Nuclear Detection

Executive Summary

In addition to our search for anomalous heat events, we also considered the possibility that D-D fusion may occur within a lattice and emit traditional nuclear byproducts. We performed experiments ranging from post-mortem "staring" to look for delayed emission of particles to in-situ measurements during ionization of PdD_x with high intensity laser pulses. In no cases did we observe nuclear products suggestive of deuteron fusion.

Background

The general premise of the LENR field is the observation of anomalous heat events; these events are suggested to be the coupling of nuclear byproducts to a material lattice, namely a 24 MeV photon, that is emitted during D-D fusion events to phonons within the material. One difficulty in this assumption is the mechanism by which the 24 MeV couples to the lattice: Generally, a high-energy *phonon* (lattice vibration) has an energy on the order of 10s of meV. This large mismatch between the nuclear and phonon energies (9 orders of magnitude difference in energy) is a major stumbling block in theoretical attempts to understand LENR.

Rather than assuming an unknown scattering/coupling process arises for the emitted byproduct, we also considered the possibility that D-D fusion is occurring within the lattice and simply emitting the expected uncharged nuclear radiation – a 24 MeV photon or a 2.45 MeV neutron. Further, we consider the possibility that a reaction occurs between Pd ions and the deuterons within the lattice, leading to transmutation of the Pd atoms; this transmutation would lead to the emission of a characteristic x-ray/gamma ray that is easily identifiable with isotope libraries. These forms of nuclear detection are implemented in several of our experiments: These nuclear detection experiments range from us performing a standard "stimulation" experiment on PdD_x followed by placing the material in an ultra-sensitive "well detector" that eliminates background counts, to active stimulation of materials to conditions well above their ablation/ionization threshold with arrays of various detectors actively looking for particle emission. As detailed in this section, we ultimately **observe no evidence of nuclear transmutations or fusion reactions (i.e., LENR) within a solid-state lattice via nuclear detection.**

Detectors and analysis

Our experiments on nuclear detection rely on three primary detector types: Active gamma detectors, gamma ray well detectors, and both plastic and liquid scintillators. In this section, we provide a brief background on each detector type, their advantages, and their use for LENR investigations.

One of the primary claims in LENR/AHE research is that D-D fusion within a solid-state lattice results in the emission of 24 MeV that couples to the lattice to generate heat. However, one channel of traditional D-D fusion would simply emit this as a 24 MeV photon without heat generation and be detectable by gamma ray detectors. Thus, we implement two forms of gamma ray detection. The first is with an in-situ detector that allows for gamma detection during stimulation experiments; in other words, the detector can be placed next to our sample/pressure vessel during any experiment performed. This looks for "prompt" gamma rays that are generated during stimulation. The second form of gamma detection is performed using a gamma ray well detector; in this instrument, a sample is placed within a deep well that is highly shielded by highly dense, thick walls to almost entirely remove radiation that is *not* emanating from the sample of interest. While this well detection method significantly improves signal to noise ratios, the geometry of the well limits the use to only post-mortem measurements of samples that have been stimulated. In other words, we use a gamma ray well detector to investigate potential *delayed* gamma emission – gamma rays that have been emitted sometime after stimulation occurs. These may take the form of delayed D-D reactions or signatures of transmutation as the isotope decays. Our other method of detection is via liquid or plastic scintillators. These detectors provide the advantage of not only detecting gamma rays, but detecting *any* ionizing radiation that reaches the detector. This allows us to broaden our search to include potential 2.45 MeV neutrons which are likely to occur from a branching ratio perspective.

Prompt gamma rays from D-D fusion or transmutation of elements

To investigate potential prompt gamma rays, we use an ORTEC high purity Germanium (HPGe) solid state detector. For these experiments, we place the detector near our pressure vessel; based on the geometry used, our detector's solid angle corresponds to a 5-10% detection probability[97] assuming isotropic emission. This "prompt gamma" detector was used in nearly every experimental campaign, including Calorimetry, USP, TI, HPE, and CHIPS.

[97] Our "standoff" distance, the distance between detector and sample, varies from 6" to 12" in most experiments, corresponding to ~5 and ~10% solid angle coverage, respectively.

In this example, shown in Fig. 1, we can see example spectra for both isotopes of Pd as well as a control experiment with no Pd in the calorimeter. As shown, there is no discernible differences between the plots, suggesting no additional nuclear activity in any given case. However, it is worth highlighting the background features from having an exposed detector (i.e., a non-well detector with sufficient shielding to external radiation); a large amount of background counts is due to the elements that exist within normal construction materials, for example, the peak at 511 keV is due to Na-22; the large signal at ~0 keV is simply background noise from thermal excitations; etc. Overall, **the fact that there is no isotopic variation observed in *any* prompt gamma measurements suggests a lack of nuclear-related processes within these experimental campaigns.**

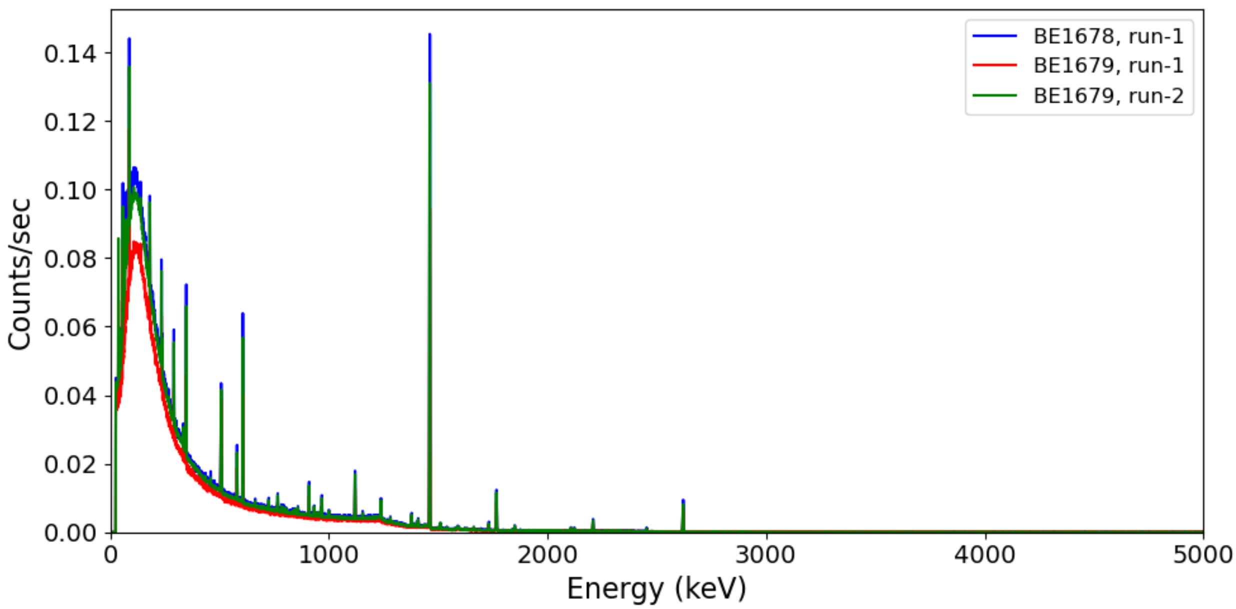

Figure 1: Prompt gamma emission detected during a loading experiment with (red) PdD_x, (blue) PdH_x, and (green) no sample.

Delayed gamma rays from D-D fusion or transmutation of elements

One alternative approach to detection of prompt emission is placing an already-stimulated sample of PdD_x within a gamma well detector that reduces these background counts by orders of magnitude. This approach would allow for a greatly increased probability of detecting transmutations of Pd that may be due to nuclear events. The decay chains following neutron capture by isotopes Pd^{102}, Pd^{108}, or Pd^{110} involve steps slow enough so that emitted gamma rays can be detected by promptly placing the Pd into a gamma well detector after its use in an experiment. Notably, this form of detection was used in multiple studies by NASA, in which deuterated materials such as Ti and Er were exposed to high energy gamma rays for prolonged durations; afterwards, the samples were placed in a low-background environment and delayed gamma events were measured. In these studies, the authors observe non-negligible increases in gamma rays suggestive of transmutation; while this work was indicative of solid-state driven nuclear reactions, it is critical to recall their use of >1 MeV stimulation methods, which is energy well-in-excess of the energy required to drive traditional nuclear processes. In other words, this method of delayed gamma emission has been utilized to identify when *lattice-based* nuclear reactions occur *at high energies*; comparable evidence at low energies, which is our primary interest, has not been observed.

An example of a delayed-gamma experiment is shown below in Fig. 2; this data was obtained following a calorimetry experiment using Pd nano-powder. One immediate contrast relative to our prompt data in Fig. 1 is the significant reduction in additional peaks: While the Na-22 peak at 511 keV is still present, for example, a large number of other isotopes associated with building materials have been removed. Further, one can note the total counts/sec is reduced by over an order of magnitude when comparing Fig. 2 to Fig. 1.

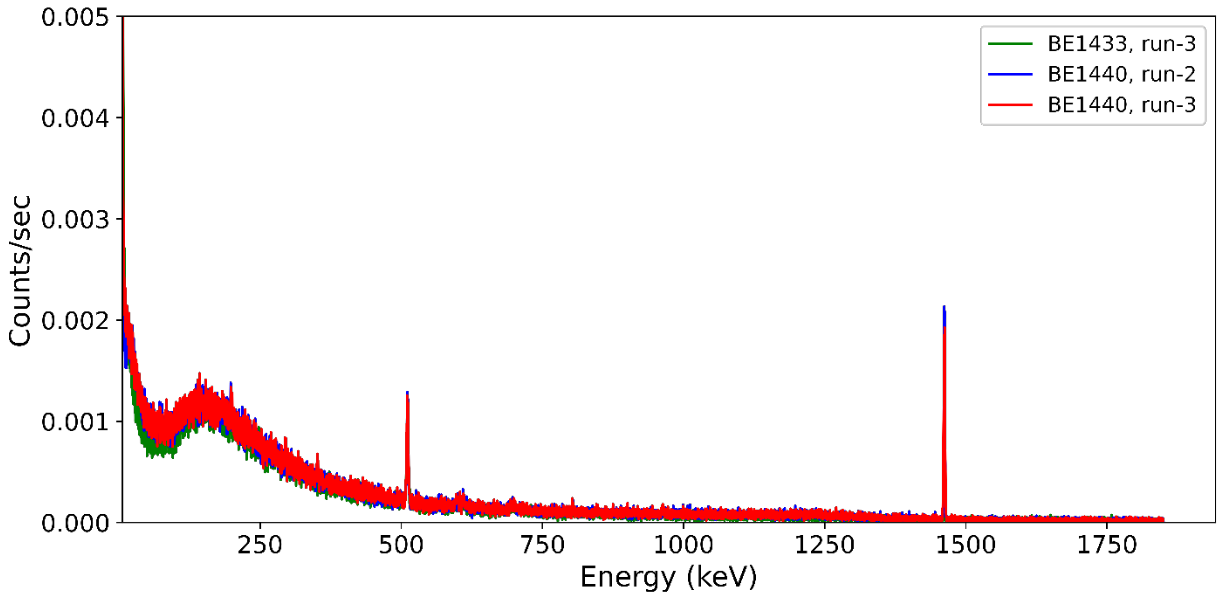

Figure 2: Delayed gamma emission detected during a calorimetry experiment with (red) PdD_x, (blue) PdH_x, and (green) with no sample.

Notably, we were able to perform *in-situ* electrochemical experiments with PdD_x and PdH_x using this gamma well detector in BE4056, thus greatly reducing background noise while providing *prompt* gamma detection. Despite the order of magnitude reduction in background counts, no form of isotopic contrast nor transmutation elements were observed. Further, we note that time-localized spikes in gamma-ray counts *were* observed in a few instances; for example, during a case in which one of our pressure-vessels failed, there was a corresponding increase in the total counts per second observed in the detector. While one may argue that the failure *could* be indicative of AHE driven during the depressurization, these results were able to be mimicked by us through other seismic events and are observed during earthquakes or intentional motion of the detector itself. Again, the lack of isotopic contrast in *delayed* gamma experiments is suggestive of a lack of deuterium LENR.

Prompt gammas, neutrons, and electrons

In contrast to our HPGe detectors, the use of modern liquid scintillators allows for detection of *any* ionizing radiation above some energy threshold. The intensity of the scintillation signal provides a measure of the radiation's energy, while the shape of the scintillation signal provides a measure of the type of particle. In other words, to differentiate different particle types, one can rely on pulse-shape discrimination (PSD), where the signals are binned according to both their pulse shape as well as their energy. An example of this is shown below in Fig. 3; the contour provides a measure of the number of counts that are measured by the detector at a given intensity (energy) and pulse shape (PSD), allowing differentiation, in this example, of neutron and gamma rays over a wide energy spectrum.

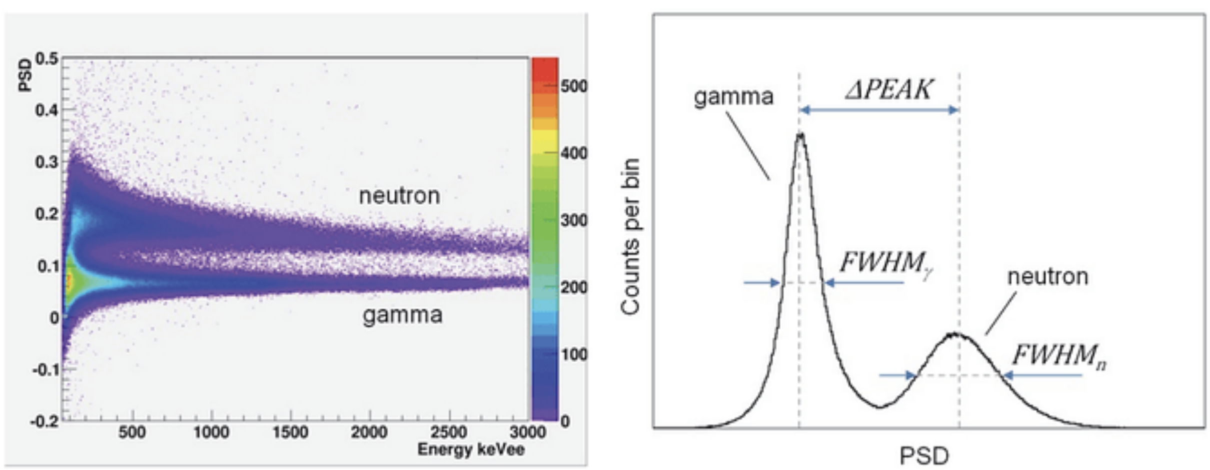

Figure 3: (Left) Contour of measured counts (color axis) for a given pulse shape (y-axis, PSD) and varying intensities/energy levels (x-axis). This allows for simultaneous measurements of different types of ionizing radiation. (Right) Comparison of a gamma-ray signal in contrast to a neutron-induced signal.

In one instance, we relied on these liquid scintillators to look for potential LENR events in our HPE calorimetry studies, where large voltage spikes were observed during electrochemical loading. An overview of this experiment is shown below in Fig. 4 for PdD_x. Despite large variations in the electrochemical characteristics over time, the liquid scintillators measure a constant number of events per second. To understand the sensitivity of these detectors to LENR reactions, we note that four detectors are surrounding the HPE vessel; each detector has a *conservative* estimate of 3.5% areal coverage. Given the Pd mass (50 mg) and near-unity loading, there are an estimated $3*10^{20}$ deuterons ($1.5*10^{20}$ potential reaction sites since 2 deuterons are involved in the reaction). At our background counts per second of <50 cps, we can use these values to set a probability on the fusion rate for us to observe an event. If we assume that a signal of >100 cps is easily resolved, this suggests that we need $100 \text{ cps} / (0.035 * 1.5 * 10^{20}$ reaction sites) = $2 * 10^{-17}$ events *per deuteron pair* each second. In other words, these measurements would suggest that in ~10^{17} seconds we may observe events exceeding the background. This analysis procedure includes *any* ionizing radiation and is not discriminating based on pulse shape nor intensity.

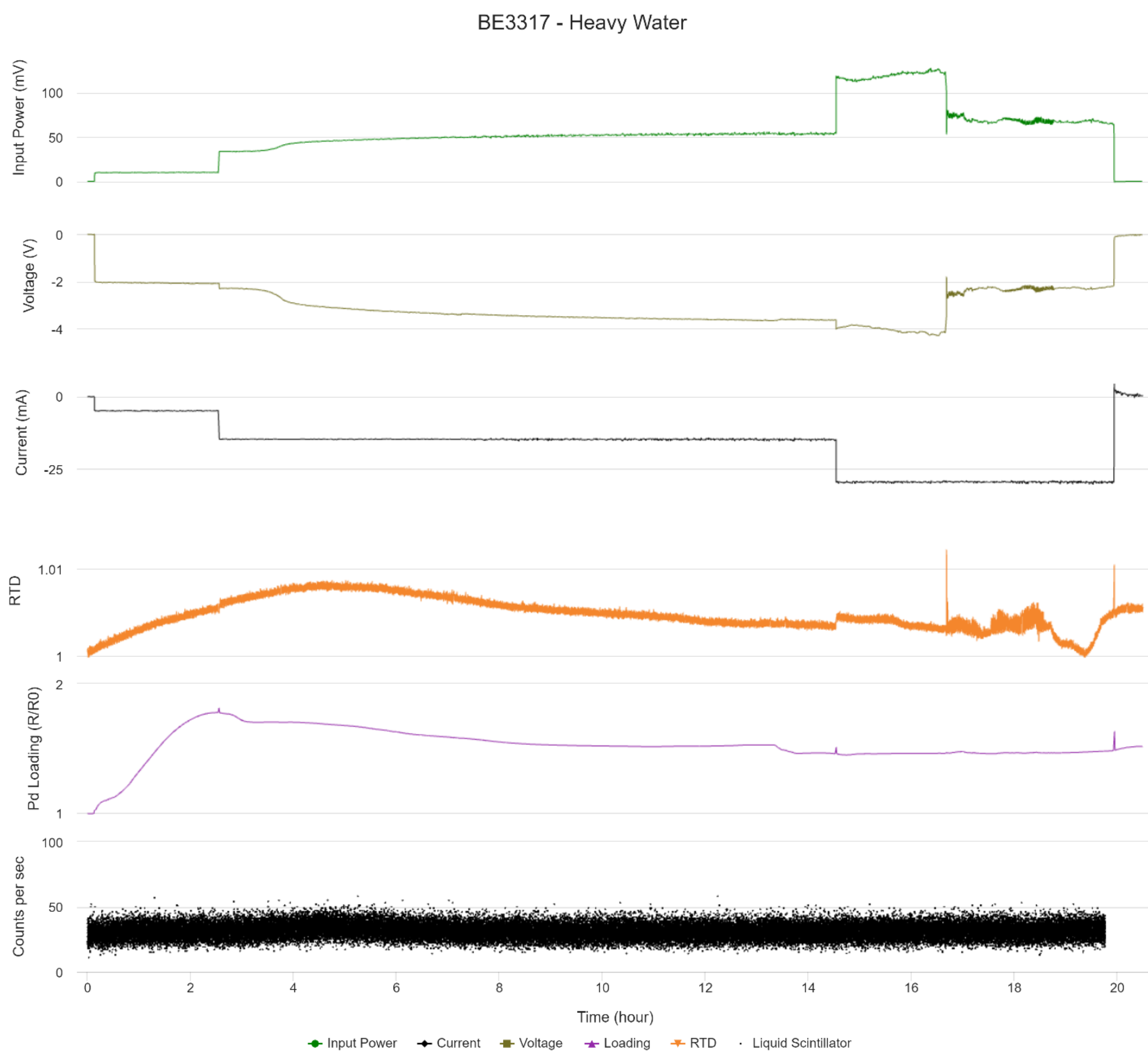

Figure 4: Overview of data from BE3317 in which 4x liquid scintillators were placed around an HPE vessel during various voltage instabilities/anomalies. The bottom plot provides the scintillator data of counts per second.

In other instances, we implemented arrays of these detectors in our USP campaign. In particular, we used multiple forms of nuclear detection to investigate potential D-D fusion events when stimulated with an ultrashort laser pulse at intensities in excess of 10^{16} W cm^{-2} – at these power densities, the material is effectively vaporized. These experiments are of interest due to evidence suggesting that D-D fusion can occur *in the absence* of a lattice with comparable laser intensities in molecular deuteron jets/clusters[98,99]. While we observed significant amounts of ionizing radiation being produced in PdD_x, increased counts were observed in PdH_x. Further, a number of alternate, non-loading materials exhibited even greater production of ionizing radiation at these laser intensities. Figure 5 displays the comparison of radiation produced across several materials in a vacuum environment, including “pre-processed” Pd that was stimulated in a gaseous environment before the radiation measurements[100]. This combination of effects clearly rules out AHE or D-D related reaction processes; additional nuclear diagnostics suggest this is a form of inverse Bremsstrahlung, where electrons are accelerated by the high intensity laser.

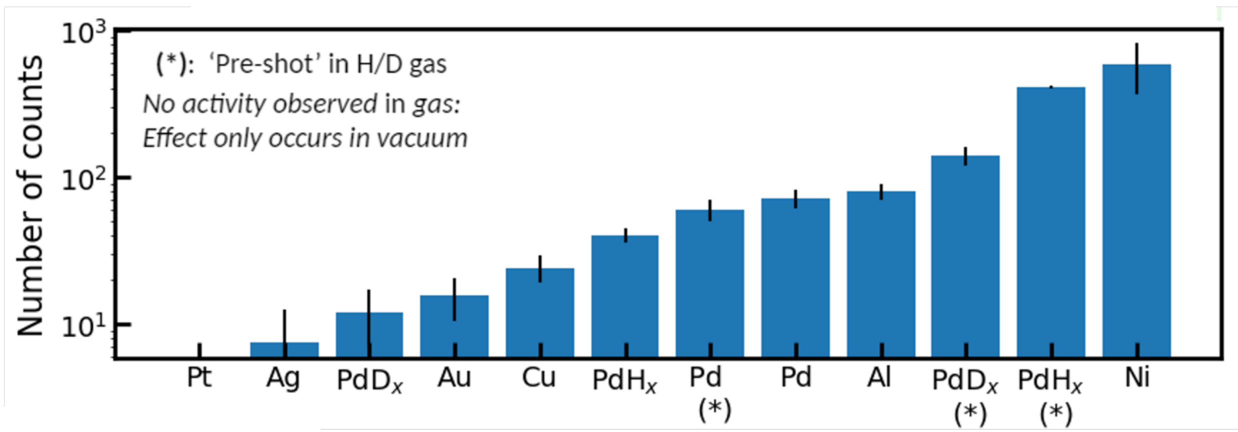

Figure 5: Relative amount of produced ionizing radiation with high intensity laser stimulation across different materials, both loaded and unloaded.

Summary

In summary, across multiple forms of nuclear detectors and implementation into a variety of stimulation and “staring” based experiments, we observe no evidence of energetic radiation from LENR processes or AHE-like effects. These observations provide lower limits on the probability of nuclear processes occurring and producing conventional byproducts; this lower limit suggests the likelihood of observing nuclear reactions on a meaningful timescale is effectively null.

[98] Ditmire *et al., Nature* **398**, 491 (1999).
[99] Grillon *et al., Physical Review Letters* **89**, 065005 (2002).
[100] We observe *no* produced radiation with a gaseous atmosphere; vacuum is required to observe this effect. This is the result of nonlinear optical effects that occur due to the high intensities; the beam is effectively absorbed *by* the gas, reducing the intensity on-target.