THE SOLAR ISOTOPE SPECTROMETER (SIS)

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ABSTRACT

The Solar Isotope Spectrometer (SIS) is scheduled for launch on NASA's Advanced Composition Explorer (ACE) mission. SIS has two solid-state telescopes that are designed to measure the elemental and isotopic composition of solar energetic particles and anomalous cosmic rays in the energy range from ~ 10 to 100 MeV/nucleon, including elements from He to Zn ($2 \leq Z \leq 30$). This paper presents a brief description of the design and operation of SIS.

INTRODUCTION

The energy region from ~ 10 to ~ 100 MeV/nucleon contains several distinct particle populations (see Figure 1), including contributions from galactic cosmic rays (GCRs) and anomalous cosmic rays (ACRs) that vary over the solar cycle. In addition, particle fluxes below 100 MeV/nucleon are occasionally dominated by solar energetic particles (SEPs). The Solar Isotope Spectrometer (SIS) is designed to measure the elemental and isotopic composition of energetic nuclei from He to Zn ($2 \leq Z \leq 30$) over the energy range from ~ 10 to 100 MeV/nucleon, with excellent mass resolution and collecting power.

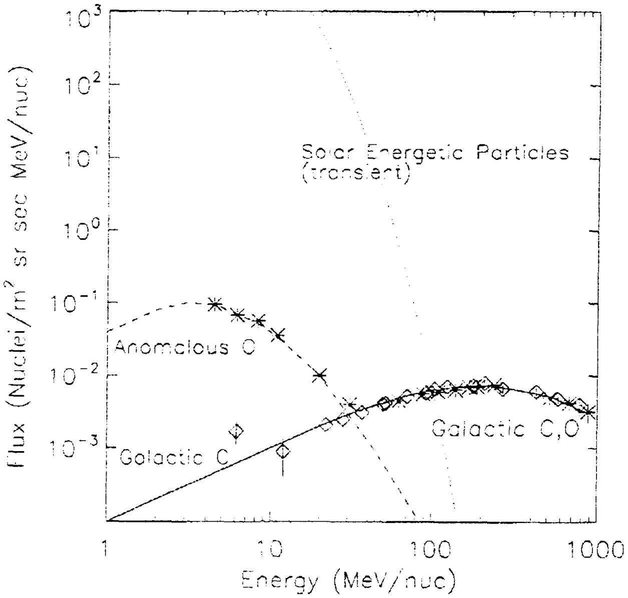

Fig. 1: Sample energy spectra for carbon and oxygen nuclei. Carbon (diamonds) and oxygen (stars) data shown were collected by previous missions. A "typical" SEP spectrum is also shown.

SIS is one of nine instruments to be launched on the Advanced Composition Explorer (ACE) mission in August 1997. Together these nine instruments will measure the elemental, isotopic, and ionic charge state composition of energetic nuclei from solar wind energies (< 1 keV/nucleon) to GCR energies (≈ 500 MeV/nucleon), in an effort to address a wide range of questions having to do with the origin, acceleration and transport of energetic nuclei in space (Stone et al. 1990; Garrard et al. 1997).

The goal of resolving isotopes of elements from He to Zn ($2 \leq Z \leq 30$) over this energy range while operating under a variety of interplanetary conditions requires excellent mass resolution, a large geometrical factor, and a large dynamic range. The sensor's design and capabilities are described below along with results from various calibrations.

INSTRUMENT DESCRIPTION

SIS utilizes the standard $dE/dx \times E'$ technique to identify particles that stop in the telescopes. For a particle incident at angle θ that loses energy ΔE in a detector of known thickness (Δx), the quantity $\Delta E/(\Delta x \sec\theta)$ is a useful measure of dE/dx. When combined with the residual energy loss (E') in a following detector (or detectors), the charge (Z), mass (M), and kinetic energy (E) can be determined.

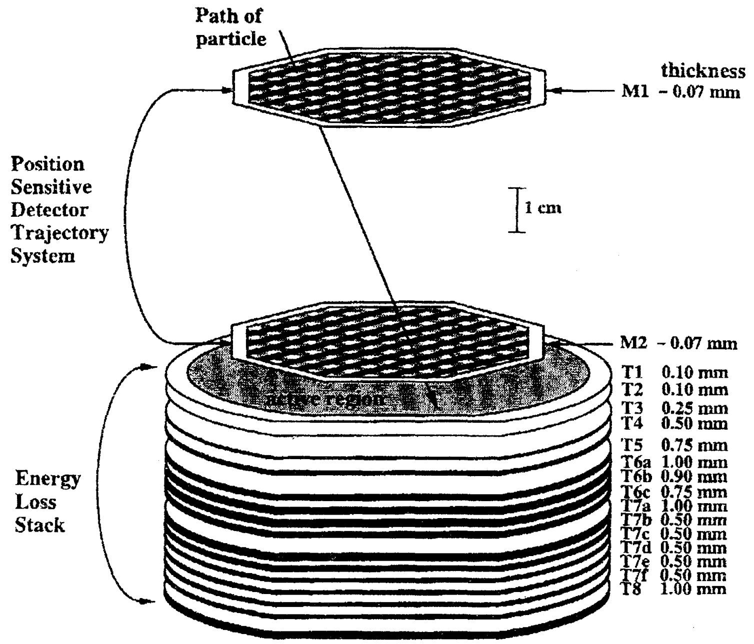

Fig. 2: Schematic of one SIS stack.

SIS consists of two identical telescopes, one of which is illustrated schematically in Figure 2. The first two detectors (M1 and M2) are two-dimensional "matrix detectors" that form a hodoscope to measure the trajectories of incident nuclei. M1 and M2 are $\approx 70\mu m$ thick devices with a matrix of 64 parallel "x" strips on one side and, orthogonal to these, 64 "y" strips on the reverse side. The strips are spaced at 1-mm intervals. Each strip is pulse-height analyzed with low-power VLSI circuitry designed especially for SIS (see Wiedenbeck, et al. 1997); strips that record energy losses of more than ~ 0.5 MeV are read out into the telemetry stream. During high-flux periods such as large SEP events there is a high probability of chance coincidences (especially in M1) between the heavy ions of interest and low energy protons. The capability to record pulse heights from multiple strips will allow the trajectory and pulse heights of heavy ions to be identified in even the largest solar events.

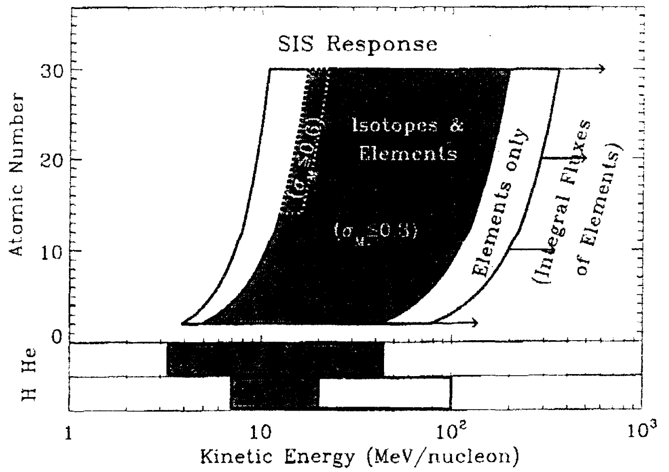

Fig. 3: Energy intervals over which elemental and isotopic analysis can be performed by SIS. At the lowest energies (M1M2 events), only elements and some key isotopes will be resolved.

Located below M2 is the energy-loss "stack" composed of 8 sets (T1–T8) of large-area (65 cm^2) silicon detectors of graduated thicknesses, made up of 15 separate silicon wafers (see Dougherty et al. 1997). Detectors T1 through T8 are individually pulse-height analyzed with custom VLSI circuitry also designed especially for the ACE mission. Valid events in SIS require a coincidence between M1 and M2, and include nuclei stopping anywhere from M2 to T8, as well as those that penetrate the entire telescope. Figure 3 shows the energy range covered for nuclei with $1 \leq Z \leq 30$. Note that anywhere from 1 to 9 separate measurements are made of the charge and mass of incident nuclei that stop in the detector stack. This redundancy provides background rejection and improved mass resolution. The combined geometry factor of the two telescopes is more than 40 cm^2 sr (see Figure 4). Taking into account the low threshold, the resulting collecting power for SEP and ACR isotopes is considerably greater than earlier instruments of this type.

Another requirement for achieving excellent mass resolution is precise knowledge of the thickness of the stack detectors. Thickness maps of the SIS stack detectors were created using a laser interferometer system (Milliken et al. 1995). To normalize the resulting maps, the stack detectors were taken to Michigan State University (MSU) and mapped using an ^{36}Ar beam. Comparison of these maps enabled detector thicknesses to be known to ≈0.4–0.5 μm rms. Combining the trajectory information with the maps yields an accurate determination of the pathlength traversed by the incident particle. Further information about the SIS stack detectors is contained in Dougherty et al. (1997). A summary of SIS's resource utilization is contained in Table 1.

At times of high intensity, such as SEP events, it is not possible to transmit data from all events due to limited telemetry. In order to maintain an emphasis on heavy isotopes, an onboard priority scheme is utilized. Events are gathered and assigned to one of 94 buffers based on range (how deep in the sensor the particle traveled), pulse height (roughly classifying events as H, He, $3 \leq Z \leq 9$, or $Z \geq 10$), and approximate incident angle ($\theta < 15°$, $15° < \theta < 25°$, $\theta > 25°$). They are read out of these buffers in a commandable order with highest priority going to particles which have long ranges, high Z, and small incident angle. In addition, a number of events (also commandable) in each 256 second instrument cycle are read out using a simple polling scheme, sequentially going through each of the buffers in turn. This ensures a more uniform sample of all event types and prevents the possibility of lowest priority events being eliminated entirely during periods of high flux. Rates and livetimes needed to derive absolute fluxes for each category of events are also measured.

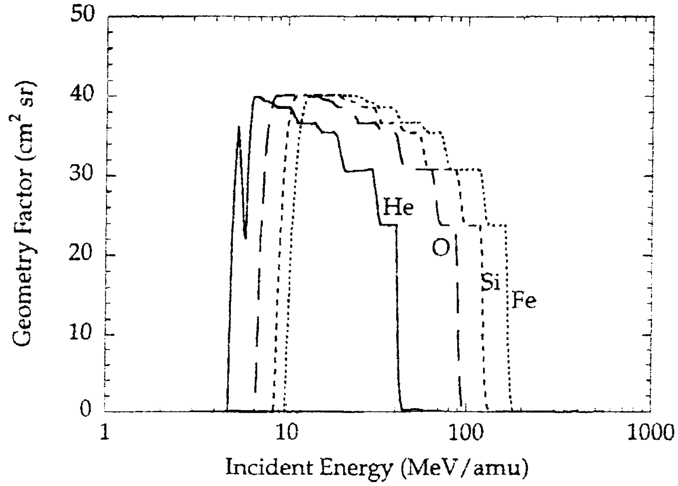

Fig. 4: Geometry factor for various elements as a function of energy.

INITIAL PERFORMANCE RESULTS

SIS was calibrated at the MSU cyclotron and the GSI accelerator in Darmstadt, Germany. Figure 5 illustrates the results of one of the GSI runs in which an ^{56}Fe beam was fragmented in a CH_2 target. It is apparent that SIS achieves the required mass resolution necessary to resolve the isotopes of heavy elements.

Table 1: SIS Resources

Resource	Usage/Availability
Weight	22 kg
Power	18 W
Bit Rate	1992 bits/sec

ACKNOWLEDGEMENTS

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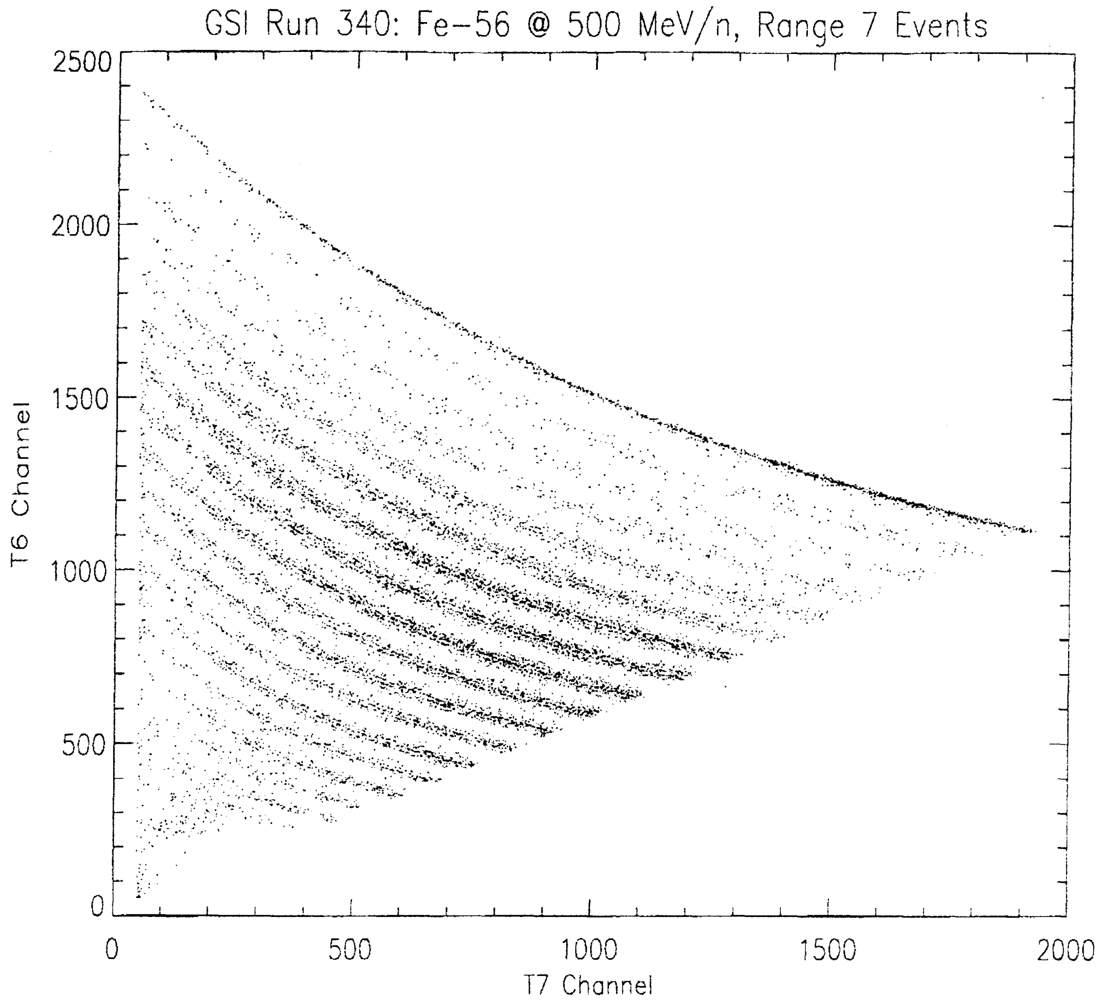

Fig. 5: Raw pulse heights measured in T6 and T7 detectors during an ^{56}*Fe fragmentation run at GSI for events stopping in T7. Several isotopes of elements from Ne—Fe can be identified as separate tracks. See Figure 2 for definition of T6 and T7 detectors.*

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