[0029] "Differentially pumped volume" refers to a section in a vacuum chamber that can be isolated and evacuated independently from the rest of the system.

[0030] "Excimer" means an "excited dimer" or a diatomic molecule for which the ground state is unbound.

[0031] "Energetic particle" refers to an atom nucleus, electron or proton that has a kinetic energy above about 1 eV

[0032] "Fluence" means the total number of particles that pass through a unit area in a specified time interval.

[0033] "High cross section nucleus" means a nucleus that has a high probability of reacting (interacting) with an incident neutron.

[0034] The present invention relates to apparatus and methods for use in highly sensitive and efficient neutron detection, including trigger reactions to initiate far-ultraviolet (FUV) optical emissions. In some embodiments of the present invention, a method for the detection of slow neutrons includes absorption of a slow neutron by a high neutron absorption cross section nucleus with subsequent decay of the compound nucleus into energetic particles, creation of excimers by the energetic particles in a gas, radiative decay of the excimers resulting in emission of far ultraviolet (FUV) radiation, and detection of the FUV radiation using an optical detector.

[0035] FUV photons may be detected from the reaction occurring in a gas cell filled with a mixture of gas-phase or solid neutron absorber and noble gases. Exemplary neutron absorbers that can be used in a cell include ^{3}He, ^{10}B, ^{6}Li, and the like. In one embodiment of the present invention, FUV radiation is detectable in gas mixtures using ^{3}He with a base pressure of 26 kPa combined with varying pressures of Ar, Kr or Xe. In other embodiments of the present invention, gases containing ^{10}B or ^{6}Li can be incorporated in the noble gas in the cell, or solid-phase neutron absorbers may be used. Exemplary solid-phase neutron absorbers include ^{10}B, ^{6}Li, and the like.

[0036] The signal from gas cell is due to the formation and radiative decay of excimers in a gas mixture including noble gases. In one embodiment of the present invention, Ar, Kr and Xe can be combined with an appropriate neutron absorber to form gas mixtures that facilitate the formation of excimers in a reaction cell. An appropriate neutron absorber is one that has a high probability of absorbing a neutron with subsequent decay into energetic particles. These energetic particles collide with the surrounding noble gas atoms to form excimers resulting in the production of photons in the FUV range. The noble gases are essentially transparent to the FUV photons, making it possible for the light to pass from the gas cell and be detected.

[0037] The present invention provides a highly efficient neutron detector as an alternative to existing proportional counters. The present invention uses optical radiation from excited atoms as the signature of a neutron reaction.

[0038] Referring now to the drawing, and more particularly, to FIG. **1**, there is shown an apparatus for detecting slow neutrons, generally designated **100**, which comprises embodiments of the present invention. The slow neutron detection apparatus **100** includes a reaction cell **102**, a detector **104**, a processor **106**, and a gas handling system **108**. Reaction cell **102** provides a chamber for slow neutrons from a neutron source to interact with a mixture of neutron absorber and nobles gases. Detector **104** detects FUV radiation emitted by reactions occurring in cell **102** filled with a mixture of gas-phase neutron absorber (e.g. ^{3}He or BF_3) or a solid phase neutron absorber (e.g. ^{10}B or $^{6}Li_2CO_3$) and noble gases. Detector **104** produces electrical signals and processor **106** converts electrical signals from detector **104** into a measure of slow neutron fluence. A measure of FUV radiation from the reaction of neutron absorption products and background neutral gas is indicative of the presence of slow neutrons.

[0039] Gas handling system **108** transports neutron absorbers and noble gases from their respective sources to cell **102**. Gas handling system **108** also includes at least one vacuum pump to maintain differentially pumped volume in a compartment **220** (FIG. **2**) between reaction cell **102** and detector **104**. Gas handling system **108** monitors pressure in reaction cell **102** with a digital pressure indicator without requiring correction for gas type. Exemplary digital pressure indicators for gas handling system **108** include Omega DPI 705 with an operating range from about 0.013 kPa (0.1 Torr) to about 200 kPa (1500 Torr) with a measurement resolution of about 13 Pa (0.1 Torr).

[0040] FIG. **2** illustrates one embodiment of a reaction cell, generally designated as **200**, for detecting slow neutrons using gas phase neutron absorbers. Reaction cell **200** includes a stainless steel cube **202** with cylindrical metal-seal flange ports **204**, **206**, **208**, **210**, **212** (five ports shown in FIG. **2**) on each of its six faces. In one embodiment of the present invention, metal-seal flange ports **204**, **206**, **208**, **210**, **212** (five ports shown in FIG. **2**) on each of the six faces of cube **202*a*-*e*** (five faces shown in FIG. **2**) is cylindrical with a diameter of about 70 mm. Metal-seal flange port **204** on front face **202*a*** of cube **202** includes an entry window **204*a*** through which a neutron beam is capable of entering cube **202** of reaction cell **200**. An exit window **208*c*** is located on cube face **208** through which the neutron beam is capable of exiting cube **202** of reaction cell **200**. In one embodiment of the present invention, entry window **204*a*** and exit window **208*c*** have a diameter of about 35 mm and a thickness of about 3.3 mm. Exemplary materials for entry window **204*a*** and exit window **208*c*** include silicon, magnesium, fused silica, and the like.

[0041] Cube **202** includes a cylinder **214** positioned vertically in the center of cube **202** such that cylinder **214** defines a neutron interaction region **218**. Cylinder **214** is thin-walled and is made from a material that is vacuum compatible and neutron transparent. Exemplary materials that can be used for the construction of cylinder **214** include magnesium, aluminum, silicon, and the like. In some embodiments of the present invention, cylinder **214** has a thickness from about 0.5 mm to about 1 mm and a diameter of about 24 mm to about 26 mm. In one embodiment of the present invention, cylinder **214** is thin-walled magnesium cylinder having a diameter of about 25 mm. Entry window **204*a***, exit window **208*c*** and cylinder **214** are transparent to neutrons, and neither scatter nor absorb a neutron beam passing through them. Top face **202*b*** of cube **202** includes an exit window **206*a*** for FUV light emissions exiting from interaction region **218**. In one embodiment of the present invention, exit window **206*a*** is about 29 mm in diameter. Exemplary materials of exit window **206*a*** include MgF_2, CaF_2, Al_2O_3, SiO_2, and the like.

[0042] Detector **104** is positioned inside a detector housing **224** such that interaction region **218** is within the field of view of detector **104**. Detector housing **224** is mounted above top face **202*b*** of cube **202**. In one embodiment of the present invention, detector **104** is a photomultiplier tube (PMT). An exemplary detector for detecting emitted radiation include Hamamatsu solar-blind R6835 photomultiplier tube in a modified model 658 end-on housing from McPherson Instru-