CREAM
Science Requirements Document

This Science Requirements Document is a preliminary version. The instrument configuration is in the definition stage, and many of the specifications represent an educated guess at what the final numbers are likely to be. Actual numbers will be available when a detailed design is completed.

1.0 Introduction

1.1 Scope

The Cosmic Ray Energetics And Mass (CREAM) investigation was approved in 1998. This document establishes the scientific requirements for the CREAM mission. It is divided into six sections, including this introduction. A brief description of the mission and scientific objectives is provided, followed by the science requirements for mission design, ballooncraft configuration, mission operations, and data handling.

1.2 Related Documents

Additional information can be found in the following related documents:

- "Cosmic Ray Energetics And Mass" – NASA NRA-98-03-ULDB Proposal.
- "The CREAM Balloon Experiment" – NASA NRA-98-03-CRP Proposal.
- "An ULDB Mission to Study High Energy Cosmic Rays", E.S. Seo et al., Proc. 26th ICRC (Salt Lake City), OG.1.2.30.
- "Cosmic Ray Energetics And Mass (CREAM): A Detector for Cosmic Rays near the Knee", J.J. Beatty et al., Proc. 26th ICRC (Salt Lake City), OG.4.1.16.

2.0 The CREAM Mission

2.1 Scientific Objectives

The Cosmic Ray Energetics And Mass (CREAM) project will measure the energy spectra and elemental abundances of H to Fe over the energy range 10^{12} eV – 10^{15} eV. The goal is to observe spectral features and/or abundance changes that might be related to a supernova acceleration limit. The CREAM instrument will consist of a sampling tungsten/scintillator calorimeter preceded by a graphite target with scintillator layers for trigger and track-reconstruction purposes, a transition radiation detector (TRD) for heavy nuclei, and a segmented scintillator-based charge detector. A key feature of this instrument is the simultaneous measurement of the energy and charge of a subset of nuclei by complementary techniques, allowing inter-calibration of the calorimeter and TRD energy scales. A large exposure can be accumulated in a series of ULDB flights of identical instruments. The different flights could be carried out at essentially any latitude, including the polar regions of either hemisphere. The overall CREAM objective is to accumulate at least 500 particles each for protons, helium, CNO, Ne-Si, and Fe group nuclei above 10^{14} eV, with a statistical accuracy of 30% above 10^{15} eV. This requires an exposure of about 300 m^2-sr-days for protons and helium nuclei and about 600 m^2-sr-days for heavy nuclei. With three ULDB flights CREAM would accumulate 100 m^2-sr-days for an energy reach of about 5×10^{14} eV. CREAM can also perform a sensitive measurement of secondary nuclei produced in the interstellar medium, allowing detection of a change in energy dependence up to about 10^{12} eV/nucleon, an order of magnitude above the reach of existing data.

2.2 Mission Strategy

The CREAM mission strategy is to push for longer duration flights even at the cost of reduced likelihood of payload recovery. The exposure would be accumulated in a series of 100 day (or longer) flights of identical instruments. A single 100-day flight of CREAM would give more statistics than all the currently existing high-energy data. Three flights would reach 5×10^{14} eV and therefore provides a significant overlap with ground-based air shower data. The development of the instrument could begin in late 1999, and the first ULDB flight could occur as early as the late 2002. A LDB flight in the winter of 2002 is planned as a fallback option in case the ULDB program is delayed.

2.3 Instrumentation

The main components of CREAM, the institutes responsible and the components' function are listed in the following table.

Instruments	Responsible Institution	Performance
Charge Detector (QDET)	Penn State U	Identify incoming particle charge
Transition Radiation Detector (TRD)	U of Chicago	Measure velocity of cosmic ray nuclei $Z \geq 3$
Calorimeter (CAL)	U of Maryland	Measure energy of cosmic ray $Z \geq 1$

2.4 Detector Performance Objectives

The following performance objectives must be met for full project success.

Parameter	Performance Objective
Element Coverage	From $Z = 1$ through $Z = 26$
Absolute Energy Calibration	Better than 10%
Collecting Power	≥ 10 protons above 10^{15} eV
Charge Detector Resolution	Individual elements $Z < 15$; individual or element groups $Z \geq 15$
TRD Element Coverage	$Z \geq 3$
TRD Velocity Resolution	15% carbon; 7% iron (for $\gamma > 3000$)
Calorimeter Energy Resolution	Better than 50%

2.5 Mission Success Criteria

2.5.1 Desired Project Success

- To meet science goals CREAM needs >10 good proton events at energies > 1000 TeV.
- Minimum total exposure > 860 days (to obtain 300 m^2-sr-days) with altitude > 110,000 ft.
- Multiple flights over multiple years.

2.5.2 Minimum Project Success

- At least 10 good proton events at energies > 500 TeV.

- Minimum total exposure > 265 days (to obtain 100 m^2-sr-days) with altitude > 110,000 ft.
- 3 or more ULDB flights.

2.5.3 Desired Performance per Flight

- 100 – 200 days with altitude > 124,000 ft.
- All detectors fully operational.
- Telemetry of all data.

2.5.4 Minimum Performance per Flight

- 60 days with altitude > 110,000 ft.
- 90% of charge detector area operational, S1 and S3 hodoscopes operational, calorimeter layers number 3 through 16 operational.
- Recovery of data from telemetry or flight recorders.

3.0 Science Requirements on Mission Design

3.1 Launch Site and Flight Path

The detection of cosmic ray particles in the energy range to be investigated by CREAM is not dependent on geographic location, or day/night conditions, providing a great deal of flexibility in launch sites and times. The flight path does not affect the collection of data, so any flight path consistent with operational requirements is acceptable.

3.2 Launch Window

There is no scientific requirements on launch window, other than those dictated by mission requirements to optimize flight duration and altitude.

3.3 Duty Cycle

It is desirable to maintain 100% duty cycle for all instrumentation. Reducing the nighttime power consumption by operating portions of the instrument during daytime only is not a viable option, as this would require a significant increase in overall flight operations and/or science mass.

3.4 Mission Lifetime and Balloon Performance

The most important requirement is to maximize the collection of particles to produce statistically meaningful data. This can best be accomplished by multiple flights, and optimization of the geometric factor of the instrument in accordance with the tradeoff in altitude that is likely to result from the increased mass. The optimal configuration is estimated to be a 1200 kg instrument. A nominal altitude of 115,000 ft with flights of at least 100 days would yield good statistical results with this configuration. Each flight would extend the capability to detect a kink in the proton spectrum to higher energies. Studies have indicated that reduction of mass cannot effectively be compensated by increased flight duration, as relatively small mass reductions require substantial increases in flight duration. Altitude is important, particularly for the heavier nuclei, and the highest possible altitude is the best, but it may be possible to reduce the required altitude if it would result in a longer duration flight. Attitude control is not required, since the entire field of view is essentially equal and symmetrical about the vertical axis. Coarse knowledge of attitude (+/- 1 degree) and altitude (+/- 1%) is required.

Parameter	Desired	Minimum Acceptable
Float Altitude (ft)	124,000	110,000
Altitude Stability (ft)	± 5,000	± 10,000
Flight Duration	200 days	60 days
Attitude Control	N/A	N/A

3.5 Telemetry Data Rates

The instrument processes data on a per-event basis. Each triggered event will produce a quantity of data which varies according to the complexity of the event, and could be as much as 66 Kbytes. The typical event record size, however, will be about 3 – 4 Kbytes. The expected trigger rate is about 1.5 Hz. The total average data rate will not exceed 50 kbps, including instrument housekeeping data, which consists mostly of temperature and high voltage monitoring. The science data will be transferred to the ballooncraft flight computer through a standard MIL-STD-1553B interface.

3.6 End-to-End Data Accuracy

A maximum bit error rate of 10^{-6} is required. Error checking information, which identifies bad or potentially bad data, is desirable.

3.7 Real Time Data Requirements

Two issues drive real-time requirements. First and foremost, housekeeping, pedestal and some fraction (e.g. 0.1%) of science data is required to monitor instrument health and make adjustments to any element showing anomalous behavior (e.g. overheating, significant shifts in pedestals and/or gains). Monitoring data will be kept under 100 bps. Second, science data recovery is a mission critical requirement. Since payload recovery is not assured, real-time telemetry is desirable as the best means to assure minimal data loss if the payload is lost. If that is not available, a reduced set could be transmitted that includes high priority events (e.g. above 50 TeV and/or $Z > 6$) and (e.g.) 1% of all events. In line of sight, during ascent, real-time telemetry becomes more important as temperatures and pressures change more rapidly than during float. Instrument commanding is anticipated to be no more than several times per day at float altitude. Command sequences should be less than 1 Kbyte, with 100 bps deemed sufficient. In some cases (e.g. overheating) real-time or near real-time transmission of commands would be needed.

4.0 Science Requirements on Ballooncraft Configuration

4.1 Instrument Alignment and Field of View

The instrument needs to look upward, with no further requirements for orientation. Alignment with respect to azimuth sensor should be known to better than 0.25^{o}. The balloon itself being in the field of view is not a concern at these energies.

4.2 Contamination and Interference Control

The instrument uses sealed detectors, and is not particularly sensitive to contamination. Many of the plastic fiber components can be affected by vapors from solvents, so reasonable cautions should be exercised to avoid the use of solvents near the instrument. Interference from ballooncraft equipment is unlikely, however charge sensitive amplifiers are used throughout the instrument and may be affected by some of the ballooncraft equipment, particularly transmitting devices. If interference is detected during integration, it will be mitigated by relocation of offending emitters and/or additional shielding of susceptible components.

4.3 Power Requirements

The instrument is expected to draw less than 620 watts from the primary 28 volt supply, while operating with a duty cycle of 100%. The table below details the various power consumers and their estimated needs. These numbers are based on the present design of CREAM detectors and may change as designs mature. We are currently aggressively pursuing designs that will reduce power consumption from these levels. Additional power of TBD may be required for heaters during nighttime operations, but our thermal design goal is to keep temperatures within the specified ranges without heaters. The ballooncraft will provide power switching (on/off) capability for the instrument. There is a minimal power requirement for survival.

Consumer	Power Requirement (Survival)
Charge Detector	100 W (0 W)
Transition Radiation Detector	35 W (3 W)
Calorimeter & Target Scintillators	240 W (0 W)
Trigger Electronics	20 W (0 W)
Housekeeping Electronics	20 W (0 W)
Data Computers	30 W (0 W)
Subtotal	445 W (3 W)
Converter Losses (80% Efficiency)	111 W (0 W)
Contingency (10%)	62 W (0 W)
Total Power Requirement	618 W (3 W)

4.4 Data and Command Interface Requirements

The instrument will interface to the ballooncraft flight computer through a standard MIL-STD-1553B interface. Both data and commanding will be transferred through this interface.

4.5 Mechanical Requirements

The gondola design will be an integrated one, accommodating both instrument and ballooncraft subsystems. The large instrument mass and complexity of subsystems will be the primary drivers of the gondola design. The gondola will have provisions for attachment of all ballooncraft subsystems and all thermal control subsystems as described below.

4.6 Thermal Requirements

The thermal design will be an integrated design, which includes both the instrument and the ballooncraft subsystems. It will be necessary to locate heat generators at appropriate locations to prevent sensitive assemblies from becoming too cold during night operations, and provide adequate heat flow to radiators during daytime operations to prevent items from becoming too hot. A design which uses a base panel with heat sources attached to it, and a thermal blanket enclosing the entire gondola is the most likely configuration. Internal reflective surfaces on the thermal blanket and adequate spacing away from the instrument will promote effective re-radiation of heat to upper components. Heat pipes will be used to isothermalize the base panel, and variable conductance heat pipes (VCHP) will be used to transport heat to the radiator. The following table lists the major instrument subassemblies and the appropriate temperature ranges for each.

Subsystem	Operating Range (°C)	Non-Operating Range (°C)
Charge Detector		
Detector Assembly	-20 to +50	-55 to +70
Readout Opto-Electronics	-10 to +50	-55 to +125
Transition Radiation Detector		
Detector Assembly	-10 to +40	-30 to +60
Readout Electronics	-10 to +50	-55 to +125
Gas Makeup Supply	-10 to +40	-30 to +60
Target Scintillators		
Detector Assembly	-20 to +50	-55 to +70
Readout Opto-Electronics	-10 to +50	-55 to +125
Calorimeter		
Detector Assembly	-20 to +50	-55 to +70
Readout Opto-Electronics	-10 to +50	-55 to +125
Support Electronics		
Trigger Processor	-20 to +70	-55 to +125
Flight Computer	0 to +50	-55 to +125
DC-DC Converters	-40 to +70	-55 to +125

5.0 Science Requirements on Mission Operations

5.1 Pre-Launch and Line of Site (LOS) Command and Data Requirements

During ground checkout, flight line checkout, and during the period after launch when the balloon is in direct line of site of the launch site, real-time science data and command capability is required. The science data telemetry rate of 50 kbps is desirable, but a reduced data rate not lower than 10% of the full data rate is acceptable. A command instrument control data rate will not exceed 100 bps.

5.2 Normal Command and Data Requirements

During normal flight operations, near real-time data is required to determine the health and status of the instrument. It is desirable to have the full science data available with no more than a ten minute delay, however the minimum requirement would be to have the housekeeping data (approximately 100 bps) available in real-time. Following any period of reduced telemetry (below 50 kbps) an increased transmission rate (above 50 kbps) will be required to clear out the back-log of archived data. Periodic adjustment of the instrument by command uplink is expected to be no more than several times per day with command sequences being less than 1 Kbyte total, at 100 bps. Commanding will primarily be used for adjustments of high voltage settings, threshold settings, and gas pressure adjustments within the TRD. Command and data capability from home institutions via network connections is highly desirable.

6.0 Data Handling Requirements

CREAM data will be recorded and transmitted to the ground for real-time evaluation and offline analysis. Readout channels with pedestal-only contents will be sparsified by the Flight Data System to reduce data volume. Compression of data before archiving and/or transmission will be considered if needed to accommodate the experiment data rate.

6.1 Data Types

CREAM will generate several types of data records. Each will have its own TBD structure.

6.1.1 Science Data

Collection of science data is the main mission objective. These records will include a header and pointers to specific types of detector readout data and addresses. All above-pedestal ADC channel contents will be recorded with the address identifying the relevant ADC channel.

6.1.2 Housekeeping Data

This record type will allow data quality control as well as verification of temperature and other parameters relevant for science data analysis.

6.1.2.1 Software Status

Flags showing the status of all software processes in the on-board Flight Data System. Examples may include data-taking, data-archiving, power control, detector control, housekeeping, etc.

6.1.2.2 Physical Environment

Records of temperatures, pressures and position from a range of sensors.

6.1.2.3 Power Control

Records of HV and LV settings and actual values.

6.1.3 Calibration Data

Records of detector channel contents and addresses for LED flasher events, empty events and possibly non-interacting particle traverses to allow the construction of a set of time-dependent correction functions to compensate for pedestal and gain changes due to changes in temperature, HV, etc.

6.2 Data Processing

Data processing will be a cooperative process performed by the instrument team at their home institutions. The data will be processed using hardware and software tools that will be available at each of the institutions.

6.3 Data Products, Archiving, and Distribution

The expected total data volume is about 50 Gbytes for a 100 day flight. These data will be sent by telemetry and will also be archived on-board. The data set will be delivered to the Principal Investigator on TBD media with format TBD. The Principal Investigator will provide copies of the data set to the Co-Investigators. The Principal Investigator will have responsibility for archiving and distribution of processed data.