Evaluation of Cosmic Rays for Use in the Monitoring of the MEDUSA Scintillator–Photomultiplier Diagnostic Array

Current and planned ICF implosion experiments require the detailed measurement of physical conditions on the imploded core. Glass and plastic shells filled with D_2 open a window into the core by measuring the ratio of the various fusion reactions occurring during the implosion.[1] The number of each reaction is measured by characterization of the energy spectrum for the penetrating reaction products (either neutrons or protons). The measurement of the neutron energy spectrum around the 3-MeV neutron from the $d(d,He^3)n$ reaction and around the 14-MeV neutron from the $d(t,He^4)n$ reaction has evolved into the most used nuclear core diagnostic.

For a target filled with D_2, the $d(t,He^4)n$ fusion reaction is a secondary process and will generate about 10^{-3} times less neutrons than the primary D_2 reaction, $d(d,He^3)n$. Large area detectors that measure the neutron energy spectrum by the time-of-flight (TOF) method have become the standard for determination of the details of the 14-MeV neutron spectrum.[2] Adaptations of this instrument are being built to also measure the neutron spectrum from the various primary fusion reactions with high energy resolution.[3] The Laboratory for Laser Energetics at the University of Rochester is building such a detector for implosion experiments planned for the OMEGA Upgrade. This diagnostic, a multi-element detector using a scintillator array (MEDUSA),[4] will be used to study the details of the neutron energy spectrum around the 14-MeV neutron emitted from the $d(t,He^4)n$ secondary reaction.

MEDUSA

The MEDUSA diagnostic consists of 960 separate scintillator-photomultiplier detectors arranged in an array with 32 columns and 30 rows. This array is located in a separate instrumentation room 19 m from the center of the target chamber. At this distance the time-of-flight for the 14-MeV neutrons will be 370 ns after their creation. The center of the target chamber is about 9.3 m above the center of the instrument. This requires that the array be tilted at an angle of 26° relative to the vertical so that the detector plane is normal to the line connecting the center of the array with the center of the target chamber. The active area of the array is 3.87 m^2, resulting in a subtended solid angle of 0.011 sterad. Each element of this array is constructed from a solid block of NE 110 scintillator 6.35 cm high × 6.25 cm wide × 7.62 cm deep. A Thorn EMI 9257B photomultiplier is attached to the rear of the scintillator block. A schematic for each of the individual detection channels is shown in Fig. 59.23.

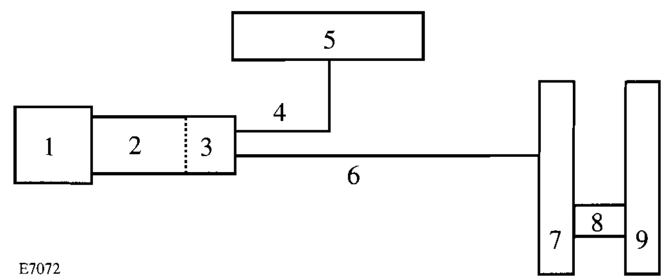

Figure 59.23
Schematic of each MEDUSA scintillator-photomultiplier channel.

Each MEDUSA channel (Fig. 59.23) consists of nine separate components, giving a total of 8640 components for the whole diagnostic array. All such large arrays require that all of these individual pieces continue to work during the lifetime of the instrument. The large neutron scintillator array (LaNSA) at the Lawrence Livermore National Laboratory[2] uses radioactive sources placed in each channel to monitor individual channel performance. LaNSA is a horizontal array at the bottom of a deep well, which makes the use of naturally occurring ionizing radiation difficult. The LLE MEDUSA array is nearly vertical and, as such, is a prime candidate for the use of cosmic rays as a source of ionizing radiation to monitor channel performance. The calculation of the counting rates and signal levels will determine if this technique will work.

Cosmic Rays

The flux of cosmic rays incident onto the surface of the earth is known to be 110 particles/(m^2 str s),[5] about 73% [80 particles/(m^2 str s)] of which are penetrating particles. Most of the particles at the earth's surface are muons. Muons are generated from the decay of pions created when a high-energy particle in space interacts with a nucleus in the earth's atmosphere. The muons have sufficient energy to be classified as minimum ionizing particles, which are particles that have energies greater than or equal to the energy of a particle at the minimum of the dE/dx ionization loss curve. Counting rates for the detectors in the MEDUSA array are calculated to be 2.9 particles/h for a single column of 30 scintillator-photomultiplier channels. This gives a total counting rate of 93.2 particles/h for all 32 columns in the diagnostic array. An overnight run of 16 h will result in 50 counts for each detector—enough counts to determine the status of all components in the diagnostic.

A minimum ionizing particle passing through a NE 110 scintillator has an energy loss (dE/dx) of 2.0 MeV/cm. The minimum path length of a cosmic ray detected by the MEDUSA scintillator-photomultiplier channel is 6.35 cm, resulting in a total energy deposition from the cosmic ray of 12.7 MeV. This is very well matched to the maximum energy deposited by a neutron of 13.7 MeV. Since there is sufficient signal to detect a neutron, there will be enough signal to detect a cosmic ray.

A test on a small subarray will determine if both a sufficient count rate and signal level exist to detect cosmic rays in the MEDUSA diagnostic array.

Cosmic Ray Tests

A smaller subarray of detectors was constructed to simulate the larger MEDUSA diagnostic. A schematic of this setup is shown in Fig. 59.24. It is constructed from a 4×4 array of MEDUSA scintillator-photomultiplier channels and two separate trigger counters. The trigger counters are used to establish the presence of a cosmic ray that has passed through the detectors in the subarray. Sixteen detectors were used from the MEDUSA diagnostic for the test so that the test was conducted with a sample of detectors used in the primary array. The trigger counters are scintillator-photomultiplier detectors constructed for a high-energy physics experiment conducted at the Fermi National Accelerator Laboratory in the 1970's and 1980's. The scintillator in the trigger counters is NE 111, 8.89 cm long $\times$ 7.62 cm deep $\times$ 1.27 cm thick. An Amperex 56 AVP is used as the photomultiplier. The voltages required by the trigger counters were 1750 V and 2200 V. The size of the trigger counters allowed tests to be conducted on four of the 16 subarray detectors during a single data-acquisition session.

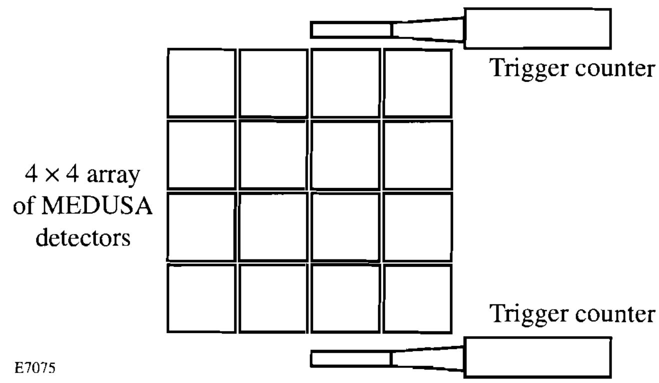

Figure 59.24
Schematic of the subarray used to test the cosmic-ray count rate concept for monitoring the MEDUSA diagnostic.

The trigger counters and the subarray detectors were connected to the electronics shown schematically in Fig. 59.25. The trigger counters were connected to a discriminator located in a NIM bin with the threshold set to 100 mV. The discriminator outputs were used as inputs for a coincidence logic unit. This logic unit gave an output when both discriminators detected a pulse above threshold to establish the presence of a particle passing through both trigger counters. The output of the logic unit was used as the start trigger for a time-to-digital converter (TDC) and as a gate signal for the charge-to-digital converter (QDC). The MEDUSA scintillator-photomultiplier outputs are fed into a CAMAC discriminator and a CAMAC QDC. The discriminators have computer-selectable thresholds. Outputs from the CAMAC discriminator were used as the stop triggers for the TDC. CAMAC scalars counted outputs from the trigger counter discriminators, logic unit, TDC start trigger, and MEDUSA channel discriminator. The CAMAC crate was controlled with an IEEE 488 interfaced controller connected to a Macintosh computer using National Instruments' Lab View as the data-acquisition software. This electronics and software configuration allowed a great deal of flexibility in the tests conducted with this subarray.

Three primary tests were conducted with the 4×4 subarray of MEDUSA detectors: (1) determination of the count rate as a function of the discriminator threshold; (2) measurement of the charge distribution as a result of cosmic rays depositing energy in the scintillators; and (3) studying the temporal histogram from the CAMAC TDC stop trigger generated when a cosmic ray is detected by the MEDUSA scintillator-

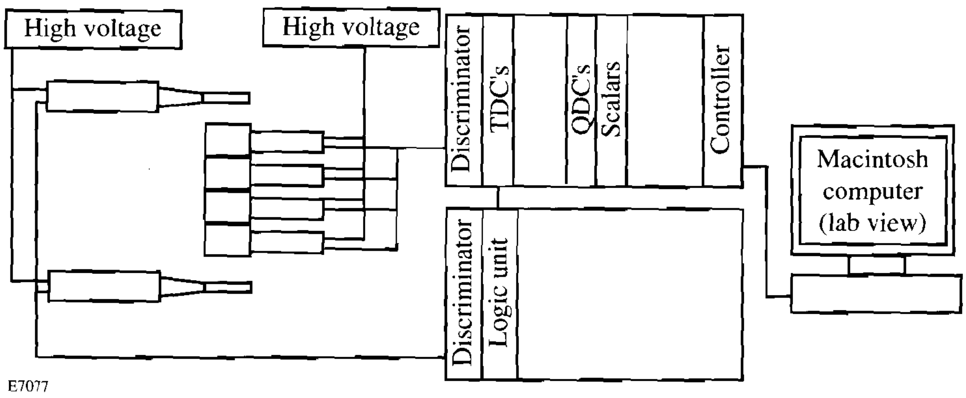

Figure 59.25
Schematic of the electronics used to test the cosmic-ray monitoring concept on the MEDUSA subarray.

photomultiplier channel. The output signal uniformity of the four channels tested is an indication of the expected performance for the whole array during a cosmic-ray test sequence. The results from the above measurements are shown in Figs. 59.26–59.28.

Data from the counter threshold measurement is shown in Fig. 59.26. The number of counts in 1000 s is plotted as a function of the CAMAC discriminator threshold. Four of the MEDUSA subarray detectors are plotted on the same graph. The minimum discriminator threshold is 20 mV, and the maximum threshold is 1020 mV. The first important observation is that all four detectors show nearly identical performance. There are two regions evident in the threshold data. The region below 50 mV is dominated by the noise from the scintillator-photomultiplier detector. These data are fit by an exponential, and the function can be integrated to determine the probability for a noise count during the active time of a neutron spectral measurement. All four channels show a 5% probability that there will be a noise trigger in all 960 detectors for a 1-μs diagnostic time window for a discriminator threshold of 17 mV. These data are being used to determine the thresholds for all 960 MEDUSA channels.

The results from the charge distribution test are shown in Fig. 59.27. As in the previous data, it is evident that all four counters have a nearly identical charge spectrum from cosmic ray energy deposition. There is a well-defined peak that is well separated from any noise. All four detectors show a peak at around 400 counts, corresponding to an integrated charge of 100 pC. The signal was attenuated by 2 before it was connected to the QDC. The total integrated charge from the detector is 200 pC. It was shown previously that a cosmic-ray event simulates a 13.7-MeV neutron that deposits 12.7 MeV in the scintillator. The data from the charge spectrum imply that a 13.7-MeV neutron will yield a total output charge of 216 pC.

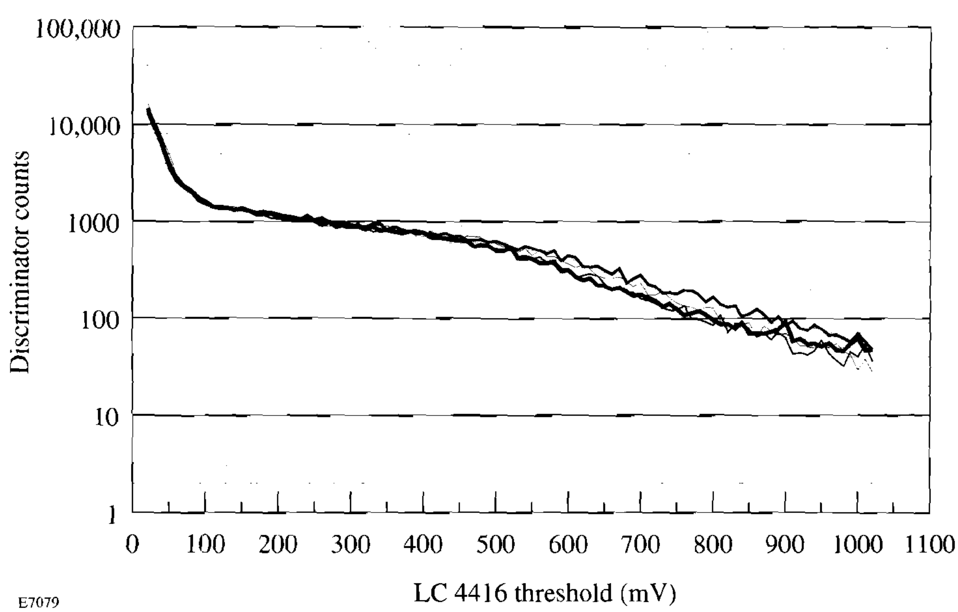

Figure 59.26
Plot of the number of counts from the discriminator verses the discriminator threshold for the MEDUSA channel subarray.

The uniformity of the spectrum from each of the four detectors will allow the cosmic-ray data to correlate to the calibration data from the nuclear fusion product source used to check selected detectors.[6] The cosmic-ray data will thus be able to serve not only as a monitor of the performance of each channel but also as a check of the energy calibration for the detectors.

The TDC data, plotted in Fig. 59.28, are nearly identical for each of the channels, as was the case in the two previous tests. All four channels show a peak around 20 ns. This time is determined by the added delay in each channel to insure that the stop triggers arrive after the start triggers. The width [full-width at half-maximum (FWHM)] for all of the channels is less than 0.5 ns, which is equivalent to one count of the TDC output. The consistency of these data indicates that it will be possible to use the cosmic ray data to check the performance of the TDC's used on the MEDUSA diagnostic.

Summary

The results from the initial tests to determine the utility of using cosmic rays to monitor the performance of the MEDUSA detectors indicate that this source of ionizing radiation is quite suitable. All tests imply that the data from the cosmic-ray monitoring sessions can be used to not only monitor the channels but also check their calibrations. The calculated counting rate for the subarray was 392 particles/h; the measured rate was 349 particles/h. MEDUSA's calculated counting rate of 93.2 particles/h should be close to the actual

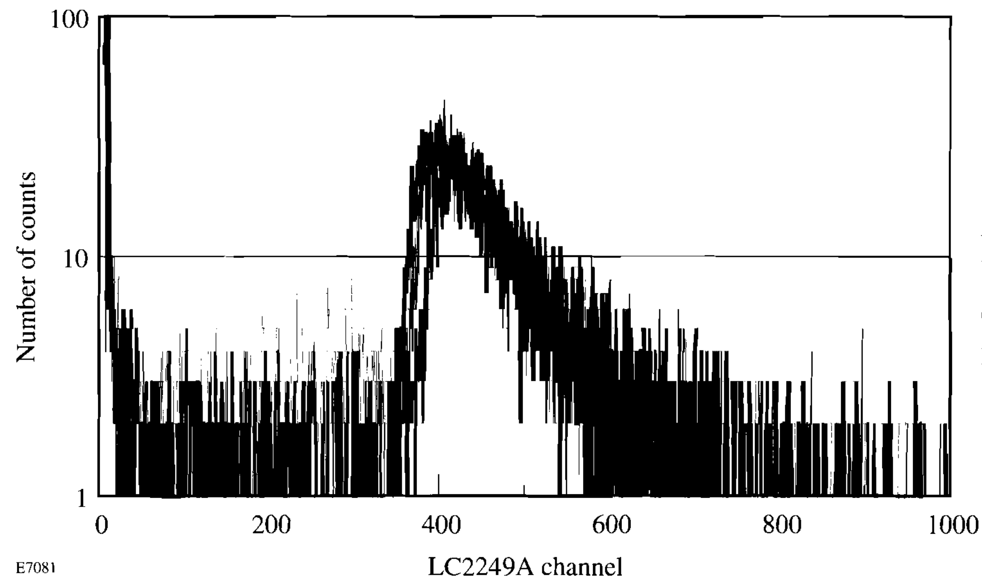

Figure 59.27
Pulse-height spectrum from the CAMAC charge-to-digital converter connected to the MEDUSA channel subarray.

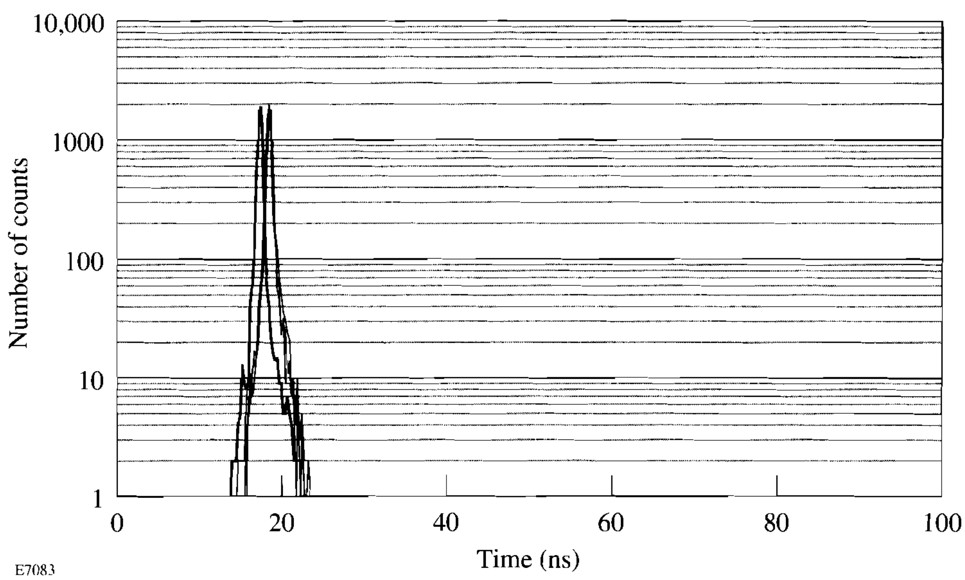

Figure 59.28
Temporal count spectrum from the CAMAC time-to-digital converter connected to the MEDUSA channel subarray.

counting rate when the full detector is completed and ready for testing. There is excellent agreement with the expected signal levels and temporal stop trigger jitter. Radiation sources or optically coupled sources should not be required to monitor the individual channels. To test the MEDUSA diagnostic, only a data-acquisition routine will be required to collect and analyze cosmic-ray events when the detector is not needed to acquire data from an ICF implosion.

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