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GAMMA HEATING MEASUREMENTS WITH PROPORTIONAL COUNTERS

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GAMMA HEATING MEASUREMENTS WITH PROPORTIONAL COUNTERS

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A new data acquisition technique (the Continuously-varied Bias-voltage Acquisition mode) has been developed and tested for the low-flux broad-energy regime characteristic of existing fusion blanket mock-ups. This method of analysis allows for the acquisition of data spanning several orders of magnitude in energy with a single proportional counter. Utilizing this method, the gamma energy deposition in a mixed neutron and gamma field was measured.

1. Introduction

Knowledge of the heating due to gamma radiation in test assemblies surrounding an experimental fusion device will help shape the material and structural design constraints of blankets in future devices. Methods that contribute to this end must provide spatial and energy characterizations of the gamma radiation field with discrimination against neutron-induced signals. Presently one method is readily available for resolution of radiation in a mixed field: calibrated proportional counters. Use of proportional counters to observe discrete signals allows for the rejection of fast pulse-rise events, which are characteristic of the nuclear recoils produced by elastic neutron scatter [1-3].

A coupled calculational and experimental program to develop proportional counters for gamma-ray heating measurements is currently underway at the Argonne National Laboratory (ANL). Methods for absolute energy calibration and determination of signal amplification as a function of bias voltage applied to the proportional counters have been demonstrated and codified. Analysis software for neutron-induced signal rejection has been developed and

tested. A novel data acquisition scheme that enables the user to collect data over a wide portion of the proportional regime with a single counter in a single exposure (the Continuously-varied Bias-voltage Acquisition mode) has been developed. An experiment to test measured energy deposition against calculated energy deposition in materials of interest is currently in the second phase of implementation.

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2. Background and Key Considerations

The well known Bragg-Gray effect states that the electron energy-loss spectrum present in a sufficiently small cavity is representative of its surrounding walls [4,5]. It was further observed by Fano [6] that if the effective Z of the cavity is equivalent to the Z of the walls, then the electron energy-loss spectra of the two are equivalent. This is the key implication of Cavity Ionization theory: for a sufficiently small cavity, with a matched effective Z filling, the measured energy-loss response in the cavity is equivalent to the response in the surrounding material. Also, if the characteristic electron energy-loss spectra are known for both the wall material and the cavity fill-gas for the irradiation of interest, a correction factor [namely $cS(E)_w/cS(E)_c$] from theoretical calculations can be applied to the measured result $[S(E)_c]$ to derive the desired quantity $[S(E)_w]$, the electron energy-loss spectrum in the bulk material. In this discussion:

$cS(E)_w$ is the calculated electron energy-loss spectrum of the walls.

$cS(E)_c$ is the calculated electron energy-loss spectrum of the cavity.

$mS(E)_c$ is the masured cavity spectrum.

$S(E)_w$ is the spectrum of interest.

$cS(E)_w/cS(E)_c$ is known as the $1/f$ factor.

Neutron sensitivity is an important issue in this application. After all, the interest of this project is gamma heating. Only electron and charged particle production can be viewed as local effects. Consequently, the major portion of a gamma's initial energy (via Compton scatter) is deposited near the interaction site. Charged particles (neutron induced recoil gas atoms) have a higher linear energy transfer coefficient than electrons; hence the respective differential rise time of a charge particle pulse is greater than that of an electron of comparable kinetic energy. This fact gives the researcher a method to discriminate between gamma and neutron effects in a proportional counter.

Energy deposition in the counters is a function of the effective Z of the fill material and the amount of material in the counter. Thus f-factors are implicit functions of gas filling and pressure. To obtain these f-factors, we will calculate the electron energy-loss distribution for selected materials in slab geometry, and utilize the calculated results to interpret measurements made under similar conditions.

The relationship between gas amplification and bias voltage can be determined by observing and recording the change of the counter output signal as the bias voltage is changed. A functional relationship can be established by best curve fitting the recorded data. This has been done, and the procedure for doing so is well developed [7].

3. Experimental Apparatus and Procedure

Presently at ANL, proportional counters and support systems developed by Bennett [1] for proton recoil experiments have been refurbished. The proportional counters are composed of stainless steel-walled cylindrical

cathodes fitted with insulating end-plugs, with a 1 mil wire running along the axis as the anode. The counters are fitted with gas feed lines, which allow for the quick change of gas fillings.

In taking data over a broad range of energy with a proportional counter, one encounters a physical limitation in the collection method: a proportional counter operating at a fixed (discrete) bias-voltage will only sample a small region in energy. This limitation results from the need to provide a signal sufficiently strong to be distinguishable from amplifier noise at the low end, and yet not so strong as to incur space charge separation in the counter. A complete picture of the spectrum must be derived by normalization and piece-wise fitting of the overlapping regions of data taken with different bias voltages. The disadvantages of such a data collection method in observing a difficult to repeat exposure are patently obvious: one must utilize many counters (and associated sets of driving electronics), each operating at different bias-voltages to collect the necessary data, and then normalize and combine the spectra. To overcome this difficulty a continuous voltage biasing mode of data acquisition has been developed [7] and adapted for this pursuit: the Continuously-varied Bias-voltage Acquisition mode. This new method offers a marked improvement over the discrete voltage-biasing mode in that an energy-loss spectrum covering several orders of magnitude in energy can now be observed with a single counter in a single exposure. This is significant because many energy-loss distributions of interest span several orders of magnitude in energy. Additionally, the equipment needed for data acquisition and the time spent in data analysis have been reduced substantially.

In the CBA mode, the bias voltage is swept from a predetermined minimum to a predetermined maximum corresponding to the minimum and maximum gas amplification that allows for observation of the radiation of interest. This

is done by feeding a cyclic ramp voltage input into a programmable high voltage power supply. These voltage limits are taken from a log (amplification) $[\log(A)]$ vs. bias-voltage functional fit derived for the specific counter in use. From this fit a look-up table of $\log(A)$ can then be generated for each value of voltage in the range of interest. The $\log(A)$ vs. voltage fit must be rederived each time a different fill gas prescription is used.

The CBA mode is essentially a set of assembler instructions that instructs a signal generator to feed a cyclic driving input whose endpoints correspond to the bias voltage endpoints of interest into a programmable high voltage supply. The choice of a cyclic ramp rather than a sinusoidal input is predicated by the desire to increase acquisition time in the region between the endpoints rather than around the endpoints. The assembler code also permits one to specify what quantities the ADC of the system encodes. Quantities such as the time (t), voltage (V), pulse height distribution $Y(t,V)$ and the pulse width distribution $X(t,V)$ are encoded. The $\log(A)$ vs. V look-up table is then accessed via the software to provide the appropriate weighting factor for each value of Y for its corresponding V .

The advantage this method holds over the discrete biasing mode is in analysis time. In analysis of an exposure taken with the CBA mode, one can derive information over the entire span of interest without the need for multiple normalizations and matchings. The uniformity of equipment and environmental parameters during exposure is an added bonus.

To calibrate a gas-filled counter with respect to energy, one can simply inject a low-energy beta decay isotope into the fill-gas. The endpoint and the peak of the beta decay spectrum are observed, and the related bias voltages are recorded. A functional relationship can then be derived for the

range in energy defined by these points and the corresponding bias voltages. The region is then calibrated in energy.

Utilizing the CBA mode the energy-loss spectrum of tritium (T) was observed. The end-point of this spectrum was used to calibrate the energy range of the proportional counter currently in use. Graphing the observed spectrum and a theoretical Fermi distribution in the form of a Kurie plot shows good agreement between experiment and theory. This process was done for all counters in the inventory.

The energy of each individual pulse is related to the intensity of its electron avalanche onto the anode. Each pulse also carries information about its rise-time. In this system the signal from the counter is fed into both an integrating (Y) amplifier for pulse height (energy) analysis and a differentiating (X) amplifier for pulse stretching. The rise time of each pulse can be obtained by forming the ratio of the signals from the X and Y amplifiers. A distribution of X/Y data spanning 32 channels is assembled for each value of Y, over the 512 possible Y channels available in this system. It is then possible to separate (set a cutoff for) Compton scatter events from neutron recoil events by carefully observing the individual X/Y distributions for each Y and the sum of X/Y events over all possible Y's, as the electrons and recoils will appear in different regions of the X/Y distribution. Rejection of the neutron-induced atomic recoil signal (or, conversely, the gamma signal) can then be accomplished via a software option to blank out the appropriate portion of the output array.

The resulting data show the population distribution as a function of pulse height. This can be converted into a population distribution as a function of energy by observing the pulse height of a radiation of known energy. In doing so, tritium was chosen as the calibrator because of its beta

decay electron. Having done so, the appropriate weighting values have been programmed into the analysis software. The software then compiles a complete energy*fluence vs. log(energy) distribution from the weighted data.

The experimental setup consists of an isotopic source incident on a pile assembly. The pile assembly is formed by stacking 5 cm x 5 cm x 60 cm rectangular magnesium sleeves filled with graphite into a cube. The source is either a Co-60 sample or a Texas Nuclear Model 9400 neutron generator. The proportional counter is set into its own Mg sleeve, which is then back-filled with graphite. This design allows us to change material and counter position in the assembly with little effort. The counter occupies different positions away from the source in the central drawer-line of the pile perpendicular to the source during different exposures. This will map out the secondary electron energy-loss profile of the assembly as a function of distance from the source. From this profile, the heating due to the incident radiation can be determined as a function of distance from the source.

4. Results

By observing the decay of tritium in the CBA mode, the complete spectrum is observed. A Kurie plot of the data appears in Fig. 1. Associating the Y channel in which the maximum pulse-height of the beta spectrum falls with a value of 18.6 keV calibrates the counter for the system conditions (settings of the amplifiers, etc.) at which the data were taken.

The following three figures illustrate the process of rise-time separation. The counter used for this measurement is filled with 90% Ar, 10% CO₂ to a pressure of 1078.5 mm Hg. In Fig. 2, a X/Y distribution is shown at Y = 100 (~9 keV), for both a bare counter and a counter shielded by two layers (10 cm) of graphite-filled Mg sleeves for a two-hour exposure at 10⁸ n/s, 24

cm from the tritium target of the Texas Nuclear 9400. The dominant feature is the gamma peak. Figure 3 shows for the same conditions the X/Y distribution at channel Y = 250 (~ 25 keV). A clear separation of the gamma and recoil events is apparent. If the counts of the events are considered, the number of the more energetic neutron recoil events are over-shadowed by the vast number of gamma events. This is shown in Fig. 4, which shows the composite X/Y distribution summed over all Y. A counter with different gas filling will exhibit different sensitivities.

Figure 5 shows the final gamma-only energy*fluence distribution plotted against log(energy). Using this information the gamma heating from this exposure is derived, defined as:

$$\text{heating} = \frac{(\text{Sum of the E*fluence-distribution})}{[(\text{active counter volume}) * (\text{fill-pressure/atmospheric}) * (\text{collection time}) * (\text{mol-wt}/22.41 \text{ l})]}$$

$$= \text{energy deposition/cavity mass/time.}$$

For the shielded exposure shown in Fig. 5, the gamma heating was 1.35×10^{-13} w/g $\pm 7\%$.

5. Future Directions

In order to evaluate the utility of this experiment, we must be able to calculate the conditions at the point of measurement. That is, we are interested in the neutral flux (gamma + neutron) profiles in the assembly, as well as the coupled neutral to charged-particle (CP) flux response. The calculation should be flexible enough to allow us to vary the neutral-to-CP

(charged particle) interaction matrix. In this light, codes such as MCNP or the integrated TIGER series are considered.

From these calculations the f-factors of cavity theory, which relate energy deposition in the counter cavity with energy deposition in the counter wall, can be established. This result allows for the interpretation of the

heating of the counter wall material as a scaling of the measured heating to the counter fill-gas.

6. Summary

The problem of gamma heating measurements in a mixed gamma and neutron field has been considered. An experimental system for gamma heating measurements has been designed and built at ANL. Techniques for calibration and neutron signal rejection have been developed and examined. An experiment designed to test the applicability of these developed techniques has been built, and the above mentioned capabilities have been demonstrated. Numerical modeling of the experiment, and subsequently a C/E comparison for the experimental setup, is planned.

It is hoped that by comparing calculated to experimental results, a clearer picture of gamma heating be obtained in a mixed neutron and gamma environment.

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Figure Captions

Figure 1. Kurie plot of ^3H β -decay data taken with the CPA mode.

Figure 2. Rise-time distribution for keV.

Figure 3. Rise-time distribution for keV.

Figure 4. Composite rise-time distribution for both shielded and un-shielded exposure to 14 MeV ^1_0n .

Figure 5. Gamma only distribution.

($\gamma=100$)

(Y=250)