per unit time} = N_j A [1 - e^{-\sigma n l}] / t \quad (1)$$

where  $N_j$  is the measured neutron beam fluence,  $A$  is the area of the beam,  $\sigma$  is the neutron absorption cross section of the neutron absorber,  $n$  is the number density of the neutron absorber,  $l$  is the length of the path where the neutrons are exposed to the neutron absorber, and  $t$  is the observation time; and

$$\text{Number of photons produced per unit time} = [P_C - B - R] / [E_{PMT} E_F E_W \omega_a] \quad (2)$$

where  $P_C$  is the raw number of counts from the PMT,  $B$  is the background counts associated with the experiment,  $R$  is the calculated reflection contribution,  $E_{PMT}$  is the efficiency of the PMT for the emission spectrum,  $E_F$  is the filter efficiency for the emission spectrum,  $E_W$  is the window efficiency for the emission spectrum, and  $\omega_a$  is the fraction of the solid angle the PMT covers of the reaction volume. The number of photons per neutron reacted are calculated using

$$\{ [P_C - B - R] / [E_{PMT} E_F E_W \omega_a] \} / N_j A [1 - e^{-\sigma n l}] \quad (3)$$

## EXAMPLES

[0052] A more complete understanding of the present invention can be obtained by referring to the following illustrative examples of the practice of the invention, which examples are not intended, however, to be unduly limitative of the invention.

### Example 1

[0053] Far-ultraviolet signatures of  $^3He(n, tp)$  reaction in noble gas mixtures.

[0054] Trigger reaction of  $^3He(n, tp)$  process, in which a neutron reacts with a  $^3He$  nucleus to produce a proton and a triton with excess energy of 764 keV, is used to initiate far-ultraviolet (FUV) optical emissions, rather than electrical discharges. At a  $^3He$  pressure of 100 kPa, tens of FUV photons are produced for every reacted neutron. When mixtures of Ar, Kr or Xe are added to the  $^3He$  cell, larger FUV signals were observed. These signals were larger than the ones observed when the cell contained only  $^3He$  and, in some