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Advanced Composition Explorer
(A C E)

Level 1 Requirements Definition

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Explorer Program
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Advanced Composition Explorer

Level 1 Requirements Definition

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ACE Level 1 Requirements Definition

1.0 PURPOSE

This document defines the Level 1 requirements for the development of the Advanced Composition Explorer (ACE). Concurrent with the initiation of the Development Phase, the Level 1 requirements will be incorporated into the ACE Project Plan and approved by the Associate Administrator of Space Science and the Director of the Goddard Space Flight Center.

2.0 PROGRAM REQUIREMENTS

In implementing the ACE program, the following principles apply:

- The mission will be developed using the Level 1 requirements as a baseline against which performance will be measured. A Confirmation Review, to be conducted prior to the initiation of the Development Phase, will confirm mission content and the Level 1 Requirements.

- The total cost of ACE Phase C/D development will not exceed the agreed-to cost cap and the launch date will be no later than December 1997. As described in Section 7, mission scope is to be considered as a parameter to control mission cost and schedule.

- Mission design will incorporate a balance of subsystem reliability, redundancy, system reliability and robustness, and the lower-cost, rapid response philosophy of the Explorer Program.

3.0 MISSION OVERVIEW

The Advanced Composition Explorer (ACE) will be used to collect data to study the origin and subsequent evolution of both solar system and galactic material to investigate a wide range of fundamental problems in space physics. ACE will be located at the Earth-Sun libration point, L1, to carry out *in situ* measurements of particles originating from the solar corona, the interplanetary medium, the local interstellar medium, and galactic matter.

ACE will be developed and operated by NASA, with GSFC acting as the lead Center. The science instruments will be defined and developed under the management of the California Institute of Technology (CIT). The spacecraft will be built and integrated with the instruments by The Johns Hopkins University Applied Physics Laboratory (APL).

4.0 LEVEL 1 SCIENCE REQUIREMENTS

4.1 Scientific Objectives

The prime objective of ACE is to determine and compare the elemental and isotopic composition of several distinct samples of matter, including the solar corona, the interplanetary medium, the local interstellar medium and galactic matter. The comparison of these samples of matter will be used to study the origin and subsequent evolution of both solar system and galactic material by isolating the effects of fundamental processes that include nucleosynthesis, charged and neutral-particle separation, bulk plasma acceleration, and the acceleration of supra-thermal and high energy particles.

The objective is approached by performing comprehensive and coordinated determinations of the elemental and isotopic composition of energetic nuclei accelerated on the Sun, in interplanetary space, and from galactic sources. These observations will span five decades in energy, from solar wind to galactic cosmic ray energies, and will cover the element range from $_{1}H$ to $_{30}Zn$. Specifically, these observations will allow the investigation of a wide range of fundamental problems in major areas summarized below.

1) The Elemental and Isotopic Composition of Matter

A major objective is the accurate and comprehensive determination of the elemental and isotopic composition of the various samples of "source material" from which nuclei are accelerated. The ACE measurements will be used to:

- Generate a set of solar isotopic abundances based on direct sampling of solar material.
- Determine the coronal elemental and isotopic composition with greatly improved accuracy.
- Establish the pattern of isotopic differences between galactic cosmic ray and solar system matter.
- Measure the elemental and isotopic composition of interstellar and interplanetary "pickup" ions. (Galactic neutrals ionized by solar ultraviolet radiation or the solar wind.)
- Determine the isotopic composition of the "anomalous cosmic ray component", thought to represent a sample of the local interstellar medium.

2) Origin of the Elements and Subsequent Evolutionary Processing

Isotopic "anomalies" in meteorites indicate that the solar system was not homogeneous when formed, while other data suggest that the solar composition continues to evolve. Similarly, the galaxy is neither uniform in space nor constant in time due to continuous stellar nucleosynthesis. The measurements from ACE will be used to:

- Search for additional differences between the isotopic composition of solar and meteoritic material.
- Determine the contributions of solar-wind and solar flare nuclei to lunar and meteoritic material, and to planetary atmospheres and magnetospheres.
- Determine the dominant nucleosynthesis processes that contribute to cosmic ray source material.
- Determine whether cosmic rays are a sample of freshly synthesized material (e.g., from supernovae), or of the contemporary interstellar medium.
- Search for isotopic patterns in solar and galactic material as a test of galactic evolution models.

3) Formation of the Solar Corona and Acceleration of the Solar Wind

Solar energetic particle, solar wind, and spectroscopic observations show that the elemental composition of the corona is differentiated from that of the photosphere, although the processes by which this occurs, and by which the solar wind is subsequently accelerated, are poorly understood. The detailed composition and charge-state data provided by ACE will be used to:

- Isolate the dominant coronal formation processes by comparing a broad range of coronal and photospheric abundances.
- Study plasma conditions at the source of the solar wind and the solar energetic particles by measuring and comparing the charge states of these two populations.
- Study solar wind acceleration processes and any charge or mass-dependent fractionation in various types of solar wind flows.

4) Particle Acceleration and Transport in Nature

Particle acceleration is ubiquitous in nature and is one of the fundamental problems of space plasma astrophysics. The unique data set obtained by ACE measurements will enable the investigators to:

- Make direct measurements of charge and/or mass-dependent fractionation during solar flare and interplanetary acceleration.
- Constrain solar flare and interplanetary acceleration models with charge, mass, and spectral data spanning up to five decades in energy.
- Test theoretical models for ^{3}He-rich flares and solar gamma ray events.
- Measure cosmic ray acceleration and propagation time scales using radioactive "clocks". (Particles that decay radioactively.)
- Test whether the "anomalous cosmic rays" are a singly-ionized sample of the neutral interstellar gas by directly measuring their charge state.

4.2 Approach for Accomplishing Science Objectives

The science objectives are accomplished by performing comprehensive and coordinated *in situ* measurements of the elemental and isotopic composition of energetic nuclei in the interplanetary medium outside the Earth's magnetosphere. The instruments used for the measurements are listed below. Table 1 shows the relationship of the instruments to the scientific objectives. Table 2 shows the relevant performance requirements for each instrument.

<u>High Resolution Spectrometers</u>

CRIS	Cosmic Ray Isotope Spectrometer
SIS	Solar Isotope Spectrometer
ULEIS	Ultra Low Energy Ion Spectrometer
SEPICA	Solar Energetic Particle Ionic Charge State Analyzer
SWICS	Solar Wind Ion Composition Spectrometer
SWIMS	Solar Wind Ion Mass Spectrometer

<u>Monitoring Instruments</u>

EPAM	Electron, Proton and Alpha-particle Monitor
SWEPAM	Solar Wind Electron, Proton, and Alpha-particle Monitor
MAG	Magnetic Field Monitor

TABLE 1
Scientific Objectives

	CRIS	SIS	ULEIS	SEPICA	SWIMS	SWICS	EPAM	SWEPAM	MAG
Composition of Matter									
Generate table of solar isotopic abundances		P	P	P	P	C	C	C	
Determine coronal composition		P	P	P	P	P	C	P	
Compare cosmic ray and solar isotope pattern	P	P	P	P	P	C	C	C	
Measure interstellar/interplanetary pickup ions				C	C	P		C	C
Determine anomalous cosmic ray composition	P	P	P	C			C		
Origin/Evolution of Elements									
Identify solar/meteoritic composition differences		P	P	P	P	P	C	C	
Solar particle contributions to moon/planets/meteorites		P	P	C	P	P	C	C	
Identify cosmic ray nucleosynthesis processes	P	P							
Determine age of cosmic ray source material	P	P							
Search for evidence of galactic evolution	P	P	P	C	P	C			
Corona Formation/Solar Wind Acceleration									
Isolate coronal formation processes		P	P	P	P	P	C	P	
Study solar plasma conditions				P	P	P		P	C
Study solar wind acceleration/fractionation					P	P		P	P
Particle Acceleration/Transport									
Fractionation in solar flare/interplanetary acceleration		P	P	P	P	P	C	P	C
Constrain particle acceleration models	P	P	P	P	P	P	P	P	P
Test 3He-rich and gamma ray flare models	C	P	P	P			P		C
Measure cosmic ray acceleration/transport time scales	P	P							
Test anomalous cosmic ray origin	P	P	P	P					

P = PRIMARY MEASUREMENTS
C = CONTRIBUTING MEASUREMENTS

TABLE 2
Performance Requirements for ACE Science Instruments

Particle Spectrometers

Instrument	Required Geometry Factor (cm2.sr)	Required Species Coverage	Energy Range for Element Composition (MeV/nuc) C (Z=6)	Energy Range for Element Composition (MeV/nuc) Fe (Z=26)	Energy Range for Isotopes(1)/Charge States (2) (MeV/nuc) C (Z=6)	Energy Range for Isotopes(1)/Charge States (2) (MeV/nuc) Fe (Z=26)
CRIS	> 200	$3 \leq Z \leq 28$	70 to 200	100 to 500	70 to 200	100 to 500
SIS	> 20	$2 \leq Z \leq 28$	10 to 100	15 to 200	10 to 70	20 to 100
ULEIS	> 0.5	$2 \leq Z \leq 28$	0.1 to 10	0.3 to 2	0.2 to 10	0.3 to 2 (3)
SEPICA	> 0.2	$2 \leq Z \leq 28$	0.3 to 10	0.1 to 20	0.3 to 2	0.1 to 2
SWIMS		$2 \leq Z \leq 28$	.0001 - .005	.0001 - .001	.0001 - .005	.0001 - .001
SWICS		$2 \leq Z \leq 28$	.0001 - .01	.0001 - .01	.0001 - .01	.0001 - .01

Energetic Particle and Solar Wind Monitoring Instruments

Instrument	Required Geometry Factor (cm2.sr)	Required Species Coverage	Electron Energy Range (keV)	Proton Energy Range (Mev)	Helium Energy Range (MeV)	Time Resolution (min)
EPAM	0.5	Electrons, H, He	50 to 200	0.1 - 2	0.5 - 3	2
SWEPAM		Electrons, H, He	.001 - 0.5	.0001 - .01	.0001 - .01	2

Magnetometer

Dynamic Range:	+/- 4 nT to +/- 60,000 nT
Precision:	better than +/- 0.5%
Accuracy:	< 0.1 nT
Sampling Time:	< 0.35 sec

Notes:

(1) To resolve individual isotopes requires an rms mass resolution of < 0.3 amu; to resolve $\Delta M = 2$ isotopes requires an rms mass resolution of < 0.6 amu.

(2) For SEPICA and SWICS, the energy range for resolving charge states is given.

(3) For ULEIS the Fe energy range corresponds to < 0.6 amu rather than < 0.3 amu

4.3 Minimum Mission Success Criteria

The comprehensive set of scientific objectives described in Section 4.1 can be realized by carrying out the ten measurements listed below. Because of the complementarity of the measurements and their statistical accuracies, the ACE mission will be considered successful if it accomplishes at least seven of these ten measurements. See Table 3 for a summary of the instrument requirements for each measurement.

a) Composition of heavy nuclei in both the bulk solar wind and in several high speed streams

b) Composition of coronal mass ejection events over a one year period.

c) Solar wind pick-up ions over a one year period

d) Composition of heavy nuclei in CIR (co-rotating interaction region) events over a one year period

e) Composition of heavy nuclei in ESP (energetic storm particle) events over a one year period

f) Composition of heavy nuclei in ten solar particle events, including three large events

g) Composition of heavy nuclei in small impulsive solar flares over a one year period.

h) Isotopic composition of anomalous cosmic rays

i) Abundances of radioactive clock isotopes in galactic cosmic rays

j) Isotopic composition of the "primary" galactic cosmic ray elements from carbon to zinc.

Table 3
Instrument Requirements for Each Measurement
to Meet Minimum Success Criteria

Instr ---> Meas	CRIS	SIS	ULEIS	SEPICA	SWIMS	SWICS	EPAM	SWEPAM	MAG
a)					1	1		+	+
b)					1	1		+	+
c)					+	1		+	+
d)		+	2	2	2	+	+	+	+
e)		+	2	2	2	+	+	+	+
f)	+	2	2	2	+	+	+	+	+
g)	+	+	1	1	+	+	+	+	+
h)	+	1	1						
i)	1	1							
j)	1	1							

1 - One of these instruments must work for a successful measurement
2 - Two of these instruments must work for a successful measurement
\+ - Significant supporting measurement

5.0 LEVEL 1 DEVELOPMENT REQUIREMENTS

5.1 Flight Segment

- The flight segment consists of
  - Spacecraft
  - Science instruments
- It is anticipated that two years of in-orbit measurements will be required to attain mission success. The instruments and spacecraft will be designed for a mission life of at least two years. Sufficient spacecraft fuel to permit an operational life of five years is highly desirable.
- The mission classification is Class C, as per NMI 8010.1A "Classification of NASA Payloads," with modifications commensurate with mission requirements, acceptable technical risks, and cost.
- The design of the spacecraft and the science instruments (EPAM, SWEPAM, and MAG) will allow for the accommodation of a NOAA-provided Real Time Solar Wind capability as a secondary objective. This objective will be accommodated on a best efforts, non-interference basis, with no increase in cost to the Explorer Program.

5.2 Launch Segment

- The launch vehicle will be a Delta II 7920, two-stage, expendable launch vehicle.
- Launch date

Target	August 1997
No Later than (budgeted)	December 1997

- ACE will be launched from Cape Canaveral Air Force Station, Florida.
- ACE will be inserted into a halo orbit at the Earth-Sun libration point (L1).

5.3 Ground Segment

- The Payload Operations Control Center (POCC) will be located at GSFC.
- The ACE Science Analysis and Archive Center will be located at the California Institute of Technology
- ACE tracking support will be through the Deep Space Network.

6.0 LEVEL 1 MISSION OPERATIONS REQUIREMENTS

The Level 1 mission operations and data analysis requirements are contained in a Level 1 Mission Operations and Data Analysis Plan

7.0 LEVEL 1 RESOURCE POLICY AND REQUIREMENTS

7.1 Cost Containment Agreement

The ACE mission development will be accomplished by GSFC and OSS on a not-to-exceed cost basis. OSS and GSFC agree that the total cost of ACE, from start of phase C/D detailed design and development through launch plus 30 days, will not exceed $141.1M. To meet this commitment, OSS will commit to providing the necessary fiscal-year funding as identified in the Project Plan and as updated in the POP. In addition, OSS will agree that GSFC may, in consultation with the Science Working Group, pursue scope reduction, as outlined below, as an additional resource to manage cost. These agreements will be finalized in the ACE Project Plan, which will be approved by both OSS and GSFC.

7.2 Scope Reduction

Provided that the Level 1 Science Requirements, are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, GSFC should pursue scope reduction as a means to control cost. The Project Plan should include several potential scope reductions and the timeframe in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised without further Program Office approval. Any scope reductions will be implemented only after consultation with the Project Scientist. Any other potential scope reductions affecting Level 1 requirements will be agreed to by GSFC and the Program Office prior to their execution.

8.0 KEY POSITIONS

The key positions identified for ACE are Project Manager, Project Scientist, Program Manager, and Program Scientist. A change of personnel in any of these positions will be treated as a Level 1 change.