

# Nature of energetic radiation emitted from a metal exposed to H<sub>2</sub>

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## Abstract

Layers of metals were applied so as to cause local stress, which is proposed to create voids in which nuclear reactions can be initiated when the material is exposed to H<sub>2</sub>. Photon emission having energy sufficient to pass through 3.86 g/cm<sup>2</sup> of absorbing material was detected using a Geiger-Mueller detector. This radiation was observed to last many hours and is not typical of what is called fractofusion.

## I. INTRODUCTION

Numerous reports have been published[1] describing radiation emitted from a nuclear process called LENR when palladium, nickel, and other materials are exposed to deuterium and normal hydrogen. Because such energetic radiation cannot be mistaken for a prosaic or chemical effect and can only result from a nuclear reaction, these observations are highly anomalous and in conflict with conventional understanding. This radiation, in addition to revealing how nuclear reactions can be initiated in ordinary materials, must be explored to avoid health risks when such systems are studied or used as energy sources.

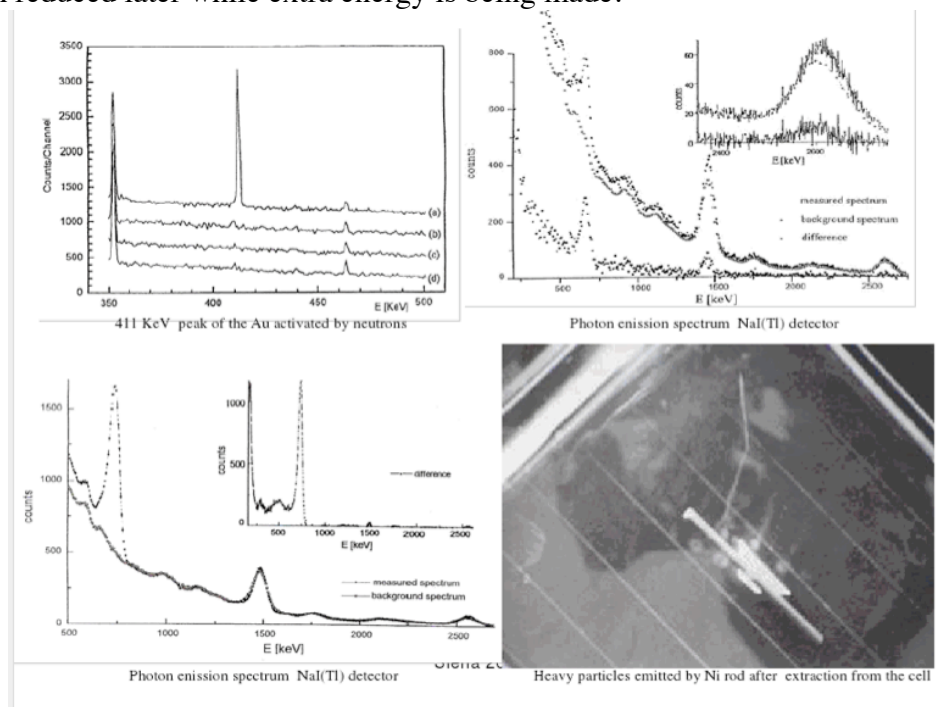
For this study, samples were made and treated so as to form the kind of voids proposed by Storms[2-4] to be the location of the LENR process. Three different materials were used, with each showing the same behavior once the active conditions were produced and the materials were exposed to H<sub>2</sub>. Radiation, which had the characteristics of photons, was detected using large area Geiger-Mueller detectors. The amount of material was too small for the nuclear process to produce detectable energy.

Unusual radiation, both particle and photon, has been found when certain materials are exposed to H<sub>2</sub> or D<sub>2</sub>. For example, such radiation has been produced during electrolysis[5, 6], gas discharge[7-10], and by exposing specially treated metal to H<sub>2</sub>[11, 12] or D<sub>2</sub> gas. Focardi [12] places the photon energy resulting from specially treated Ni being exposed to H<sub>2</sub> at 661±0.8 keV. This value was corrected to 744 keV by Takahashi[13]. Piantelli et al. [12] [11, 14] published a detailed description of various kinds of radiation emitted from Ni rods after being heated repeatedly in H<sub>2</sub>, after which the metal was found to generate extra energy. Evidence for photon radiation of various frequencies, energetic particles that were visible in a cloud chamber, and neutrons is shown in Figure 1. Violante et al.[15] electrolyzed a thin layer of Ni that was sputter-deposited on polyethylene. The electrolyte was H<sub>2</sub>O-Li<sub>2</sub>SO<sub>4</sub> and radiation was detected using a planar HPGe detector after the radiation had passed through the polyethylene cell wall. Figure 2 shows the behavior when a blank cathode was examined and Fig. 3 shows the presence of radiation. Although the amount of radiation leaving the cell as photons is small, radiation is clearly present when none would be expected. Matsumoto<sup>1</sup> [16] detected radiation using X-ray film produced by a nickel cathode in a glass electrolytic cell containing H<sub>2</sub>O+K<sub>2</sub>CO<sub>3</sub>. One side of the foil was electrolyzed while the other side was in contact with the film. As a result, any radiation had to pass through 0.1 mm of Ni.

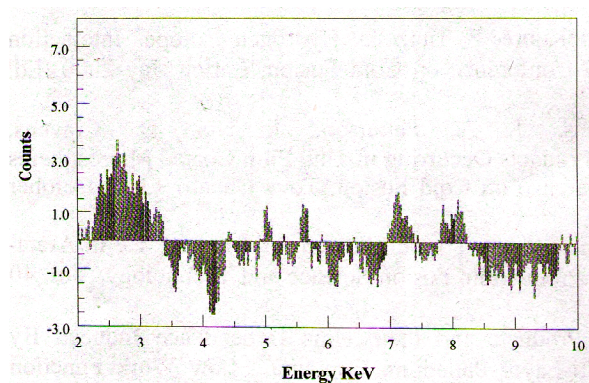
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<sup>1</sup> This author has published many papers describing how variations in the cold fusion conditions can generate strange tracks in film.

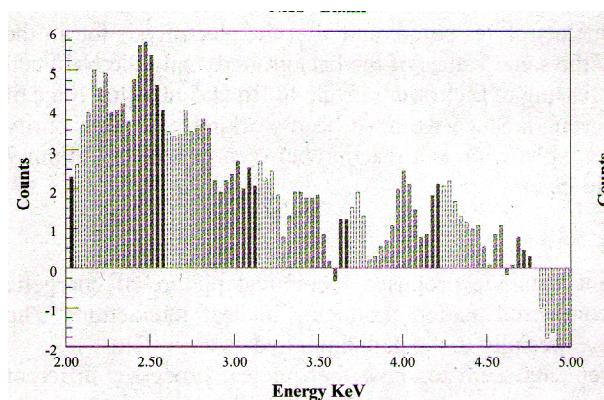
Many unusual complex tracks were seen, suggesting secondary nuclear reactions were produced in the film by radiation from the nickel. Bush and Eagleton[17] used a NaI scintillation detector to measure photons from a Ni cathode (fibrex) electrolyzed in  $\text{H}_2\text{O}+\text{LiOH}$ . They claimed to find a rough correlation between excess power and the amount of total radiation as shown in Fig. 4. Anecdotal experience has been reported by Rossi[18] and Celani, claiming radiation is detected when heat production is first initiated but is much reduced later while extra energy is being made.



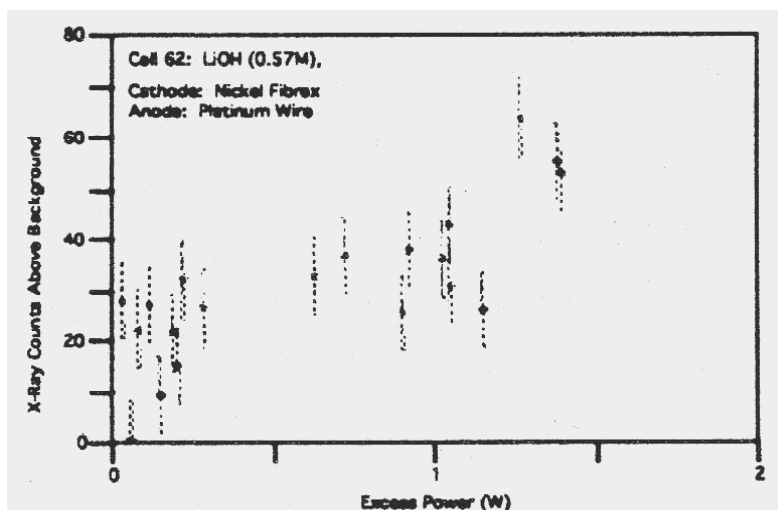
**FIGURE 1.** Examples of radiation reported as a result of studies by Piantelli et al. using specially treated Ni exposed to  $\text{H}_2$ .



**FIGURE 2.** Count rate in excess of background for an inactive Ni cathode reported by Violante et al.[15]



**FIGURE 3.** Count rate in excess of background for an active Ni cathode reported by Violanti et al.[15].



**FIGURE 4.** Radiation detected by Bush and Eagleton[17] from a cell having a Ni cathode and  $H_2O$  electrolyte while it was making excess power.

## II. METHOD

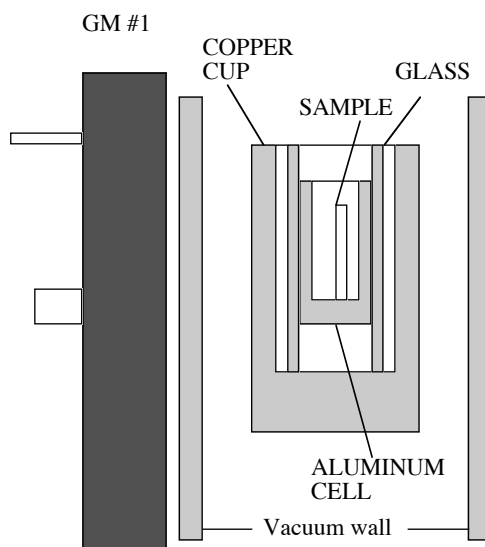
### II.1 Radiation measurement

Figure 5 shows a cross-section drawing of the sample, cell, vacuum housing, and GM detector (GM #1) (LND-7313) and Fig. 6 is a photograph of the system. The radiation had to pass through the absorber material listed in Table 1. As a result, a large fraction of the radiation being emitted by the sample was removed before measurements were made. The pulses from the detector were fed to an electronic circuit where the pulses were amplified and used to charge a resistor-capacitor circuit to produce an average voltage that was recorded. Consequently, the plotted values are arbitrary units for which only a change is important. The average background was about 60 c/m for the large-area detector.

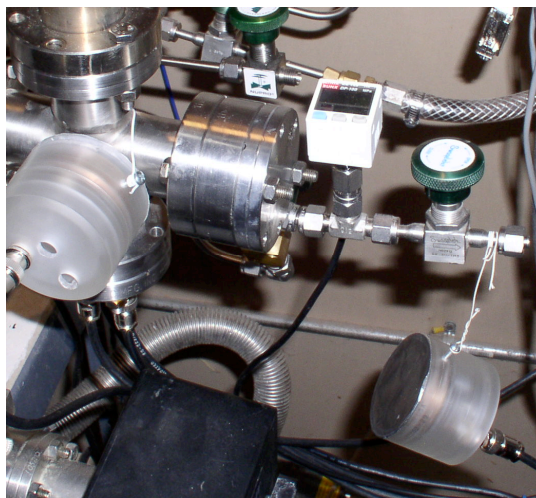
A second GM (GM #2) of the same type was located about 30 cm from the source (Fig. 6), such that any radiation from the source had to pass through 1 cm of steel and the back of the detector before it entered the active region of GM#2. As a result, ambient background radiation was detected along with only very energetic radiation that might be

emitted by the sample or GM#1. The background flux at GM#2 was found to be essentially constant during the studies.

The sample was contained in an aluminum cup that could be heated in  $H_2$  to  $350^\circ$  with pressures up to 5 atm. The samples were exposed to a variety of conditions in order to activate the material, a process important to achieving success.



**FIGURE 5.** Cross-section of region around sample and relationship to GM #1.



**FIGURE 6.** Photograph of apparatus with GM#1 attached to the apparatus and GM#2 hanging by a wire off to the right.

**TABLE 1**

0.9 mm Al	= 0.24 g/cm <sup>2</sup>
2 mm Cu	= 1.79 g/cm <sup>2</sup>
1 mm Pyrex	= 0.22 g/cm <sup>2</sup>
2 mm stainless steel	= 1.61 g/cm <sup>2</sup>
TOTAL	= 3.86 g/cm <sup>2</sup>

## II.2 Sample Preparation

The samples consisted of palladium or nickel sheet on which various metals were deposited by electroplating or sputtering.

The palladium samples were prepared by reducing the thickness of stock palladium to a convenient value using a rolling mill. The sample was then heated near the melting point using a propane-oxygen torch in air. This treatment purified the surface and created a thin oxide coating. Heating to 200-280° followed by cooling in 30 psi H<sub>2</sub> resulted in the sample coming to equilibrium with the H<sub>2</sub> and acquiring a H/Pd ratio between 0.70 and 0.72. This step was used to make sure the Pd was clean and would react quickly and completely with H<sub>2</sub>. The hydrogen was then removed by heating in vacuum to 200° before the metal coating was applied.

One sample was made by applying Cr to the clean Pd surface by sputtering to give a thickness of 101 nm on both sides. This was followed by 262 nm of Pd and another 101 nm layer of Cr. The sample was heated in 4.8 atm of H<sub>2</sub> to 213° C and cooled in order to bond the layers to the base material. When the sample cooled in H<sub>2</sub>, the Pd expanded as it formed beta-PdH resulting in H/Pd=0.70, which caused stress in the Cr layer to form the required voids.

A second sample was made by applying 101 nm of Ni, and 252 nm of Pd on the Pd substrate. The sample was heated in vacuum to 415° and cooled in 4.9 atm of H<sub>2</sub>. This caused the sample to reach a composition of H/Pd=0.73, which would produce stress in the Ni layer as the Pd expanded while forming beta-PdH and the Ni did not.

A sheet of Ni was cleaned by electrolysis in NaOH solution followed by applying an electroplated layer of Cu 552 nm thick. This was heated to 481° in vacuum followed by heating in H<sub>2</sub>. The surface is shown in Fig. 7 on which the sought-for pits are clearly seen.



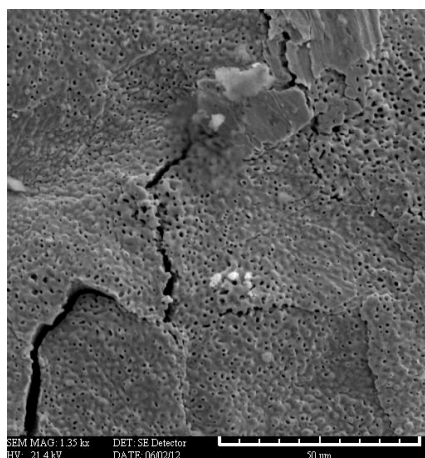
**FIGURE 7.** Surface of Ni on which Cu was deposited after heating in vacuum at 481° C.

The active regions were not stable so that the amount of radiation was not constant with time or conditions. Nevertheless, the samples were active long enough to obtain useful measurements and could even be removed to air for weighing without losing the ability to produce radiation once returned to the system.

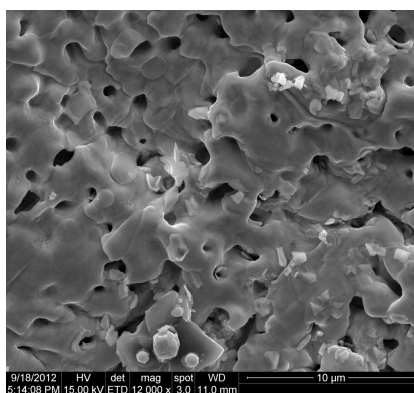
The voids proposed to be the nuclear active environment (NAE) appeared to have a range of sizes, some of which were too small to be resolved in the images. Figures 8 and 9 show a topical void formation at different magnifications for samples of Ni applied



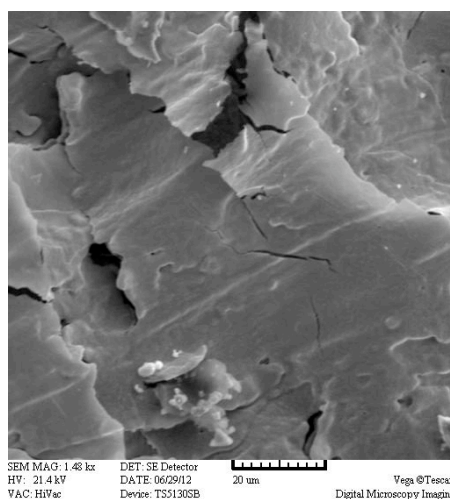
to Pd. Figure 10 shows the surface after study of a sample created by applying Cr to Pd. This layer delaminated from the Pd at some point during the study, probably when the radiation abruptly stopped at the end of the study.



**FIGURE 8.** SEM image of a surface of Ni on Pd after the study containing voids and cracks.



**FIGURE 9.** Detailed SEM examination of the Pd-Ni surface after the study.



**FIGURE 10.** SEM image of surface of Cr on Pd after the study.

### III RESULTS

Four samples were found to produce radiation after being prepared using a variety of conditions, three of which are described here. The most important requirement is that the layer not detach from the substrate metal and the pit structure form. These pits are expected to be the mouth of voids that extend into the material. Their formation requires a narrow range of conditions, some of which are described here.

#### III.1 Pd-Cr

Figure 11 shows the counting history for a sample of Pd coated with 100 nm of Cr followed with about 200 nm of Pd. In this case the voids are produced in a volume of about  $0.0001 \text{ cm}^3$  of Cr, which emphasizes the small volume of material from which radiation is typically emitted. A brief exposure to  $\text{H}_2$  was done before this sequence was started. Several heating and vacuum cycles were required before significant radiation was started at 1350 min while the sample was at  $305^\circ$  and  $\text{H}_2$  was being pumped out. Such treatment would cause the gap in cracks that had formed during previous treatments to become smaller as hydrogen was lost causing the Pd to contract. Presumably this smaller size was required for the process to function and radiation to be produced. Only this sample required loss of  $\text{H}_2$  to produce radiation.

The effect of inserting sheets of lead absorber ( $1.3 \text{ g/cm}^2$ ) is shown in Fig. 12. Every time an absorber was inserted, all samples showed an immediate reduction in radiation followed by slow decay. The absorber changed the distance between GM#1 and the sample by no more than 2 mm. Once the absorber had been removed, an immediate increase in radiation occurred that was followed by slow increase to a steady value. The effect when Pb was inserted can be seen clearly in Fig. 13, but unfortunately the radiation stopped before the Pb could be removed. This abrupt termination of radiation near 3000 min is presumed to have resulted when the coating detached from the Pd substrate, the consequence of which can be seen in Fig. 10. GM #2, located at a distance from the sample, also shows unusual behavior. Radiation was being detected by GM#2, which slowly decreased when an absorber stopped radiation from the sample from reaching GM#1, as seen in Fig. 13. This means the radiation being detected by GM#2 originated from GM#1, not from the apparatus. This behavior was observed on several occasions when other samples were treated in the same way.

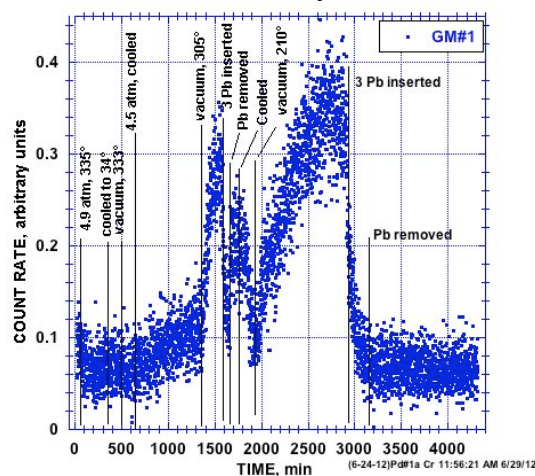
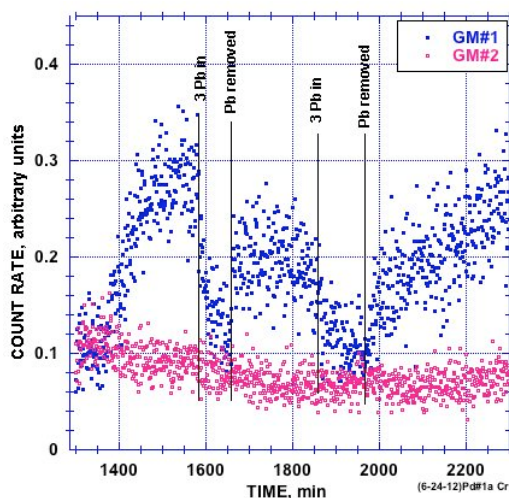
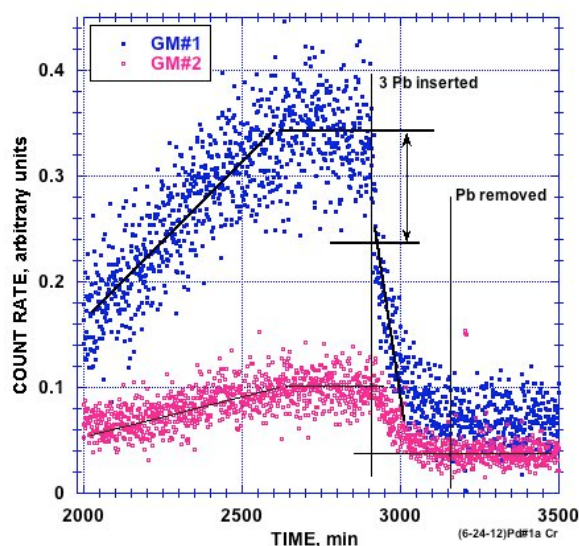


FIGURE 11. History of sample of Pd coated by Cr.



**FIGURE 12.** Sample of Pd coated by Cr. Time sequence taken from Fig. 11.

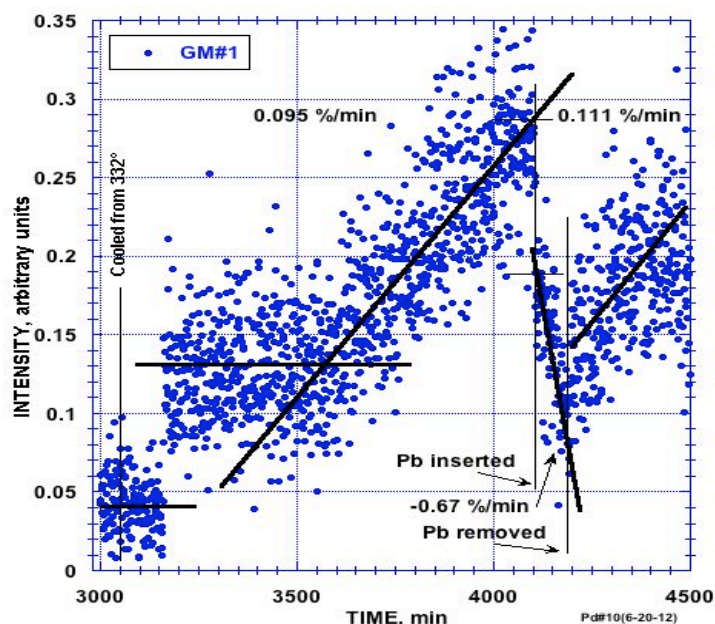


**FIGURE 13.** Sample of Pd coated by Cr. Time sequence taken from Fig. 11.

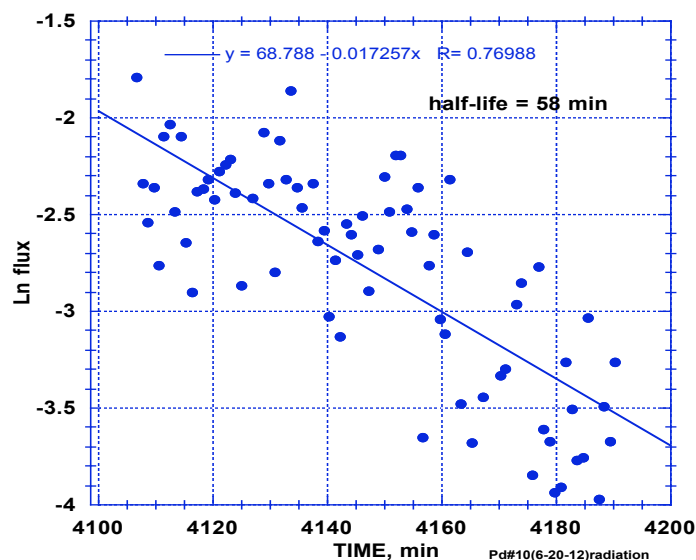
### III. 2 Pd-Ni

This sample was heated at various temperatures under as much as 5 atm of  $H_2$  over a period of 3000 min before any radiation was detected. The sample was at  $33^\circ C$  under of 4.4 atm of  $H_2$  when radiation was detected. Fig. 14 shows onset of radiation and the effect of inserting a Pb absorber. Once again, immediate reduction was produced followed by slow decay having a half-life of 58 min, as calculate using the linear least-squares fit of  $\ln(\text{rate})$  vs time during the decay phase (Fig. 15). The rate was obtained by subtracting the GM#1 signal when no radiation was produced from the value measured for each point during the decay. When the absorber was removed, radiation immediately increased followed by a slow increase with a slope close to the increase occurring before the absorber was inserted.





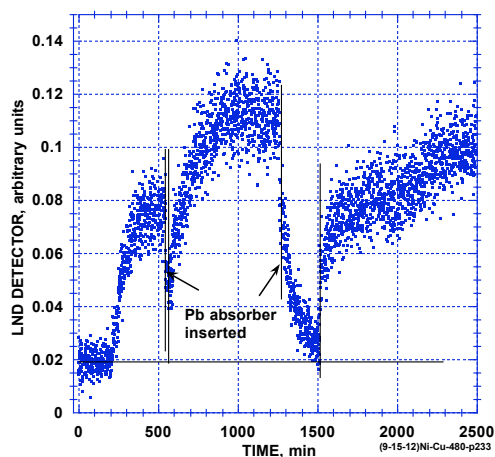
**FIGURE 14.** Example of inserting a lead absorber using Pd coated by Ni.



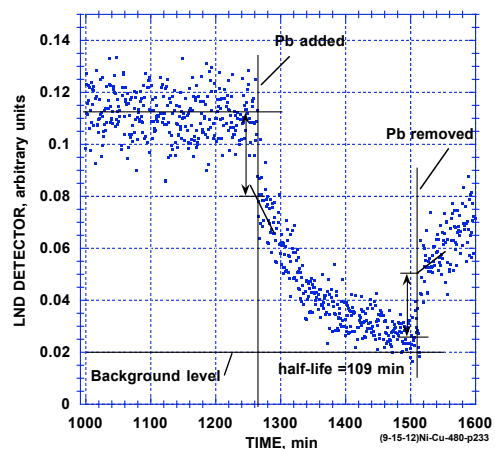
**FIGURE 15.**  $\ln(\text{flux})$  vs time for decay after absorber is inserted.

### III. 3 Ni-Cu

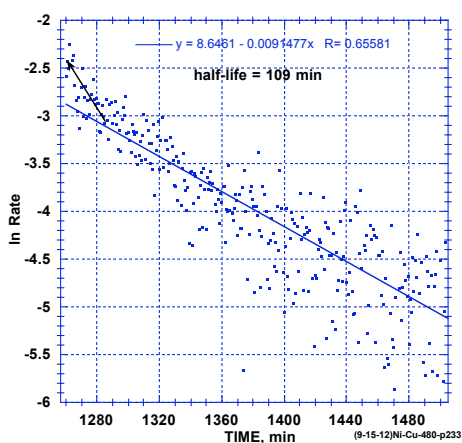
The sample was heated through 212° in 3.7 atm of  $\text{H}_2$  when the radiation intensity first increased at 200 min. Lead (Pb) was briefly inserted at 548 min and then removed. Lead was again inserted at 1260 min, which had the effect shown in Fig. 16. The decay in Fig. 17 had a longer average half-life (Fig. 18) compared to a shorter time shown in Fig. 15, with an indication that the initial decay had a shorter half-life than the average. This shorter initial decay rate might account for the smaller half-life obtained from the smaller data set shown in Fig 15.



**FIGURE 16.** Behavior of radiation during the full study while Ni-Cu was being heated in  $H_2$ .



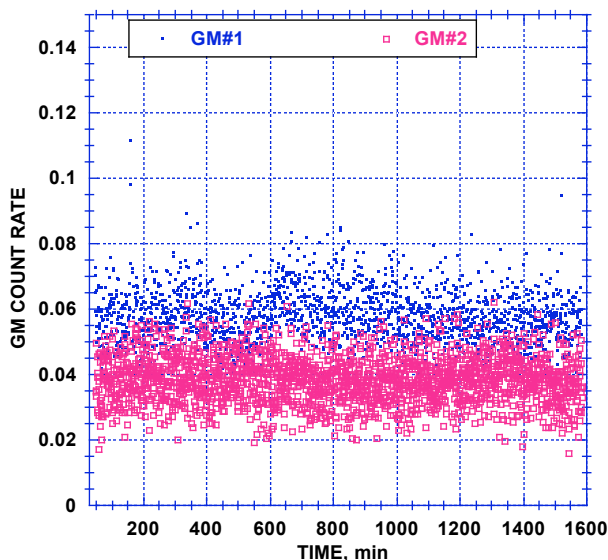
**FIGURE 17.** Effect of inserting a Pb absorber between 1262 min and 1510 min shown in Fig 16.



**FIGURE 18.** Half-life calculation for decay shown in Fig. 17.

### III.4 Radon

When a fan was used to circulate air around the GM and apparatus, the count rate increased and then decreased when the fan is turned off. This change is attributed to radon in the air that is made available to the surface, where it deposits. This extra count rate was not present in the absence of the fan. Inactive samples, of which many were studied, and the empty cell show a steady count rate at the normal background level. All data was obtained in the absence of the fan. Figure 19 shows the behavior of a typical inert sample exposed to  $H_2$ .



**FIGURE 19.** Behavior of GM#1 and GM#2 when a typical inert sample is in the apparatus. The difference between the two GM count rates is arbitrary. Only the constant value over time is important.

## IV. DISCUSSION

A recently published explanation of LENR proposes that the nuclear reactions are initiated in voids or cracks[2]. Consequently, these experiments were designed to generate cracks in various materials while photon radiation was measured outside the apparatus using a Geiger-Muller detector. Because the energy of photons is not altered by penetration through matter, only a small flux that leaks from the apparatus is required to identify a source of radiation. Most of radiation would be stopped within the apparatus.

Two sources of radiation are detected. One source is produced by the sample and can be stopped almost completely by  $1.6 \text{ g/cm}^2$  of lead in addition to the  $3.9 \text{ g/cm}^2$  provided by the apparatus. This radiation originates from samples proposed to contain characteristic voids that are observed to penetrate to surface where they appear as pits. The voids visible at the resolution used are too large to be nuclear active. However, the observed voids have a wide range of size, suggesting some may have the required small size, but would be too small to be resolved by the SEM.

The other kind of radiation originates in GM #1. This radiation grows slowly when GM #1 is exposed to radiation from the sample and decays away when an absorber stops radiation from the sample. This secondary radiation has enough energy to pass

through considerable absorber and be detected by GM #2 located well away from the primary source. The radiation from the sample apparently causes growth of a radiation emitter within GM #1 having an average half-life of about 109 min. As a result, GM#1 detects the sum of radiation from the sample and from the activated source. Insertion of an absorber immediately stops radiation from the sample, which stops further activation. As a result, the activated source decays away with the measured half-life. When the absorber is removed, activation starts again and the concentration of activated source slowly increases, causing a slow increase in count rate that becomes constant when the activation rate equals the decay rate of the activated source.

The activated nuclei cannot be Al, Si, O, Ni, Fe, or Cr, because these elements are present in the sample and in construction materials, which show no such activation. Only the mica window of GM #1 contains elements not present anywhere else. These elements are listed in Table 2 based on EDX analysis. Only C and K are present in the detector and nowhere else, both of which have unstable isotopes. A GM detector having a plastic window rather than one made from mica did not show this activation. Consequently, the likely activated nucleus is  $K^{40}$ .

**TABLE 2**  
Composition of mica window based on EDX analysis

<b>C - 55 wt. %</b>
O - 16 wt. %
Si - 10 wt. %
Al - 9 wt. %
<b>K- 5 wt. %</b>
Fe - 3 wt. %
Mg, Ti, Na - < 1 wt. %

The radiation being emitted by the sample is proposed to result from a fusion reaction that produces coherent photons. These photons are proposed to react with  $K^{40}$  nuclei in the mica window of the GM to stimulate its decay by beta and gamma emission that is easily detected by the GM. Some of the energetic gamma from this decay can reach GM #2 and cause a slight increase in count, as shown in Fig. 13.

This study raises many questions that are not answered and demonstrates some very unexpected behavior. Having this behavior made known without delay is more important than taking time to answer all questions before publication. Therefore, this paper should be viewed as a progress report about an important behavior.

## V. CONCLUSION

Material treated in a manner to produce voids is found to radiate photons when exposed to  $H_2$ . This radiation is able to activate a nucleus exposed to this radiation, which decays with an average half-life of about 109 min. This photon radiation can be produced using Cr, which is not magnetic, and Ni, which is magnetic after the metals are subjected to stress. Ni also reacts with Cu to form the same type of structure, after which photon radiation is produced when the alloy is exposed to  $H_2$ .

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