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RADIATION PRODUCED BY GLOW DISCHARGE IN A DEUTERIUM CONTAINING GAS (Part 2)

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Abstract

This is the second paper in a series describing the radiation produced by the cathode during glow discharge in low-pressure gas using DC voltages between 400 V and 800 V. Evidence for energetic electrons, low-energy X-rays, and occasional proton(deuteron) emission has been obtained. The energy, intensity, and type of the radiation are sensitive to gas composition and the material used as the cathode.

I. INTRODUCTION

The LENR effect has been most frequently studied using the production of anomalous heat as an indicator of success. In fact, this was the diagnostic used by Fleischmann and Pons[1] in their original studies that started widespread interest in the phenomenon. While heat production is the practical result of such a nuclear process, its use in studying the phenomenon is very inconvenient. Heat is a challenge to measure accurately and a significant reaction rate is required to generate an amount that can be reliably detected. A much better tool involves measurement of radiation. Radiation of various types always results from a nuclear reaction and these emissions can be detected even though the rate might be very small. With these considerations in mind, this work was undertaken to detect nuclear radiation resulting from a low-voltage glow discharge that previous studies suggest can initiate nuclear reactions.[2-7] Based on these and other studies, high-energy X-ray was anticipated. Instead, the detected X-ray energy was comparable to the voltage used to create the discharge. The possible source of this X-ray is discussed. To avoid issues of reproducibility, most significant aspects of this study have been replicated in separate laboratories located in New Mexico and Connecticut. The first results from this effort were reported in Catania[8] in 2007. This paper will add knowledge obtained in the last year from ongoing work.

II. EXPERIMENTAL

A detailed description of the apparatus can be found in the Catania paper[8]. A glow discharge is created in different gas mixtures at a pressure between 15 and 30 Torr using constant current and a voltage between about 400 V and 800 V. A 2 mm diameter palladium or platinum wire is used as the anode and various metals are used as the cathode, with a distance of 2 mm to 6 mm between the cathode and end of the anode wire. A shroud made of Al_2O_3 surrounds the cathode to confine the discharge to a region of the metal surface. Direct water-cooling of the cathode allows a large amount of power to be applied to a defined region of the cathode surface in order to achieve the required high voltages and plasma density.

Radiation is measured using either a Geiger-Mueller (GM) tube or a silicon barrier detector (Ortec BU-015-100-100). This paper will concentrate on the results obtained using a GM counter. Two types of GM tubes are used, one having a 9.1 mm diameter opening and 2.0 mg/cm^2 (measured) mica window (LND712) and the other one having a 1.5 mm diameter opening and a 0.3-0.4 mg/cm^2 (Vendor value) mica window (LND705). Both windows are made opaque to light by application of colloidal carbon, although this is found to be unnecessary. Counts are recorded as individual events using a National Instruments data recording system in contrast to measuring a voltage that is proportional to count rate, as reported in the previous paper[8]. As a result, much larger fluxes could be measured over a wider voltage range. Even though the area of the thick-window is 37 times that of the thin-window GM, the count rate measured by the thin-window tube is much greater because the window is more transparent to the radiation. Moveable absorbers of thin aluminum or Mylar are used to study the characteristics of the radiation detected by the GM tubes.

The large window GM tube and the Si detector assembly are shown in Fig. 1. The

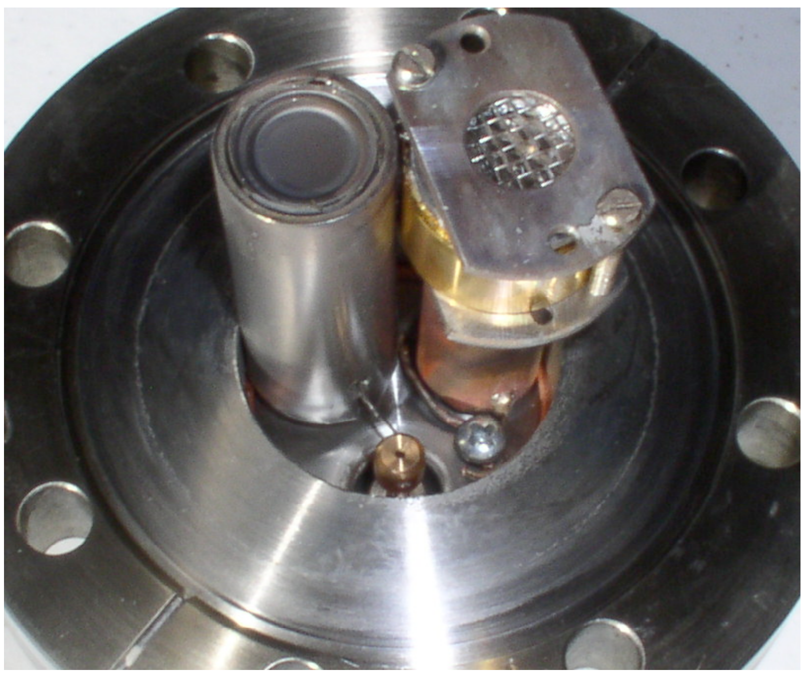

FIGURE 1. The large window GM tube is on the left and the Si detector is on the right. The Si detector is covered by a 1.2 μm aluminum light-shield, which is protected by a wire screen. The GM is surrounded by a grounded steel tube to reduce noise pickup. The assembly is mounted on a Conflat 4” flange.

Si detector is protected by a 1.2-1.8 μm aluminum light shield. Shielding of the preamplifier was found to be necessary to eliminate counts generated by RF radiation produced by the discharge. The lowest energy that can be detected by the Si detector is determined by the small amount of light from the discharge that passes through small holes in the light shield. This limit is near 0.2 MeV for protons and 0.4 MeV for alpha.

The detector and the aluminum absorbers are calibrated using alpha emission of 5.302 MeV from Po^{210}.

The values plotted in Fig. 2 were used to calculate the energy of electrons required to pass through the indicated mass density of aluminum[9]. For this study, the effect of mica on the range was assumed to be the same as aluminum. Figure 3 shows the values used to calculate the energy of X-rays passing through the absorbers.

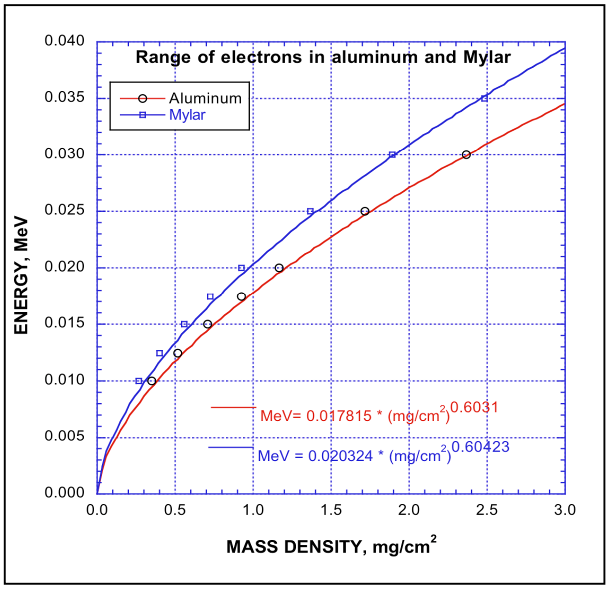

FIGURE 2. Relationship between energy and range of electrons in aluminum and Mylar obtained from http://physics.nist.gov/PhysRefData/Star/Text/ESTAR-t.html

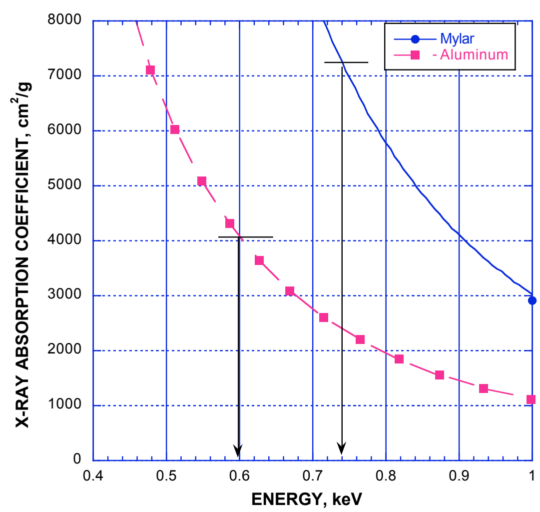

FIGURE 3. Relationship between absorption coefficient for X-rays as a function of energy for aluminum and Mylar. http://physics.nist.gov/PhysRefData/XrayMass The mass density of the aluminum and Mylar absorbers at 600 V are shown.

The radiation was explored using a magnetic field, as the diagram in Fig. 4 shows. A magnetic field of 1500 G is achieved by applying a current of 2 A to the coils of the electromagnet. The window of the GM has a diameter of 1.5 mm.

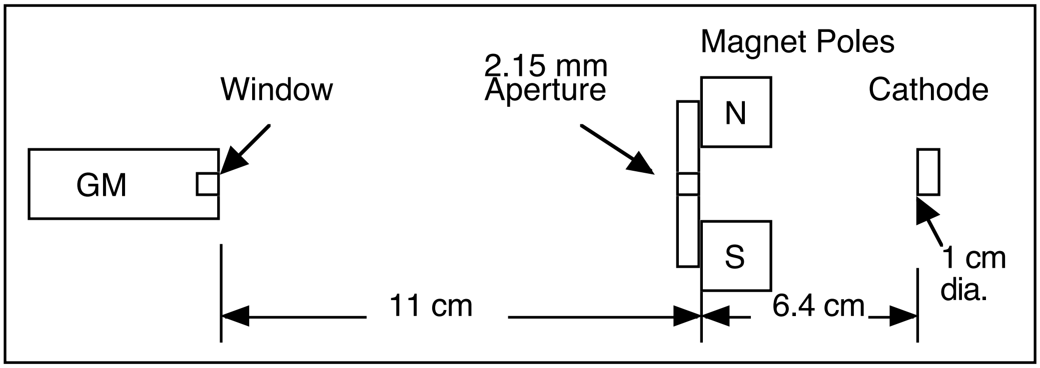

FIGURE 4. Diagram of apparatus used for the magnetic study.

III. RESULTS

Two issues will be discussed. These are: (1) what is the radiation and (2) how is its intensity altered by changing the conditions of the discharge.

III.1 Kind of Radiation

Three types of radiation are explored in an attempt to determine the nature of the detected radiation. These are X-rays, energetic electrons or protons(deuterons).

III.1.1 X-rays

X-rays can result from ionization of the K, L or M electron levels of many atoms if the energy of the ionizing electrons is sufficiently high. This process produces a fixed energy of X-ray emission characteristic of the elements being ionized. A broad spectrum of Bremsstrahlung X-rays can also result when the path of an electron is deflected by encounter with an atom without producing ionization. Bremsstrahlung radiation produced by electrons passing through a solid is a small fraction of the total electron flux and becomes even more rare as the energy of the electron is reduced, with a maximum being no greater than the energy of the initiating electron. Both processes can occur at the same time, although the intensity of X-rays caused by ionization is generally much greater than the intensity caused by Bremsstrahlung. Whether 800 eV electrons can actually produce measurable Bremsstrahlung or k X-rays in a glow discharge is an issue not resolved by this work.

X-radiation is normally distinguished from other types by observing several behaviors. X-rays are attenuated when they pass through matter without having a definite range. As a result, the flux through an absorber at a fixed energy can be calculated using the equation $\ln(I/Io)=-(\mu/p)*M$, where Io is the flux entering an absorber, I is the flux leaving, μ/p is the absorption coefficient as shown in Fig. 3, and M is the mass density in mg/cm^2. On the other hand, electrons and other charged particles are at first attenuated but eventually have a definite range beyond which they are completely stopped. In addition, materials through which X-rays pass can show an abrupt change in absorption behavior when the X-ray energy passes across a so-called absorption edge. This change happens when the X-ray has enough energy to ionize atoms within the absorber. Consequently, X-rays can be distinguished from charged particles by examining the behavior of several types of absorbers.

The relationship between count/second and applied voltage is shown in Fig. 5, where a large number of data points help define the initial shape of the curve. Fig. 6 reveals the behavior over a wide range of count rates. The data sets in both figures are fit very well by an equation having the form c/s = C*(V-B)^3, where C is an arbitrary coefficient, B is the voltage at which the first particles are detected and V is the voltage applied to the cell. This form follows the data up to about 20,000 c/s at which rate dead-time becomes important. This fitting function has been found to fit all the data, including after absorbers have been imposed. This power function is similar to the power function that fits the absorption coefficient when it is compared to the energy of X-radiation, which suggests a change in flux is controlled mainly by how the absorption changes with energy, hence applied voltage. Nevertheless, a straight line is occasionally drawn through the nearly linear part of the curve when some data are compared.

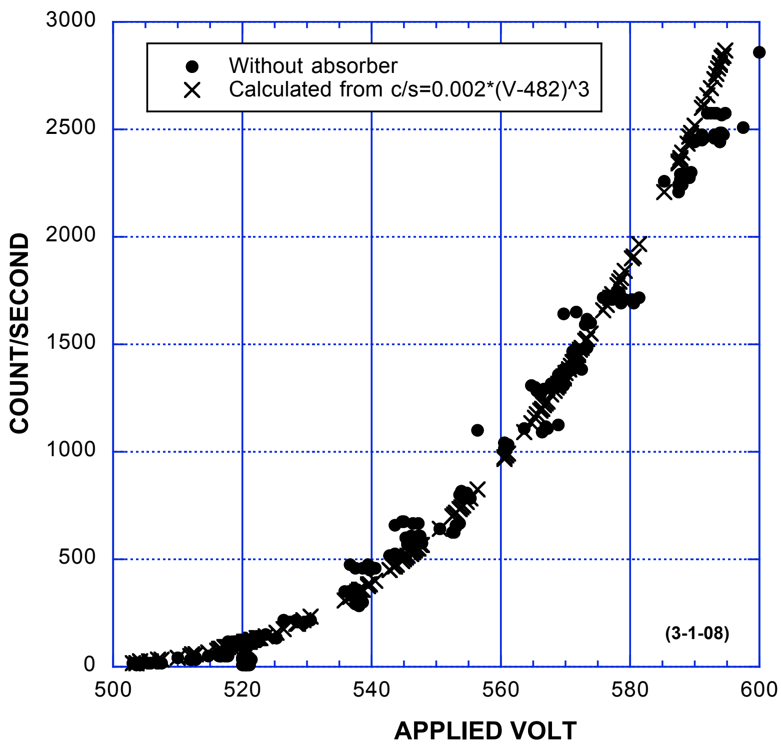

FIGURE 5. An example of count rate as a function of applied voltage. The gas is a mixture of D_2O+D_2 and the cathode is Mo.

Absorbers made of either aluminum or Mylar are used. The count rate as a function of voltage for various thickness is compared in Fig.7. When the count rate produced by the GM without an absorber is divided into the count rate with an absorber, Fig. 8 results. A change in I/Io can only occur when the energy of the radiation changes or if the end of a particle range has been reached. Clearly, energy of the radiation increases as voltage is increased. Although, the decrease in I/Io between 600 and 650 V might indicate the end-of-range for the radiation, which is not typical of monoenergetic X-rays, other explanations can be suggested, such as an artifact caused by using the wrong function to fit the Io data. These possibilities become important because an actual decrease in energy would not be consistent with the behavior of the thick-window GM, which shows an increase in energy within this voltage range, as can be seen in Fig. 9.

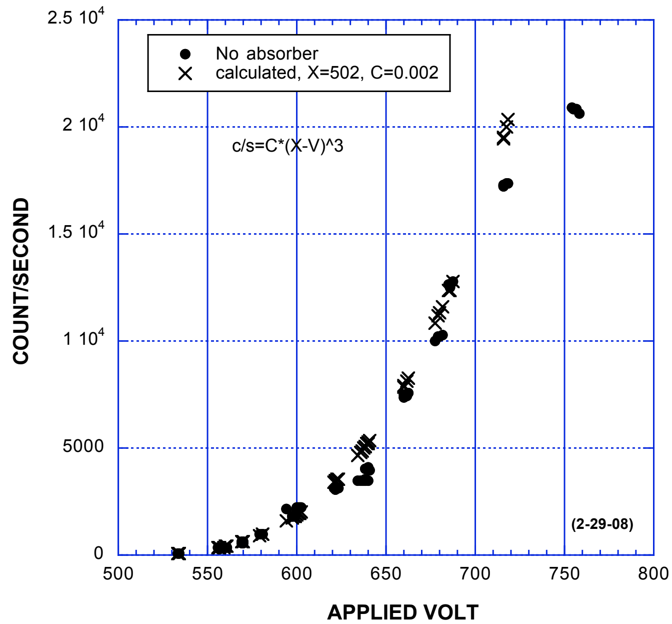

FIGURE 6. Example of the behavior over large range of count rate. The deviation near 20,000 c/s is believed caused by dead-time effects in the GM.

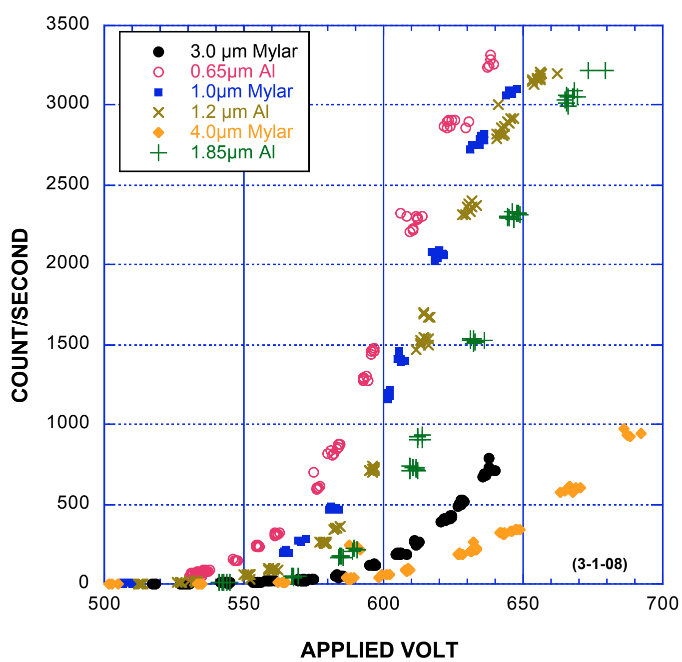

FIGURE 7. Count rate produced by imposing various absorbers.

The steep increase in flux shown by the GM as voltage is increased shows that the intensity of the radiation also increases as voltage is increased. The rate of increase is taken into account using the behavior of the GM without an absorber when the I/Io value is calculated. Consequently, no assumptions need to be made about the form or magnitude of this behavior.

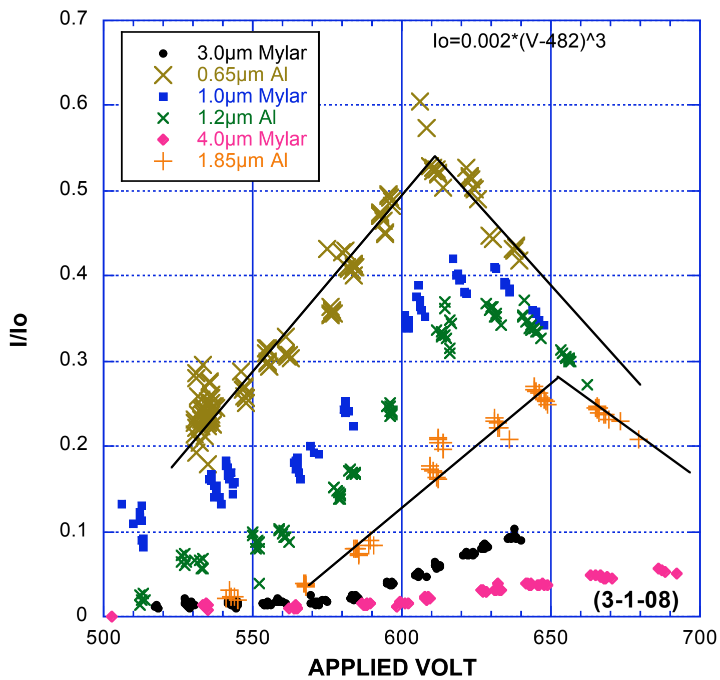

FIGURE 8. I/Io values calculated using the data in Figs. 5 and 7.

The I/Io values in Fig. 8 are next plotted as ln(I/Io) vs mass density for the various absorbers at 600 V in Fig. 10. Straight lines fit to the points by the least squares method are found to extrapolate to near zero as required by such a relationship. This behavior gives confidence in the accuracy of the measurement. The slope of the line is equal to the absorption coefficient, μ/p for the respective material. These values can be compared to the values published by NIST (Fig. 3) and used to calculate the average energy of X-rays that would be consistent with the measurements. Aluminum requires X-ray energy of 600 eV to exhibit the observed behavior while Mylar requires energy of 740 eV. In the case of aluminum, this energy corresponds to the maximum energy available within the discharge.

When an absorber is placed in front of the GM, the count rate is reduced, but the intensity will increase as the energy (voltage) is increased. This increase in intensity caused by an increase in energy can be calculated, as shown in Fig. 11. The absorption coefficient for aluminum is assumed to equal that produced by an X-ray having an energy equal to the voltage applied to the cell. The calculated count rate is obtained from the formula:

$$I=c/s=I_o*EXP(-M*1203*V^{-2.2439})$$

where I_o is the count rate produced by the GM without an absorber, M is the mass density of the aluminum (0.00032 g/cm^2), V is the cell voltage in kV, and the coefficients are those that describe how the absorption coefficient changes with energy in the range of interest. The fit between the measurement and the calculation is very good except over an energy range near 580 V. This is another example of behavior that is basically consistent with X-ray emission.

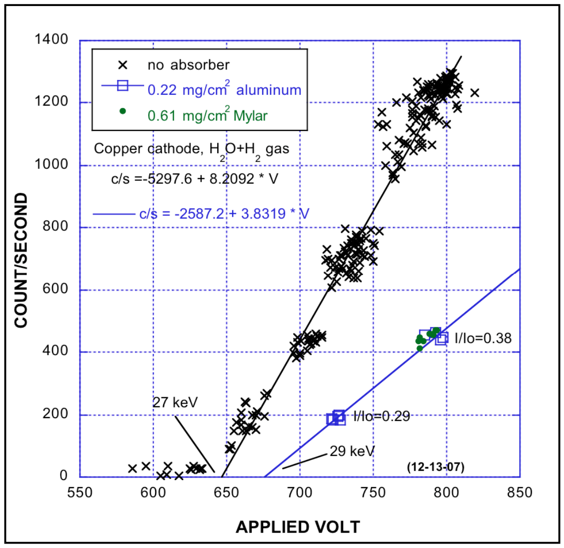

FIGURE 9. Example of the behavior of the thick-window GM showing the larger critical voltage compared to the thin-window GM. The abrupt increase in intensity is typical of electron radiation of the indicated energy.

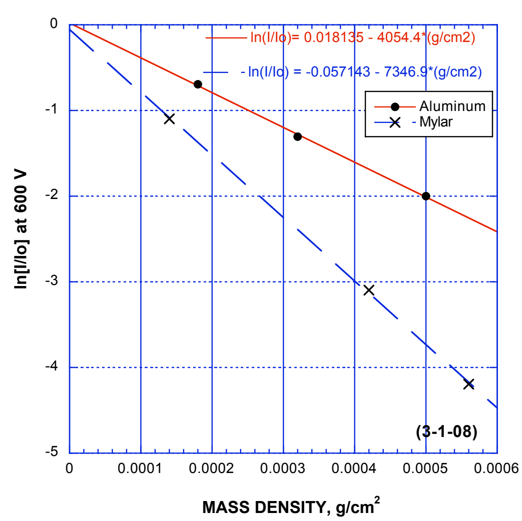

FIGURE 10. ln(I/Io) at 600 V vs mass density for Mylar and aluminum based on the data in Fig. 8.

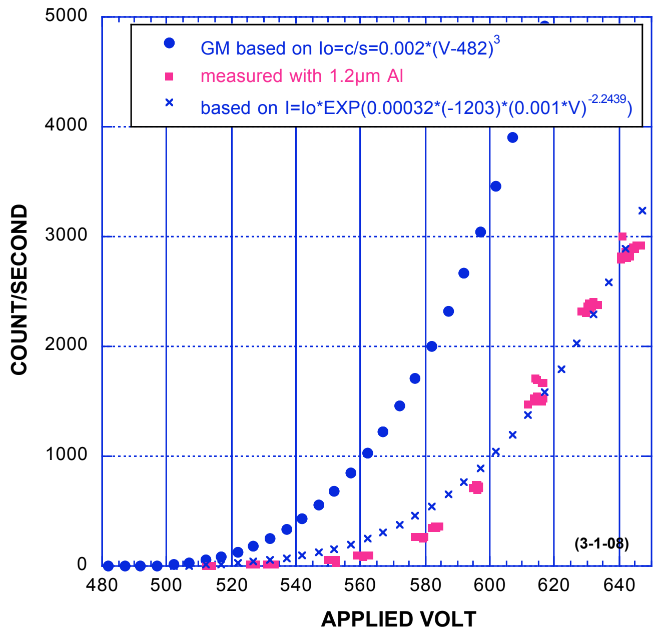

FIGURE 11. Radiation detected using the thin-window GM tube shown as a function of voltage between the anode and cathode. The effect of 1.2 μm of aluminum absorber is shown. If the radiation were X-rays, the count rate would be expected to follow the curve created by x based on the intensity obtained without an absorber.

III.1.2 Electrons

If electrons were present, they would need to pass through the window of the GM before they could be detected. The thin window GM has a mass thickness of 0.30 mg/cm^2. According to Fig. 2, energy of about 9 keV would be required. Likewise, the thick-window GM, with a window of 2.0 mg/cm^2, would require energy of about 30 keV to permit detection. With addition of absorbers, even greater energy is required. Although energy of this magnitude is not thought to be available in a 600 V gas discharge, an effort was made to determine if the radiation could be deflected by a magnetic field. Using a device as described in Section II, no defection was detected using a magnetic flux up to 1500 G. Nevertheless, indication of electron emission was obtained on occasion in the past.

III.1.3 Protons (deuterons)

Protons or deuterons might be present if a nuclear reaction were initiated by the discharge. Such particles are easily stopped by very thin absorbers and would be detected by the Si detector. On infrequent occasions, peaks were observed in the Si energy spectrum that could be produced by such particles. However, the rate was much less than the count being revealed by the GM operating at the same time. This work will be described in detail in a later paper. For the present, we conclude that the behavior of the GM is not influenced by these particles.

III.1.4 Noise

Electromagnetic radiation (EMR) generated and emitted by the discharge can produce counts by the GM. This problem was experienced many times and efforts were made to eliminate it by shielding and by changing the electrical properties of the system supplying current to the discharge. When this effort is successful, imposing an absorber of modest thickness (1mm Cu) causes the count rate to drop to zero as a greater fraction of the GM window is covered. Use of thick Plexiglas, a nonconductor, has the same effect as copper. On occasion, brief localized discharges would cause a brief burst of counts that were ignored as being caused by EMR. The data reported here were taken from experiments where EMR noise was not a factor and did not produce extra counts.

III.2 Effect of Conditions on the Behavior of Radiation

The relationship between voltage applied to the glow discharge cell and the measured flux, as reported previously, continued to be observed. However, the previously observed 0.8 MeV electrons have not reappeared. This study extends an understanding of the presently observed radiation by using various gases and cathode materials.

A variety of materials have been tried as the cathode, including Pd, Pt, Pd+Pt alloy, Ti, Zr, Ag, Cu and Mo. The anode has been made of Pd, Pt or W+Th alloy without any difference being observed. All cathode materials produced some radiation, but many failed to produce a steady glow discharge. Copper and silver are found to work well except the high sputtering rate quickly makes the Al_2O_3 shroud conductive, which causes local discharge and electrical noise. Nonmagnetic stainless steel works well and has a lower sputtering rate. The best material found so far is molybdenum. The sputtering rate is low and it allows a very smooth, stable glow discharge to form.

Various gas compositions have been explored. The behavior of nitrogen containing various amounts of deuterium is shown in Fig. 12. Tank nitrogen containing an unknown amount of D_2 impurity, resulting from that released from the walls of the vacuum chamber, shows the smallest slope, hence the least efficiency in making radiation. The most efficient composition observed in the presence of nitrogen is D/N=0.19. This is close to the most efficient atom ratio of D/O = ~0.1 when oxygen is present instead of nitrogen. Addition of oxygen as H_2O to nitrogen causes no obvious change in behavior, as shown in Fig. 13. Radiation is produced when helium is mixed with D_2O or D_2. The behavior of various gas mixtures is compared in Fig. 14.

Some gases are especially injurious to a smooth discharge, such as carbon containing gases that decompose and deposit carbon on the cathode. As a result, great care needs to be used when comparing behaviors to avoid certain gases that might be present in unknown small amounts.

Radiation produced at two different voltages using two different gas compositions is show in Fig. 15. The change in I/Io, noted on the figure, shows that energy of the radiation is highest for data taken at the highest voltage and the energy increases faster as voltage is increased compared to the data taken at the lower voltage,

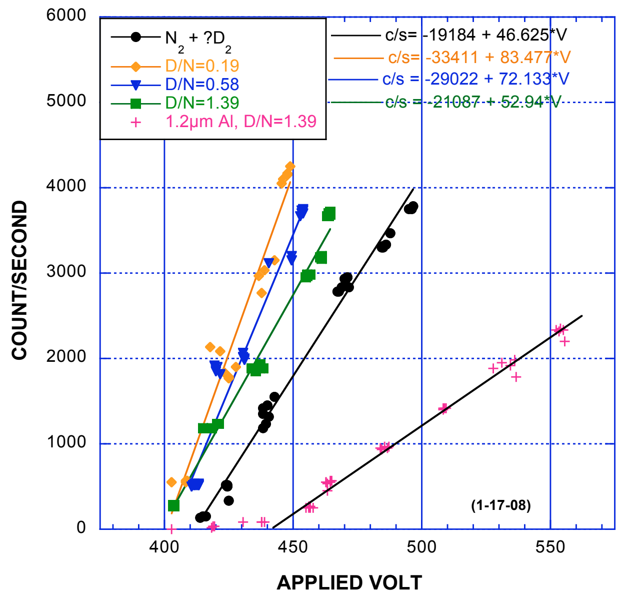

FIGURE 12. A comparison of the behavior when the D/N ratio is changed. The "pure" nitrogen contains a small but unknown amount of deuterium. Consequently, the D/N ratio is very small. Copper is used as the cathode in this study.

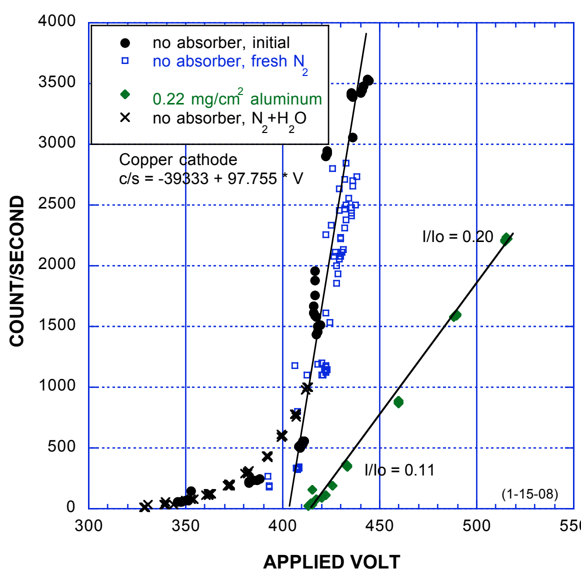

FIGURE 13. The null effect of adding H_2O to N_2. The effect of imposing an Al absorber is also shown.

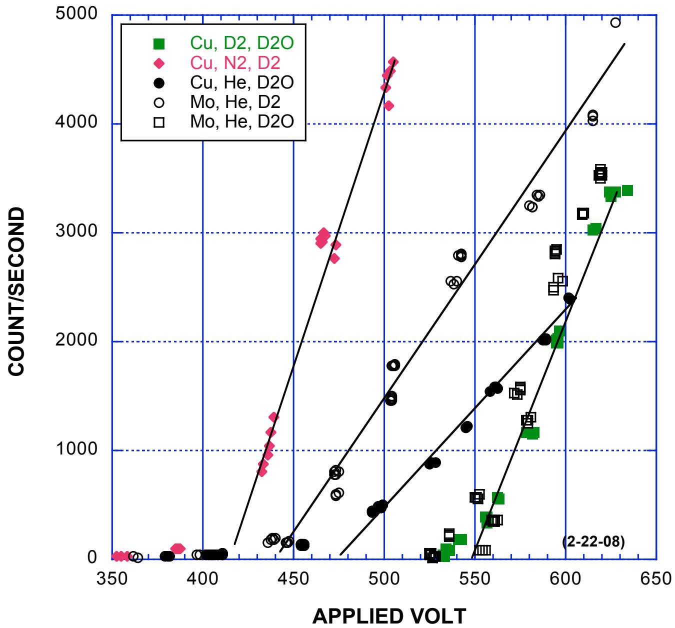

FIGURE 14. A comparison between the behavior of various gas mixtures and cathode materials.

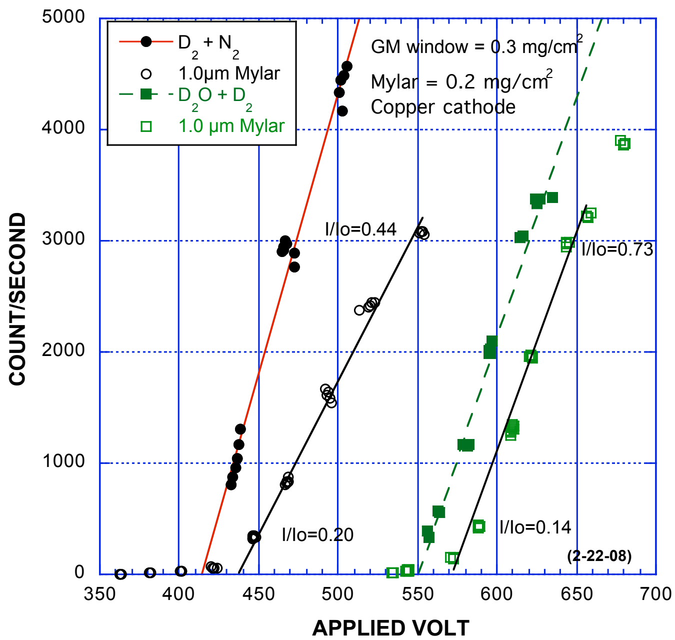

FIGURE 15. Two conditions are compared to show how the I/Io changes with voltage using the respective GM counts vs voltage without an absorber as Io.

IV. DISCUSSION

When an absorber is imposed, the I/Io value is found to change with applied voltage. This behavior shows that the energy of the radiation increases as voltage is increased. As a result, no radiation is detected by the GM until the most energetic member of flux has gained sufficient energy to penetrate its window and the imposed absorbers. For this reason, the apparent critical voltage for radiation production observed using both detectors is simply caused by limitations of the detector, not by a critical voltage related to the process.

The combined effect of energy and intensity change on the count rate of the GM is described very well by a power function with the form $c/s=C*(V-B)^3$, where C is an arbitrary constant that is sensitive to the intensity after passing through an absorber, V is the measured voltage, and B is the voltage at which radiation is first detected. The value for C decreases as the amount of radiation removed by absorption increases. This power function is similar to the one used by NIST to fit the relationship between energy and absorption coefficient for x-rays in the range of interest. This behavior suggests that the change in count rate is caused mainly by more radiation being able to penetrate the window of the GM as energy is added by increased voltage.

The flux is also a function of voltage, with an apparent decrease as voltage is increased. For example, X-radiation having an energy of about 400 eV has to be over 36 times more intense than an X-ray energy of 550 eV to produce a similar count rate, as shown in Fig. 14, because absorption of radiation is so much greater at the lower energy. This general behavior applies regardless of the kind of radiation being detected.

The nature of the radiation has been determined by using various absorbers. The behavior of ln(I/Io), shown in Fig. 10, and the calculated increase in intensity shown in Fig. 11 indicate that the radiation consists mostly of low-energy X-rays, having energy nearly equal to the voltage applied to the cell. Explaining how X-rays of this energy can be generated requires several unsupported assumptions be made that are in conflict with the observations. The first assumption is the production of k X-radiation.

In principle, nitrogen can emit k X-radiation at 392 eV and oxygen can emit 525 eV X-rays if the energy of ionizing electrons exceeds the respective energy. As can be seen in Fig. 15, radiation starts at 410 V when nitrogen is present and at 550V when oxygen is in the gas. However, when only D_2 and He are present, two elements that do not generate k X-rays, the radiation starts at 440 V, as shown in Fig. 14. Although a small amount of oxygen would be present in the gas as impurity, it would not be expected to produce a flux comparable to that when a large amount of oxygen is present. In addition, a mixture of He and D_2O produces significant radiation well below the voltage observed when the mixture is D_2+D_2O. As a result, not all onset voltages are consistent with the energy at which k X-rays are expected.

K X-radiation occurs at a fixed energy, which cannot be changed by a change in applied voltage. Because energy of the radiation changes with applied voltage, as shown in Figs, 8, 9, 13, and 15, it cannot be caused by k X-rays.

Changes in gas composition cause the slope of flux vs voltage and the critical voltage at which radiation is detected to change. In addition, the gas composition has a significant effect on the resistance of the plasma, which changes the relationship between applied current and voltage. As a result, some gas mixtures give greater flux and stability than others. All gas mixtures able to maintain a smooth discharge are found to produce radiation. The role of hydrogen and deuterium are unknown because the gas will always contain a small amount of both gasses caused by out-gassing from metal surfaces. Nevertheless, change in the deuterium content is found to change the intensity of radiation.

The authors wish to acknowledge the help of Rick Cantwell and Matt McConnell at Coolescence (LLC) in discovering that the radiation is not electrons.

V. SUMMARY

A glow discharge made under the conditions used in this study produces radiation that acts like X-rays having a very low energy. The energy is increased by an increase in voltage between the anode and cathode. The process that produces this radiation is also sensitive to the gas composition and the material used as the cathode. The source of this radiation has not been identified.

References

[1] M. Fleischmann, S. Pons, and M. Hawkins, J. Electroanal. Chem. 261, 301 and errata in Vol. 263 (1989).

[2] G. Miley, Y. Yang, A. G. Lipson, M. Hague, I. Percel, and M. Romer, in *Intense non-linear soft X-ray emission from a hydride target during pulsed D bombardment*, Yokohama, Japan, 2005 (World Scientific), p. 314.

[3] A. B. Karabut, in *Excess heat power, nuclear products and X-ray emission in relation to the high current glow discharge experimental parameters*, Tsinghua Univ., Beijing, China, 2002 (Tsinghua Univ. Press), p. 151.

[4] J. Dufour, J. Foos, J. P. Millot, and X. Dufour, Fusion Technol. 31, 198 (1997).

[5] T. N. Claytor, M. J. Schwab, D. J. Thoma, D. F. Teter, and D. G. Tuggle, in *Tritium production from palladium alloys*, Vancouver, Canada, 1998 (ENECO, Inc., Salt Lake City, UT.), p. 88.

[6] I. Savvatimova, in *Reproducibility of experiments in glow discharge and processes accompanying deuterium ions bombardment*, Lerici (La Spezia), Italy, 2000 (Italian Physical Society, Bologna, Italy), p. 277.

[7] H. Yamada and T. Fujiwara, Int. J. Soc. Mat. Eng. Resources 6, 14 (1998).

[8] E. K. Storms and B. Scanlan, in *Radiation produced by glow discharge in deuterium*, Catania, Sicily, 2007 (http://www.iscmns.org/catania07/index.htm).

[9] http://physics.nist.gov/PhysRefData/Star/Text/ESTAR-t.html.