

cases, these signals were larger by factor of 1000. Using spectral analysis discussed below, this radiation was identified to be predominantly due to rare gas excimer (X_2^*) emissions.

[0055] The experimental apparatus consists of a gas cell, photomultiplier tube (PMT) detector and gas handling system connected to a turbo-molecular/molecular-drag pump backed by an oil-free diaphragm pump. The gas cell is a stainless steel cube with 70-mm diameter metal-seal flange ports on each of the six faces. It also includes a compartment to allow the insertion of spectral filters in front of the PMT. Al_2O_3 , CaF_2 and SiO_2 filters were used to form a coarse spectrometer to analyze the wavelength of the emitted radiation. Neutrons enter and exit the gas cell through two fused silica windows. A 25-mm diameter thin walled magnesium tube mounted vertically in the center of the gas cell defined the neutron interaction region viewed by the detector. Both silica and magnesium are essentially transparent to neutrons, and the neutron beam is neither significantly scattered nor absorbed upon passing through these materials. Under normal operation the cell is baked for a minimum of 10 h at 70° C. while being evacuated. This removes water and other contaminants from the walls and results in a base pressure of about 3×10^{-8} kPa. After baking and evacuating the cell to the base pressure, ultrahigh purity 3He was introduced into it with a gas handling system. This consists of a stainless steel manifold connected to the gas cell through a Microtorr, Model MC1-902-F gas filter to remove trace contaminants from the gas. Subsequent introduction of ultrahigh purity Ar, Kr, and Xe was also through Microtorr filters connected between the manifold and gas cell. Gas pressure in the evacuated cell was measured with a Pfeiffer Vacuum PKR251 gauge. An Omega DPI 705 digital pressure gauge measured the pressures of the admitted gases in the gas cell.

[0056] A 4 mm diameter neutron beam from the NG6-A beam line at NCNR was directed into the gas cell. The neutron beam fluence rate was $2.61 \pm 0.37 \times 10^5 \text{ s}^{-1} \text{ cm}^{-2}$, as measured with a calibrated fission detector. FIN radiation is detected with a solar-blind PMT (Hamamatsu R6835), operated at a bias of -2200 V, and located behind a MgF_2 window in the gas cell. The response of the detector system is limited by the absorption edge of the MgF_2 and the work function of the PMT photocathode, which correspond to wavelengths of 115 and 190 nm respectively. The solid angle subtended by the PMT about the center of the reaction region defined by the magnesium cylinder is 0.0373 ± 0.0008 sr. No radiation produced outside of the cylinder can reach the PMT.

[0057] For each reacted neutron, a significant increase in the detected signal was observed when Ar, Kr, and Xe were mixed with the 3He . In this experimental system, the $^3He(n, tp)$ reaction in the presence of these gases yielded a signal of up to 1000 times greater than that which occurs in the presence of 4He or Ne. The energetic particles traversing the noble gas formed excimers. These excited diatomic molecules radiatively decay with photon emissions in the FUV. FIG. 3 shows the emission spectra of Ar_2^* , Kr_2^* , and Xe_2^* . The emissions from He_2^* and Ne_2^* are below the absorption edge of the MgF_2 window of the PMT.

[0058] In order to test the hypothesis that the increased signal is due to excimer formation and excimer radiative decay, CaF_2 , Al_2O_3 and SiO_2 filters were used. These filters are capable of discriminating among the emissions from the Ar_2^* , Kr_2^* , and Xe_2^* . The transmission of each filter as a function of wavelength was measured from 113 to 226 nm at

the NIST Far-Ultraviolet Calibration Facility. These measurements revealed that the filters had poor spatial uniformity, but that the absorption edges were at the expected wavelengths. FIG. 4 shows the response of the PMT in combination with the various filters. The signal enhancements shown in FIG. 5 are due to excimer emission. When each filter is inserted between the MgF_2 window at the top of the cell and the PMT, the short wavelength cutoff of the detector system shifted from 115 nm to a longer wavelength: 122 nm for CaF_2 , 142 nm for Al_2O_3 , and 160 nm for SiO_2 . The Ar_2^* excimer emission can be detected only with the CaF_2 filter in place; the other two filters are opaque to the emitted radiation. Emission from Kr_2^* can be detected through CaF_2 and weakly through Al_2O_3 , while emission from Xe_2^* can be detected through all three filters.

[0059] When the reaction cell was filled with Ar, an enhanced signal was seen only with the CaF_2 filter. A Kr-filled cell yielded enhanced signal with CaF_2 and Al_2O_3 . Significant signal gains were observed with all three filters when the cell was filled with Xe. Expected signal enhancements were modeled using the measured filter transmissions and the excimer emission spectra from FIG. 4. FIG. 6 shows that the observed signal enhancement was consistent with the modeling results, indicating that the observed emissions are from noble gas excimers formed by collisions of the energetic proton and triton with noble gas atoms. It is likely that this mechanism is present when the 3He is mixed with 4He or Ne, but the excimer emission of these species is outside the spectral range of the detector used.

[0060] Quantitative measurements of the photon yield were made with none of the spectral filters in place. Experimental count rates were corrected for dark current, background gamma radiation, and radiation from the direct interaction of the neutrons and the noble gases. Contributions to the signal from sources other than neutron absorption by 3He were removed by first taking measurements in the evacuated gas cell and then taking measurements with the cell filled with different pressures of the pure noble gases, but without 3He . The measurement data obtained from the PMT were also corrected for FUV radiation that is reflected into the photomultiplier by scattering from the wall of the magnesium cylinder. Ray tracing calculations were performed based on a 4 mm diameter cylindrical neutron source and tabulated optical constants for MgO (the surface is assumed to be oxidized rather than unreacted Mg). Depending on the particular model of optical scattering used, the calculations indicated that the ratio of scattered to direct radiation received by the PMT is between 0.14 and 0.31. The results are independent within 10% of whether a point source, line source, or finite cylinder of various diameters is assumed for the origin of the FUV radiation.

[0061] The number of photons was calculated from the corrected count rate and the response of the PMT. The PMT was calibrated as a function of wavelength from 125 to 210 nm at the normal-incidence radiometry beamline at the NIST SURF III facility. The calibration results were convolved with the emission spectrum of each excimer to determine an effective efficiency of the PMT for each of the noble gases investigated. From the detected photon flux, corrected for background, window transmission, and solid angle, the total number of photons generated was calculated. Using the known cross section of the $^3He(n, tp)$ reaction and the neutron flux, the number of neutrons reacted was calculated. The noble gases were added to a base pressure of 26 kPa of 3He .