Is Reported "Excess Heat" Due to Nuclear Reactions ?

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ABSTRACT

A portable X-ray detector has been developed to complement "cold fusion" studies. Our reasoning is that any set of nuclear reactions which produce measurable heat must also produce abundant secondary X-rays. However, at the Nagoya meeting and elsewhere, we found that errors and uncertainties in current experiments prevent unambiguous interpretation of claims of excess-heat generation. Hence, this paper also outlines criteria for establishing calorimeter performance for definitive measurements of "excess heat" in cold-fusion experiments.

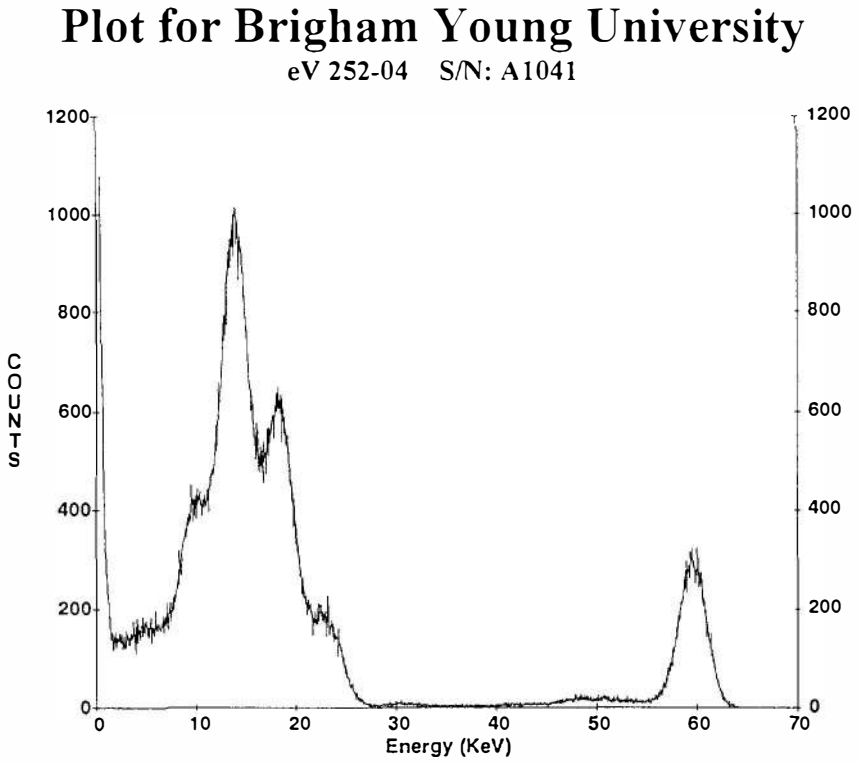
PORTABLE X-RAY DETECTOR

Nuclear reactions are characterized by release of MeV-scale energies, hence their importance to power-production schemes. (Chemical reactions typically involve eV-energies, down by a factor of 10^6 from nuclear reactions.) But energy release at the nuclear level implies that secondary x-rays will be produced, since only tens of keV are required to generate x-rays. If nuclear reactions are indeed producing heat at the levels claimed ($>$ 1mW), then sufficient x-rays should be produced to be detectable. The x-rays arise from the ionizing effects of nuclear products on the materials in which the heat develops. Thus, x-ray measurements may provide a crucial test for the presence of heat-generating nuclear reactions.

Characteristic x-rays of Pd or Ni (for example) which result from K shell vacancies produced by fast nuclear products are readily detected using a 10mmX10mm photodiode. The energy of the x-rays provides information on what reactions are taking place. (For example, if the Ru K-alpha line at 19.2 KeV is strong, one may surmise the production of Ru.) A typical response spectrum for this detector is shown in Figure 1. Note that the noise level is well below the nickel K-alpha line (7.5 keV) and the Pd K-alpha energy (21.1 keV). The detector is small enough (2.8 cm-diameter X 3 cm long) to fit next to or even into an operating cell. Furthermore, it operates well near room temperature.

A Monte Carlo computer code was written in order to estimate the number of x-rays detected near an electrolytic cell in which one of several fusion reactions occur. The cell is assumed to be cylindrical in shape, to have glass walls, and to contain a cylindrical palladium (or nickel) electrode immersed in D_2O. The number of x-rays detected per fusion event is calculated.

FRONTIERS OF COLD FUSION



Source	^{241} Am
Photodiode Size	10 x 10 mm
Bias Voltage	+40 VDC
Shaping time	3 μsec
Oper. temp.	+20^{0} C
FWHM	4.4%

Fig. 1: Typical x-ray energy spectrum from small x-ray detector.

The input parameters are:
·rod radius and length
·thickness of the surface layer in which fusion events occur
·distance from center of cell to rod
·cell radius and height
·glass thickness
·reaction: d+d-->p+t, d+d-->n+^{3}He, d+^{6}Li-->2α, d+^{7}Li-->n+2α
·detector aperature (assumed to be square)
·distance from center of cell to detector
·quantum efficiency of the detector
After these parameters are determined, the program follows the charged particles event by event.

First a fusion site is determined. This site is randomly selected from points within the specified skin thickness of the palladium electrode. (End effects are neglected.) The skin thickness may be set to the electrode radius in order to model fusion events occurring uniformly throughout the volume of the electrode.

Then the direction of the first outgoing charged particle is randomly selected and the particle is stepped through the palladium rod. At each step the energy is calculated using the proton stopping powers of Zeigler, Biersack, and Littmark, *The stopping and ranges of ions in matter*, Pergamon Press, New York (1985). The stopping powers of other ions are determined from proton values by using Z^2 scaling. At each step, the K-shell ionization cross section is calculated using ECPSSR cross sections from Chen and Crasemann, *At. Data and Nucl. Data Tables*, **33**, 217, and Chen from Johansson and Campbell, *PIXE*, Wiley, New York (1988). The x-ray production cross section is then calculated by multiplying the ionization cross-section by the fluorescence yield. The cross section for ions other than protons is determined by taking Z^2 times the proton cross section for the same energy per nucleon.

From the cross section, an x-ray production probability is determined. Since the cross sections are very small, the probability is augmented by a suitable factor which is later divided out of the results. (This is equivalent to making each "event" correspond to a large number of identical fusion events.) On the basis of this probability, it is determined at each step whether or not an x-ray is emitted.

If an x-ray is emitted it is determined if the x-ray is a K-α or K-β x-ray on the basis of the β/α ratio. The direction of travel is then randomly chosen. The x-ray is followed along this direction through the electrode, D_2O, and glass to the detector. Each event is then given a weight corresponding to the overall attenuation factor. The sum of such weights then represents the total (fractional) number of detected x-rays.

Since K-α and K-β x-rays have different attenuation factors, they are summed separately so as to provide an estimate of the numbers detected in each peak.

Whether or not an x-ray is emitted at a given step, the ion continues its path through the electrode. Each ion is then followed until it stops or leaves the electrode, the possibility of x-ray emission being considered at each step. If more than one charged particle is produced in the fusion event, the second particle is tracked in a similar fashion.

EXAMPLE: Fusion occurs at the rate of 10^{11} events per second (10^{-1} W assuming d-d fusion) in the volume of a 1.0 mm diameter Pd wire, 3.0 cm long. The average path of x-rays through D_2O is 2.0 cm and through glass is 2.0 mm. The detector is 3.0 cm from the Pd wire.
5.86×10^5 K-α x-rays make it to the surface of the Pd each second.
The solid angle factor is 0.00774
Transmission through the D_2O is 0.307
Transmission through the glass is 0.378
Detector efficiency is 0.115
The product of the last four factors is 1.03×10^{-4}, so 60 K-α x-rays per second are detected. This is of order 10^2 above the sensitivity limit imposed by typical backgrounds.

We strongly encourage use of x-ray detectors in connection with cold-fusion experiments in order to determine the presence of nuclear reactions. Our detector including multi-channel analyzer board and portable computer cost only about $5,500 so that expense should not be a major obstacle to its use. This detector system was developed at the suggestion of Dr. Tom Passel of EPRI.

OUTLINE OF CRITERIA FOR ESTABLISHING CALORIMETER PERFORMANCE FOR MEASUREMENT OF "EXCESS HEAT" IN COLD-FUSION EXPERIMENTS

The calorimetrist has the responsibility to conclusively demonstrate the accuracy and precision of the heat measurements. Accurate heat measurement is far from trivial and nothing should be assumed without good justification. Experience shows that gross errors can occur from obscure and difficult to detect effects.

I. A precise and complete description of how the calorimeter functions must be given together with a detailed physical description of the instrument. The physical description must include materials and accurate dimensions for all calorimeter components. The functional description must include the method of heat measurement and a description of the calorimeter system and surroundings.

   A. There are three methods of heat measurement.

      1. In the heat conduction method, the temperature difference across a thermal path with constant thermal conductivity between the system and surroundings is measured. This temperature difference is linearly proportional to the rate of heat flow through the path (Newton's law of cooling). For accurate measurement as much as possible of the heat flow must be through the measurement path. All other heat flow paths must also have a constant thermal conductivity.

2. In the power compensation method, the heat rate is measured by the change in input power required to maintain a constant temperature in the calorimeter when the measured process occurs.

3. In the temperature change method, total heat is obtained by multiplying a measured temperature change in a known amount of material by the heat capacity of the material. If the material is flowing at a known rate, the heat rate is obtained.

B. The calorimeter surroundings may be one of two types.

1. In isoperibol calorimeters, the surroundings are kept constant.

2. In adiabatic calorimeters,the temperature of the surroundings is kept at the same temperature as the calorimeter system so no heat is exchanged.

C. The calorimeter may interact with the surroundings in ways other than heat exchange.

1. The calorimeter may be open and mass may be transported between the calorimeter system and the surroundings. An open system usually is operated at a constant pressure, i.e. atmospheric pressure. At constant pressure heat is equatable with enthalpy.

2. A closed system is also usually a constant volume system where heat is equatable with total energy.

II. Three kinds of experiments have been done in efforts to determine the "excess heat" that may be due to cold fusion.

A. Absolute heat measurements have been made by comparison of the heat effects of the reactions to the heat from an electrical heater. To be accurate, an absolute measurement must meet several criteria.

1. All heat generated in the heater must be transported to the calorimeter system. The amount of heat generated in and lost through the heater lead wires must be negligible or corrected for.

2. All heat transport paths between system and surroundings must be quantified, controlled, and accounted for.

3. The heat distribution in space and time produced by the heater must closely match that from the reactions.

4. Calibrations and tests must be alternated in time and done in approximately equal numbers.

B. Relative heat measurements have been made by comparison of the heat effects of the reactions in control (e.g. light water) and test (e.g. heavy water) systems. Precision is more important than accuracy in such measurements, thus the following criteria.

1. To assess random errors and detect any changes in calorimeter function, controls and tests must be alternated or simultaneous in time, approximately equal in number, and if possible done both in parallel and sequentially.

2. The thermal conductivities of all heat transfer paths must be shown to be the same for both controls and tests.

3. The heat distribution in space and time must be the same for controls and tests.

C. Some experiments have been designed to show that the "excess heat" effect is so large that no conceivable errors or chemical effects could possibly account for the results, and thus the observed heat must come from nuclear reactions. Such experiments require verification by sufficient and proper controls.

III. The calorimeter output signal must be consistent with the heat transfer characteristics of the calorimeter. For example the time constant for changes in the measured heat rate must be the same as the time constant for transport of heat from the calorimeter to the surroundings in a heat conduction calorimeter. Proper functioning of temperature sensors in the calorimeter environment must be verified. As an example, thermocouples are prone to errors caused by chemical corrosion of the junction and by stray electrical currents.

IV. Finally, to verify actual performance, the calorimeter must be tested with a reaction having an accurately known enthalpy change.

V. Because all electrochemical calorimetric experiments intended to demonstrate "excess heat" require correction for the heat of the electrolysis reaction, the expected reaction must be verified and quantified. Otherwise an incorrect value for the thermoneutral potential will be used in the correction. For example, deposition of an alkali metal under a silicate (or aluminate or borate)

coating on an electrode in aqueous solution possible at cell voltages near 3 volts. The thermoneutral potential for Li is about 2.9 volts, compared to 1.5 volts for hydrogen. A negative "excess heat" rate proportional to the rate of deposition of Li would thus be found if the reaction were assumed to be strictly generation of hydrogen. The accuracy of the thermoneutral potential must also be assessed. A value derived from a single source or type of the measurement cannot be considered reliable. Note also that if a lithium layer is deposited on an electrode under a coating (e.g., silicate, borate or aluminate coating) and later should the coating crack, then exothermic water-lithium reactions would result, producing "heat bursts".

"Excess heat" can only be proven to be nuclear in origin by showing that the products of the nuclear reactions are produced at the same time and rate as the heat and in amounts commensurate with the law of mass-energy conservation. X-rays would, however, be a strong indicator of nuclear (MeV-scale) reactions and would be an effective tracer of high-energy reactions when the precise nature of the processes remains hidden. Until such proof exists, application of Occam's razor demands that "excess heat" be regarded as having its source in ordinary chemical reactions.