UCRL-13880

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Final Report

"Development of Fast Neutron Spectrometer System for Study of Short-Lived Nuclides Important to the Decay Heat Problem"

UCB-ENG-4485

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Lawrence Livermore Laboratory Purchase Order No. 7915503

July 15, 1977 - December 31, 1977

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April 15, 1978

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1. Performance

The objectives of this study as specified in the purchase order were a) to develop techniques for measurement of delayed neutron spectra with resolutions approaching 8.0 keV at the thermal peak and b) to explore techniques for measuring gamma rays and neutrons in coincidence. During the contract period the following have been accomplished: a) the electronic, accoustical and inherent noise characteristics of the 3 He neutron ionization chambers purchased from SEFORAD, LTD have been characterized. Through construction of an accoustical shield and replacement of several components at the input stage of the preamplifiers associated with the detectors, the resolutions of the spectrometers have been improved by about 10 - 15% and the environment has been controlled to permit maintenance of the improved resolution under normal laboratory conditions. The improvement in resolution corresponds to the removal of approximately 5 keV of noise equivalent. The resolution of the best spectrometer is now 9.3 keV; b) it has been shown that the amplitude and resolution for neutrons from a thermalized Pu-Be source are dependant upon pulse risetime. For the risetime range 0.2 - 1.2 μ s, the amplitudes of pulses were found to vary by 0.7 - 0.8 keV and the longer risetime pulses led to a full energy peak narrower than that from the short risetime pulses by about 0.2 keV. Model calculations have shown that the energy spectrum of neutrons from the source can contribute as much as 1.0 keV to the width of a "thermal peak"; c) based on the information available in the literature on the Fano Factors of gas mixtures approximating that existing in the spectrometers, and the measurements made on one of the detectors, we can conclude that external factors are still contributing significantly to the resolution and that it should be possible to obtain a resolution of near 8.0 keV with no change in the gas mixture; c) the principal limitation in the use of the ^3He spectrometers for neutron - gamma ray coincidence measurements lies in the long times required for drift of electrons from the site of interaction in the device to the grid surrounding the anode. While the anode signal will be thus delayed, the cathode signal should be essentially "prompt" and it is proposed that attempts be made to examine the time distributions for coincidences using both signals to obtain information for the possible improvement in timing performance.

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A. Improvement in Resolution of ^3He Neutron Spectrometers

The ^3He ionization chambers obtained from SEPORAD were supplied as cylindrical devices with integral preamplifiers. They were known to be very sensitive to the accoustical environment and to yield resolutions considerably degraded from theoretical. In order to identify and correct for noise sources external to the ionization chambers, a program was initiated to a) determine the accoustical sensitivity of the spectrometers and construct a sound shield to minimize resolution degradation from environmental noise, b) eliminate electronic noise from controllable sources such as the power supplies and c) study the construction of the input section of the preamplifiers and the quality of the components with the view toward direct reduction of noise at this stage of amplification. Details of these investigations are given below.

a) Microphonics

The study of microphonic sensitivity of the spectrometers was undertaken with the aid of the reverberation chamber in the laboratories of the Department of Mechanical Engineering, University of California, Berkeley. In the following, a review of this work is given and the complete study is described in the M.S. thesis of Jeffrey S. Marsh, entitled "Accoustical Sensitivity of the ^3He Neutron Spectrometer" (to be submitted to the Department of Nuclear Engineering, University of California, Berkeley).

Under normal operating conditions, one of the spectrometers was subjected to varying noise amplitudes of known spectral composition and the induced noise at the output of the associated linear amplifier was recorded. Actual measurements were made over intervals of $1/3$ octave band and the data converted into noise equivalent at full-width-at-half-maximum (fwhm) for Pu-Be moderated neutrons. A simple mechanical model for the interaction of sound with the spectrometer was developed, shown to account for the experimental observations over the frequency range studied, and used to derive an expression that permits the calculation of resolution degradation under any accoustical environment as measured by field survey instruments. For the accoustical spectrum existing in the Reactor Laboratory of the University of California, Berkeley, it has been shown that up to 4.2 keV noise equivalent can result from this source. The noise levels found at accelerator facilities are, for example, much greater and thus appreciable resolution degradation can be expected.

The data acquired in these measurements have been used to obtain parameters for the design and construction of a sound shield that will permit negligible resolution degradation under reasonable noise backgrounds. A small version of such a shield has been constructed and shown to provide a reduction in noise level of over 10 dB in the octave bands centered about 63 to 250 Hz and over 20 dB for the octave bands centered at 500 to 16000 Hz. Empirically, we have been able to measure neutron spectra with no apparent degradation due to accoustical noise under typical laboratory conditions.

b) Noise Associated with Power Supplies

Because of the small signals from the detector, power supplies that are of sufficient quality for Ge(Li) detector systems may still contribute significantly to the noise of the neutron spectrometer system. The main source of

interest is the high voltage power supply. The magnitude of the "ripple" from many bin mounted supplies is clearly large enough to contribute to degradation in resolution. We have compared the noise from a standard, high quality power supply from Fluke, Inc and found it to be a factor of about 200 greater than that obtained with a battery pack and that the use of the battery pack actually resulted in a slightly improved overall resolution. For routine usage, a well filtered output from a high quality high voltage supply should be used.

c) Preamplifier Characteristics and Detector Feedthrough

The preamplifier supplied with the detectors is a good quality, low noise device with a room temperature fet in the first stage of amplification. Through examination of the quality of various components in this stage and the voltage divider circuit used to supply power to the anode and grid, it was found that a significant improvement in performance could be obtained by replacement with lower noise components or by upgrading ratings. The following changes were of significance:

- 1) the decoupling capacitor was replaced by a device with significantly lower leakage
- 2) the series resistor in the voltage divider was upgraded from 6 to 25 Ω
- 3) the filter capacitors in the voltage divider circuit were replaced by devices of somewhat lower leakage characteristics
- 4) the fet's supplied with the preamplifiers were replaced with selected devices which exhibited only 0.6 of the noise of the originals
- 5) the feedback capacitance, originally supplied by the capacitance of standoffs, was supplied by a 1pf Vitterman device.

These changes have led to a small but significant improvement in the electronic noise of the system. As measured by the width of a precision pulser, the electronic noise was reduced from 8.3 to 7.6 keV.

Relative to the overall resolution of the full energy peak from moderated Pu-Be neutrons, all of the efforts summarized above have led to the reduction in fwhm from 11.8 keV to 10.2 keV for the oldest of the three spectrometers and from 10.4 to 9.3 keV for one of the newer devices.

b) Detector Characteristics

Because of the proprietary nature of the spectrometers, very little information on detailed characteristics ^{was} supplied by the manufacturers. Thus a major part of our effort was directed toward measurement of those characteristics of importance to improvement in resolution.

By mass spectrum analysis, the fill gas has been determined to be (mole-percent): Ar, 29.45; CH₄, 8.13; 3He, 62.65. No traces of 4He or of other organic components were found.

Through use of a calibrated capacitor, the average energy required to produce an ion pair in the fill gas was found to be 27 ± 2 ev, which compares well with literature values for Ar - CH₄ (26.0) and He - CH₄ (30.3).

From the best resolution obtained for moderated neutrons from the Pu - Be source and the electronic noise of the system, the Fano Factor was calculated to be 0.32 ± 0.12 . This is considerably larger than the values 0.17 for Ar + CH₄, 0.075 for He + CH₄, and 0.055 for He + Ar. While the latter were measured at pressures near one atmosphere and the present detectors are at pressure near 10 atmospheres, it still appears that our result is too large. Since all electronic effects have presumably been accounted for, we have considered the possibility that the apparent large Fano Factor results from the non thermal nature of the neutron spectrum and that some degradation in resolution accrues from the variable risetimes of detector pulses.

The Pu - Be source was moderated with 12 cm of paraffin. Measurements of the cadmium ratio for neutrons incident upon the detector gave values between 3 and 4, indicating that a substantial fraction of the neutron interactions in the detector were from neutrons with energies greater than about 0.4 ev. While the actual spectrum is not known, a simple calculation of the mean energy of neutrons emerging from the paraffin moderator gave a value of about 40 keV. Assuming that the spectrum is described by a 1/E slowing down distribution, the mean energy of neutron interactions contributing to the "thermal peak" when the detector is surrounded by the integral cadmium - boron nitride - cadmium shield was calculated to be about 0.2 - 0.7 keV. This would directly affect the width of the full energy peak by the same order of magnitude. Without a substantial change in the moderator type or the use of a much stronger source with a very thick moderator, no change in the neutron spectrum can be affected.

Measurements of the risetime distribution of pulses associated with events giving full energy depositions in the detector showed that essentially all events corresponded to the time range 0.15 - 1.2 μ s. By gating on the time ranges 0.15 - 0.25 μ s and 1.1 - 1.2 μ s, the full energy peaks were shown to differ in energy by 0.7 keV and the widths of the distributions differed by 0.2 keV. The peak corresponding to the longer risetimes had both higher energy and better resolution. Several measurements under differing conditions of neutron spectrum and electronic gating showed similar results.

The preamplifier associated with the detectors has a nominal clipping time of 1 ms. To estimate the variability in the output of the preamplifier due to variable pulse risetime, a calculation was performed assuming that charge collection from an event occurs linearly in time with risetimes (measured as the 10 - 90% change in pulse amplitude) in the range 0.1 - 1.2 μ s. Under these conditions, the amplitude variations amount to as much as 0.5 keV. Since the real pulses will be described more nearly by exponential rises from the baseline, it is expected that the above estimate underestimates the real variation in amplitudes.

As a result of these experiments and calculations, it appears that the amplitude variation with risetime is due to the combined effects of the non-monoenergetic nature of the neutron spectrum and the risetime variation of the pulses. Even the later may be strongly dependent upon the neutron spectrum. The risetime distribution must be sensitive to the mean location of interactions in the detector. For purely thermal neutrons, the macroscopic cross section of the fill gas is so large that most interactions will be found in the vicinity of the detector wall where wall effects and loss in charge due to the low fields are most severe. On the other hand, for neutrons with energies above 0.4 ev range, the cross section is already so low that the interactions are distributed roughly uniformly over the entire detector volume. Thus both the mean value and

range of risetimes could vary significantly for thermal and epithermal neutrons. Clearly, experiments are required to separate the effects of the two phenomena discussed above and a proposed series of measurements is discussed below which should at once give an indication of the two effects and illustrate the improved resolution obtained with control of the variables.

c) Proposed Measurement

The Berkeley Research reactor has a thermal column that provides a thermal neutron beam with a cadmium ratio near 60. This may be improved to near 100 by use of an external column of graphite. In any case, a considerable softening of the neutron spectrum is possible with this facility. We then propose that the response of the detector to the well-thermalized beam be measured. Attendant with this measurement will be measurements of the risetime distribution of the pulses. Under the same electronic conditions, the energy and risetime spectra from the moderated Pu - Be neutrons will be measured. These data should at once give the spectral dependence of full energy interactions and the width of the full energy peak. If indeed the majority of neutron interactions from the moderated Pu - Be neutrons have energies well above thermal, a substantial difference in the risetime spectra between the two sources should be observed.

It is in principle possible to correct for the amplitude variation due to variable pulse risetime with a gated integrator. If the output pulses from the associated linear amplifier are impressed upon a gated integrator set for the time range from rise above noise to decay into noise, the resulting pulses will have nearly integrated all of the charge from single events. The output from the gated integrator then should exhibit improved resolution. Since it is known that the range in risetimes increases as the neutron energy increases, any improvement in resolution at thermal energies should be translated into even greater improvement for high energy neutrons.

A gated integrator of the type designed by J. McQuaid of the Electronics Group, Nuclear Chemistry Division, Lawrence Livermore Laboratory is now being constructed. After performance tests at the bench, this device will be used to compare the shape and widths for full energy peaks from thermal neutrons obtained with and without the gated integrator in the circuit.

While we have not achieved the goal of improvement in detector resolution to near 8 keV, substantial improvement has been effected through the efforts described above. Further, two external effects that can contribute significantly to the degradation in resolution from the theoretical limit have been identified and the combined effects have been estimated to account for as much as 1 - 2 keV in direct contribution to the peak widths. The measured Fano Factor for the detector fill gas would then be larger than inherent due to these effects and it can be shown that if the above estimate is correct and the spectral and risetime dependences corrected for, a resolution of near 8 keV can be achieved and the Fano Factor would now approach the literature values for similar gas mixtures.