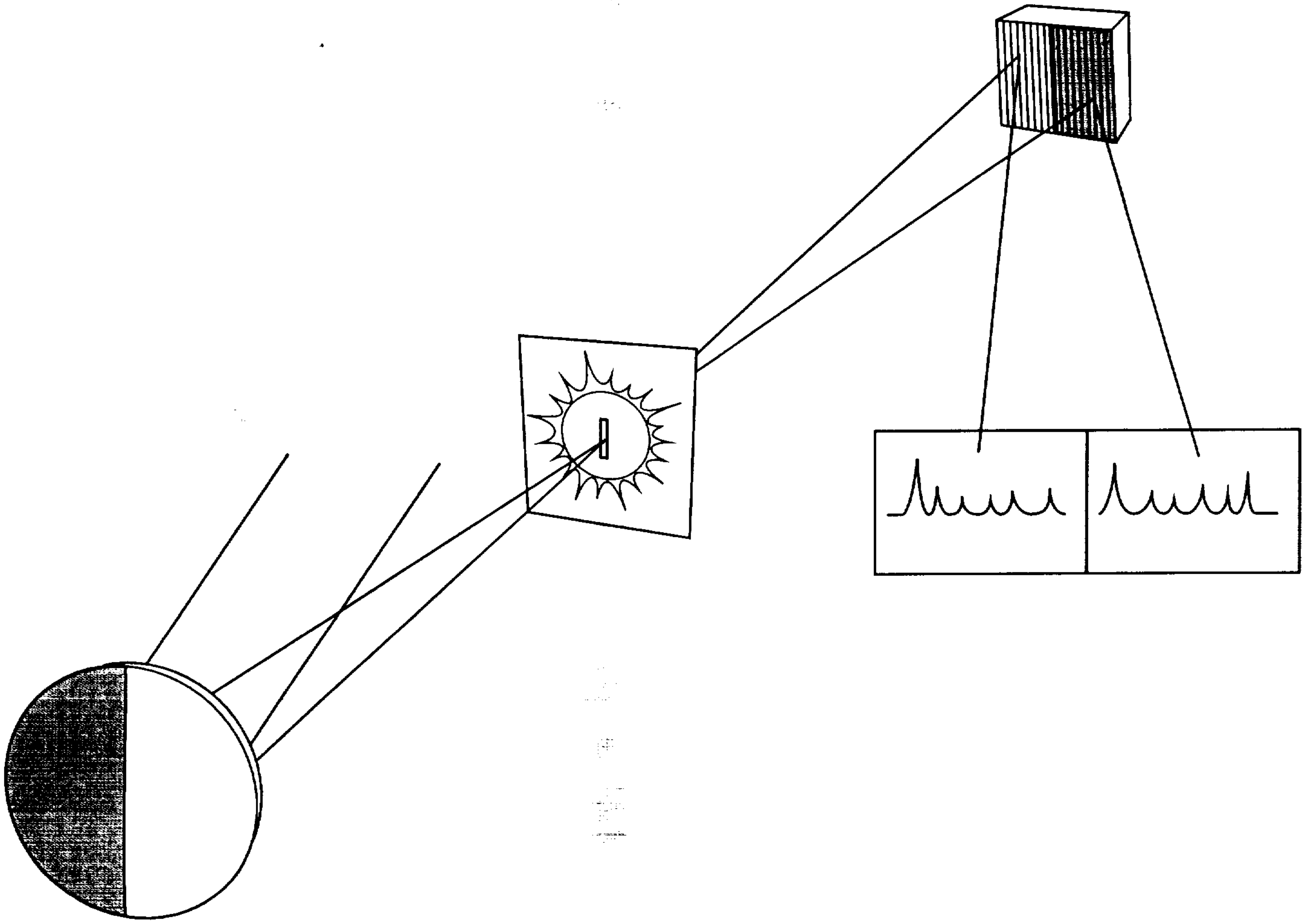

EIS
SOLAR-B

Concept Study Report

Data Requirements Document 866MA-001

5 November 1999

AO 98-OSS-05	Solar-B

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Proposal Title

EUV Imaging Spectrometer (EIS)

Abstract

We propose a next generation Extreme-ultraviolet Imaging Spectrometer (EIS) that for the first time combines high spectral, spatial, and temporal resolution in a single solar spectroscopic instrument. The instrument consists of a multilayer-coated off-axis telescope mirror and a multilayer-coated grating spectrometer. The telescope mirror forms solar images on the spectrometer entrance slit assembly. The spectrometer forms stigmatic spectra of the solar region located at the slit. This region is selected by the articulated telescope mirror. Monochromatic images are obtained either by rastering the solar region across a narrow entrance slit, or by using a very wide slit (called a slot) in place of the slit. Monochromatic images of the region centered on the slot are obtained in a single exposure. Half of each optic is coated to maximize reflectance at 195 Å; the other half to maximize reflectance at 270 Å. The two EUV wavelength bands have been selected to maximize spectral and dynamical and plasma diagnostic capabilities. Spectral lines are observed that are formed over a temperature range from about 0.1 MK to about 20 MK. The main EIS instrument characteristics are: wavelength bands – 180 to 204 Å; 250 to 290 Å; spectral resolution – 0.0223 Å /pixel (34.3km/s at 195 Å and 23.6 km/s at 284 Å); slit dimensions – 4 slits, two currently specified dimensions are 1" x 1024" and 50" x 1024" (the slot); largest spatial field of view in a single exposure – 50" x 1024"; highest time resolution for active region velocity studies – 4.4 s.

Institutional Endorsement

Name of Authorizing Official	
Dr. Herbert Gursky	
Title	
Superintendent, Space Science Division	
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Proposal Title

EUV Imaging Spectrometer (EIS)

Cost	
NASA Investigation Cost	Phase A $730,000 (Real-Year $) Phase A $697,027 (FY98 $)
	Phase B/C/D $6,905,848 (Real-Year $) Phase B/C/D $6,708,927 (FY98 $)
	Phase E $9,716,718 (Real-Year $) Phase E $7,112,000 (FY98 $)

Instrument Type

Extreme Ultraviolet Imaging Spectrometer

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List of Acronyms

Acronym	Definition
3D	Three dimensional
AAS/SPD	American Astronomical Society/Solar Physics Division
BCS	Bragg Crystal Spectrometer
CCD	Charge Coupled Device
CCP	Contamination Control Program
CDR	Critical Design Review
CDS	Coronal Diagnostic Spectrometer
CME	Coronal Mass Ejection
Co-I	Co-Investigator
CORE	Central Operations of Resources for Teachers
COTS	Commercial Off The Shelf
CPT	Comprehensive Performance Test
CPU	Central Processing Unit
CSR	Concept Study Report
DM	Development Model
DR	Data Recorder
DRAC	Data Reduction and Analysis Center
EBIT	Electron Beam Ion Traps
EF	Eruptive Flare
EGSE	Electrical Ground Support Equipment
EIS	Extreme Ultraviolet Imaging Spectrometer
EIT	Extreme ultraviolet Imaging Telescope
EUV	Extreme Ultrviolet
FFA	Front Filter Assembly
FM	Flight Model
FPC	Focal Plane Camera
FTE	Full Time Equivalent
G&A	General and Administrative
GRA	Grating Assembly
GSFC	Goddard Space Flight Center
H/W	Hardware
HRTS	High Resolution Telescope and Spectrograph
I&T	Integration and Test
IAU	International Astronomical Union
IC	Integrated Circuit
ICD	Interface Control Document
ICU	Instrument Control Unit
IMS	Integrated Master Schedule
IPDT	Integrated Product Development Team
IR	Infrared
LASCO	Large Angle Spectrometric Coronagraph
LOE	Level-of-Effort
M&P	Materials and Processes
MAHRSI	Middle Atmosphere High Resolution Spectrograph
ME	Mechanical Engineer
MGSE	Mechanical Ground Support Equipment
MHC	Mechanism and Heater Control Box
MHD	Magnetohydrodynamic
MIR	Mirror Assembly
MO&DA	Mission Operations and Data Analysis
MSSL	Mullard Space Science Laboratory
NAR	Non-Advocate Review
PAP	Product Assurance Program
PC	Personal Computer
PE	Project Engineer
PEP	Personal Excellence Partnership
PM	Project Manager
POETRY	Public Outreach, Education, Teaching, and Reaching Youth
PPARC	Particle Physics and Astronomy Research Council
PS	Project Scientist
PSF	Point Spread Function
PZT	Piezoelectric Translator
QA	Quality Assurance
QAE	Quality Assurance Engineer
QAP	Quality Assurance Plan
RAL	Rutherford Appleton Laboratory
RE	Reliability Engineer
RID	Review Item Discrepancy
SB/SDB	Small Business/Small Disadvantaged Business
SEF	Spectrometer Entrance Filter
SERTS	Solar Extreme-Ultraviolet Rocket Telescope and Spectrograph
SLA	Slit Slot Assembly
SMM	Solar Maximum Mission
SOLRAD	Solar Radiation
SR&QA	Safety, Reliability, and Quality Assurance
SSM	System Safety Manager
SUMER	Solar Ultraviolet Measurements of Emitted Radiation
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SVLS	Spherical Variable Line Spaced
SXR	Soft X-Ray
SXT	Soft X-Ray Telescope
TBR	to be resolved
TMC	Total Mission Cost
TRACE	Transition Region and Coronal Explorer
VAULT	Very high Angular resolution ULtraviolet Telescope
WBS	Work Breakdown Structure
WWW	World Wide Web
XRT	X-Ray Telescope

1. Executive Summary

1.1 Overview. The Extreme-Ultraviolet Imaging Spectrometer (EIS) for Solar-B is a next generation instrument both scientifically and technically. While minimizing costs and making maximum use of precious spacecraft resources, EIS offers dramatic improvements over current and previous high resolution solar spectroscopic instrumentation. Recent images from Yohkoh, the Extreme ultraviolet Imaging Telescope (EIT), and now the Transition Region and Coronal Explorer (TRACE) reveal a dynamic Sun with a complex morphology of elementary structures at arc-second spatial scales and a few seconds temporal scale. Diagnostic information determined from spectroscopic line profiles obtained with EIS will reveal the physics underlying the formation and evolution of these elementary structures.

Major unsolved problems of solar physics that can be addressed with EIS and Solar-B include the energy storage and release mechanisms for heating the corona, for the eruption of coronal mass ejections (CMEs), and for creation of high-temperature solar flares. The resolution of these problems requires measurements of dynamic plasma properties such as bulk flows, turbulent flows, temperatures, and densities *at the spatial and temporal scales* seen in high-resolution images. These measurements—only obtainable with high resolution spectroscopy—are particularly important because they contain key signatures of energy release processes. While previous and current high resolution spectrometers have taught us much about the average properties of the solar atmosphere, none of this instrumentation has had the necessary spatial and temporal resolution, combined with high spectral resolution, required to observe the signatures of physical processes in elementary solar structures.

EIS will record extreme ultraviolet (EUV) spectra and images of the multithermal (10^5 to 10^7 K) plasmas in the quiet Sun, active regions, and flares, at the high spectral, spatial, and temporal scales characteristic of these processes.

Why observe in the EUV? The EUV solar spectrum contains lines that originate over a wide temperature range, from the lower transition region up into the quiet and active corona and beyond into the flare regime. Detailed EUV spectra will allow us to follow flows of mass and energy from just above the photosphere into the corona. Combined with coronal images from the Solar-B X-Ray Telescope (XRT) and photospheric magnetograms from the white light telescope, we will directly observe the dynamic behavior of coronal plasmas and their relationship to the evolving photospheric magnetic field. This is the prime observational objective of Solar-B. For example, we will search for spectroscopic signatures of magnetic reconnection in the extraordinarily wide, but low intensity, wings of spectral lines. The advantage of doing this at EUV wavelengths is the absence of numerous lines from neutral and singly ionized atoms and the strong continuum found at longer wavelengths which interfere with detecting these often weak signatures.

1.2 Instrumentation. EIS addresses the Solar-B science requirements by producing high spectral resolution spectra at high spatial and temporal resolution. Recent technological advances in EUV multilayer coated optics (especially gratings) and large-format, EUV-sensitive charge-coupled device (CCD) detectors have made possible a new generation of EUV spectroscopic solar instrumentation. Using these recent technologies to their full advantage, we have designed an instrument consisting of:

- ❒ A multilayer-coated normal incidence off-axis telescope with high spatial resolution, and,
- ❒ A multilayer-coated normal-incidence, toroidal-grating, stigmatic spectrometer covering two diagnostically important EUV wavelength bands.

The telescope/spectrometer combination provides the necessary spectroscopic diagnostics and EUV transition-region and coronal images to satisfy the Solar-B science requirements as well as providing structural context for coalignment with the other instruments on Solar-B. Table 1-1 summarizes the major instrument imaging and spectral characteristics.

The EIS off-axis telescope images the EUV Sun onto the spectrograph slit/slot. The light passing through the slit is dispersed and re-imaged by a torroidal grating onto two 1024x2048 pixel CCD detectors. The off-axis telescope/spectrometer combination that we have designed is an optimization of the strawman EUV spectrometer outlined in the US Solar-B Science Definition Team docu-

Table 1-1. EIS Instrument Imaging and Spectral Characteristics

Spectral Resolution	
	0.0223 Å/pixel
284 Å	23.6 km/s/pixel
256 Å	26.1 km/s/pixel
195 Å	34.3 km/s/pixel
Spatial Resolution	
Telescope	2.0" at the Sun (1.0"/detector-pixel)
Spectrometer	2.0" at the Sun (slit dimensions: 1"x1024")
Temporal Resolution	
Best Temporal Resolution for Velocities	4.4 s in active regions (includes 2 s of readout time)

ment. Our optimization significantly improves the spatial resolution of the strawman instrument; the improved resolution more closely matches that of the other Solar-B instruments. High resolution spectroheliograms are obtained by rastering the telescope image over the slit, in the same manner as the Coronal Diagnostic Spectrometer (CDS) and Solar Ultraviolet Measurements of Emitted Radiation (SUMER) spectrometers on SOHO. It is also possible to obtain an image in a single exposure over a limited spatial area by using a slot instead of a slit. The EIS slot is nominally a 50" wide slit.

1.3 Observations. The spectrometer produces stigmatic spectra in two EUV bands centered on 195 and 270 Å with coverage widths of about 20 and 40 Å, respectively. Table 1-2 lists some of the strongest spectral lines in the EIS wavelength bands along with their predicted count rates for a 1 arcsec^2 area of the Sun. The long wavelength band contains lines formed in the lower and upper transition region, and quiet and active corona. He II 256 Å is the primary transition region line for observing quiet Sun and active region dynamics. This band also contains high temperature flare lines. The short wavelength band is optimized for plasma diagnostic studies of the active and quiet solar corona, as well as flares and other transient energetic phenomena. This band is centered at 195 Å like one of the EIT and TRACE wavelength bands, but is broader to observe as many spectral lines as possible.

The selected wavelength ranges provide excellent temperature and density coverage of transition region and coronal plasmas. Figure 1-1 illustrates the temperature coverage available with EIS. The figure shows normalized contribution functions (product of ion abundance and excitation rate) for a selection of the lines in the table. Plasma temperatures ranging from the lower transition region into the flare range are observable. EIS uses three density-sensitive line ratios of Fe XII and Fe XIII that appear in the short wavelength band to measure electron densities. Figure 1-2 shows the two Fe XII line ratios. These line ratios are sensitive to the range of densities expected at coronal temperatures in the solar atmosphere.

Table 1-2. EIS Strongest Spectral Lines

Ion	λ (Å)	T (MK)	Detected Photons per Second		
			Quiet Sun	Active Region	Flare
Short Wavelength Band					
Fe X	184.54	1.0	1.3	23.5	–
Fe XII	186.884	1.6	1.1	36.6	228
Fe XI	188.232	1.2	3.7	74.8	200
Fe XXIV	192.042	15.0	–	–	73000
Fe XII	192.393	1.6	2.7	83.9	219
Ca XVII	192.819	5.0	–	57.2	3320
O V	192.904	0.25	–	–	207
Fe XII	193.521	1.6	8.0	244	551
Fe XII	195.118	1.6	13.8	424	946
Fe XIII	202.044	1.6	1.7	73.0	170
Fe XIII	203.828	1.6	–	45.8	258
Long Wavelength Band					
Fe XVI	251.07	2.5	–	10.8	310
Fe XVII	254.87	4.0	–	–	266
He II	256.32	0.1	4.7	37.0	8500
Si X	258.37	1.3	1.0	10.2	138
Fe XVI	262.98	2.5	–	29.6	842
Fe XXIII	263.76	16	–	–	2164
Fe XIV	264.78	2.0	–	36.2	396
Si VII	275.35	0.63	1.2	11.8	–
Fe XV	284.16	2.0	–	127	1700

The combination of EIS spectral images, obtained either by rastering a narrow slit or using the slot, and images obtained by XRT on Solar-B, allows nearly simultaneous coaligned EUV emission line spectra and X-ray images to be obtained. Both instruments are sensitive to overlapping temperature regions, and the EUV and X-ray observa-

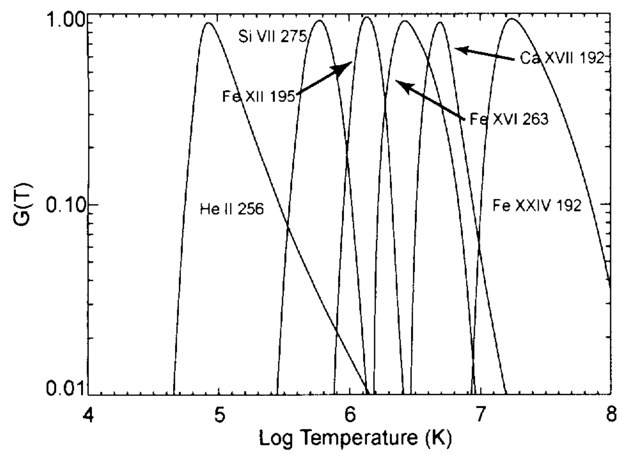


Figure 1-1. Normalized Contribution Functions for Selected Emission Lines Observed by EIS

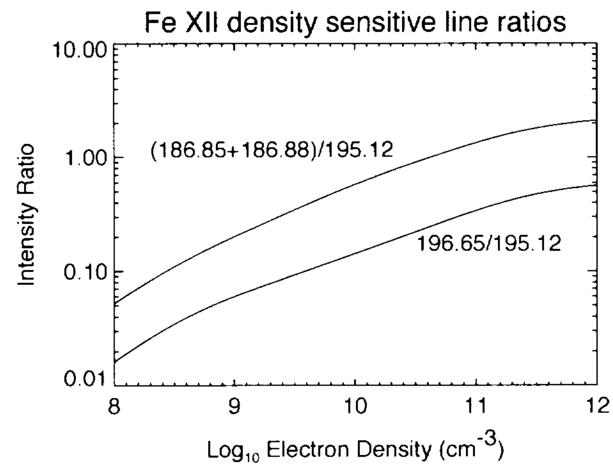


Figure 1-2. Density-Sensitive Ratios of Fe XII Lines Observed by EIS

tional techniques are highly complementary. The XRT provides detailed images of the evolving solar structures present at the slit, while the EIS stigmatic spectra provide immediate measurements of flow velocities, turbulence, densities, and temperatures of structures along the slit. The XRT images provide detailed information on the evolution of coronal structures during a spectrometer raster. Moreover, the wide field XRT solar images allow the SOT and EIS small field of view observations to be placed within a large-scale global context (e.g., coronal/photospheric response to a disappearing or erupting filament, coronal shock waves following a flare or CME, magnetic field rearrangement of coronal loops related to emerging flux in a neighboring active region or quiet Sun, etc.).

1.4 Proposed Effort. The US contribution includes providing the EIS off-axis telescope mirror including multilayer coatings for two wavelength bands and its mounting assembly, the grating with multilayer coatings and mounting assembly, a mechanism for articulating the off-axis mirror so that different regions of the Sun can be placed onto the spectrometer entrance slit, a grating focus mechanism, a thin aluminum telescope entrance filter and mount, a thin aluminum spectrometer entrance filter and mount, a slit assembly with shutter mechanism, support for assembly, integration, and verification, and an EIS liaison scientist in Japan. The US EIS team will also support pre-launch planning and pre- and post-launch operations in Japan as well as scientific data analysis.

1.5 Organization and Experience. The US EIS team is a collaboration between NRL and the Goddard Space Flight Center (GSFC) solar groups. The participating GSFC and NRL groups have over four decades experience building successful high-resolution spectrographs for space flight platforms, including the Skylab S082-A and S082-B spectrographs, the High Resolution Telescope and Spectrograph (HRTS) rocket and Spacelab 2 instruments, and the Solar Extreme-Ultraviolet Rocket Telescope and Spectrograph (SERTS). NRL and GSFC pioneered the development of CCD cameras and multilayer coatings for EUV solar instrumentation, such as the EIT and SERTS CCD-based cameras and optics. The US EIS team contains internationally-recognized experts in plasma diagnostics and the associated atomic physics of the X-ray, EUV, and UV solar spectrum. The US EIS team has extensive experience in multinational hardware efforts, including the Large Angle Spectrometric Coronagraph (LASCO), EIT, and CDS on SOHO, and the Bragg Crystal Spectrometer (BCS) on Yohkoh. In the case of BCS, the NRL EIS team collaborated successfully with the same UK and Japanese colleagues who have been selected for the Solar-B EIS program.

2. Science Investigation Description

2.1 Science Investigation Description Changes.

To understand the science changes resulting from the EIS Phase A study, it is necessary to understand the technical changes in the instrument that have resulted from this study. These differences are listed below with comments on their scientific impact. The net result is that the science that can be accomplished with the current EIS instrument has not been compromised by the technical changes. It has in fact been increased.

The current EIS instrument differs from the proposed EIS instrument in two major ways:

The focal plane camera (FPC) in the proposed EIS instrument was not selected by NASA. The science that would have been accomplished by the FPC can be accomplished better with the XRT selected by NASA. In addition, the use of the slot in many EIS observing sequences will be an acceptable (from the science standpoint) substitute for the FPC.

The proposed EIS instrument was a three optical element system in which the telescope part was a Cassegrain. The current EIS instrument is a two optical element system with a single off-axis telescope mirror. The Cassegrain design was proposed to improve on the spatial resolution of the strawman TRENDY design outlined in the Solar-B Mission Report of the Science Definition Team. It should be noted that the spatial resolution deemed desirable in this report was not technically achievable with the TRENDY instrument. However, the loss of throughput (because of an additional optical element) incurred by the Cassegrain design was considered a more serious science drawback than the gain achieved by increased spatial resolution. The Cassegrain design was therefore rejected in favor of a two optical element design. During Phase A the optical design of a two optical element system was revisited by NRL and GSFC and fortunately it was possible to recover the spatial resolution offered by the Cassegrain by simple modifications (optimization) of the TRENDY design. This was accomplished without loss of significant spectral resolution. Therefore, all the science proposed with the Cassegrain can be accomplished in an even better manner (because of the increased throughput compared with the Cassegrain) with the current two optical element design, which has been accepted by all EIS partners.

There are also some minor differences between the proposed and current EIS instruments:

The long wavelength band proposed for the Cassegrain has been moved to a slightly shorter wavelength region. The scientific capabilities are improved by this change.

Due to technical issues with vendors, the proposed 4800 l/mm grating has been reduced to 4200 l/mm. This results in a scientifically unimportant reduction of spectral resolution and a significant reduction of production risks.

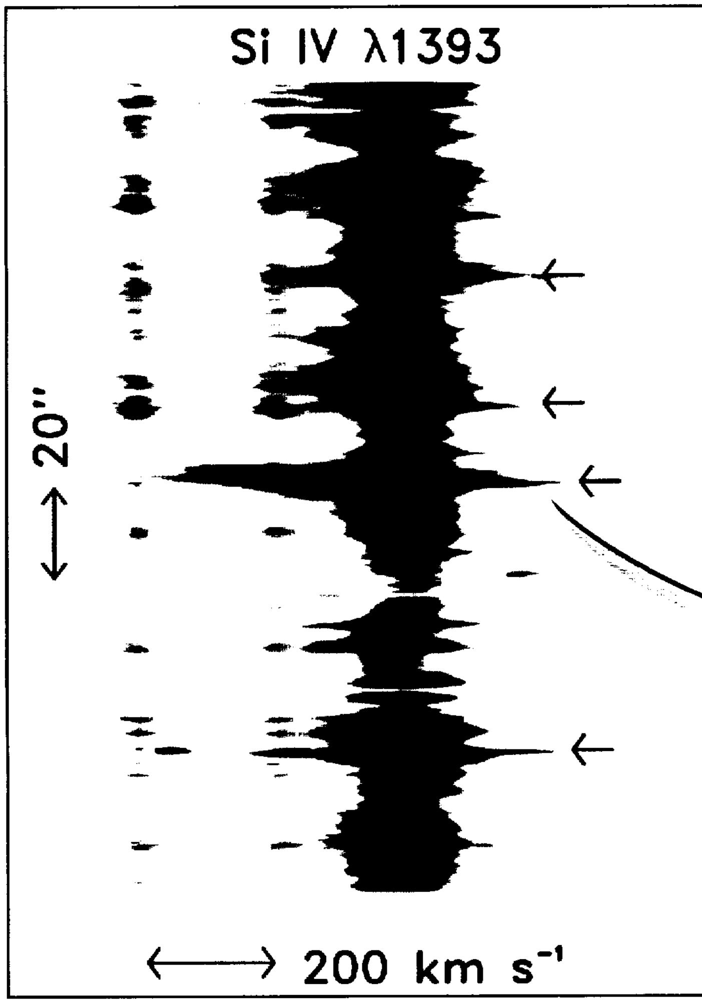
To avoid contamination problems, the proposed EIS instrument was enclosed in a vacuum container. The current EIS instrument does not have such a container, and for this reason the pre-filter is enclosed in a vacuum clamshell. This technical change has no scientific impact provided proper contamination procedures are followed at the spacecraft systems level.

In summary, the current EIS design represents a significant scientific improvement over the proposed EIS instrument without incurring an increase in instrument technical difficulties. Below we repeat the science section of the proposal, incorporating the current EIS instrument instead of the proposed EIS instrument.

2.2 Science. EIS is a unique instrument in that for the first time solar EUV data will be obtained with three powerful characteristics, i.e., high spectral, spatial, and time resolution. As summarized in Figure 2-1, these essential capabilities allow us to contribute to all areas associated with the primary Solar-B science objectives. Here, we highlight four science areas where we believe EIS, working in concert with the other instruments on Solar-B, will make major contributions.

a. Coronal Heating. Despite progress since the launches of Yohkoh and SOHO (e.g., Klimchuk and Porter 1995, Schrijver et al. 1998, Priest et al. 1998), the coronal heating problem has yet to be solved. Coronal loops, particularly in active regions, are an obvious place to search for a solution. They are distinct, easily observed structures, and they identify regions where the heating is locally enhanced.

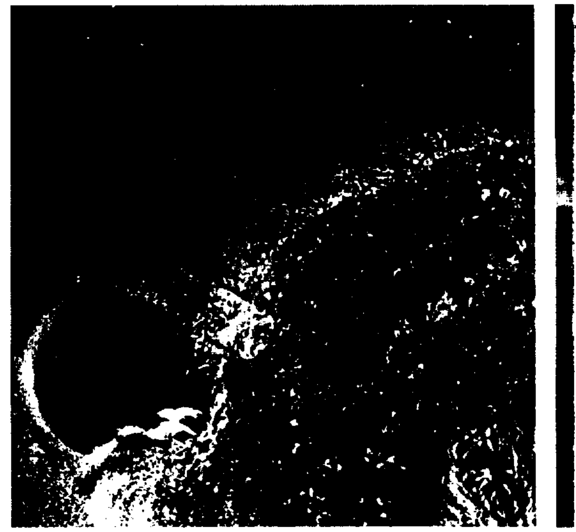
The most basic signature of coronal heating is the plasma pressure, since pressure is equivalent to

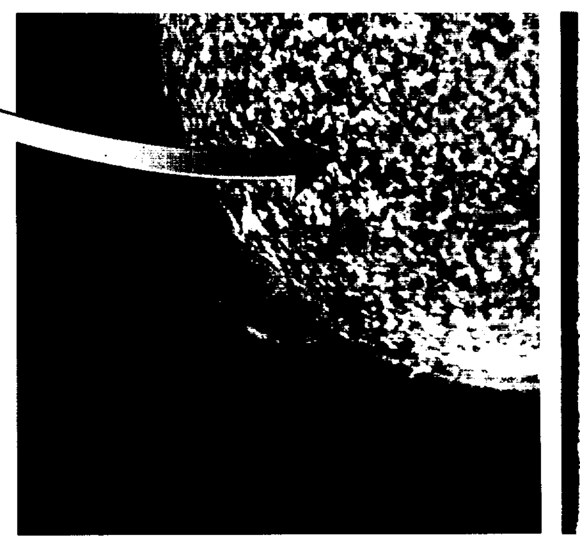


The Quiet Sun

The quiet Sun is characterized by the supergranular network seen at transition region temperatures and by bright points and a more diffuse component at coronal temperatures. Dynamical activity is always present in the quiet Sun and takes the form of explosive events, blinkers and continuous small scale mass ejections. These are apparently caused by the interaction of magnetic fields whose footprints are continually shuffled about by photospheric flows. Shown here are transition region Si IV spectra in the quiet Sun which reveal the ever present explosive events. Similar activity will be observed in the strong He II 256Å line with EIS.

Coronal Mass Ejections



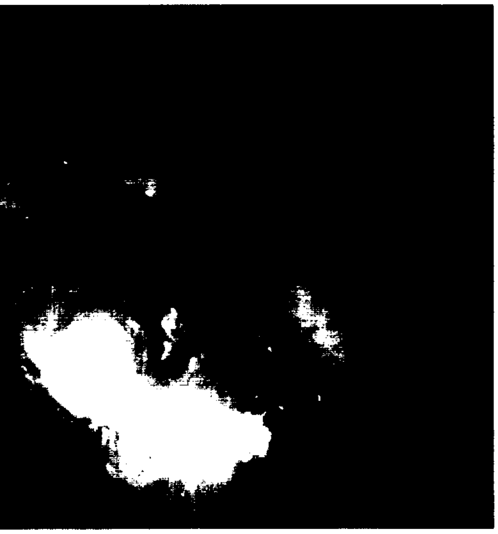


Eruptive Prominences

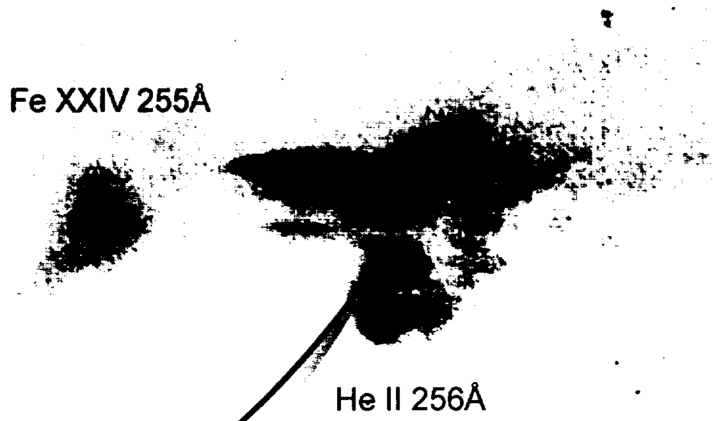
The Dynamic

The corona exhibits highly dynamic phenor with transition region explosive events at s mass ejections with sizes that approach tha small and large scale views to reveal the cc spectrometer obtains critical velocity infor events, flares, and CMEs through spectra detailed information on plasma densities and

Active Region Loops



Solar Flares



Corona

ɪena on a wide range of spatial scales
patial scales of 1 arc-sec and coronal
of the full solar disk. EIS provides both
mplete range of dynamical activity. The
nation on mass motions in explosive
line Doppler shifts and profiles, and
temperatures from line intensities.

Flares and Ejecta

Energy that is built up in active regions is sporadically released by the ejection of fields and plasma and by the dissipation of magnetic energy into thermal and kinetic energies in flares. EIS is uniquely suited for studies of both types of phenomena. The figure above shows an NRL Skylab observation of the hot component of a flare in Fe XXIV 192Å and the transition region footprints and ejecta in He II 256Å. EIS will observe the full temperature range of active region phenomena from the transition region at 10^5 K, through the corona at 1-10 x 10^6 K, to the hot flare plasma at 2 x 10^7 K. Doppler shifts of flare ejecta and X-ray jets will provide excellent diagnostics of the role of magnetic reconnection in high energy activity.

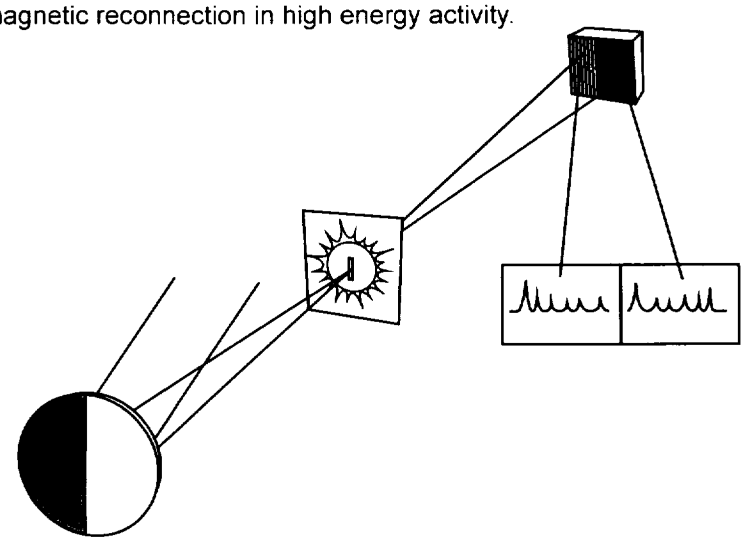


Figure 2-1. Science Foldout

thermal energy density. Quite simply, high pressure loops require more heating than low pressure loops. Filter ratio techniques have been used to infer loop pressures from broadband imaging observations like those from the Soft X-Ray Telescope (SXT) and EIT (e.g., Porter and Klimchuk 1995, Kano and Tsuneta 1996, Aschwanden et al. 1999). These determinations, however, are fraught with ambiguities and uncertainties. To infer a density, and hence pressure, assumptions must be made about the line-of-sight thickness of the emitting volume and about the unknown filling factor. Estimates of coronal filling factors range from 10^{-4} to near unity (e.g., Dere 1982, Porter and Klimchuk 1995, Brosius, Davila, and Thomas 1996, Cargill and Klimchuk 1997), so the filling factor assumption is crucial. The only way to avoid it is to make direct density measurements using density-sensitive line ratios. Hence, the EIS wavelength range was chosen to include important diagnostic line pairs of Fe XII and Fe XIII. Not only will we make accurate measurements of loop densities and pressures as a function of position in the loop, but we will also determine—not assume—the value of the filling factor. Previous electron density measurements made using line ratio techniques lacked the essential spatial information that will be provided by EIS. This information is vital for determining the small-scale spatial distribution of the heating and thereby constraining the mechanisms of energy release and transport. For example, is the heating uniform or confined to a small fraction of the loop volume?

There is also the important question of the larger-scale spatial distribution of heating. Yohkoh SXT observations suggest that the pressure is greatest at the tops of loops, both flaring and nonflaring, and that substantial pressure variations are present along the loop axes (e.g., Kano and Tsuneta 1996). These are puzzling results that, if correct, yield valuable information about loop physics. An important goal of EIS is to verify and quantify these results by eliminating the uncertainty of unknown filling factors.

EIS will also search for more direct signatures of energy release. Magnetic reconnection, the most likely candidate for energy release, is characterized by high-speed bidirectional outflows (e.g., Petschek 1964). Doppler shift patterns, that have been interpreted as evidence for such outflows, were detected by HRTS (Dere et al. 1991) and SUMER (Innes et al. 1997). But questions remain. The temperatures (approximately 10^5 K) and velocities (approximately 100 km s^{-1}) suggest that the reconnection is occurring in the chromosphere rather than in the corona (Klimchuk 1998). Direct evidence of coronal reconnection outflows would be a landmark in solar physics.

Reconnection outflows involved in coronal heating are likely to have very small spatial scales. They are not likely to be visible in images, but rather would be revealed as enhanced high-velocity wings of spectral lines. Since the outflows are expected to be quite faint (Klimchuk 1998), a high-sensitivity spectrometer with high spatial resolution is essential. EIS will be the most sensitive coronal spectrometer ever flown, and thus will be a valuable tool for studying the details of magnetic reconnection. As with all Solar-B studies, the greatest scientific return will come from a comparison of coronal and magnetograph observations. Magnetic reconnection in the corona may be accompanied by detectable changes in the transverse field in the photosphere.

Active region loop observing sequences are particularly easy to define. Loops can be chosen for detailed EIS observations from images obtained by the XRT on Solar-B. EIS can then obtain density and dynamical information by rastering the spectrometer slit over the loops, or by stepping the slit in specified angular increments over a small number of locations within a loop. Using a coordinated observing program, it should be possible to intersperse XRT images with the spectrometer observations to monitor changes in overall loop shape or intensity distribution. Alternatively, EIS slot images can be used as a substitute for XRT images if a coordinated observing program is not possible. Because the slot images are obtained with the same optical system as the slit spectra, they may have advantages over XRT images.

b. Explosive Events. One of the most intriguing facets of the so-called quiet solar atmosphere is the ubiquitous presence of highly dynamic behavior including spicules, surges, explosive events, UV microflares, and EIT microjets. Magnetic reconnection is believed to play the major role in driving the observed plasma motions (Blake and

Sturrock 1985). The coronal X-ray jets, first seen by Yohkoh (Shibata et al. 1992a), also might be explained by reconnection (Shibata et al. 1992b, Yokoyama and Shibata 1996). Similar models have been proposed for X-ray bright points as well (Priest, Parnell, and Martin 1994).

The physical feature apparently unifying all this observed dynamic activity is the relative motion of magnetic flux systems in a multipolar photospheric region (Antiochos 1987, 1998). Theoretical investigations have examined both shear-driven reconnection in chromospheric eruptions (Karpen et al. 1995, 1996, 1998), and emerging flux driven reconnection in soft X-ray (SXR) jets (Shibata et al. 1992b, Yokoyama and Shibata 1996). These chromospheric and coronal events appear quite similar in terms of relevant morphologies and energy requirements, but manifest significant differences in temperatures, height of initiation, and association with specific patterns of photospheric magnetic flux evolution. Existing observations clearly indicate that explosive events are not flare-related and are more closely linked with flux emergence and cancellation (Dere and Martin 1994). On the other hand, SXR jets are related to flares and flux emergence.

By combining the EUV spectroscopic capabilities of EIS with the other instruments on Solar-B, we will be able to observe and compare energetic events such as X-ray and EUV jets over a wide range of plasma temperatures and discern for the first time the underlying magnetic structures. It is crucial to observe simultaneously the vector magnetic field and the associated plasma with sufficient resolution and sensitivity to detect the key signatures of reconnection in the relevant environments. Previous space missions (e.g., SOHO and TRACE) have been able to detect emerging flux but not the shear component of the magnetic field, which is essential for determining pre-event energy storage and real-time energization through footpoint motions.

For eruptive events, the full life cycle of a flux element in a supergranule must be studied from birth (emergence) to death (cancellation at the network). This will involve correlated magnetic field and EIS observations, that follow the magnetic evolution of the underlying flux element while monitoring the ensuing motions and plasma diagnostics from the transition region (He II) into the corona (Fe XII and Fe XV). For X-ray jets, coincident observations with the vector magnetograph and EIS will not only detect the heated plasma over a broader temperature range than that accessible to Yohkoh, but also will provide for the first time the three-dimensional (3D) magnetic information necessary for deciphering the relative importance of flux emergence, convergence, and footpoint shearing. These data also will yield much-needed constraints and input for ongoing 3D modeling efforts aimed at determining the role of reconnection in many forms of solar activity.

The primary EIS diagnostic for transition region explosive events will be the dynamical signatures that appear in the He II 256 Å line profile. To evaluate the effectiveness of this line for dynamical measurements, the opacity in the line, due to the high abundance of helium in the Sun, must be considered. SERTS observations have shown that even the He II 304 Å line, which has a much larger opacity than the 256 Å line, can be used to determine bulk flow velocities in the transition region and that nonthermal mass motions significantly alter its width. Thus, opacity in the He II 304 Å line does not reduce its utility as a dynamics diagnostic, and therefore the effectiveness of the He II 256 Å line will certainly not be compromised by opacity. EIS images obtained by rastering or with the slot in the He II line will clearly show the boundary regions of the supergranule network. Thus, EIS high spatial and temporal resolution observations of the He II line profile will allow us for the first time to unambiguously correlate dynamic events with the magnetic network. Moreover, EIS He II images will allow us to coalign with observations made with the Solar-B magnetograph.

c. CME/Flare Initiation. Among the most energetic manifestations of solar activity are the giant eruptions of the Sun's magnetic field that produce a CME. The most violent of these events are usually accompanied by an eruptive flare (EF)—a prominence/filament eruption along with an intense X-ray burst. A large CME/EF like the 1997 Nov 6 X-class event observed by SOHO can eject up to 10^{17} g of coronal and prominence/filament plasma into the heliosphere with speeds exceeding 2000 km s^{-1}, producing strong interplanetary shocks. However, the mechanism for CME/EF initiation is unknown and has long been a core solar physics problem.

The instrumentation on Solar-B can contribute key observations essential for our understanding of CME/EF initiation. The problem with observations so far is that the eruptions are most easily detected as proper motions on the limb, but studying the initiation process requires measurement of the magnetic field topology—something very difficult to quantify on the limb. To solve the CME/EF initiation problem, we need high-quality disk observations of the field and simultaneous quantitative spectroscopic measurements of coronal plasma velocities and temperatures. These observations are exactly what Solar-B, and EIS in particular, have been designed to deliver.

A number of theories for CME/EF initiation have been proposed. They can be classified according to whether the eruption is purely magnetically-driven (e.g., Sturrock 1989, Moore and Roumeliotis 1992, Mikic and Linker 1994, Antiochos et al. 1998, Antiochos 1998) or whether the plasma thermal and gravitational energies play a crucial role (e.g., Low and Smith 1993, Wolfson and Dlamini 1997). Since the models predict distinctly different dynamical signatures, EIS will be able to distinguish among them. For example, magnetically driven models depend on reconnection as the mechanism that initiates a rearrangement of magnetic flux producing a CME/EF. The individual models differ in magnetic topology and location of the reconnection. These differences in turn produce different dynamical signatures. For example, the temperatures at which strong dynamical signatures are expected depend on the location of the reconnection region. Because EIS can measure dynamical effects over a temperature range from 0.1 (He II) to 20 MK (Fe XXIV), its observations can be used to distinguish among magnetically driven models.

Similar remarks apply to thermal/gravity models. For example, in thermal/gravity models, the flux rope becomes buoyant as cool material drains. Assuming typical heights of 10^4 km, this material should reach free-fall velocities of 100 km s^{-1}. Since typical energies for CME/EFs are of order 10^{32} ergs, the mass and, hence, the emission measure of the falling material must be large ($>10^{50}$ cm^{-3}), which will be easily detectable with EIS.

Although EIS will provide key dynamical measurements for distinguishing among different CME/EF initiation models, actually accomplishing this goal also requires theoretical models with sufficient sophistication to make firm predictions. Such models are currently being developed at NRL and other institutions. The state-of-the-art numerical technology developed at NRL will be a vital resource for the EIS program and Solar-B as a whole. This technology, developed over the past decade with NASA and other funding, will be available to the whole of the Solar-B program.

Detailed 3D magnetohydrodynamic (MHD) models may even prove useful for planning observations. For example, model calculations based on Solar-B vector magnetograph data could be used to select an active region for a CME/EF initiation observing sequence. These could be similar to coronal potential field extrapolation. Alternatively, a region could be chosen in the traditional observational manner, such as those regions with highly complex fields and strong shears. Once a region is chosen, EIS will obtain high time resolution line profiles in a number of lines from ions that span a range of temperatures, e.g., He II (0.1 MK), Si VII (0.6 MK), Fe XII (1.6 MK), and Fe XV (2 MK). These measurements would be made at different locations within the region, thereby measuring mass motions as a function of temperature, space, and time. These measurements, coupled with Solar-B vector magnetograph observations, would locate and characterize regions where magnetic reconnection is effective in producing major changes in magnetic topology.

d. Flare Main Phase. Yohkoh has provided convincing evidence in support of the standard model for flare heating (e.g., Carmichael 1964, Sturrock 1966, Hirayama 1974, Kopp and Pneuman 1976, Tsuneta 1996), in which X-point (or X-line, in an arcade) reconnection is a consequence of a magnetic eruption, typically a filament ejection. Initially closed magnetic field lines are stretched open by the eruption to form a vertical current sheet in the corona. The field then closes back down by reconnection, starting just above the photospheric neutral line and then rising steadily. The newly closed field lines appear on the limb as a system of growing X-ray loops. In this model, illustrated in Figure 2-2, the flare is the manifestation of the plasma heating and mass motions that result from reconnection along the X-line between the escaping eruption and the underlying growing arcade. Through its ability to obtain both images (with the slot) and spectra, EIS will quantify many of the observable characteristics of flare reconnection.

Using the EIS slot, images of a flare can be obtained at the 2 s CCD readout time. Alternatively, in a joint observing program flare images can be provided by XRT. The EIS wavelength bands will reveal the flare at temperatures ranging from 0.2 to 20 MK. Images obtained early enough in the flare will show the footpoint locations of loops traversed by nonthermal particles through emission in the He II and O V transition region lines (e.g., Widing 1982). The loops traversed by the nonthermal emission can be spatially compared with the loops that produce the thermal SXR flare as seen, for example, in the Fe XXIII and Fe XXIV emission lines. All these features can be related to the underlying magnetic field as revealed by the magnetograph. EIS will follow decay-phase cooling of the flare loops in lines such as Ca XVII, Fe XV, and Fe XII.

By stepping the EIS slit over the flaring region to construct spectroheliograms, the temperature and density of the flare can be determined with a spatial resolution more than a factor of two better than that provided by the SXT on Yohkoh. Temperature as a function of position in the SXR emitting loops can be estimated from the ratio of the hot Fe XXIV line relative to the Fe XXIII line and the intermediate temperature Ca XVII line (Widing and Dere 1977). Electron density as a function of position can be obtained in the cooling loops from Fe XII density sensitive line ratios. Thus EIS will follow both the heating and cooling of flare loops with high spatial and temporal resolution. By switching between spectrometer observations and slot and/or XRT imaging, all ambiguities resulting from the broadband nature of the XRT flare images can be removed.

Although determining the morphology and physical characteristics of flares is necessary for testing the general validity of the model outlined in Figure 2-2, it is the mass motions that provide the closest link to the actual reconnection process. The key observational signature of flare reconnection models is the production of fast jets of hot plasma. As the only coronal spectroscopic instrument on Solar-B, EIS will be the only instrument capable of unambiguously seeing these jets. In addition, EIS will determine precisely the locations of the well-known blueshifted flare emission with respect to the footpoints of the flare loops. This emission is thought by many to be direct evidence of chromospheric evaporation. The turbulent broadening of high-temperature SXR flare lines can also be investigated as a function of position in the flare. These spectroscopic observations, coupled with simultaneous coaligned magnetograph observations, will finally provide a stringent test for models such as that illustrated in Figure 2-2.

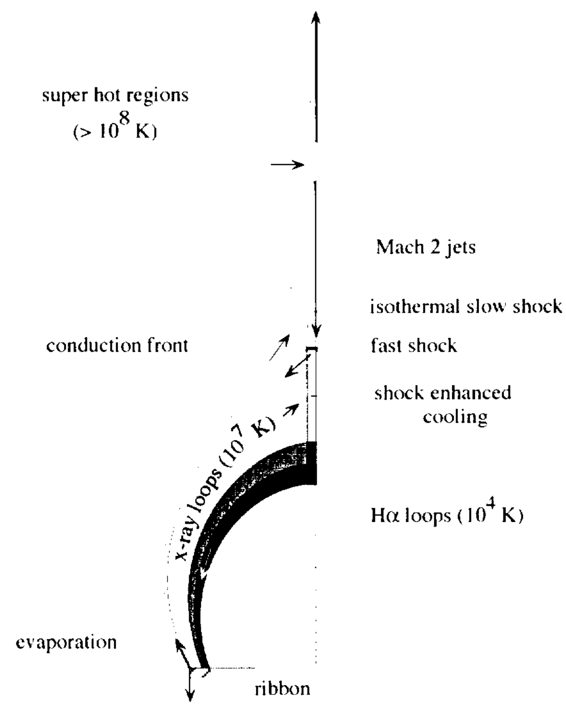


Figure 2-2. Reconnection in a Flare Loop Geometry

2.3 EIS Observations and Data.

a. EIS Observations. EIS will return measurements of EUV line profiles and spectral EUV images of the Sun obtained with the slot. These data are complementary to each other and to the other instruments on Solar-B in following the dynamical nature of the solar transition region and corona. The EIS spectrometer will record EUV line profiles along a 1" wide slit over a length of about 1024". The pixels in the spectrometer camera are equivalent to a size on the Sun of 1"x1". For each pixel along the slit, the solar EUV spectrum is dispersed by the grating to produce line profiles of the strong emission lines. From these, the line intensity, net Doppler shift, and line width can be determined for symmetric Gaussian profiles. For observations of dynamic features such as explosive events or ejections, the line profile provides detailed information about the distribution of velocities in the plasma.

A rich set of diagnostic techniques exists for the analysis of spectroscopic data. To a good approximation, most of the lines that will be observed by EIS are optically thin and produced by electron excitation of ions in coronal ionization equilibrium. From integrated line intensities, it is straightforward to derive the emission measure as a function of temperature. Temperatures are determined from intensity ratios of lines formed at different temperatures in ionization equilibrium. Electron densities are determined from intensity ratios of lines of ions whose relative level populations vary with density. A good example is the Fe XII line pair at 196 and 195 Å near the peak of the short wavelength band sensitivity (Figure 1-2). An important use of density diagnostics is to determine the plasma filling factor of coronal loops. Quantitative analysis of the observed line intensities will make use of the CHIANTI database (Dere et al. 1997).

The spectrometer will generally operate in a raster mode where the slit is repeatedly stepped across a region of interest, for example, a supergranular cell or an active region. Spectra at each resolution element of the two-dimensional area will be recorded so that images of intensity and velocity can be constructed. Since the strength of the Solar-B mission will be the coordinated observations of the various instruments, the EIS rastering will generally be limited to the target chosen for those observations. For example, in the quiet Sun, intensity maps can be made with exposure times of 7 s with sufficient detected photons to achieve a signal to noise ratio (SNR) of 10. At this rate, a 3×10^4 km supergranular cell can be repeatedly rastered with 1" steps at a cadence of 6.3 min. An active region with a width of 0.1 solar radii (7×10^4 km) could be rastered at a cadence of 3.6 min, depending on the observing requirements (see Table 2-2) and choice of spectral lines (see Table 2-1). Smaller regions could be rastered even more frequently. For example, many of the explosive event studies with the HRTS rocket were performed with 10" wide rasters and a 20 s cadence.

b. Coalignment. The EIS spectra and slot spectral images must be coaligned with the other instruments on Solar-B. Coalignment of EIS rastered spectra and/or slot images to XRT images will be accomplished by a straightforward cross-correlation among the data sets as they will all contain considerable information from the same solar structures. Coalignment to the optical instrument will proceed by a comparison of chromospheric network structures observed with EIS in the He II 256 Å line and the magnetic network observed with the magnetographs. Our experience with the EIT data is that this can be accomplished to an accuracy of about 1 pixel. We anticipate that on Solar-B, an accuracy of 1 pixel will be maintained even with the higher resolution. Since the Solar-B orbit will keep the satellite in nearly continuous sunlight, we expect to encounter only gradual changes in the coalignment calibrations.

We will establish our cross-correlation technique using previous experience as a guide. For example, CDS and EIT images have been aligned as described in Thompson and Carter (1998). Briefly, a cross-correlation matrix was built up by calculating the cross-correlation between two images for a series of small offsets in X and Y from the nominal coalignment. This cross-correlation matrix was then fitted with a bi-lateral Gaussian function to determine the position of the peak. An adjustment for solar rotation between the two data sets is included in their procedure, but is not needed if both images are recorded simultaneously. The same alignment procedure was used to coalign SERTS and EIT images. In this case, an initial coalignment was made by visually matching features seen in both observations. The SERTS image was then rotated by the angle determined by this initial coalignment. After rotation, each SERTS image was individually cross-correlated with EIT, using the procedure outlined above.

c. EIS Data Considerations. EIS telemetry is stored on the spacecraft Data Recorder (DR), which has a total capacity of 4.8 Gbits. The EIS allocation of one eighth of the total thus corresponds to 600 Mbits. Only half of the total DR capacity can be transmitted in a 10 min ground contact. Thus, the EIS share of a typical ground contact corresponds to a data rate for the orbit of about 55 kbps. For the sake of comparison, this is about 10 times the nominal rate for the combined LASCO and EIT experiments on SOHO and represents a real improvement in our ability to study the solar corona. Assuming that five ground contacts a day will cover a full 24 hr of EIS operations, the average downlinked data rate will be 17.4 kpbs.

The spectrometer employs a 1024x2048 pixel CCD (2 chips, one for each wavelength band). Typically only 512x2048 of the CCD will be selected. Our experience with EIT data and recent studies shows that using a wavelet compression algorithm (H-compress) allows compression factors of a factor of 5 with minimal loss of information. Typically, the complete CCD face would not be transmitted to the ground. Instead, only windows about selected spectral lines appropriate to the observing program would be transmitted. Table 2-1 lists a typical selection of available strong lines for transmission to the ground. If 25 pixels along the dispersion direction were devoted to each of 4 lines from this list, then 100x512 pixels would be transmitted from each exposure, the equivalent of 7.2×10^5 bits at a 14 bit analog to digital conversion. Assuming a compression factor of 5, it would take 2.6 s to transmit this quantity of compressed data using the complete nominal EIS data rate (55 kbps). This can be compared with estimates of the minimum exposure times needed to meet several criteria for spectroscopic diagnostics listed in Table 2-2. Clearly, the nominal data rate constrains most observations. This is a serious problem for the other instruments on Solar-B as well.

The required data rate could be reduced if fewer lines are transmitted or fewer pixels along the slit are transmitted. Also, it is likely that most pixels will not contain the full 14 bits of information.

For the purposes of scientific analysis, the Solar-B data set from all experiments will be treated as a whole. For EIS scientists to participate efficiently in this, it will be necessary for the data to be physically stored at NRL. Assuming only 5 10-min. station contacts per day, the Solar-B data will be collected at a rate of about 1.5 GB per day. Thus distribution and archiving of this data at various data centers in Japan, the US, and the UK should be a straightforward task. Put in terms of current proven technology, 9 GB disk drives are readily available at a cost of about $1K. By 2003, this price may drop by a factor of 10. Storing one year's worth of data on hard disks would thus cost approximately $6K per year for the disk array. Other technologies such as DVD may provide a better alternative. Clearly, data analysis will be greatly facilitated by a common approach to data archiving and access.

Table 2-1. Selected Lines for Transmission

Ion	Wavelength (Å)
Fe XII	186
Ca XVII	192
Fe XXIV	192
Fe XII	193
Fe XII	195
Fe XII	196
He II	256
Fe XVI	263
Fe XIV	264
Si VII	275
Fe XV	284

Table 2-2. Spectrometer Exposure Time Criteria

Criteria	Minimum Exposure Times (s)	
	Quiet Sun	Active Regions
SNR > 10 for strong Fe XII lines	7	0.25
SNR > 10 for density sensitive Fe XII lines	90	2.7
1 km s^{-1} velocity accuracy in strong Fe XII lines	71	2.4

2.4 Instrument Description Changes. The major and minor changes to the instrument have been summarized in Section 2.1. Only optical changes require an expanded discussion. This is given below.

a. Design Studies. Phase A was devoted to detailed studies of a variety of optical systems to meet the science requirements. Both the original TRENDY design and the Cassegrain telescope of the original NRL proposal were examined. In the end, the instrument consortium decided that a two reflection system was preferable to a three reflection Cassegrain system. Thereafter, we sought to optimize the optical performance and throughput of a combined telescope and spectrometer subject to the constraints listed in Table 2-3. The design optimization process looked at the sharing of the available optical length between the telescope and the spectrometer. A suitable match was made with a telescope focal length of 1.934 m, a spectrometer with a magnification of M=1.4 and a grating radius of 1.18 m.

The telescope has a plate scale of 1"/10 micron, which when magnified by 1.4 gives a good match between a 10 micron slit and a 13.5 micron pixel dimension. We thus obtain a 1 arcsec/pixel plate scale. A raytrace study of this off-axis parabolic telescope operating at f/13 shows that the theoretical blur is less than 0.5 arcsec for all angles less than 10 arcmin from the optical axis (and less than 0.75 arcsec for 15 min). The mirror is provided with separate multilayer coatings on each half to serve the two wavelength bands optimally. The telescope mirrors will be fabricated from a material such as Zerodur and will be superpolished to better than 5 Å microroughness. Optical Systems Technology, Inc. provided comparable surface finishes for the NRL Very High Angular Resolution Ultraviolet Telescope (VAULT) rocket optics.

For the two reflection systems, several grating types were considered. Among them are: a single conventionally ruled spherical grating; two separate spherical gratings; a single dual ruling density grating; a spherical variable line spaced grating (SVLS); a toroidal grating; mechanical and holographic recorded ruled gratings; and triangular and laminar groove profiles. Cost, reliability, schedule risk, heritage, and simplicity played a large role in the grating selection. With considerable effort, it was found that a toroidal grating with a single laminar ruling of density 4200 l/mm, was the simplest and lowest risk option. This simple grating provided good performance in the two wavelength bands simultaneously. Two CCD chips observe the wavelength bands of interest. Each detector views one half of the grating, each half of which is coated with a multilayer optimized for that band. The optical design optimization process for the spectrometer is based on a raytrace code that minimizes the RMS spot diameter over the full field and wavelength bands of the spectrometer in a least squares sense. Equal weight was given to both bands, and designs were rejected wherein the RMS blur exceeded the pixel size within the observation range. Figure 2-3 summarizes the results of raytrace calculations for some of the better designs considered, together with the baseline TRENDY concept. They present the full instrument resolution applying the Nyquist theorem for SVLS and toroidal gratings. The SVLS and toroid both deliver good performance, while the TRENDY design offers lower spatial resolution because of its plate scale. The current EIS-7T design (a toroidal grating with 4200 l/mm) was selected as being best suited to our requirements.

Table 2-3. Design Constraints

Size	Overall Length < ~3 meters
	Overall Width < 0.5m
	Overall Depth <0.25m
Telescope Mirror Diameter	150mm
Plate scale	1 arc-sec/pixel spatial
Two Detectors cover 40Å each	Short Wavelength Centered at 195Å
	Long Wavelength Centered at 270Å
13.5 micron square pixels	
4200 l/mm grating- Single Ruling Density	
Half ML Coated for 195Å	
Half ML Coated for 270Å	
Detector Must Clear Input Path	

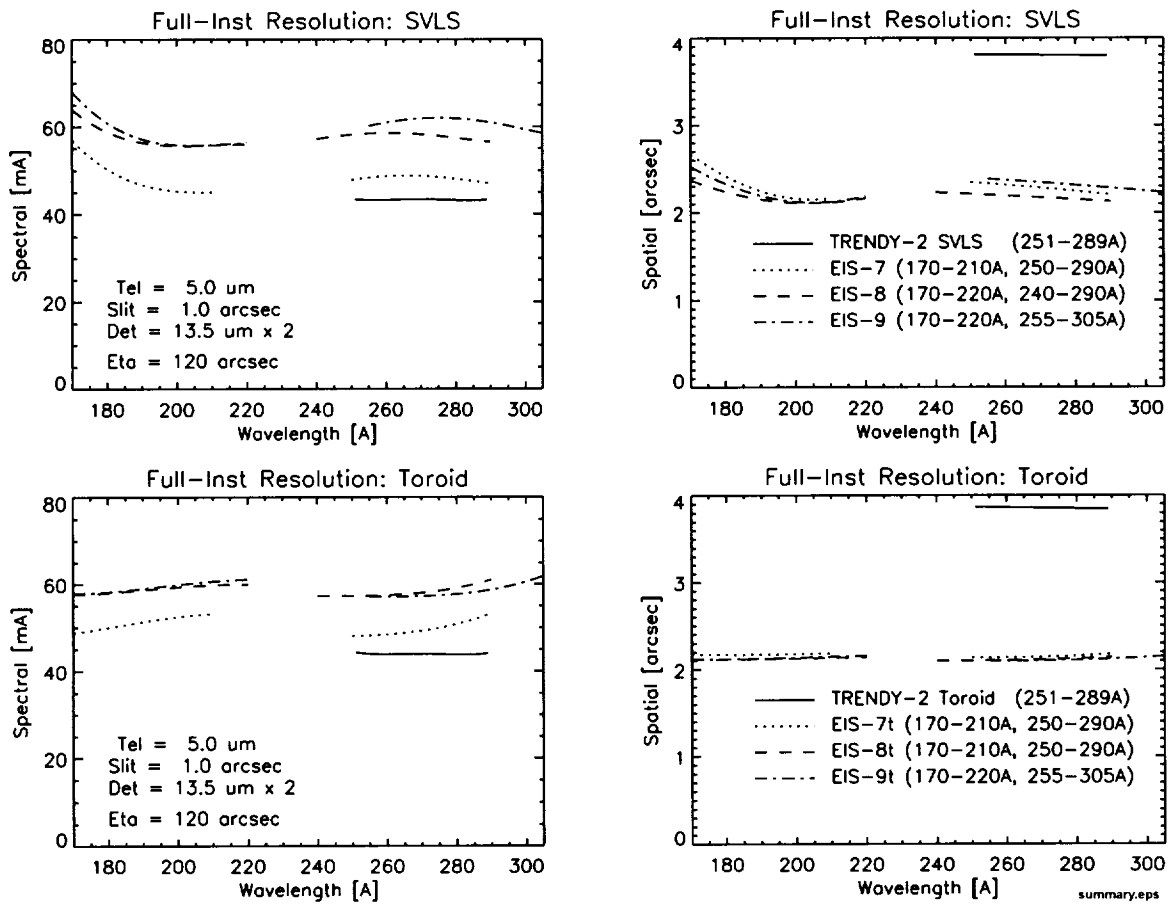


Figure 2-3. Summary Comparison of Several Candidate Spectrometer Designs

3. Education/Public Outreach, Technology, and Small Disadvantaged Business Plan

3.1 Education/Public Outreach Activities.

a. E/PO Approach. An important scientific goal of EIS is to observe unmistakable signatures of an elusive but significant process: magnetic reconnection. Reconnection occurs in very small regions over short timescales, and up until now has been very difficult to detect. The EIS team will be able to determine the role of reconnection in solar flares, coronal mass ejections, coronal heating, and chromospheric eruptions with the aid of the photospheric magnetic-field and X-ray imager data gathered by the other Solar-B instruments. Achieving this scientific objective along with other EIS science objectives will provide a powerful resource base of data from which to impact specific areas in the middle school and high school physical sciences curricula: States of Matter, The Sun-Earth System; Magnetism; Energy; and Technology. The NRL Education and Public Outreach program will serve as a facilitator between the scientists and the teachers, to enrich the learning experiences of K-12 students in the physical sciences; an area in which the US school system lags, compared to other industrialized countries.

A successful E/PO program identifies and develops learning tools specifically relevant to the research program. In addition, the program disseminates mission discoveries in a manner that is attractive and accessible to teachers, students, and the general public. To develop such a program, the EIS team will collaborate with experienced E/PO specialists. This will allow them to take advantage of existing E/PO facilities and personnel at their home institutions (NRL and GSFC). All EIS team members will participate in formulating, organizing, and realizing the wide range of planned E/PO activities. To implement this program efficiently, the EIS team will collaborate with Dr. Sten Odenwald (Raytheon ITSS), an expert on effective communication of the wonders of science and technology to all segments of the public. The EIS team will rely heavily on Dr. Odenwald to develop World Wide Web (WWW)-based mechanisms for informing the public about the goals and discoveries of EIS and Solar-B. To obtain the maximum possible benefit from the limited financial resources available, the team will use Dr. Odenwald's expertise on effective construction and use of diverse educational tools.

The budget available for EIS education and public outreach will constrain these activities to a small number of carefully-focussed venues in order to maximize their impact on the state of physical science education. It is common for more lavishly funded NASA missions to develop a broad suite of posters, CDROMS, pamphlets, study guides and promotional materials. EIS will need to target its budget to only those modalities which have the highest leveraging potential, and ability to significantly impact the science literacy issue. To this end, we will consider three products which have served other missions extremely well in terms of their 'unit cost' and information content: 1) A web site; 2) A CDROM; and 3) NASA/CORE publications.

❒ *Web Site:* The EIS web site will be the premier contact point between the EIS mission and both the general public and education communities. This is a trend which is rapidly escalating in the modern education marketplace. Teachers are routinely familiar with how to navigate the Web to extract classroom resources, lesson plans, and audio-visual materials. EIS will develop, prior to launch, a series of web pages designed to specifically highlight teacher-oriented topic areas, and what EIS will contribute to illustrating and explaining these topics. Several primer modules will be provided on the topics, Plasma: The Fourth State of Matter; The Doppler Effect; Atomic Spectra; The Magnetic Universe; and Space Weather. Each module will have three explanatory tracks for grades 3-5, 6-8 and 9-12, along with a series of new activities for classroom use. We will work with the already-existing network of teachers employed by the IMAGE mission, to develop these products and to test them under actual classroom conditions.

For the public, the EIS web site will also include a multi-media gallery that will highlight animations, real data, and numerical simulation movies of the basic processes being investigated. It will also serve as a library for teachers and students to use as part of laboratory activities in learning about magnetism and basic physics. The web site will also include a FAQ area, and a basic resource area describing in simple terms how the instrument works and why scientists require the kinds of data it provides to further our understanding of how the sun operates.

❐ *CDROM:* A variety of surveys of teacher resources in the modern computer age, finds that more teachers each year are becoming comfortable with CDROMS as a medium for introducing new materials into their lesson plans, classroom activities, or other professional activities. The IMAGE/POETRY mission has long worried that CDROMS may not be a worthwhile medium through concerns that only a small percentage of teachers feel comfortable with them. This mission recently reassessed this opinion, and has now decided to augment its web-based activities with a CDROM in 2001. The primary factor which caused this re-evaluation was that IMAGE/POETRY had developed a suite of classroom activities which were expensive to reprint in paper form, and which also relied on using actual data from the satellite. A self-contained CDROM was selected as the most cost-effective way to place these materials into the hands of teachers likely to use them, and at nearly 1/10 the cost of printed materials. A similar rationalization applies to the EIS educational products. Moreover, a significant advantage of CDROMS is that full-color images and MPEG movies can be added at no additional cost. The mastering of the CDROM can be done with existing technology at NRL/GSFC, and the unit cost for replication is about $0.75 in lots of 10,000 from many commercial printers.

The EIS CDROM will contain a full copy of the EIS web site, along with copies of other related web sites integrated into a main page on the CDROM via embedded HTML links. The EIS Science team will contribute graphics, movies, and perhaps a series of short RealMedia interviews to highlight specific personal aspects of the mission.

❐ *NASA Publications:* NASA Education Resource Centers and the NASA CORE program are a major distributor of education products and resources within the NASA community. At no additional cost to a mission, Goddard's Education Office will review a candidate publication, and if it passes a series of educational criteria, the publication will be entered into the ERC/CORE system. There it will be available to tens of thousands of teachers across the country. These products can be as simple as 2-page Education Briefs or 50-page classroom activity guides. The EIS Education and Public Outreach program will develop a series of NASA Education Briefs to explain the basic science of EIS along the lines of the topic areas described above. We will also develop a new 10-page NASA publication on magnetism, which will include updated information about solar magnetism, highlighting the issues of magnetic pressure and energy. Most teachers and students recognize from their experiences with magnets that opposed poles can create a resisting force, but do not realize that magnetic fields store energy. This feature is crucial in understanding how magnetic reconnection works, and how it is a source of energy.

In addition to these three products, the EIS E/PO program will capitalize on already existing E/PO activities at NRL and GSFC to leverage the reach of EIS without having to invest significant budgetary resources. At each institution, an existing office already carries out a broad spectrum of E/PO efforts: the NRL Personal Excellence Partnership (PEP) Program (contact point: Mr. Dom Panciarelli), and NASA's GSFC Education Office. Both of these offices have invited us to take full advantage of their services. NRL and GSFC have pre-existing ties to local and remote school districts and universities, experience with arranging teacher workshops, setting up facility tours for classes and other groups, and other aid which will be important in our E/PO program. It should be noted that the NRL is the only Navy center which subsidizes the salaries of employees engaged in E/PO activities, which adds leverage to our participation in Solar-B.

Both institutions also are proud of their long-term efforts to enhance minority and disadvantaged participation in science and technology. For example, extensive programs bring students from Washington, DC schools into the laboratories to observe and work with the researchers. GSFC sponsors an existing program, which brings teachers into the research environment for eight weeks in summer. For example, Dr. Carol Crannell, a solar physicist at GSFC, developed the current summer program for science teachers in the DC school system.

b. E/PO Program Management. Dr. George Doschek, the US EIS Instrument Components PI, will direct the NRL/GSFC EIS team in supporting the proposed educational and public outreach activities. All team members will assist with presentations and provide input for curriculum development, according to their respective areas of expertise.

Dr. Sten Odenwald at Raytheon ITSS will be responsible for the bulk of the public outreach component and will serve as our contact point in the NASA/OSS SEC Education Forum. Dr. Odenwald is highly respected as an astronomer and E/PO pioneer. Currently he is in charge of the IMAGE/POETRY project; the E/PO program of NASA's IMAGE satellite *(http://image.gsfc.nasa.gov)*. He privately created the Astronomy Cafe, an award-winning website *(http://www2.stx.com/cafe/cafe.html)* that has answered over 22,000 questions thus far about astronomy and space physics (answers for only the most interesting 4600 questions are given by the web site). He has developed educational materials for a wide range of astrophysical topics, and he recently published a book entitled *The Astronomy Cafe* (Freeman and Sons 1998). He also has collaborated with Dr. T. Kucera and Mr. Mike Carlowicz in running ISTP-related teacher workshops at GSFC where new educational resources, for distribution to teachers, are created. Dr. Odenwald is familiar with the National Education Standards, effective dissemination mechanisms for educational materials, and meaningful evaluation metrics for space-related E/PO activities, all of which will prove extremely valuable throughout the EIS program.

3.2 New Technology. The technologies being used for the development of the EIS Instrument Components are derived from heritage on previous NRL missions. There are no new technologies being used in this program.

3.3 SB/SDB Subcontracting Plan. The NRL EIS Instrument Components development team is committed to exceeding NASA's goal of 8% for SB/SDB subcontracting. NRL has an aggressive program designed and implemented to use SB/SDB in our subcontracting and procurement actions. It includes women-owned businesses, historically black colleges and universities, and minority institutions. Table 3-1 compares NRL's FY98 goals and achievements. While some of these categories overlap, it is clear that the sum of these activities exceeds NASA's 8% goal.

During Phase B, the EIS team will work with NRL's Business Operations Directorate to identify and maintain additional contracting options that meet these goals. The EIS SD/SDB program will be administered by the assigned Program Analyst and will be approved by the PI. Both will be jointly responsible to assess and supervise the acquisition program and to establish SB/SDB subcontracting goals that satisfy the NASA guidelines. Throughout Phase B and the duration of the mission, detailed records associated with the SD/SDB Subcontracting Plan will be maintained. A listing of these records is provided in Table 3-2.

Table 3-1. NRL Subcontracting Goals and Achievements

% of NRL Contracts Awarded	Goal (%)	Achieved (%)
Women-owned business	5	3.5
SB/SDB (minority-owned)	7.5	10.3
Historically black colleges, universities, and institutions	5.0	0

Table 3-2. Subcontracting Records

- Documentation of NRL and key subcontractor's SB/SDB outreach activities, including participation in SB/SDB programs, and source search activity.
- Documentation of industrial contracts and their subcontracts for awards in excess of $100,000, indicating whether or not SB/SDB concerns were solicited and the reason for the award not being made to a SB/SDB.
- Documentation of acquisitions and demonstration of compliance with SB/SDB procedures and performance.
- Documentation of workshops, guidance, and training given acquisition personnel regarding use of SB/SDB concerns.

4. Technical Approach

4.1 Investigation Strategy Approach. The primary science requirements of the EIS Instrument have been presented in Section 2. To achieve these objectives the NRL team, in cooperation with the UK team, will build, assemble, test, launch, and operate the EIS Instrument aboard the Solar-B spacecraft with a scheduled Japanese launch in August 2004. The EIS Instrument will be developed in cooperation with the UK engineering and science teams under the direction of the principal UK Institution, the Mullard Space Science Laboratory (MSSL). The top-level strategy for development and mission operation of the EIS Instrument includes:

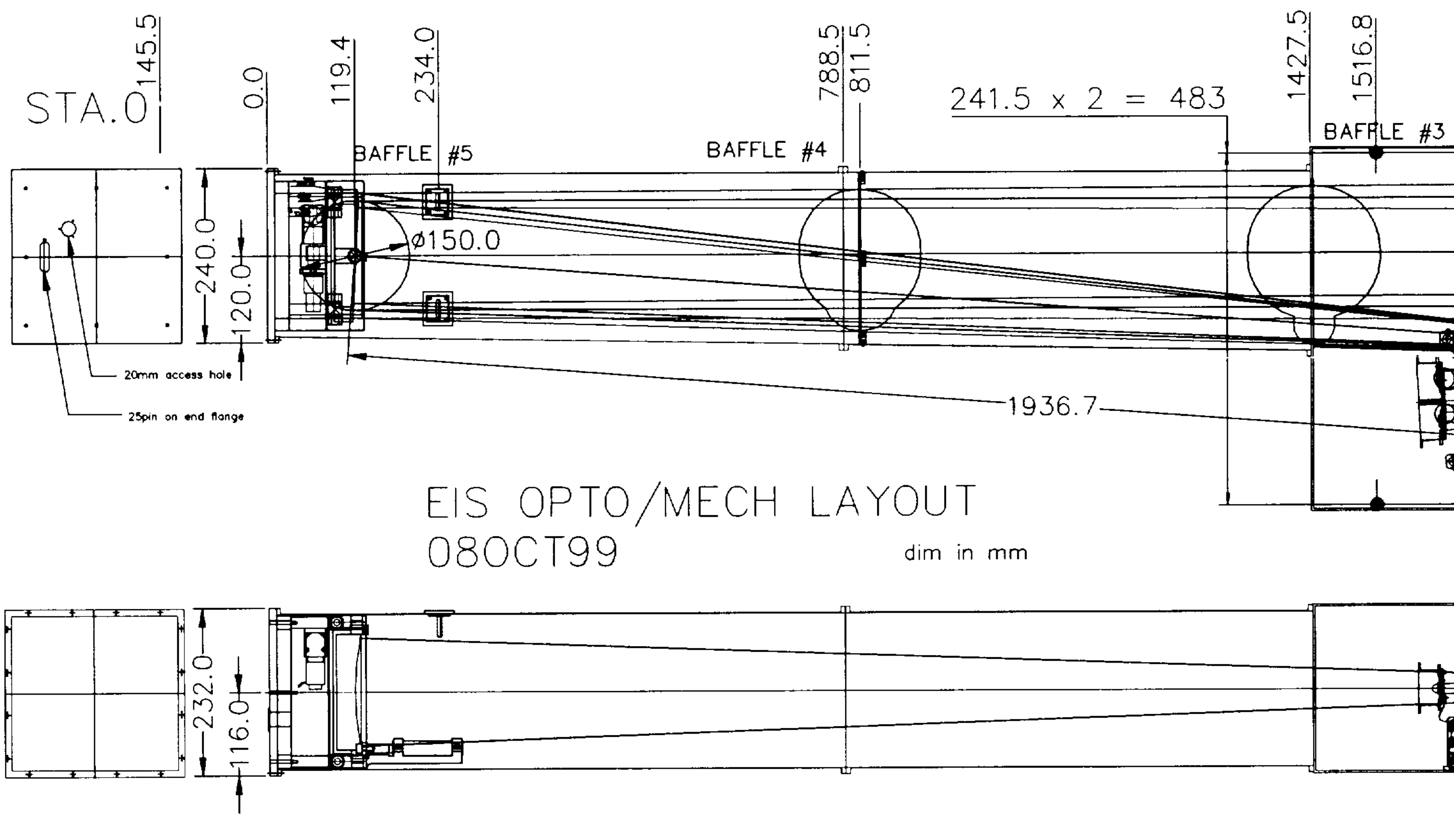
- NRL will design, verify, and test flight EIS Instrument Components consisting of the Front Filter Assembly, Primary Mirror Assembly, Slit/Shutter Assembly, Spectrometer Entrance Filter Assembly and the Grating Assembly. All activities for the EIS Instrument Components will be conducted at NRL facilities.
- Integration of the EIS Instrument will occur in the UK. EIS UK team members, under the direction of MSSL, are developing the EIS Instrument Structure, Focal Plane Package, Instrument Control Unit, and Mechanism and Heater Control Unit. Integration, system test, and calibration of the EIS Instrument will occur at the Rutherford Appleton Laboratory facilities in the UK. The NRL/GSFC engineering and science teams will participate in the EIS Instrument integration, test, and calibration activities in the UK.
- Integration of the EIS Instrument to the Solar-B spacecraft, pre-launch, and launch activities will occur at the ISAS facilities in Japan. NRL, GSFC, and UK EIS team members will support these activities.
- NRL will participate in Mission Operations and Data Analysis (MO&DA) of the EIS Instrument for a period of three years after launch. Participation in the MO&DA will be through an international consortium of the NRL, GSFC, UK, and Japanese science teams.

The following sections discuss each aspect of the EIS Instrument development through launch and subsequent MO&DA.

4.1.1 Instrument Description. Figure 4-1 shows the EIS optical/mechanical layout and the nominal location, fit, and mounting points of the NRL supplied subassemblies. Table 4-1 summarizes the general instrument characteristics and Table 4-2 presents the electrical interfaces of the NRL supplied subassemblies. Figure 4-2 shows an electron-

Table 4-1. EIS Scientific Characteristics

Telescope	
Type	Off-axis paraboloid 15 cm dia. clear aperture
Focal length	1934 mm
Off-axis distance	70 mm
Nominal coarse mirror motion	±8 mm ±800 arcsec solar image motion
Plate scale at slit	9.37 microns/arcsec
Nominal fine mirror motion	±2 arcmin tilt ±4 arcmin solar image motion
Multilayer coating	Mo/Si pairs
Slit/Shutter geometry	▪ 1024" long ▪ 4 possible positions: - 1" slit - 50" slot - TBD - TBD
Spectrometer	
Grating type	Toroid Holographic laminar, uniform line spacing
Multilayer coating	Mo/Si
Operating order	1st
Wavelength range	▪ Maximum Wavelength Coverage: - 170-210 Å - 250-290 Å ▪ Useful Coverage: - 180-204 Å - 250-290 Å
Dispersion	1.65 Å/mm
Plate scale at CCD	13.5 μm/arcsec
Pixel equivalent width	0.0223 Å/pixel 34.3 km/s @ 195 26.1 km/s @ 256 23.6 km/s @ 284
CCD characteristics	1024x2048 pixels 1 each bandpass MPP structure EEV 42-20 13.5 micron pixels temperature: TBD
NOTE: CCD format and corresponding slit length have not been fully agreed to within the EIS consortium; the remaining parameters show the present agreed upon baseline.	



STA.0
145.5
0.0
119.4
234.0
788.5
811.5
241.5 x 2 = 483
1427.5
1516.8
BAFFLE #5
BAFFLE #4
BAFFLE #3
ø150.0
240.0
120.0
20mm access hole
25pin on end flange
1936.7
EIS OPTO/MECH LAYOUT
08OCT99
dim in mm
232.0
116.0

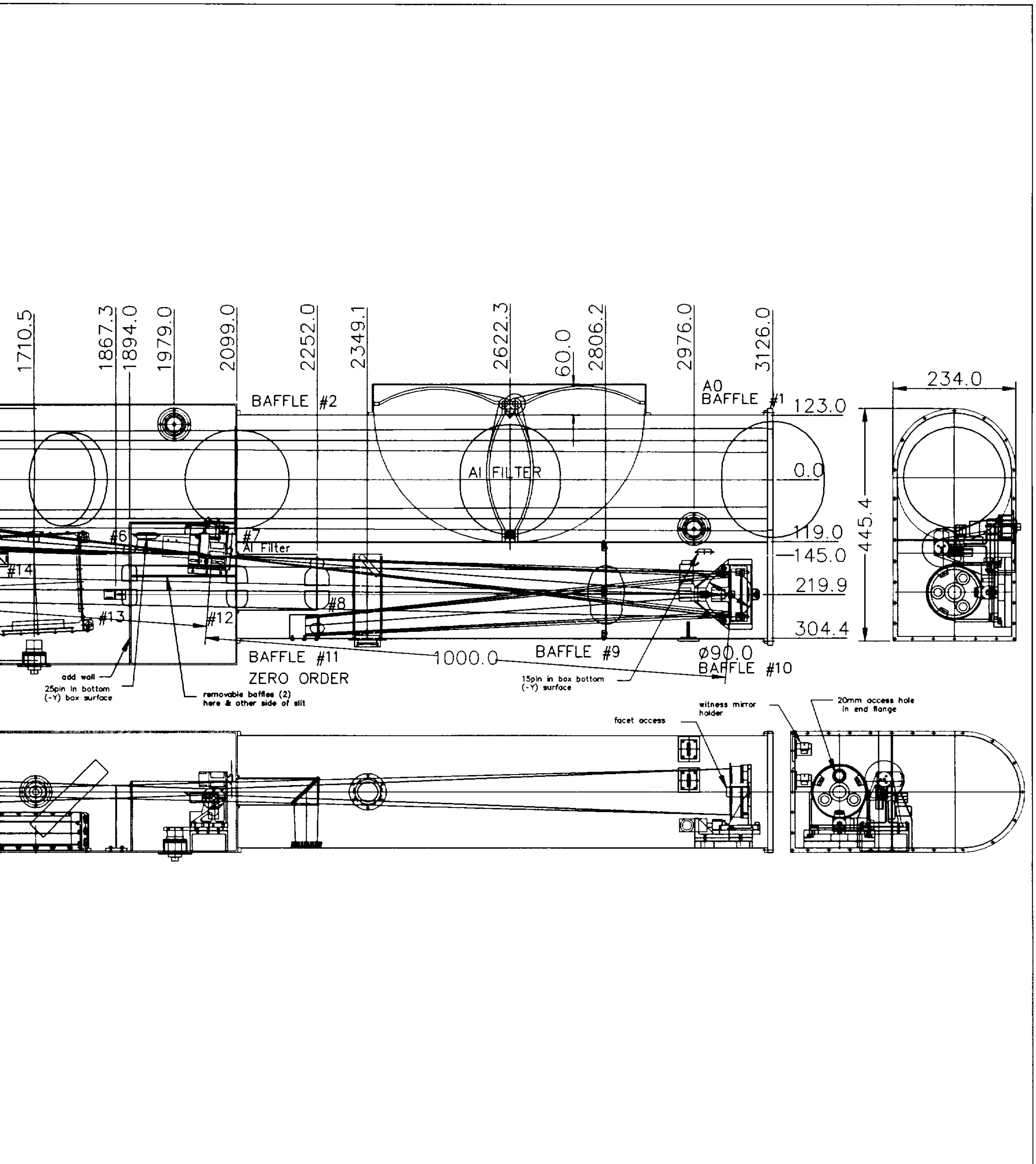


Figure 4-1. EIS Optical/Mechanical Layout

Table 4-2. Electrical Interfaces to US Subassemblies

Mechanism Subassembly	Translation	Actuator	Encoder	Average Duty Cycle	Peak Internal Power	Average Power
MIR Primary Mirror Subassembly	Coarse Position	Size 16, 4 phase stepper motors	Resolver	2 (20 sec) operations per day	10 W	0.0046 W
	Fine Position	Piezoelectric Transducer	Strain gauge	0.5V step per five seconds	0.29 W	<0.05 W
SLA Slit/Shutter Subassembly	Slit/Shutter Exchange	Size 12, 4 phase stepper motors	Resolver	2 operations per hour	3 W	0.0042 W
	Shutter	Brushless DC motor	Optical encoder	1 operation every 5 seconds	2.65 W	0.0122 W
GRA Grating Subassembly	Focus Mechanism	Size 16, 4 phase stepper motors	Optical Encoder	2 (20 sec) operations per month	10 W	0.0046 W
NOTE: Duty cycle, peak internal power, and average dissipated power values are preliminary estimates.						

ics block diagram. Solar radiation enters the instrument through its aperture and is incident on a thin film aluminum front filter that reflects the majority of the incident solar energy into deep space. The EUV radiation of scientific importance passes through the front filter and is imaged onto the spectrometer slit by the off-axis parabolic mirror. This mirror is articulated to allow fine and coarse motion of the solar image perpendicular to the slit. The combination of the length of the slit and the range of the coarse mirror motion allows a reasonable level of adjustment to provide alignment between EIS and the Solar-B Solar Optical Telescope. The radiation passing through the spectrometer slit and spectrometer entrance filter is then dispersed and reimaged by the multilayer coated grating onto two CCD detectors.

In a manner similar to that used for the EIT and TRACE optics, the telescope mirror and grating are divided into two sectors. This provides optimal coverage of the 180-204 Å (dominant quiet Sun and active region emitter, Fe XII) and the 270-290 Å (dominant emitter, He II) wavelength bands. The spectral coverage includes emission lines generated in plasmas from the transition region, quiet corona, hot active regions, and flares. Two wavelength bands are required to provide both acceptable temperature coverage and exposure times. These two wavelength bands are focussed onto two separate chips that are components of a single CCD camera (provided by MSSL).

4.2 Design Strategy Approach.

4.2.1 Technical Overview. The scientific goals of Solar-B require an instrument that records spectra at high spectral and temporal resolution. Spatial resolution must be comparable to existing EUV images. Previous EUV spectrometers were not capable of simultaneously achieving these results. This is demonstrated in a straightforward comparison of spectra and images from the SERTS sounding rocket instrument, images constructed from rastered spectra obtained by the CDS instrument on SOHO, and images obtained by EIT and TRACE. Furthermore, the dynamics and size of basic structures in the coronal scene appear incompatible with 50 minute duration spectrometer rasters, which are typical of presently operational and past instrumentation. The primary objective is to obtain sufficient counts in a single 3-10 s spectrometer exposure to characterize the emission line profiles of interest and to correlate them with the images. A fundamentally new approach is required.

The preliminary conceptual design of the instrumentation will produce high-quality EUV spectra with high time and spatial resolution. The spatial resolution is achieved by either rastering the slit over a selected solar region or by using a slot, i.e., 50" wide slit, to obtain single images. EIS consists of a simple, single element multilayer off-axis telescope and a magnifying toroidal grating spectrometer (Figure 4-1).

The off-axis telescope mirror focuses an EUV disk image onto a focal plane slit assembly that

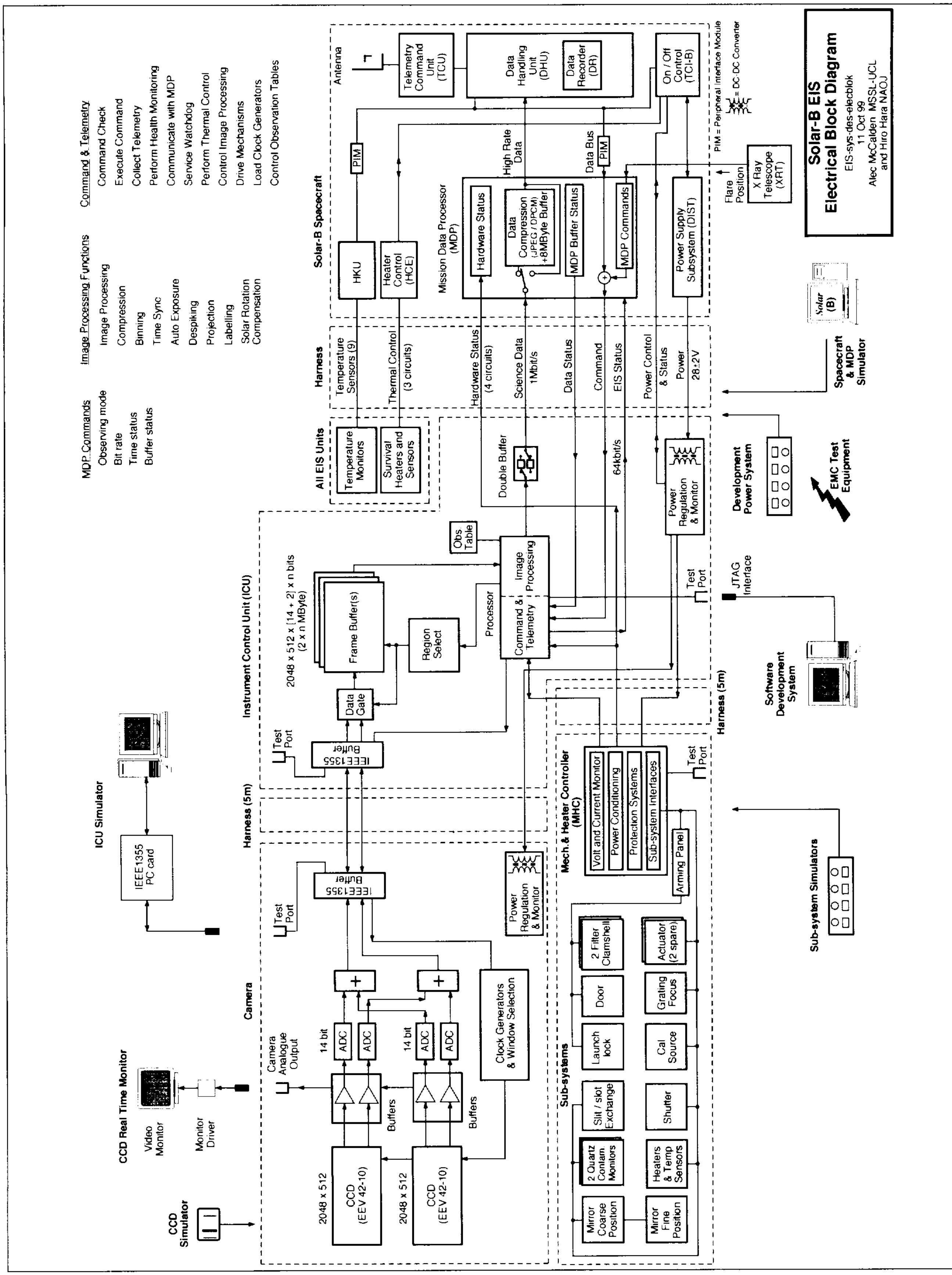


Figure 4-2. Electronics Block Diagram

contains a choice of four slit sizes. One slit, designated a slot, is 500 microns wide and spectra obtained with the slot are effectively 50" wide images. The telescope mirror is articulated to accomplish several purposes: post-launch coalignment with the white light telescope, and rastering of the solar image across the slit. The He II slot images and spectra will track features in the chromospheric network and will be used to coregister the coronal images and spectra with the white light telescope observations. The overlap in temperature sensitivity between EIS and XRT is sufficiently great that the same solar features should be identifiable in XRT images and EIS images obtained by rastering and with the slot. A simple cross-correlation calculation is all that is needed to accurately coregister EIS and XRT data.

EUV radiation passing through the slit is dispersed by the grating and reimaged at the spectrometer CCD camera. A focus mechanism is provided for the grating. Both wavelength bands are observed in the first order of the grating. The ruling density of the grating is 4200 lines/mm. The two wavelength bands can be observed simultaneously in the spectrometer because each wavelength band is focused onto a separate CCD chip.

4.2.2 Design Details.

a. Filter Assemblies (FFA and SFA). The EIS CCDs are sensitive to visible and near infrared (IR) radiation. The solar energy in these bands can be as much as 10^8 times that of the bright lines in the EIS wavelength bands. This requires a filter to reject the visible and IR while passing the desired EUV band. Thin Al supported on a mesh is ideal for this purpose, passing radiation between 170 Å and 860 Å while blocking the visible and IR. The curve in Figure 4-3 includes the naturally occurring Al_2O_3 layers on both sides of the filter. The oxide reduces the transmittance, particularly at the longer wavelengths. This curve is in good agreement with the Skylab filters, filters fabricated by Luxel, and the NRL X24C NSLS synchrotron beamline filters. Large format filters of this kind were developed at NRL for the Skylab mission, and have subsequently been flown on other missions such as TRACE, EIT (SOHO), and ROSAT, and are planned for the XRT on Solar-B. These large filters are fragile and require launch under vacuum to prevent acoustic damage. Space debris

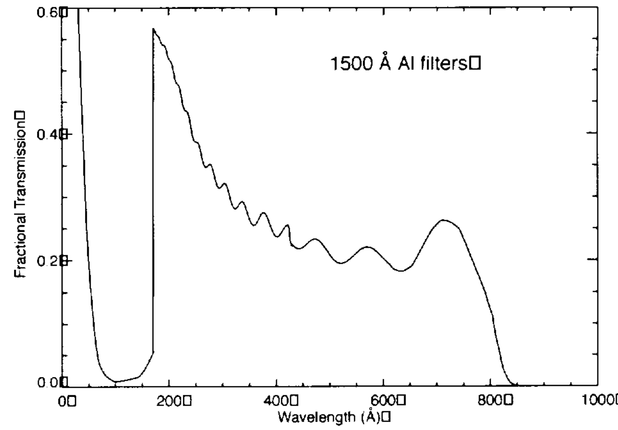


Figure 4-3. Aluminum Filter Transmittance

and micrometeorites can create punctures, so two filters are employed, one in the large entrance aperture, and a second small filter behind the slit.

The entrance filter serves as a thermal control element as well, reflecting 90% or more of the incident solar energy back through the entrance aperture. Thermal models and experimental measurements show that such filters can heat up to as much as ~250°C when exposed to the full Sun. They heat up in a matter of seconds, so they must withstand thermal cycling when the door is opened, or when the orbit goes into seasonal eclipses. The high temperatures will tend to evaporate volatile contaminants, but the glues used in filter fabrication could be evaporated into the optical system.

Small filters can be produced with pinhole transmittance of 10^{-7} to 10^{-9}, but large items such as the entrance filter are often limited to 10^{-4} to 10^{-5}, and can be expected to degrade with particle impacts. The filter behind the slit is expected to retain its high rejection ratio. The spectrometer slit acts as a spatial filter for visible light leaking through the first filter, a 10 micron slit passing ~5×10^{-4} of the light from the disk. A 500 micron slot on the other hand passes 0.027 of the light. Long wavelength light striking the grating can only diffract into zero order where it can be trapped, but a small fraction will scatter from any roughness or dust on the grating surface and be seen by the detectors. Assuming the scattering goes into 2π solid angle, the fraction subtended by each CCD is only 1.5×10^{-5} (or 1.5×10^{-11} per pixel).

Table 4-3 gives the expected debris and micrometeorite fluxes in the Solar-B orbit for a flat, Sun facing surface (normal to the velocity vector). The area of the entrance filter is 0.045 m^2, and it is located 0.5 m deep in the telescope tube, giving an acceptance angle of ±10°, or $f = \pi\sin^2(10°)/2\pi = 0.015$. As a result, we expect about 0.3 hits/year. The mesh supporting the aluminum has 344 micron square openings, so assuming one square lost per hit corresponds to a visible light leakage increase of ~3×10^{-6} in the filter as a whole. This allows us to require an initial visible light rejection ratio of 10^{-4} or better for the large filter and 10^{-6} or better for the small spectrometer entrance filter. The combination of the front filter location and the spectrometer entrance filter should allow any reasonable debris-induced damage to be ignored.

Table 4-3. Expected Debris and Micrometeorite Fluxes (MSFC, 1995)

Particle Diameter (microns)	Debris Flux (#/m^2yr)	Metoroid Flux (#/m^2yr)	Total Flux (#/m^2yr)
12.5	310	100	410
50	10	10	20

b. Primary Mirror Assembly (MIR). The primary mirror subassembly must satisfy the following functional requirements:

1. Mount the optic with minimal distortion over the applicable temperature range.
2. Tilt the optic to move the solar image perpendicular to the slit (±2').
3. Sense the relative position of the optic tilt with <1 arcsec accuracy.
4. Translate the optic ±8 mm perpendicular to the optical axis.
5. Sense the position of the optic to <20 microns.

A conceptual design of the mechanism is shown in Figure 4-4. The mirror is bonded into the holder with flexible epoxy. The baseline bonding procedure will be that used in the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) program at NRL. The optic cell will be mounted on two flex pivots which will allow the appropriate tilt of the optic. A low voltage piezoelectric translator (PZT) actuator with 60 micron extension will provide the necessary motion. Strain gauges integral to the PZT will be used to both linearize the PZT response to voltage and to sense the position of the optic. The translation of the optic will be accomplished by mounting the entire flex pivot stage on three linear, self-aligning bearings. The motion of the moving stage will be accomplished using a stepper motor with gearhead coupled into a ball screw. A resolver will be mounted to the ball screw shaft to sense the position of the moving stage. The resolver will be mounted with nonbacklash gearing to permit unambiguous sensing of the load over its full range of travel.

The conceptual design of the scanning mirror subassembly included a baseline selection of all critical mechanical components. The optic bonding procedure will be developed and tested during Phase B. In particular, we will examine the optical figure of a bonded test mirror and validate the strength of the bond. We also intend to test the optical figure and survivability of the mirror/cell at various temperatures during Phase B. We have selected a Lucas Aerospace 5/8" off-the-shelf flex pivot rather than a conventional ball bearing in the fine motion. The combined load bearing capacity for the two flex pivots baselined for EIS is >4000 N. For a low amplitude of motion space application, the flex pivots have significant advantage over a classical bearing approach. The desirable features include: high radial and axial stiffness, inherent frictionless, all metallic construction, infinite life cycle for low amplitude motion, stiction free, and a large operating temperature range. The actuator selected for the fine scanning is an off-the-shelf, UHV compatible, 60 micron, high load, low voltage PZT from Physics Instruments with embedded strain gages and a flexible tip to eliminate lateral loads (catalog number P-845.40 PZT with P-176.60 flexible tip). The 15 micron extension version of this unit was used successfully in the LASCO/SOHO Fabry-Perot mechanism and the M1 tilt mechanism. The PZT strain gauge is implemented in a Wheatstone bridge with 1400 ohms of nominal resistance in each branch. The accuracy of the off-the-shelf controller from Physics Instruments is advertised to obtain 0.1% linearity over its range; similar performance is expected with the EIS electronics. The preload on the PZT is 700 N which is sufficient for the application.

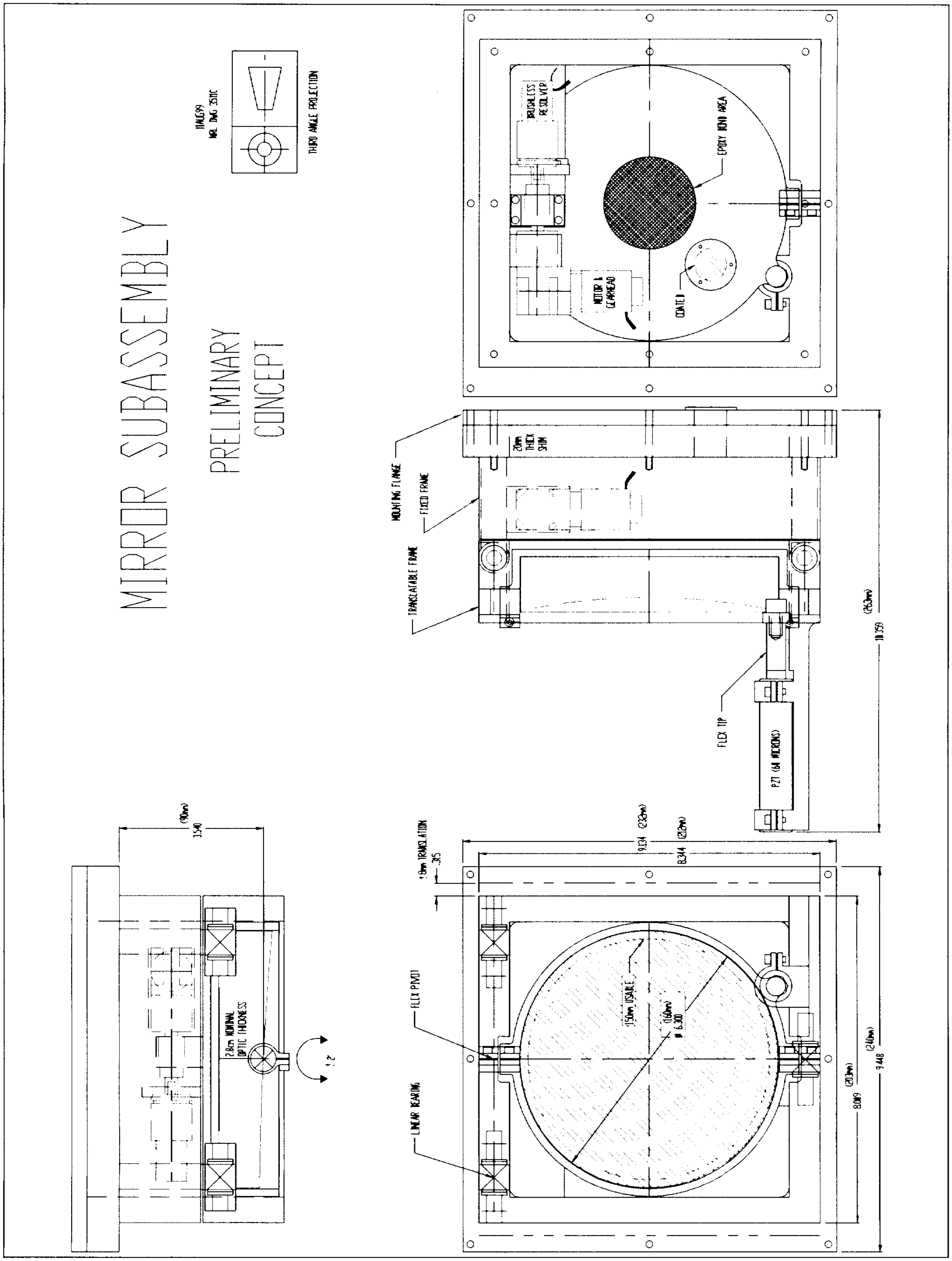


Figure 4-4. Primary Mirror Subassembly

The coarse motion is provided by a second moving frame mounted with three linear bearings riding on hardened steel rods. The linear bearings are mounted with flexures to the moving stage to minimize alignment issues. The match and fit of the linear bearings to the hardened steel rods will be accomplished using tight tolerance machining as well as final machining adjustments on the various mechanical parts. We have selected off-the-shelf Thomson linear bearings (catalog number super 6). These bearings consist of a "cage" (outer sleeve and ball retainer) of black Delrin, bearing plates of 8260 heat treated steel and balls of grade 25 chrome steel. The linear bearings provide self-alignment in all direction which reduces sensitivity to machining tolerances. The bearings are of space grade material and may be disassembled for precision cleaning.

The coarse scan drive consists of a 30 degree stepper motor with a 96:1 gearbox followed by a linear actuators with a 0.049 cm pitch. The actuator assembly will be provided by CDA Astro Intercorp. Backdriving will be prevented with a passive brake on the back of the motor rated for loads up to 30 g. The ball screw backlash will be selected to provide <13 microns of motion. The load bearing capacity of the thrust bearings are sufficient (>4000 N) for this application. These actuators have extensive heritage in other programs (a list provided on request); we will procure these parts as complete units. During Phase A, the NRL EIS team conducted a vendor survey of spaceflight motors and selected Astro Intercorp. We then negotiated a nominal set of specifications and cost for these actuators.

The position of the moving stage will be sensed with a resolver attached to the end of the ball screw. A small gearbox with an antibacklash drive will be incorporated in front of the resolver to associate a linear position with a unique resolver angle. The resolver and gearbox will be provided as an integral unit by Astro Intercorp.

As a portion of our Phase A study, the NRL team conducted a preliminary trade study to determine the appropriate lubricant for the EIS mechanisms. The most compelling candidates were as follows: Demnum grease (a teflon based grease), Braycote 601 (a teflon based grease), molybdenum disulfide, and tungsten disulfide. The dry lubricants are preferred from a contamination point of view but require a low humidity environment and have less desirable mechanical properties. The greases have excellent mechanical properties but have disadvantages from a contamination point of view. In particular, the concerns are film migration, migration by touch, and overall outgassing. Detailed discussions with a number of experts revealed that film migration is probably negligible, migration by touch could be carefully controlled with appropriate procedures, and outgassing could be further reduced by a high temperature vacuum bake prior to application. During our trade study, we interviewed experts associated with AXAF, HST, FUSE and LASCO/EIT as well as experts at the NRL Space Systems group, the MSFC contamination control group, and Swales Aerospace Inc. Finally, the actuator vendor has extensive experience with the application and use of Braycote 601. Thus, we have made a preliminary selection of vacuum conditioned, filtered, Braycote 601 as the lubricant for the EIS mechanisms.

c. Slit/Shutter Assembly (SLA). The principal requirement on the slit/shutter assembly is to position the spectrometer slits and slots reproducibly in the telescope focal plane. Reproducible positioning should allow a standard wavelength calibration and instrument profile to be obtained for the EIS instrument. The spectrometer slits must be reproducibly positioned to <2 microns perpendicular to the optical axis and <26 microns along the optical axis. A performance goal for the mechanism would be <1 and <13 microns, respectively. As shown in Figure 4-5, we propose to accomplish this by using a geared stepper motor with the direction of motion along the optical axis. The load position will be sensed by a shaft resolver. Unfortunately, the present optical design does not permit the resolver to be directly attached to the end of the shaft. Thus, the resolver is coupled to the output shaft with antibacklash gearing. The backlash inherent in the system is ±3 arcmin with a 15 arcmin step size. This corresponds to an uncertainty of ±10 microns in the position of the slit along the optical axis with a 50 micron step size. The resolver is expected to have an accuracy of <15 arcmin, sufficient to discriminate between individual steps. Operationally, we anticipate that the mechanism would be rotated only in a single direction. This

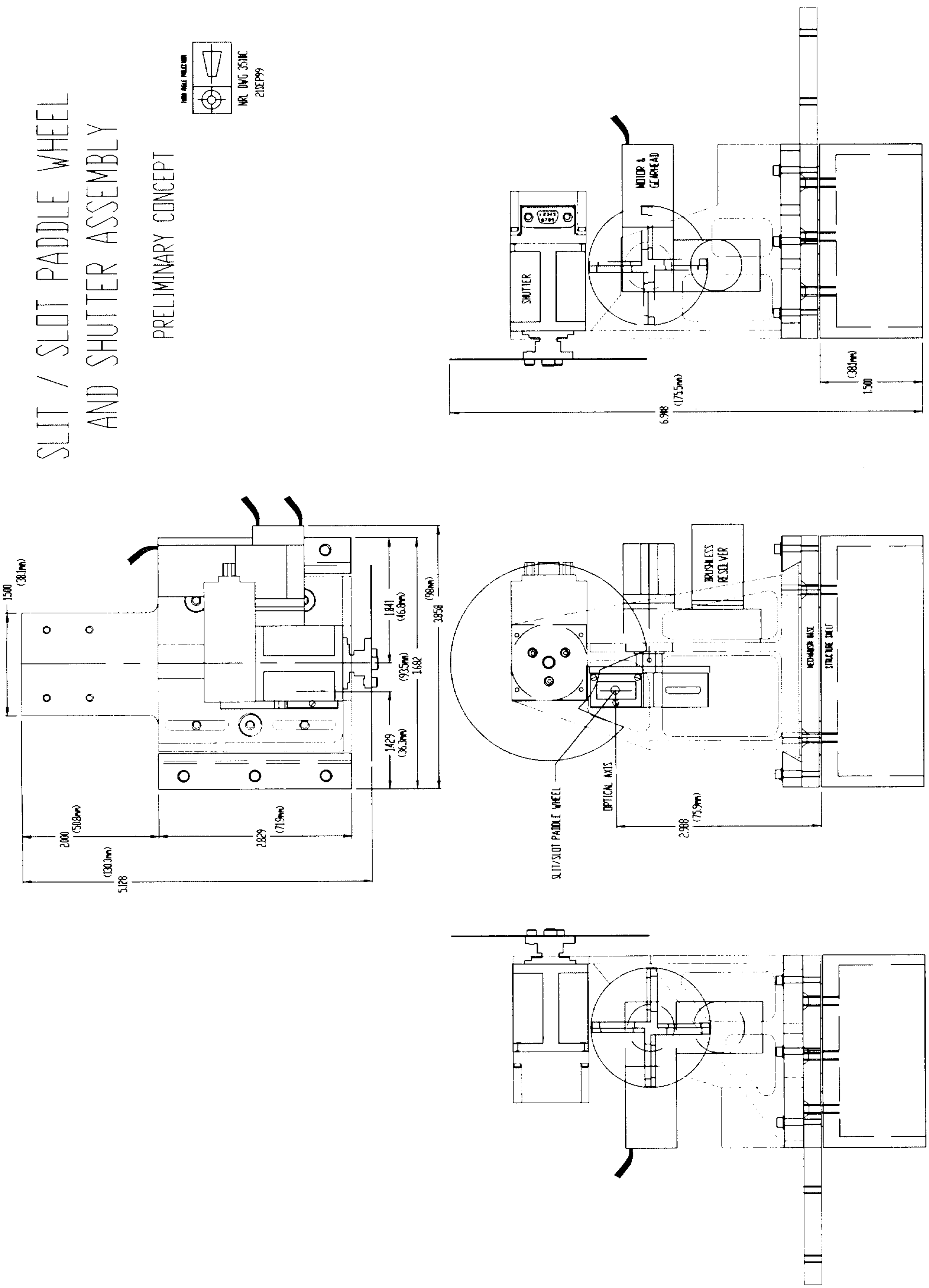


Figure 4-5. Slit/Shutter Assembly

would remove the uncertainty in slit position due to the backlash; the resulting performance should meet the performance goal. No difficulty is anticipated in meeting the reproducibility restriction along the rotation axis.

During Phase A, NRL negotiated a set of specifications and cost with CDA Astro Intercorp for a motor with a gearbox incorporating an integral resolver which met the above requirements. The motor is a 30 degree stepper motor attached to a gearbox with a 1:108 mechanical advantage. This gives 324 steps between 90 degree paddle wheel positions. The resolver is directly geared to the motor output shaft with antibacklash gearing (<3 arc-minute error) and will allow determination of the individual steps of the motor with 12 bit precision.

The instrument slits will be fabricated from a silicon substrate with the same photolithography process used at GSFC to fabricate the slits for the SERTS suborbital program. The starting material for the slit is a double side polished <100> plane silicon wafer, 75 microns thick and 2" in diameter. A thick silicon oxide is grown on the wafers and used as the etch mask for anisotropic etching of the <100> plane silicon from the slit area, while the orthogonal <110> planes act as the etch stop. The mask is printed on the wafer using standard techniques that remove oxide in the region to be etched. The bare silicon on the slit area is then etched away. Once the slit is opened up, oxide is removed from the rest of the wafer, forming the frame around the slit. The EIS slit fabrication does not present any significant challenge beyond that of the successful SERTS slit (18 microns wide by 3 mm long). The slit will be bonded onto a substrate (material TBD) using a flexible epoxy (nominally, Epotek 301) which will be bolted to the paddle wheel. Precise machining and tolerancing will be used to place the slits at 90 degrees. Provision will be made to accomplish the final adjustment using shims to place the slits in the same focal plane. The fabrication of the slots is considerably easier and will be done via. standard techniques.

The shutter assembly is included as part of the slit/shutter assembly. The envisioned design is a copy of the Lockheed Martin SXI shutter. We are in the process of transferring that design from Lockheed to NRL. The shutter has a demonstrated performance to take a 50 ms exposure with <5% photometric error. As shown in Figure 4-5, the shutter blade has a nonuniform opening to accommodate the off-axis location of the shutter. The shutter motor is a frameless, six phase, brushless DC motor available from Kollmorgen. The motor is specifically designed to provide high speed, high torque capacity for controlled rotating assemblies and is ideally suited to this application. We intend to carry out vacuum conditioning of the motor at NRL. The detailed performance and design of the motor are proprietary to Kollmorgen; the demonstrated performance of the SXI mechanism exceeds the solar B requirements. A photograph of the SXI shutter is given in Figure 4-6.

Figure 4-6. SXI Shutter

d. Grating Assembly (GRA). The requirements of the grating subassembly are as follows:

1. Mount the grating with minimal distortion over the operational temperature range.

2. Provide a focussing capability of ±1 cm to permit adjustment of the spectrometer focus.

The conceptual design of the mechanism is shown in Figure 4-7. The EIS grating will be bonded into a cell. The cell will be mounted onto a crossed roller slide translation stage. The translation stage will be driven with a geared stepper mo-

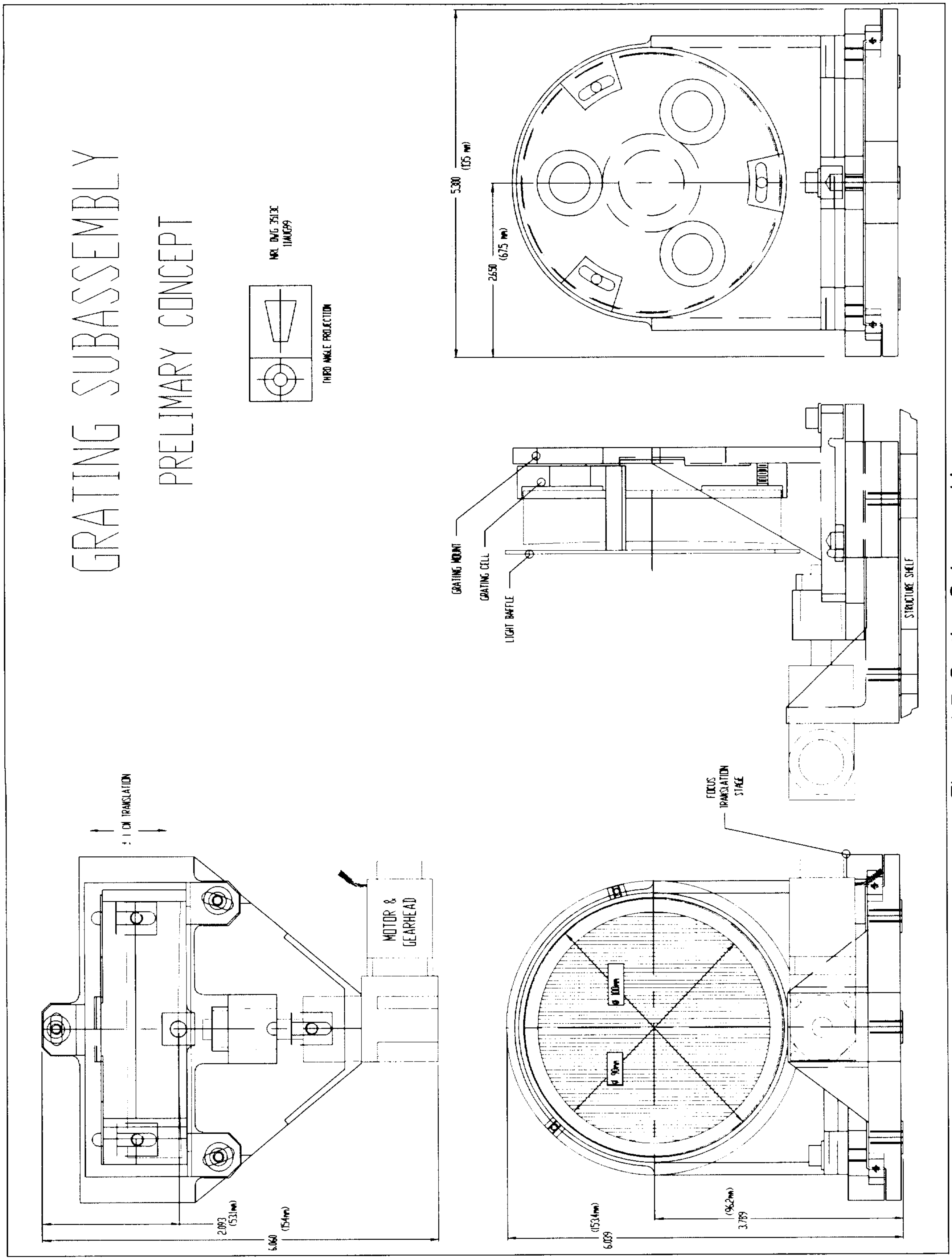


Figure 4-7. Grating Subassembly

tor and ball screw combination. To reduce costs, this actuator is identical to that used to drive the primary mirror scan drive. The mechanism is operated in open loop mode. The position is sensed with optical encoders.

The linear actuator for the focus mechanism will be identical to the actuator provided for the primary scan assembly. Since the loads for this mechanism are significantly less, the margins for backdriving, torque, etc. are considerably larger than the already generous margins incorporated into the scan mechanism. The optical bonding procedure and assembly procedure of the focus mechanism will be similar to the scan mechanism. The focus mechanism will incorporate a set of optical encoders (light emitting diode/photodiode combination) similar to those used on past missions to indicate an in-limit, an out-limit, and a proportional position sensor.

The grating and cell subassembly are placed on a moving stage mounted to the mechanism base plate with a pair of crossed roller bearing slides. These rails are compact precision bearings that can support and guide large loads with high accuracy and repeatability, low friction, and low starting force and are used routinely in applications requiring precise, uniform linear motion of large loads. The off the shelf rails (PIC part number PNB2-045) selected for the focus mechanism have a combined load capacity of 450 N in all directions. Each bearing consists of a pair of hardened steel ways containing 90 degree vee grooves and a row of alternatively crossed cylindrical rollers. The hardened steel rollers are captive in a brass cage for easy handling, assembly, and permanent alignment.

Each half of the grating and the corresponding half of the primary mirror receives a MoSi multilayer coating tuned for a total bandpass of about 20 Å and 40 Å fullwidth centered at 190 Å and 270 Å, respectively. Multilayer coatings are required to give normal incidence optics an acceptable reflectivity at these short wavelengths. The expected reflectance of the EIS coatings is given in Figure 4-8. They in turn require super smooth surfaces (<5 Å RMS) as substrates to attain high efficiency. The efficiencies of the two optics are multiplicative, so the two bands are quite peaked and narrow. Thus, each CCD sees spectra from only one half of the optics. The efficiency of the multilayer grating was calculated from first principles using the modified integral formalism. The code accounts for the groove profile of the grating substrate and the optical properties of the coating layers. The grating substrate has a laminar groove profile with 4200 l/mm. The groove depth, optimized for high efficiency in the two EIS wavelength bands, is 58 Å. The multilayer coating has 20 Mo/Si periods with $MoSi_2$ interdiffusion layers between each Mo and Si layer. The period spacing is 105 Å and 145 Å for the shorter and longer wavelength bands, respectively. As shown in Figure 4-9, the calculated 1st order peak efficiencies are approximately 13% and 9% in the shorter and longer wavelength bands. The wavelengths of the peak efficiencies in the two wavelength bands can be adjusted by changing the period spacings of the multilayer. In Figure 4-9, (+1, -1) refers to 1st order efficiency, etc. The label 0 refers to zero order.

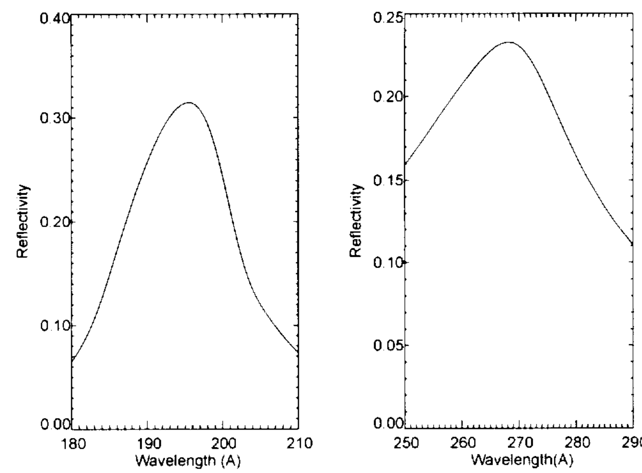


Figure 4-8. Reflectance of EIS Multilayer Coatings

4.3 EIS Instrument Components Development Strategy Approach. The primary objective during the development phase of the EIS Instrument Components Program at NRL is to qualify all components and subsystems such that very reliable and highly qualified flight hardware is delivered on schedule that meets or exceeds all mission requirements and specifications. To meet the program schedule, a smooth transition is made from the design to the fabrication phase of the mission. To facilitate this transition, NRL's engineering approach retains a single team of subsystem engineers from design through subsystem level accep-

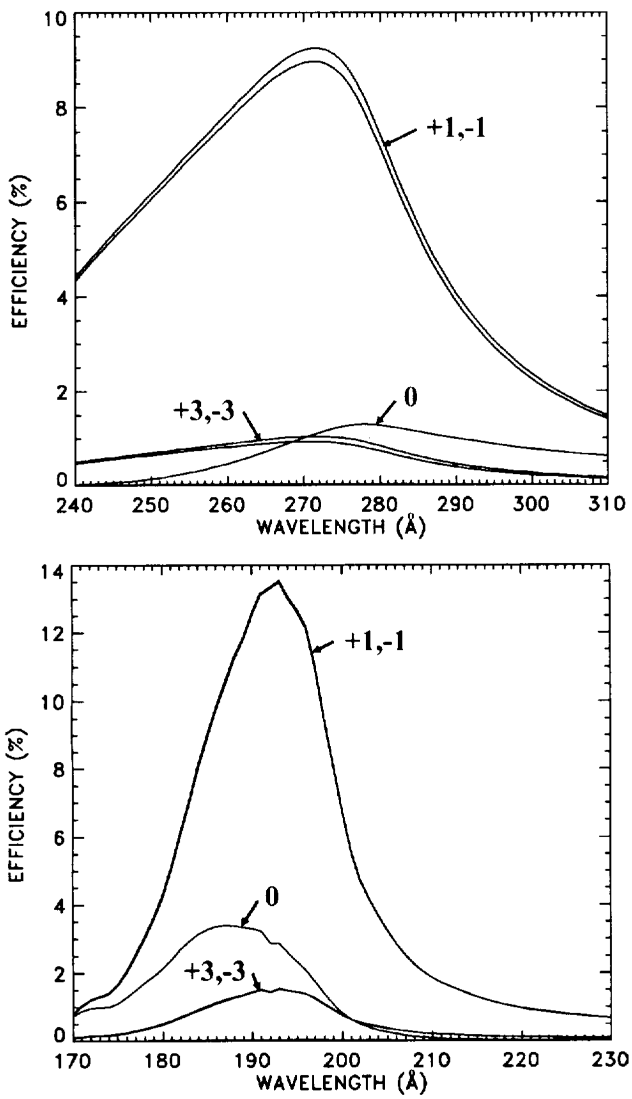


Figure 4-9. First Principles Calculation of Multilayer Grating Efficiency.

tance testing, thereby ensuring cost-effective and reliable flight hardware verification. The maintenance of this team from program start-up enables timely resolution of problems during the fabrication, integration, and test phases because the team is involved in the initial system and requirements definition, design analyses and trades, manufacturing, and test plan development.

4.3.1 Manufacturing Strategy.

a. Hardware Procurement and Fabrication Processes. All procured hardware, along with long-lead items and consumables, are procured in a timely manner to minimize any schedule complications. With NASA Project Office approval, procurement of flight gratings will commence in Phase B, with the remainder of the long-lead flight components procured at the start of Phase C/D. Fabricated hardware is obtained from a select list of vendors. All manufactured and procured hardware will adhere to the quality assurance ground rules stated in Section 4.7. During Phase A, detailed preliminary specifications were developed for the grating, PS-GRA-001, and the mirror, PS-MIR-001, assemblies. Copies of these specifications have been given to three respective vendors (i.e., three grating vendors and three mirror vendors) for comments and preliminary pricing and delivery schedules.

b. Parts. The EIS Instrument Components parts, materials, and processes are selected with special care. The optical components are sensitive to contamination, driving the need for careful material selection, and a Contamination Control Program (CCP). The EEE parts selection program is guided by the NASA Parts Selection List with a quality level no lower than Grade 2 and the guidelines of GSFC 311-INST-001 Level 2. Our QAE works with IPDT members to develop project-specific EEE parts selection guidelines. We will take advantage of GSFC's experience in EEE parts engineering and GSFC's 311-INST-001 with selective screening as required.

c. Materials. A formal, documented, materials and processes (M&P) control program assures that instrument performance, contamination control, and safety requirements are met. NRL will maintain a database of metallic and non-metallic materials usage. All M&P are certified for compliance with safety requirements and for specified outgassing requirements. NRL reviews M&P in flight hardware and provides compliance certification. Well-established processes (e.g., soldering, conformal coating, cable harness fabrication, plating) will be used in building the EIS Instrument Components. Control procedures and work instructions will be used for special processes.

d. Workmanship. Equipment will be manufactured, processed, tested, and handled such that finished items are of sufficient quality to ensure reliable operation, safety, and service life in the operational environments. All parts and assemblies will be designed, constructed, and finished in a quality manner intended to produce defect free equipment. Particular attention will be given to critical operations (e.g., adhesives, soldering, plating, painting, riveting, machine screw assembly, welding, brazing, deburring, cleaning, and marking of parts and assemblies). The items will be free of defects that would interfere with operational use (e.g., excessive scratches, nicks, burrs, loose material, fluxes, contamination, and corrosion).

4.3.2 Verification and Test. NRL will use an incremental design verification and test program throughout the development process of the EIS Instrument Components to provide program visibility against cost, schedule, and technical performance. Emphasis is placed on performance-based testing, early verification of system design and environmental predictions, and demonstrated margins during testing.

a. Verification Program. The following paragraphs define the verification phases in terms of objectives and deliverables as they apply to the EIS Instrument Components during development at NRL.

❒ *Developmental Test Phase:* The objective of the developmental test phase is to assure that testing of critical items at all levels of assembly is sufficient to validate the design approach. This generally requires the use of a development unit. Verifications in this phase are not used as formal verification of requirements, but as early evidence that the development or prototype unit will prove the feasibility of the design approach. It will demonstrate the capability of the selected configuration to satisfy performance requirements under ambient and environmental test conditions. This phase will develop confidence in the ability of hardware to accomplish the mission objectives. Development tests are used in the confirmation of performance margins, manufacturability, testability, maintainability, reliability, life expectancy, and compatibility with system safety requirements. While the use of system level development tests is generally not applicable in a protoflight program, development testing on critical components, when possible, is recommended.

❒ *Qualification and Acceptance Test Phase:* A Qualification/Acceptance test program will be implemented at the protoflight component level. This is accomplished, in most cases, by applying controlled environment test levels that generally exceed predicted flight level extremes but do not exceed the design values. The test durations are limited to those defined for flight acceptance testing. This phase includes all EIS Instrument Component verification activities up to its integration into the EIS Instrument. For convenience this phase is also used for all formal analysis submittals, document releases, and records validation since they are used to show requirement compliance as justification for "acceptance" of the hardware. Note that formal analysis can be performed and submitted much earlier in time than acceptance or joint qualification/acceptance testing and still fall under this phase. The Protoflight test program:

- Demonstrates that each component, as designed and built, exhibits a positive margin on the performance specification.
- Avoids hardware fatigue by limiting the test durations to those defined for flight acceptance and testing.

❒ *Post Acceptance Test Phase:* This phase is used to indicate testing after EIS Instrument Components integration into the EIS Instrument, and includes any verification testing related to the EIS, spacecraft interfaces, or end-to-end testing that is required for the Solar-B mission. This phase is covered under Section 4.4.

❒ *Verification Documentation:* NRL will make all verification documentation available to inspection, test, and assessment personnel. Applicable verification drawings, specifications, and procedures will be physically located at the verification site at the time of the verification event. When each verification event is complete, the information required to validate compliance to each requirement shall be entered into a VCRM database for completion of the verification matrix.

b. Test Program.

❒ *Interface Testing:* Electrical interface tests will be performed to verify that all interface signals are within acceptable limits of applicable performance specifications before the integration into the next higher hardware assembly level. Prior to mating with other hardware, electrical harnessing will be tested to verify proper characteristics such as routing of electrical signals, impedance, isolation, and overall workmanship.

❒ *Qualification/Acceptance Testing:* The qualification/acceptance program will be applied to the Development and Flight models of the EIS Instru-

Table 4-4. Environmental Test Matrix (Preliminary) for EIS Instrument Components

EIS Instrument Component	Acoustic[a]	Vibration[a]	Thermal Vacuum and Thermal Cycling[a]	Lifetest
Front Filter Assembly (FFA)	✓	✓	✓ (w/solar simulator)	✓ (w/thermal cycling)
Spectrometer Entrance Filter (SEF)	✓	✓	✓	N/A
Grating Assembly (GRA)	N/A	✓	✓	✓
Mirror Assembly (MIR)	N/A	✓	✓	✓
Slit Slot Assembly (SLA)	N/A	✓	✓	✓

a. See Special Tests and Examinations (page 4-15) for applicable levels.

Table 4-5. Optical Component Test Matrix (Preliminary) for EIS Instrument Components

EIS Instrument Component	Stray Light Test	Efficiency Test	Imaging Test
Filters	Visible Rejection	EUV Wavelengths	N/A
Grating Assembly (GRA)	• Visible rejection • EUV Line Profile Measurements	EUV Wavelengths	As a Spectrometer in the EIS Instrument Configuration
Mirror Assembly (MIR)	N/A	EUV Wavelengths	Visible light
Slit Slot Assembly (SLA)	Visible rejection	Metrology on Slits	• Reproducibility of Slit Position • Shutter Timing

ment Components. Elements of the test program include:

▫ *Comprehensive Performance Test:* NRL will conduct a comprehensive performance test (CPT) that demonstrates that the EIS Instrument Components meet levied performance requirements within allowable tolerances. The CPT will be conducted at each stage of major assembly (component and EIS Instrument). At lower levels of assembly, the CPT will demonstrate that, when provided with appropriate inputs, internal performance is satisfactory and outputs are within acceptable limits. Additional CPTs will be conducted during the hot and cold extremes of the thermal-vacuum test and at the conclusion of the environmental test sequence, as applicable.

▫ *Environmental Testing:* NRL will conduct the environmental tests detailed within Table 4-4. These tests are applicable for both the DM and FM EIS Instrument Components.

▫ *Optical Testing:* NRL will conduct optical testing to verify the performance of the EIS Instrument Components prior to delivery for integration with the EIS Instrument, as shown in Table 4-5.

❒ *Special Tests and Examinations:*

▫ *Mass Properties Verification:* NRL will participate in a mass properties program with the UK team that includes an analytical assessment to comply with the allocated EIS Instrument requirements, supplemented as necessary by measurement.

▫ *Random and Acoustic Vibration:* Random vibration and acoustic levels for the DM shall be at [+3 dB] above flight levels, one minute duration in each of the three axes, with acoustic only being done for one axis. The option to perform only random vibration testing without any acoustic testing exists provided that the test levels cover the range from [20 to 2000 Hz].

▫ *Bench Release Testing (Shock):* This test is only necessary if a pyrotechnic optical bench launch restraint is used by the EIS Instrument. If a launch restraint is used, the shock test will be conducted after integration with the EIS Instrument. This test consists of releasing the optical bench launch restraint and verifying that no damage occurs to the EIS Instrument Components.

▫ *Thermal Cycling:* The thermal cycle test sequence for the DM and FM will be defined in the EIS Instrument-to-Component ICD.

▫ *Thermal Vacuum:* The thermal cycle test sequence for the DM and FM will be defined in the EIS Instrument-to-Component ICD.

▫ *Bakeout:* Components or subassemblies whose applications pose a contamination threat to the EIS Instrument or to other spacecraft components shall be thermal vacuum baked to achieve an acceptable level of molecular outgassing as defined in the Contamination Control Plan.

4.3.3 Systems Engineering. The NRL established Systems Engineering team will provide cost effective identification of conflicting interfaces, requirements, design products, and schedules. The SE team will analyze needs, objectives, and requirements to determine the functional and performance requirements for each element of the EIS Instrument Components while verifying that the engineering products and processes satisfy these requirements to the lowest level.

The SE team will work closely with the UK EIS team to ensure that all technical information relative to interfaces, requirements, design products, and schedule is distributed among EIS engineering teams. The SE team will work with the UK team to develop the EIS ICD documentation and to ensure that information relative to the EIS Instrument Components is accurate.

4.3.4 End Item Deliveries. End item deliveries of the EIS Instrument Components under Phase C/D are presented in Table 4-6.

Table 4-6. Phase C/D End Item Deliveries

Milestone	Delivery Date
Electrical Proto-Model Delivery	December 2000
Mechanical/Thermal Proto-Model Delivery	April 2001
Electrical GSE	June 2001
Mechanical GSE	March 2001
EIS Instruments Components for Flight Model Delivery	October 2002

4.4 Integration Strategy Approach. On completion of delivery of the flight EIS Instrument Components, NRL will support the optical integration and optics related end-to-end testing of the EIS Instrument to be carried out in conjunction with the Rutherford Appleton Laboratory (RAL) using the RAL EUV test facilities in the UK. A preliminary facility assessment and survey was completed during the RAL site visit in June 1999. NRL will also support the spacecraft integration, test, and prelaunch at the ISAS facilities in Japan. The Integration Strategy will encompass EIS Instrument integration, test and verification; EIS-to-spacecraft integration and test; and pre-launch activities. This section discusses each aspect of this strategy.

4.4.1 EIS Instrument Integration, Test and Verification.

a. System Level Integration Program. EIS system level integration will be performed at the RAL facilities. These facilities contain ample room for integration and an array of clean room environments to support the needs of the program. During the integration phase, qualified technicians, QA engineers, and planners, under the guidance of an experienced Integration and Test Engineer, will be used. Overall direction of the integration will be under the UK principal Institute, MSSL. To ensure a smooth transition throughout the integration phase, engineering models will have been used during the EIS Instrument development. The first step in the Instrument assembly will be the integration of the optics and mechanisms into the structure. An assembly fixture will be used to ensure proper alignment. A set of optical end-to-end tests will be conducted to verify optical alignment. Finally, the Instrument Control Unit (ICU) and Mechanism and Heater Control Box (MHC) electronics will be integrated to the instrument.

b. Test and Verification Program. NRL will support the optical related end-to-end and aliveness testing of the EIS Instrument in the UK. A discussion of the test aspects of this program is included in the following paragraphs.

❒ *Optical Related End-to-End Testing:* A preliminary list of optical end-to-end testing to be performed on the EIS Instrument include:

- Focus and image quality testing of the telescope conducted in the visible using a collimator and slit plane imaging system. This test follows procedures successfully implemented in the AS&E and HRTS rocket programs.
- Spectrometer focus and image quality/spectral line profile test at EUV wavelengths using a modified NRL supplied collimator.
- End-to-end image quality test with the NRL supplied collimator.
- End-to-end calibration scans of the entrance aperture with a standard source at RAL. This test follows the standard procedures developed for CDS and SERTS. These will be used to correct the instrument response profile in absolute magnitude.
- Visible rejection test with a heliostat or appropriate simulated solar source.

❒ *Aliveness Testing:* Complete aliveness testing of the EIS instrument will be conducted at appropriate junctures during the instrument and spacecraft level testing. In addition to routine electrical and mechanism functional tests, NRL will support special optical functional tests to verify that the instrument performance has not changed. A preliminary summary of these tests includes:

- Verification of the primary mirror back surface alignment with respect to an alignment cube.
- Focus of the primary mirror on the slit.
- Stray light assessment of the entrance filter.
- Alignment of the grating back surface with respect to an alignment cube.
- Alignment of the grating facet with respect to the alignment cube.
- Exchange and measurement of multilayer coated optical witness flats.
- Detector aliveness testing with a "blue" flat field lamp.

These tests are similar to aliveness tests conducted in support of previous NRL spaceflight solar and coronagraph instrumentation.

4.4.2 EIS to Spacecraft Integration, Test and Verification. The EIS to spacecraft level integration will be performed at the ISAS facilities in Japan. NRL and GSFC will provide engineering and science support throughout the spacecraft integration and test process. System level testing support will be identical to the support identified in section 4.4.1.b for EIS aliveness testing. NRL and GSFC will also support the pre-launch activities of Solar-B.

4.4.3 Systems Engineering. The NRL established Systems Engineering team will continue to work with the MSSL team to ensure that all technical information relative to interfaces, requirements, design products, and schedule is maintained through instrument integration and test. This support will extend to supporting information exchange during spacecraft integration.

4.5 Mission and Flight Operations Approach.

The primary operational role of the EIS team during the Solar-B mission will be to operate EIS in a manner that maximizes both its scientific output and that of Solar-B and ensures the health and safety of the instrument.

4.5.1 Mission Operations Concept. Mission operations will be controlled from the Japanese Solar-B control center. EIS co-investigators and other technical personnel will be present continuously to support operations. Each experiment team will perform several key functions: 1) plan future observing sequences, 2) construct experiment commands to perform each desired observing sequence, 3) analyze instrument housekeeping data to ensure the correct operation of the instrument, and 4) reduce quick look data both to ensure that each observing sequence is producing scientifically useful data and to plan future observing programs.

a. Planning. Based on our experience with Yohkoh and SOHO, we expect mission planning to be based on a framework of daily, weekly, and monthly planning meetings. Monthly meetings will broadly specify the scientific objectives for the following month and detail any spacecraft operations that must be anticipated. The weekly planning meeting will try to schedule observations on a daily basis for the coming week to meet the objectives determined at the monthly meeting. The daily planning meetings will coordinate detailed observing sequences for the Solar-B instrument complement based on the weekly and monthly plans and on the most recent data obtained by the Solar-B instruments.

The scientific objectives of the Solar-B mission can be achieved only if tightly coordinated observing programs involving the three experiments on Solar-B are implemented for the great majority of the time. An arrangement similar to that currently used to plan observing for the instruments on SOHO will probably be necessary. In rotation, each experiment team would take the lead for one week of observing. Late in the week before the assigned week, the lead team would poll the other instrument teams to develop a strawman plan for the upcoming week. This plan would then be discussed, modified, and agreed upon at a weekly top-level planning meeting. Daily meetings would add the final details for operations over the upcoming 24-hour period covered by a command upload. While reaching consensus on each day's observing is important, we believe that smooth operation of the satellite will probably require that the lead team for the week have final authority to select targets and enforce reasonable levels of cooperation among the experiment teams.

The outcome of the daily planning meeting will be a set of detailed observing programs based on such specifications as: target, solar coordinates, field of view, cadence, spatial resolution, and specific measurement. For EIS, the observing programs will be specified in terms of such parameters as: spectral line CCD windows, exposure times, slit or slot position, raster step size, number of spatial steps in each raster, number of rasters, and data compression algorithm and factor. The dominant EIS observing mode will probably consist of rastered slit spectra that can be used to construct spectroheliograms, but the instrument will be flexible enough to observe in a variety of modes that can be useful for certain scientific objectives.

b. Commanding and Operations. The function of experiment commanding will be to translate the desired observing program specifications into a series of commands to the onboard EIS computer. This will be accomplished by means of a command planning tool. This is a fairly complex program that will be used by the EIS team at the Solar-B command center. These command sequences will incorporate knowledge of the EIS and Solar-B capabilities. In addition to producing a set of instrument commands, its role will be to ensure that EIS observing programs do not exceed its allocated spacecraft resources such as telemetry and memory. It also must ensure that the observing programs do not exceed internal EIS resources such as CCD readout rate, intra-instrument communication rates, data handling time and data compression time, telescope movement rates, etc. Further, the planning tool should further ensure that instrument commands will not exceed predetermined limits for any mechanism functions, e.g., the pointing offset of the telescope mirror.

Making sustained, useful joint observing programs possible will require considerable investment by all three experiment teams in developing planning software that will allow each experiment team to have a reasonable degree of visibility into the observing plans of the other teams. At the very least, this should include having each team provide information to a common database that can be used to display parallel instrument observing timelines.

For normal operations, EIS will perform observations using observing control tables. A time table will be used to initiate observation sequences. These sequences will be held in a series of observation definition tables that will specify all the mechanism movements and camera exposure details necessary for obtaining the required observation. Definition tables will be held onboard. Thus only observing time table information and changes to the definition tables will need to be uplinked, saving uplink time. Once a command load is generated and validated on the EIS workstation, it will be passed to the appropriate ISAS computer for upload to the spacecraft.

EIS will also be capable of operating in real-time science mode. An event flag from, for example, the XRT would trigger this mode. Receipt of an enabled event flag would abort any current time-table-controlled exposure and initiate execution of a preplanned observing mode. The primary use of this mode would be for flare observations.

Experiment teams will monitor the housekeeping data and scientific data to ensure that EIS is operating as commanded and remains in a safe and healthy mode.

c. Quicklook Data Reduction. For daily planning purposes, it will be necessary to have reduced quicklook data products from each experiment available to all the experiment groups. These products include such elements as basic stigmatic spectra recorded by EIS and spectroheliograms of line intensities, Doppler shifts, and line widths derived from rastered spectra.

d. Observing Strategy. Working synergistically with the other Solar-B instruments, EIS will provide dynamical and plasma diagnostic information for each solar structure targeted. The operation of EIS will be very flexible and can accommodate a variety of observing modes. For example, EIS will have three slits with different slit widths as well as a wide slit that can be used to provide 'slitless' spectroheliograms, much as those obtained with the SO82A experiment on Skylab/ATM. Nevertheless, it is expected that a large amount of the observing time will be used to repeatedly construct spectroheliograms of the Sun from rastered spectra. For each target, the EIS spectrometer will build two-dimensional images in selected spectral lines within both of its wavelength bands by stepping the slit in the direction perpendicular to its length. For each observing program, adjustable spectrometer operating parameters include: emission lines to be selected for retrieval, the number of slit positions, spacing between the slit positions, and exposure times at each slit position. For many kinds of observations, it may be advantageous to intersperse the narrow-slit spectrometer rasters with images taken through the EIS slot. This would provide monochromatic images of the region under observation.

As an example, for studies of mass and energy flow in relatively quiescent solar regions, EIS can obtain spectra and images over the same region for which the white light telescope is mapping the magnetic field. If possible, the cadence of the data acquired by the two instruments could be synchronized. Regions for study would be chosen during the daily Solar-B team planning session. For detailed study, EIS would build monochromatic images by stepping the slit in increments of 1 arcsec. Alternatively, more limited information might be obtained over a larger area or at higher time cadence by stepping the slit in larger angular increments. For active regions, where structures are more distinct, the appearance of the region in earlier white light and XRT images and EIS spectroheliograms will help determine the total spatial extent of an EIS raster and the spatial increments between successive spectra. Since the EIS slit is 1024" long, each image will have a spatial extent of 1024" along the slit direction with the other dimension determined by the raster size.

Since EIS will have to raster to form spectroheliograms, observing transient events, such as flares, will be challenging. Probably the best approach for observing the earliest phases of flares will be to dedicate substantial periods of time to repeatedly making small spectroheliograms centered on regions that have been identified as likely to flare. Typically, this would be over a magnetic neutral line, since explosive events and flares occur near regions where magnetic field gradients are large. Alternatively, EIS could operate in a sit-and-stare mode at a likely site using the slot to obtain spectroheliograms in selected lines.

For observations of the later phases of flares, we anticipate providing EIS with the capability to respond to a flare flag issued by another Solar-B instrument, probably XRT. In that case, EIS could move to a location provided along with the XRT flag and begin executing a set of flare observations, such as rapid small spectroheliograms, to study flare decay-phase dynamics.

The EIS daily observing program will also include synoptic observations of selected quiet Sun areas to monitor changes in instrument performance on orbit. These regions would be observed near Sun center. Since the XRT also expects to perform daily Sun-center observations, we anticipate coordinating the EIS observations with those from XRT.

e. US Contribution to EIS Mission Operations. EIS will be operated jointly with the UK and Japanese teams; therefore, we anticipate US operational support in Japan will be about 1.5 scientists throughout Phase E.

4.6 Facilities and Ground Support Equipment.

Facilities and equipment existing at subcontractors, the NRL's facilities, the EIS Instrument Institution (MSSL), and NASA will be used to the maximum extent practical. All necessary activation and operation plans that involve NASA test facilities, equipment, personnel, procedures, and safety requirements will be established by NRL personnel. Test facilities or equipment used to test an item of hardware at more than one location will be integrated by the NRL to assure uniformity of test results. All test equipment will be qualified or certified and verified prior to any interface with flight hardware to ensure that no damage or degradation will be introduced into the hardware being tested and that the test results will not include test equipment error.

4.6.1 Facilities. NRL maintains extensive facilities for the design, fabrication, integration, and test of high performance, high-reliability spaceflight systems. No new facilities or major upgrades are planned or needed. A brief description of NRL facilities to be used during the EIS Instrument Components development program follows:

- *Spacecraft Acoustic Reverberation Chamber Test Facility:* Simulates the vibration and high intensity acoustic noise environment experienced by spacecraft structures and components during launch. The acoustic reverberation chamber consists of a 283 m^3 reverberant chamber of highly reinforced concrete designed to withstand an internal sound pressure level of 170 dB.
- *Mechanical Inspection and Optical Alignment Facility:* Provides the capability to inspect parts and verify dimensions and alignment of critical

spaceflight hardware. Levels of precision are typically to one micron linear and one arcsec angular.

❒ *Spacecraft Static Test Loads Facility:* Provides static loads tests to demonstrate that structural design requirements have been achieved. The facility can test both small (2.25 kg) and large (17,236 kg) articles.

❒ *Spacecraft Vibration Test Facility:* Used to qualify and accept components by simulating the loading environments imposed on hardware and demonstrating compliance to design specifications. Quasi-static, vibrational, and shock loads can be generated using electrodynamic shakers.

❒ *Thermal Vacuum Chamber Facility:* Provides a comprehensive environmental test complex designed to simulate the high vacuum and varying thermal conditions of space. It consists of a large test chamber (5.5 m diameter and 9.75 m long), two medium test chambers (2.5 m diameter and 3 m high), and three small test chambers (0.5 m diameter and 0.5 m high).

4.6.2 Ground Support Equipment. To carry out the verification and test programs described, NRL has compiled a preliminary list of supporting mechanical and optical equipment. The fixturing and shipping containers particular to EIS Instrument Components will have to be manufactured. The more general equipment listed in Table 4-7 already exists but may require upgrade to meet the program specific requirements.

In support of the subassembly testing, NRL will construct standalone electronics boxes based on Commercial Off the Shelf (COTS) cards with a standard computer interface. These cards will most likely plug into a PC backplane. NRL will write a simple front-end software interface, which will use manufacturer provided driver modules to execute the desired test and display the test data. These standalone electronics boxes will be available throughout the program for functional testing. NRL has identified a preliminary list of electrical GSE as presented in Table 4-8. In addition, NRL expects the need for switch and breakout boxes as well as miscellaneous (oscilloscopes, logic analyzers, ohmmeters, etc.) electronics equipment and other standard (National Instruments type) plug-in PC cards. The majority of this type of equipment is already part of the NRL equipment inventory and will be available for the Solar-B program.

Table 4-7. Mechanical/Optical Ground Support Test Equipment

▪ Fixturing for subassembly installation and handling.
▪ Shipping containers for the optics and subassemblies.
▪ Miscellaneous optical alignment fixturing (motor micrometers, precision adjustment tools, etc.).
▪ Vacuum test stand for efficiency testing at NSLS Monochromator facility.
▪ Vacuum test stand for verifying grating imaging properties.
▪ Visible light collimator of appropriate aperture with accompanying optical flat for image quality testing of the telescope.
▪ Fixturing for mounting the subassemblies in NRL test vacuum chambers.
▪ Fixturing for assembly of the NRL hardware.
▪ Portable EUV collimator for attaching to the RAL test chamber to focus the spectrometer.
▪ Theodolites and transfer flats.
▪ Visible light test stand for verifying parabolic figure.

Table 4-8. Electrical GSE Requirements (Preliminary)

Electrical GSE	Description
PZT Actuator w/ Strain Gauge Encoder	An integration of COTS vendor items that incorporate a computer interface.
Motor Control	An integration of multiple COTS vendor cards that are installed into a standard Personal Computer (PC) for interface, control, and display.
Transducers	An integrating of multiple COTS vendor cards that are installed into a standard PC for interface, control, and display.

4.7 Product Assurance. The NRL EIS team has baselined a cost-effective, tailored Safety, Reliability, and Quality Assurance (SR&QA) Product Assurance Program (PAP). It establishes requisite provisions for flight H/W and GSE concurrent with design activities, and it is commensurate with project costs and risks; emphasizing verification by test. The NRL QA Engineer (QAE) works within the IPDT structure to develop implementation plans. The project level PAP is defined in the Product Assurance Plan, 874QE-001, submitted during Phase B. The PA Plan includes reference to the program Safety Program, the Reliability Plan, and the Quality Assurance Plan (QAP). In addition, a Verification Plan is developed, 874VR-001, during Phase B defining the verification methods to be used. Specific attention is focused on simple, conservative, and test-verifiable designs. Also emphasized are procurement controls; fabrication controls and records; inspections and tests; nonconforming material; handling and shipping; and storage controls. The Reliability Plan and the QAP encompass each project element, as well as subcontractors and suppliers. Responsibilities, cost and risk trade criteria, effective implementation of quality provisions, and the consideration of project-unique conditions and requirements are addressed.

4.7.1 Product Assurance Guidelines. During Phase B, a formal QA system is defined and implemented. It is based on existing procedures that meet ANSI/ASQC Q9001-1994 guidelines. Our approach addresses the following elements: (i) Safety; (ii) Quality Assurances; and (iii) Reliability. Our PA program ensures that flight H/W and GSE are designed, manufactured, and tested to flight standards and that drawing and specification requirements are met. The PA approach is presented at the PDR.

❑ *Safety Assurance:* A Safety Program is developed as an integral part of the Product Assurance Plan during Phase B. It guides the system safety and hazard control decisions and activities during Phases C/D. It meets NHB 1700.1B requirements. During Phase B, NRL appoints a System Safety Manager (SSM) to execute the Safety function throughout Phase C/D. The SSM reports to the PM for project direction and to NASA safety officials for policy and technical direction. All safety requirements hinge on minimizing the potential for injury to personnel; equipment loss or facility damage; property damage; and potential impacts in terms of cost, schedule, public involvement, or interest.

❑ *Quality System:* The NRL EIS QA approach consists of a series of integrated actions to ensure both mission success and the meeting of all mission goals. QA is considered throughout all phases of performance. The QA program emphasizes quality tasks and their integration with design, fabrication, and test phases. The QA program implements the policies, requirements, and activities required during design, fabrication, test, and delivery. Requirements are included to detect and correct deficiencies or trends resulting in unsatisfactory flight H/W quality. Workmanship is inspected and configuration is verified beginning at the assembly level. In-process inspections continue through post-environmental test, transportation, and launch site processing activities. QA personnel certify that an appropriate set of activities has occurred to demonstrate compliance and that inspection characteristics conform to their documentation. Each IPDT Lead is charged to ensure: (i) quality requirements are continuously met, including the early and prompt detection of actual and potential non-conformances, evaluations, trends, or conditions that could result in unsatisfactory product quality; and (ii) the implementation of timely and effective remedial and preventive actions.

❑ *Reliability:* During Phase B, the NRL team will designate a Reliability Engineer (RE) to serve as single point of contact for all project reliability issues. The RE will coordinate the Instrument developmental efforts with an integrated reliability engineering program that supports reliability matters like FMEA, parts application analyses, and radiation effects analyses. Our reliability engineering plan follows GSFC-410-MIDEX-001 guidelines (Section 3.0 and Section 5.3). It provides guidance for EEE parts selection, screening, and applications.

5. Management Plan

NRL has a long history of successfully providing high quality solar scientific instruments for space missions. The data collected from these instruments have resulted in numerous articles and papers that have significantly expanded scientific knowledge in the field of solar physics. Our solar instruments have flown on V2 rockets, advanced sounding rockets, Skylab, the space shuttle, and free flying satellites. In over 40 years of constructing instrumentation, we have gained experience in all types of payload environments, from the minimal requirements of a sounding rocket payload to the very stringent requirements of long duration missions that we have participated in, such as UARS, P78-1, SOHO, and Yohkoh. The Solar-B requirements are equivalent to the long duration mission requirements that we have successfully met, and we therefore have proven capabilities and experience to provide quality instrumentation for the EIS investigation.

We are using the same basic management philosophy for Solar-B that has been successful in the NASA/NRL HRTS, SUSIM, and LASCO programs. The EIS Principal Investigator to NASA leads a small core team of scientific, technical, and management personnel. This core team is augmented with specific expertise from NRL support areas and outside contractors for tasks such as thermal and structural analysis. In-place mission assurance and management processes at NRL will ensure that the EIS investigation meets its scientific goals in a timely and cost effective manner.

The EIS investigation team is comprised of a US team composed of NRL and GSFC personnel, the UK EIS team, and two Japanese scientists. NRL and GSFC have an experience base in high resolution EUV and X-ray spectroscopy that is unmatched by any other US group. NRL is the lead US institution and is ultimately responsible for all US mission aspects. Table 5-1 summarizes the relevant capabilities and experience of the US EIS team. Within NRL, the investigation is carried out in the Space Science Division of the E.O. Hulburt Center for Space Research. The NRL PI coordinates and oversees the development, the building and acquisition of the hardware funded by NASA, its testing in the US, and subsequent deliveries to the principal UK institution, the Mullard Space Science Laboratory. NASA's GSFC is charged with specific EIS hardware and science responsibilities.

Table 5-1. EIS US Team Capabilities and Experience

NRL
▪ A leading United States solar science group ▪ Unique expertise in multilayer grating technology ▪ Many previous successful solar space instruments (e.g., OSOs, ATM Skylab, P78-1 SOLFLEX/SOLWIND, Spacelab 2, and many sounding rocket payloads, including HRTS and VAULT) ▪ Currently flying successful space instruments include LASCO and EIT on SOHO, and BCS on Yohkoh ▪ Strong solar theory and modeling support
GSFC
▪ A leading United States solar science group ▪ Many previous successful solar instruments (e.g., OSOs, SMM UVSP/HXRBS, and many sounding rocket payloads, including SERTS) ▪ Currently flying successful space instruments include CDS on SOHO ▪ Operations center for the Solar Maximum Mission (SMM), SOHO, and TRACE ▪ Supported planning and execution for SMM Repair Mission ▪ Provided multilayer coatings for solar EUV observations

5.1 Team Member Responsibilities. EIS has baselined a management structure of a science consortium, similar to that of BCS on Yohkoh and EIT on SOHO, for which NRL was not a PI institution, but provided essential hardware, science input, and software. EIS oversight will be through a US/UK international consortium, led by Professor Culhane at the UK's Mullard Space Science Laboratory (MSSL). The lead institution in the consortium is lead by a lead scientist or PI, and supporting scientists, from each participating institution. Each country's efforts are directed by that country's lead scientist or PI. The US PI, Dr. G. A. Doschek, is responsible for leading the US Team, comprised of NRL and GSFC. Table 5-2 presents the US team institutional responsibilities.

Technical issues will be resolved by the PI in close consultation with the Project Scientist, Instrument Scientist, and Project Manager. Ultimate authority for all decisions rests with the PI; however, in a practical sense, nearly all major decisions are made jointly by this group, with support from a Science Team consensus. The PI shall direct the US MO&DA efforts.

Table 5-2. EIS Institutional Responsibilities

NRL
▪ Lead institution of the US EIS program ▪ Overall management of the US EIS hardware and science program ▪ Development, test, and delivery of all EIS Instrument Component hardware ▪ Participation in data analysis software development and mission operations ▪ Participation in the scientific analysis of Solar-B data
GSFC
▪ Optical analysis and application of multilayer coatings ▪ Provide slit and slots ▪ Science support for development of EIS observing programs ▪ SERTS rocket flights after launch for calibration tests at no cost to the EIS program ▪ Participation in the scientific analysis of Solar-B data

Figure 5-1 shows the complete EIS team hierarchy. This figure illustrates the interrelationship of the international teams, showing the accountability and responsibility necessary to enable effective decision-making. These well-defined lines of responsibility and communication allow the US EIS team to successfully achieve science, cost, and schedule objectives.

Experienced personnel have been selected to meet the EIS investigation's objectives. Resumes are provided in Appendix A. Table 5-3 summarizes the US team responsibilities. Additional background and previous experience are described in the resumes.

❐ *Principal Investigator:* NRL's Dr. George Doschek, the US PI, ensures that the mission is implemented and executed to achieve science objectives within the levied constraints.

❐ *EIS Science Team Co-Investigators:* This group participates in establishing the science objectives and instrument requirements, hardware design, development, procurement, and testing, conducting required science vs. cost trades, analyzing data, and reporting scientific results. They also participate in defining the data reduction and analysis architectures, developing necessary software, and coordinating post-launch data reduction and analysis.

❐ *Project Scientist/Engineer, and Lead Engineers:* NRL's Dr. Clarence Korendyke is responsible for designing, building, testing, calibrating, and delivering the US components of the EIS instrument. He delegates development tasks to a scientific and technical support staff led by a PM.

❐ *Project Manager:* NRL/CPI's Mr. Steven Myers is designated with responsibility for interface definition and control, system design verifications, and delivery of the instrument components. He directs the analysis and trade studies and controls non-reserve developmental funds.

❐ *Other Support Functions:* Lead engineers will be assigned, consisting of a systems engineer, Quality Assurance Engineer (QAE), mechanical engineer (ME), electrical engineer, software engineer, Reliability Engineer (RE), and a technician. The ME serves as test lead after initial design and development actions are complete. NRL's support contractors provide specialty engineering. An NRL Program Analyst supports the PM and provides financial reporting.

5.2 Management Processes and Plans. The US EIS team has established an effective management approach, under the direction of the PI and PM, to assure that the program objectives are met within the cost and schedule limitations. During Phase B, a Project Management Plan will be written defining the overall processes and methods to be employed for managing the EIS activities during Phases B/C/D and E. The plan will address the management aspects of contractual, financial, data requirements, performance, configuration, engineering, logistics, test, and procurement elements of the program. The plan will be submitted sixty (60) days after the start of Phase B and be updated periodically with the concurrence of NASA.

a. Management Processes. The EIS team will employ proven methods and tools to baseline the Integrated Product Development Team (IPDT) process to define, maintain, and verify requirements. The team consists of the PI, the Project Scientist (PS), Project Manager (PM), Lead Engineers, along with the US Science Team. The approach includes a formal requirements development process, design baseline management, technical performance metrics, internal and external program/peer reviews, detailed schedules, cost controls, weekly status meetings, and weekly systems engineering conference calls with the UK EIS teams. Contract and financial support is provided by the NRL Program Analyst.

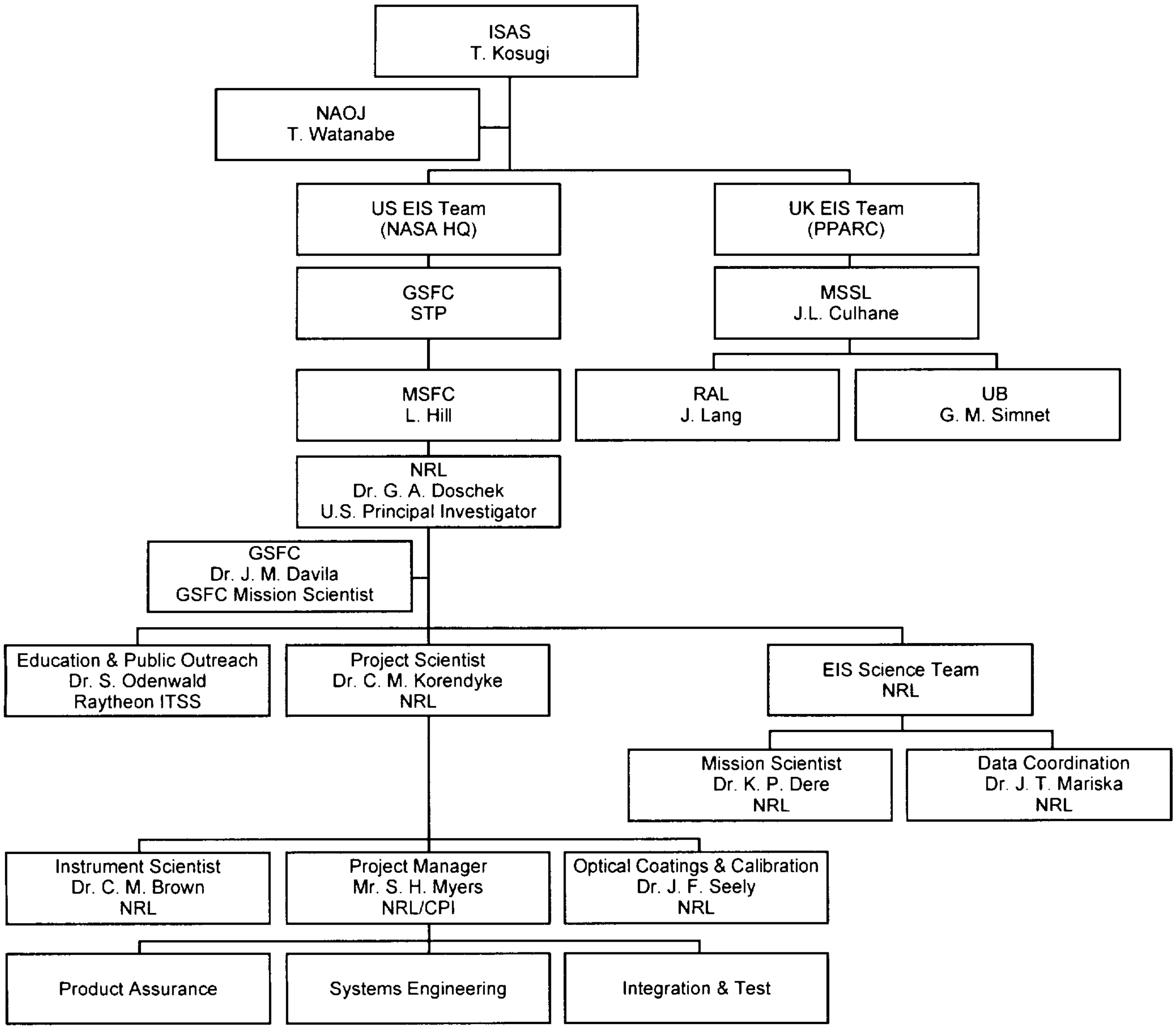


Figure 5-1. EIS Organizational Structure

b. Developmental Processes. Development follows the processes outlined in NHB 7120.5a using the streamlined NASA Mission Design Process. It includes mission definition; requirements analysis, allocation, and development; design, production, and verification; launch processing; and mission operations and data analysis (MO&DA). We have baselined periodic design reviews and Science Working Group meetings, including the seven milestone reviews of NHB 7120.5a.

c. Technology Development. The technologies being used for the development of the EIS Instrument Components are derived from heritage on previous NRL missions. There are no new technologies being used in this program.

d. Design and Development. The IPDT performs feasibility and design definition analyses. Top-level specifications identify interface and physical requirements, constraints, and performance characteristics. Test plans ensure that subsystems meet levied requirements. The PS, PM and project engineers (PEs) conduct internal peer reviews to identify design deficiencies before release of engineering drawings. Engineering models are used to mitigate potential design and interface issues.

Table 5-3. Key EIS Science Team Co-Investigators

Name, Role, and Responsibility	Relevant Experience
Dr. G. A. Doschek, the NRL Principal Investigator, provides scientific and technical leadership. He approves the science objectives and requirements, instrument requirements, and the MO&DA plan. He controls EIS reserve funds.	Provided hardware to the UK for Yohkoh's BCS experiment. He has hardware and data analysis experience with UK EIS Teams and Japanese scientists involved with Solar-B. Working relationships for BCS are similar for EIS. He is an expert on EUV spectroscopy and solar data analysis. He was a member of the US Solar-B Science Definition Team.
Dr. C. M. Korendyke, the NRL Project Scientist, is responsible for EIS instrument development, testing, calibration, and delivery. He coordinates activities with the PM, Science Team, and the PI.	Expert on EUV telescope and spectrometer design; instrument scientist for NRL's HRTS and VAULT rocket projects; hardware experience on NASA programs, e.g., LASCO and EIT on SOHO.
Mr. S. H. Myers, the NRL/CPI Project Manager, is responsible for ensuring the EIS Instrument Components technical and science requirements are met within the program cost and schedule guidelines	Managed Radio Plasma Imager science instrument project aboard the NASA IMAGE mission; extensive experience in managing multi-national ground based instrumentation programs.
Dr. C.M. Brown, the NRL Instrument Scientist, is responsible for hardware design, development, procurement, and testing. He works closely with the Project Scientist.	NRL Project Scientist for the BCS spectrometer experiment on Yohkoh; experimentalist for the DoD STP MAHRSI experiment; extensive experience in laboratory laser-plasma X-ray/EUV spectroscopy instrumentation.
Dr. J. M. Davila is the Mission Scientist for all EIS hardware activities at GSFC. Responsible for all GSFC deliverables.	PI for the GSFC SERTS rocket program that has many similarities to the EIS instrument. Well-known solar theorist and a member of the US Solar-B Science Definition Team.
Dr. K. P. Dere, the NRL Mission Scientist, defines EIS science goals, ensures that the EIS instrument can accomplish these goals, and prepares NASA science documents. He helps translate science goals into operation sequences.	Considerable EUV data analysis experience involving spectra from Skylab and HRTS; authority on plasma diagnostics and atomic data; developed extensive atomic data base and analysis programs called CHIANTI, used for SOHO data analysis.
Dr. J. T. Mariska, NRL's Data Coordination Scientist, translates EIS science into software observing programs and operations, and interfaces with the UK on these items. He participates in operations in Japan after launch. He develops data processing requirements and provides requested NASA documentation on software, processing, and archiving.	Expert on EUV spectroscopy and solar data analysis. Leading authority on the solar spectrum, plasma diagnostics, and solar atmosphere physics. Considerable computer experience; Supervised development of the IDL data analysis software for the BCS spectrometers on Yohkoh. Direct experience with the UK personnel supporting Solar-B EIS software development.
Dr. J. F. Seely, the Multi-Layer Coating Scientist, specifies, procures, and tests all optical components. He monitors the coating of optics at GSFC.	A leading authority in laboratory high resolution UV-X-ray imaging and spectroscopic instrumentation; developed numerical models of multilayer coatings; experienced in designing, procuring, and using multilayer optics and gratings.
Dr. S. Odenwald, Raytheon ITSS, responsible for implementing the US EIS Education and Public Outreach program.	Dr. Odenwald is the Education and Public Outreach manager for the NASA, IMAGE satellite program, and a member of the NASA/OSS Sun-Earth Connection Education Forum. He has conducted teacher workshops and has worked with teachers to design classroom activities and curricular enhancements for grades 3-12. He is a recent recipient of the NASA, Goddard Award of Excellence for Outreach in 1999.

e. Manage and Control Changes. Our change process follows MIL-STD-973 guidelines. The PM is responsible for and manages configuration through development, integration, test, and launch. Documentation is stored electronically and can be accessed via the Internet.

f. Systems Engineering. The PS leads the effort to integrate and validate technical requirements, while the PM supports the integration of performance, cost, and schedule. Specialty engineering personnel provide interdisciplinary support to ensure standards are met.

g. Acquisition and Procurements. NRL has identified long lead items as well as identifying major vendors, along with alternative sources, for these items. NRL performs "make or buy" decisions using a "best-value" approach incorporating schedule, cost, performance, mission assurance, and development risk. Acquisition responsibility resides with the PM/PE supported by the NRL

Program Analyst. Competitive procurements and fixed-price contracts are used whenever possible. To ensure SB/SDB goals are met, NRL's Program Analyst monitors all procurements.

h. Mission Assurance. Our quality system uses ANSI/ASQC Q9001-1994 guidelines. Table 5-4 summarizes the NRL Mission Assurance approach. Mission Assurance responsibility has been delegated to the PM to oversee reliability and quality assurance (QA), parts and vendor selection, receiving, workmanship, procedural compliance, inspection, and change control. We use MIL-STD-882 guidelines for systems safety and to define the risk levels. NRL complies with the applicable environmental security regulations.

Table 5-4. Mission Assurance Approach

- **Reliability Assurance** addresses design, fabrication, and test. Worst case, reliability, and failure modes and effects analyses at the interface level, are baselined.
- **Quality Assurance** is integrated with design, procurement, and fabrication processes.
- **EEE Parts** selection uses GSFC 311-INST-001 for quality, reliability, total ionizing dose, and single event effects (SEE).
- **Materials and Processes** are certified for compliance with safety requirements and for outgassing requirements.
- **Test Verification** includes a performance and environmental test matrix that specifies the verification methodology. A protoflight qualification test program is planned.
- **Contamination** budgets are developed, and appropriate controls are specified using NRP-1124 guidelines.

i. Manage and Control Reserves. Planning and program organization are based on the Work Breakdown Structure (WBS) and the master schedule generated by the PM. The WBS serves as a framework for budget definition, program reporting, and control. The PI approves the WBS and changes. The budget and WBS are continuously updated to reflect authorized changes. PI approval is required for any changes in scope, funding, or performance.

j. Test, Verification, and Calibration. The PM and the PEs integrate, checkout, and verify the EIS instrument and its subsystems, including calibrations directed by the PS and the Science Team. Performance tests verify successful completion of integrated systems tests.

k. Integration, Launch Processing, and Mission Operations. During the prelaunch phase, knowledgeable and experienced EIS team members will support integration and testing of the EIS payload in both the UK and Japan. Additionally, NRL will support the integrated activities occurring during launch processing. For the US EIS team, the required level of support for this phase will be about 2 full time equivalent (FTE) personnel on location in Japan. During the early months of the mission, EIS team members will determine the best operating procedures and troubleshoot anomalous behavior of the experiment package. Requirements for this support will diminish as experiment operations reach a more stable phase. At launch, we expect the level of support to be about 1 FTE in addition to the 1.5 FTE needed for science operations and planning.

l. Data Processing and Distribution. EIS Co-Investigators (Co-Is) and other technical personnel will maintain a continual presence at the Japanese Solar-B control center to support data processing and archiving, described in Section 4.5.

m. Coordination and Agreements. Technical requirements are being defined in terms of a system specification and Interface Control Documents (ICDs). Design information is transferred via file servers and the Internet within the international EIS team.

n. Provide NASA with Insight and Report Progress. Monthly progress and financial reports (financial reporting using the 533M shall commence at the start of Phase B) are submitted to NASA to present the program's technical, schedule, and financial status. Quarterly scheduled technical reviews address technical status, progress vs. plans, and issues. Internet based file transfers are being maximized for transferring technical data.

5.3 Schedules. The EIS Instrument Components master schedule presented in Figure 5-2 shows the overall task interrelationships, time phasing of events, and key activities. The master schedule has incorporated schedule contingency at various points in the program. The schedule sequences and durations are consistent with the planned NRL staffing levels. The master schedule, maintained by the PM, shall be updated monthly and approved by the PI. Any changes to the Level 1 milestones will require approval from NASA.

5.4 Risk Management. The EIS instrument team has baselined a formal process to identify and assess the probability and implications of risks as they pertain to the mission. The approach to be

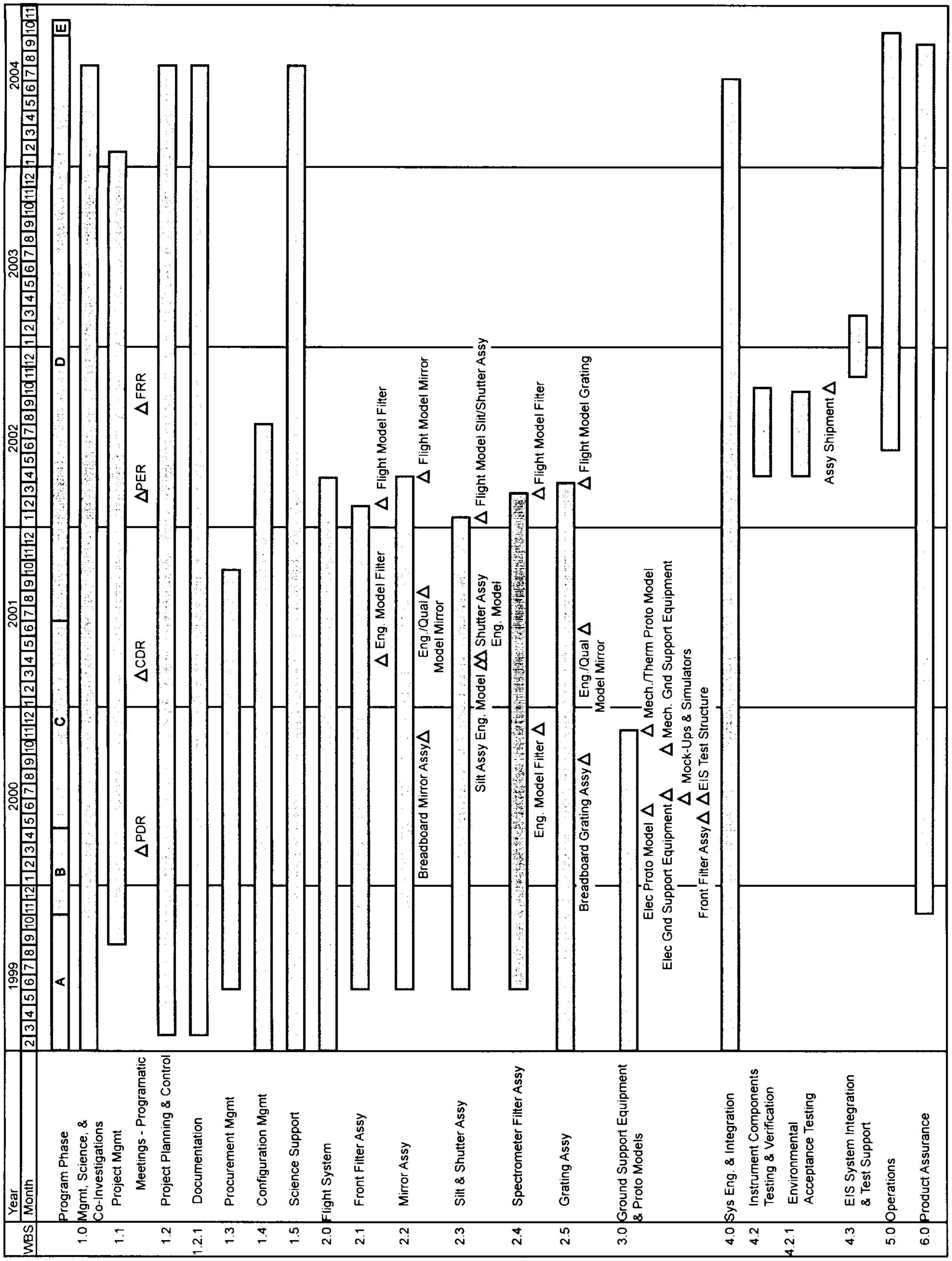


Figure 5-2. EIS Instrument Master Schedule

used by NRL is to identify and mitigate risks identified.

a. Technical Risk Management. A preliminary risk assessment report has been conducted by MSSL identifying potential technical and programmatic risks and their probability of occurrence. Risks associated with EIS have been subdivided into the System Level, Subsystem Level, Operational System Level, and Operational Subsystem Level. Table 5-5 presents the identified risks that apply to the NRL EIS components. During Phase B, a Risk Assessment Plan will be developed that will describe the NRL approach for the planning, management, control, and implementation of the NRL risk management program. During Phase C/D, this risk assessment plan will be updated.

b. Reserves. The PI holds no labor reserve for changes occurring in development during Phase C/D. To meet the mission 5% reduction, no reserves are held within the EIS investigation.

5.5 Government Services and Facilities. No government furnished property, services, or facilities are required to support the EIS Instrument Components program. All government facility usage is on a "full cost recovery" basis.

5.6 Reporting and Reviews. The EIS team uses a streamlined reporting requirement, coupled with formal and informal program reviews. The respective Phase B/C/D Statements of Work (see Appendix C) present the applicable formal reports to be submitted. In addition, weekly conference calls are held between NRL and MSSL to exchange technical issues and relate applicable progress between the two teams.

Programmatic formal reviews as well as informal technical and scientific reviews are routinely scheduled (see Figure 5-2) among the EIS team institutions to encourage effective distribution of technical and scientific data as well as cooperation among team members. NASA will be made aware of each review sufficiently in advance to allow NASA participation. Review Item Discrepancies (RID) are formally tracked and dispositioned with the PI and NASA concurrence.

Table 5-5. EIS Instrument Components Preliminary Risk Assessment

Event	Effect	Management	Notes
System Level			
Failure of contractors to deliver critical component to required performance, time scale, or cost	Any combination of: additional costs, delay, or failure to meet system requirements.	Identification of critical contracted components. Careful drafting of contracts. Allowance of margin in lead-time.	There are many critical contracted components (e.g. CCD, actuators, sensors, grating, CPUs or other IC). This type of situation is covered at the appropriate subsystem level.
Misunderstanding of interfaces (across EIS institutes)	Failure to integrate hardware or software. Delay and/or additional costs of re-work.	Rigorous attention to interface management procedures. All institutes to participate in the System Design Team activities.	
Japan delays launch date	Possible extra costs.	Defer program or delay build phase as appropriate.	Has occurred once. Considered unlikely to occur again unless start of Japanese funding also delayed.
Japan fails to fund the mission	Mission cancelled.	Strongly support mission at a political level. Avoid major outlay prior to Japanese confirmation.	Considered unlikely now. Some Japanese spending already.
Subsystem Level			
Slit exchange mechanism fails disturbance torque criteria	Mechanism motion slowed down.	Choose a single slit (or slit/slot) that gives best all-round performance, reduce speed, or seek alternative mechanisms.	See also the comments on Optics/Mechanisms.
Accidental breakage of entrance filter	Possible debris in the instrument, in the case of a large hole admitting significant white light and heat	Non-flight protective covers, spares, design for exchange procedures (including cleaning). Second filter at spectrometer entrance.	With thin foils (1500 Å Al is being considered) this is a moderately probable event.
Proposed mechanism fails to meet spacecraft disturbance torque requirement	Other Solar-B instrumentation jeopardized. Operate when the spacecraft is not in the fine pointing mode.	Seek alternative mechanisms (mass penalties are likely), or propose spacecraft-level observation (i.e., mechanism) control protocol. Seek to avoid this risk in the early stages of the program. Another alternative would be to omit the mechanism in question.	This is an important requirement for the successful operation of the Solar-B SOT. The nature of the mechanisms is dependent on the telescope type selection.
Grating manufacturing faults	Loss of throughput, image quality.	Error budget, with quantified error sources, is required. Test of grating performance prior to multilayer coating.	Allow margin in schedule for new fabrication.
Optic inadequately figured or polished	Poor focusing properties leading to loss of spatial and spectral resolution. Loss of throughput. Possible need for re-work.	Form an error budget for each optical surface, allowing the system PSF to be estimated. Measure samples to validate the error budget.	Allow margin in schedule for new fabrication.

Table 5-5. EIS Instrument Components Preliminary Risk Assessment (Continued)

Event	Effect	Management	Notes
Multilayer coating fails to provide adequate reflectivity or other property	Instrument throughput threatened.	Seek to fully understand the coating technology and the sources of variation of performance. Consider possibility of re-coating or provision of uncoated spares. Allow contingency for this. Consider alternative coating technologies.	
Operational Subsystem Level			
Slit exchange mechanism fails	Fails in a nominal slit position; loss of rapid imaging facility. Fails in slot position; loss of spectroscopy. Fails in intermediate position; loss of instrument.	Select proved technology. Life test.	(Assuming mechanism with one or more spectroscopy slit and a wide viewfinder slot)
Meteoroid strike on front filter	Possible debris in the instrument. White light ingress to detector - worsens SNR. Heat input to instrument - thermal stresses and consequent misalignment	Recess filter in exterior baffle. Use segmented filter design to limit area of breakage.	
Shutter failure	(Fail closed) Loss of instrument (fail open) image smearing	Select proven technology. Life test.	
Grating focus mechanism failure	(Fail in focused position) Flat-fielding of detector no longer possible. (Fail in de-focused position) loss of science	Omit mechanism. Redundant actuators. Provide detector flat field by another means.	
Scanning mechanism failure	Loss of scanning and alignment compensation	Life test program. No possibility to move outside of functional range. Monitoring and management of movements during mission.	
Ageing of multilayer coatings	Instrument throughput reduced.	Perform life tests on coatings whose ageing properties are unknown.	
Clamshell Door mechanism failure	Fail closed, loss of instrument.	Redundant heaters in actuator.	

6. Definition, Design, and Development (Phase B/C/D) Plan

6.1 Phase B.

a. Phase B Plans. Phase B will concentrate on completing the preliminary design, instrument tolerancing, development of error budgets, and finalization of the requirements and definition of the EIS Instrument Components. Trade studies and analysis will be conducted to evaluate the design sensitivities to the various manufacturing, assembly, and environmental factors. Management and technical documents (see Table 6-1) will be prepared in advance of the Preliminary Design Review (PDR). During Phase A, long-lead flight hardware items have been identified. During Phase B, procurement of the flight gratings will be initiated, implementing a time-phased procurement cycle with the vendor, minimizing program termination costs. A breadboard of the mirror scan mechanism will be built and tested. Acoustic testing on a sample Spectrometer Entrance Filter will be performed. Technical and scientific interchange meetings with both NASA and the international partners will occur to continue addressing issues with the mission definition, spacecraft and instrument design, and interface definition.

Phase B will conclude with the PDR that will serve as a Confirmation Review for Phases C/D/E. PDR is expected to consist of a Non-Advocate Review (NAR) style programmatic effort. Contingent upon successful completion of the PDR and NASA's confirmation, the NASA Project Office will contract with NRL to proceed with Phases C/D/E. With NASA approval, the NRL EIS Instrument Components team will begin to design and develop the flight and ground control segment immediately following the PDR.

❐ *Project Management Approach:* As the focal point for the NASA Project Office, the PI is responsible for EIS Instrument Components program success. The PI has designated a Project Manager (PM) and has delegated the requisite responsibility and authority to manage and administer Phase B tasks. The management system to be implemented will ensure achieving a range of objectives, such as cost-effective planning, organizing, controlling, and reporting. The NASA Project Office will approve any funding for long-lead part purchases made before official confirmation.

❐ *Schedules:* Consulting with the PI, the PM establishes, implements, and maintains an Integrated Master Schedule (IMS) and derivative detailed schedules that establish the interrelationships and time phasing of essential activities and events, and identifies critical paths and schedule slack. The master level-1 schedule constitutes the "baseline" schedule and is under configuration control.

❐ *Progress Reports:* NRL will submit Monthly Progress Reports using narrative text, graphs, and schedules, as applicable. The report is submitted in hard copy, and made available electronically via the MSSL project website.

❐ *Reviews:* NRL will prepare technical and programmatic data packages to be distributed and presented at the PDR. A NASA-appointed panel will receive advance materials before the formal presentation for the purpose of content review.

b. Phase B Products. During Phase B, the NRL team will provide the facilities, materials, services, and personnel necessary to further define the EIS Instrument Components. Table 6-1 defines the Phase B deliverables, delivery schedule and reviews.

6.2 Phase C/D.

a. Phase C/D Plans. Phase C/D will concentrate on further defining the flight EIS Instrument Components design, flight subsystems development, assembly and testing, EIS instrument integration, test and calibration, and spacecraft integration and test. Phase C/D will also place emphasis on the definition, design, assembly, and test of the applicable electrical and mechanical ground support instrumentation. The flight EIS Instrument Components design, flight development plan, subsystem verification plan, ground support instrumentation, and the EIS instrument/spacecraft integration, test, and calibration plan will be presented at the Critical Design Review (CDR). The technical and scientific interchange meetings with both NASA and the international partners will continue to occur to further address issues with the mission definition, spacecraft and instrument design, and the interface definition.

❐ *Project Management Approach:* The Project Management approach during Phase C/D will be a direct continuation of the management approach implemented during Phase B.

Table 6-1. Phase B Deliverables and Reviews

Data Deliverables		
DRD No.	Document Title	Initial Submission Date and Frequency
874CM-001	Configuration Management Plan	December 16, 1999; Update as needed
874CM-002	EIS Component Specification	Fifteen days before PDR
874CM-003	Preliminary Design Review Package	Fifteen days before PDR
874CM-004	Interface Control Documents	Fifteen days before PDR
874MA-001	Project Management Plan	December 31, 1999; Update as needed
874MA-002	Monthly Progress Report	Due no later than 15th of each month
874MA-003	Financial Management Report	Due no later than 10 working days after contractor's accounting month
874MA-004	Work Breakdown Structure	December 1, 1999
874MA-005	Risk Management Plan	January 17, 2000
874MP-001	Contamination Control and Implementation Plan	Fifteen days before PDR
874QE-001	Product Assurance Plan	January 31, 2000
874SE-001	System Error Budget	Fifteen days before PDR
874SW-001	Software Management Plan	Not Applicable
874VR-001	Verification Plan	December 31, 1999
Program Reviews		
Preliminary Design Review (PDR)		March 15, 2000 (TBR)

- *Schedules:* During Phase C/D, the master level-1 schedule, constituting the "baseline" schedule will continue to be maintained by the PM under configuration control.
- *Progress Reports:* NRL will submit Monthly Progress Reports using narrative text, graphs, and schedules, as applicable. The report is submitted in hard copy, and made available electronically via the MSSL project website.
- *Reviews:* NRL will prepare technical and programmatic data packages to be distributed and presented at the CDR. A NASA-appointed panel will receive advance materials before the formal presentation for the purpose of content review.
- *Subsystem Development Approach:* The protomodel, engineering/qualification model, and flight model of the FFA, MIR, SLA, SFA, and GRA subsystems will be designed, assembled, and tested at the NRL facility. Associated electrical and mechanical GSE required to support subsystem testing and subsequent integration will be designed, assembled, and tested at the NRL facility. Subsystem qualification and flight acceptance testing will be conducted at the NRL facility.
- *EIS Instrument Integration, Test, and Calibration:* Upon completion of the EIS Instrument Components subsystem flight acceptance testing, the EIS instrument integration, test, and calibration will occur at the Rutherford Appleton Laboratory facilities in the UK. The NRL technical and science teams will support the integration, test, and calibration efforts in the UK. The GSFC science team will support review of the test and calibration results.
- *Spacecraft Integration and Test:* Upon completion of the EIS instrument integration, test, and calibration, the EIS instrument will be integrated onto the Solar-B spacecraft at the ISAS facilities in Japan. The NRL technical and science teams will support the spacecraft integration, test, and pre-launch activities in Japan. The GSFC science team will support review of the test results and participate in the pre-launch activities in Japan.

b. Phase C/D Products. During Phase C/D, the NRL team will provide the facilities, materials, services, and personnel necessary to design, assemble, and test EIS Instrument Components subsystems as well as the necessary personnel necessary for the integration and test of the EIS instrument and spacecraft integration, test, and prelaunch activities. Table 6-2 defines the Phase C/D deliverables and delivery schedule, milestones, and reviews.

6.3 Key Mission Trade-offs and Options. NRL and GSFC continue to refine the preliminary design, investigate alternate mission and system concepts. During Phase B, NRL will perform design trades and studies as preliminarily defined in Table 6-3. A PDR will be held with NASA and the STP community to confirm: (i) that the system design approach satisfies the functional baseline; (ii) risks are mitigated with closure plans; and (iii) the system is ready for detailed design and fabrication.

Table 6-2. Phase C/D Deliverables, Milestones and Reviews

Data Deliverables		
DRD No.	Document Title	Initial Submission Date and Frequency
874MA-002	Monthly Progress Report	Due no later than 15th of each month
874MA-003	Financial Management Report	Due no later than 10 working days after contractor's accounting month
874CM-xxx	Critical Design Review Data Package	Fifteen days prior to CDR
Program Phase C/D Milestones		
Electrical Proto-Model Delivery		December 2000
Mechanical/Thermal Proto-Model Delivery		April 2001
Electrical GSE		June 2001
Mechanical GSE		March 2001
EIS Instruments Components for Flight Model Delivery		October 2002
EIS Instrument Flight Model for Integration to Spacecraft		August 2003
Launch		August 2004
Program Reviews		
Critical Design Review (CDR)		March 15, 2001 (TBR)

Table 6-3. EIS Instrument Component Studies

Refinement Studies	• Complete the EIS Instrument Components preliminary design; present at PDR. • Identify long-lead items and refine the schedule to minimize their potential impact. • Identify primary mechanical and electrical interfaces; present to UK partners for establishment of EIS ICDs.
Trade Studies and Design Alternatives	• Conduct disturbance torque analysis; present results to international partners. • Evaluate and specify contamination control needs for materials selection and environment control. • Address optics-specific technology issues as they relate to materials and fabrication. • Evaluate and specify mechanism and actuator electrical controls. • Evaluate and specify Front Filter Assembly clamshell design criteria; present results to UK partners. • Evaluate and specify optical baffle requirements; present results to UK partners. • Evaluate and specify EIS instrument co-alignment criteria onboard Solar-B; present results to international partners.

7. Cost Plan

The EIS Instrument Components team is confident that it will achieve maximum science while minimizing cost and maximizing precious spacecraft resources. The NRL EIS development team will use techniques previously proven on past rocket and spaceflight programs, thus ensuring that risks are minimal, well understood, and controlled. This cost plan has been developed using flight-proven hardware development processes.

7.1 Ground Rules and Assumptions. This cost plan breaks out the costs associated with each phase of the Mission and development consistent with the formats provided by the AO and the CSR instructions. The following listing provides key ground rules:

- Costs in all phases were estimated in terms of the required cost categories (direct labor hours and dollars, materials, subcontracts), the EIS Instrument Components WBS dictionary (Table 7-3), and Master Schedule. Costs are based on recent experience with LASCO, coupled with vendor quotations. A detailed month-by-month breakdown was made for NRL and contractor staffing, supplies, equipment, services, and travel for each program phase. For estimation, Phase C/D was divided into three segments based on the period and related hardware deliveries. For major procurements, cost quotations were obtained. No cost models were used.
- We used the NASA inflation index, as specified in the AO, to calculate all real-year dollar amounts.
- Our SR&QA approach uses trained personnel, H/W fabrication controls, inspection and test, calibrated measuring equipment, QA support to design reviews, tailored vendor surveys and audits, a tailored SR&QA program, and a review of materials lists for outgassing. Flight models are reviewed in formal design reviews (PDR and CDR).
- Cost estimates are based on the US EIS team providing flight H/W for the instrument optics (FFA, MIR, SLA, SFA and GRA), optic mechanisms, light baffles, systems engineering, science support, mission planning, post-launch analysis and software, and Education & Public Outreach. The EIS structure, Focal Plane Assembly, Mechanisms and Heater Control Unit, Interface Control Unit, flight software, overall systems engineering, and EIS instrument I&T and system calibration, will be furnished using funds contributed on a "no exchange of funds" basis by the UK's Particle Physics and Astronomy Research Council (PPARC).

7.2 Total Mission Cost. Table 7-1 lists the EIS Instrument Components Total Mission Cost (TMC) time-phased by Fiscal Year in real year dollars consistent with CSR Guidelines, Table F-2. It represents the optimum mission funding profile. At the time of selection, a NASA cost-cap was applied to the EIS Instrument Component mission development. During Phase A, the original proposal cost estimate was revised, as presented in Table 7-1 and Table 7-2, to meet the requirements of the NASA cost-cap and to ensure that the science goals as presented are met.

Table 7-1. Total NASA Investigation Cost Funding Profile

EIS Instrument Component Total Mission Cost Funding Profile (All Costs in Real Year $, Totals in Real Year and FY98 $)										
Item	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	Total Real Year $	Total (FY98$)
Phase B	1,226,502								1,226,502	1,137,757
NRL	1,194,162								1,194,162	1,107,757
GSFC[a]	32,340								32,340	30,000
Phase C	1,119,190	1,858,108	1,133,832						4,111,131	3,674,477
NRL	1,105,176	1,824,538	1,098,972						4,028,687	3,601,477
GSFC[a]	14,014	33,570	34,860						82,444	73,000
Phase D				803,156	765,060				1,568,216	1,277,037
NRL				766,976	736,264				1,503,240	1,224,037
GSFC[a]				36,180	28,796				64,976	53,000
Phase E						1,903,692	3,188,736	4,624,290	9,716,718	7,112,000
NRL						1,646,292	2,735,472	3,971,890	8,353,654	6,112,000
GSFC[a]						257,400	453,264	652,400	1,363,064	1,000,000
Total NASA Mission Cost	2,345,692	1,858,108	1,133,832	803,156	765,060	1,903,692	3,188,736	4,624,290	16,622,567	13,201,271

a. GSFC participation is for EIS science support.

7.3 Time-Phased Cost Breakdown by WBS (Phase B/C/D/E). Table 7-2 lists a summary of the total Phase B/C/D, and Phase E costs, time-phased by Fiscal Year, FY98 dollars consistent with CSR Guidelines, Table F-3. The cost summary is consistent with the WBS and includes all costs to NASA, including contributed costs.

7.4 Mission Cost Reserves. The PI holds no labor reserve for changes occurring in development during Phase C/D. To meet the mission 5% reduction, no reserves are held within the EIS investigation.

7.5 Civil Service Costing. Full costing of all civil service support is included. NRL is classified as a Navy Working Capital Fund Agency, meaning that all direct project costs, including salaries, are derived from project funds. Overhead is applied only to civil servant salaries. Direct costs associated with major contracts are included as procurement surcharges. NRL uses a stabilized billing rate for civil service employees that includes hourly direct labor rates, fringe rates, production rates, and General and Administrative (G&A) rates.

7.6 Proposal Pricing Techniques. At the time of proposal development, cognizant scientific and technical personnel at NRL and GSFC estimated the EIS Instrument Components resource requirements. After mission selection and subsequent NASA cost capping, the same personnel supported the cost development and reviewed the resultant program plan for continuity and completeness. The primary objective focused on realistic and supportable cost estimates for a science mission that met the requirements of the AO.

The EIS Instrument Component team has high confidence in the reliability of the cost estimates because so many of the components are the same as or similar to recent designs.

- *Inflation Estimates:* The estimating methodology applies inflation estimates to labor, material, and travel cost categories using the NASA New Start Inflation Index, Table B-4, 98-OSS-05.
- *Hardware Heritage:* The EIS team has extensive experience in multinational hardware efforts, including LASCO, EIT and CDS on SOHO and BCS on Yohkoh. This experience greatly improves the validity of our hardware development, integration and test, and data analysis estimates.
- *Mission I&T:* The integration and test costs were estimated based on experience with SOHO/LASCO.
- *Ground Operations, Data, and Science Costs:* The EIS mission operations are similar to the SOHO/LASCO programs. The operations, data processing, and science components will be operated on a cost-capped, level-of-effort (LOE) basis similar to the SOHO program. This has proven efficient to manage and has functioned well. The data processing center is a refurbishment and enhancement of the LASCO/EIT Data Reduction and Analysis Center (DRAC), which is located at NRL and collocated with the PI. Data processing costs are well understood due to the similarity of the LASCO/EIT and similar data processing requirements. The science analysis in Phase E is similarly well understood from LASCO heritage.
- *Education and Public Outreach:* The E/PO program is estimated at about the 1 – 2% level. It will be LOE with no reserves held by the PI.

7.7 Phase B/C/D Time-Phased Cost Summary.

The EIS Instrument Components Phase B/C/D cost estimates were originally developed using a product-oriented WBS using the NASA guidelines. During Phase A, these costs were revised to meet the NASA cost-cap. The revised WBS (Table 7-3) fully integrates the work efforts of the team. A master schedule has been prepared that accommodates the proposed launch schedule and develops task descriptions and a Basis of Estimate (BOE) for each WBS task. The estimating process used scientists and engineers with past performance on and relationships with analogous missions. Each developed a detailed WBS for their respective task and estimated total hours, materials and supplies by subtask. Because most of the hardware elements directly evolved from past heritage, the cost estimates are based on actual costs from those programs and take into account design maturity and heritage. Other costs reflect experience from in-house independent research efforts and from vendor quotations.

7.8 MO&DA (Phase E) Time-Phased Cost Summary. The cost estimating techniques for Phase E are based on the same methodologies used for Phase B/C/D (see Section 7.7). The WBS for Phase E applies the same WBS used for Phase B/C/D (Table 7-3). The Phase E plans remain consistent with the plans set forth in the proposal's Science Investigation, Technical Approach, and Management sections.

Table 7-3. EIS Instrument Components WBS Dictionary

WBS	Description	WBS Dictionary
1.2.3.1	Management, Science and Co-Investigators	
1.2.3.1.1	Project Management	Provides for the EIS project management function at NRL. Includes the PI, PM and supporting administrative functions. Also includes project related travel and meeting support.
1.2.3.1.2	Project Planning	Provides for the NRL EIS project development, assessment and reporting of the project status. Also provides for the efforts to plan, authorize, control, analyze and report financial and schedule performance, and to integrate and maintain overall project budgets, financial evaluation of changes to the overall project, the preparation of financial reports and implementation of cost control procedures.
1.2.3.1.3	Procurement Management	Provides for NRL procurement management of all subcontracts and task agreements of the overall project as well as procurement of all project materials.
1.2.1.3.4	Configuration Management	Includes NRL's efforts to establish and maintain an integrated CM system for all project elements.
1.2.3.1.5	Science Support	Includes Phase B/C/D (pre-launch) support costs.
1.2.3.2	Flight System	
1.2.3.2.1	Front Filter Assembly (FFA)	Includes all costs incurred to design, develop and fabricate the Front Filter Assembly through Instrument Test and Verification (WBS 1.2.3.4.2).
1.2.3.2.2	Mirror Assembly (MIR)	Includes all costs incurred to design, develop and fabricate the Mirror Assembly through Instrument Test and Verification (WBS 1.2.3.4.2).
1.2.3.2.3	Shutter Assembly (SLA)	Includes all costs incurred to design, develop and fabricate the Shutter Assembly through Instrument Test and Verification (WBS 1.2.3.4.2).
1.2.3.2.4	Spectrometer Entrance Filter (SEF)	Includes all costs incurred to design, develop and fabricate the Spectrometer Entrance Filter through Instrument Test and Verification (WBS 1.2.3.4.2).
1.2.3.2.5	Grating Assembly (GRA)	Includes all costs incurred to design, develop and fabricate the Grating Assembly through Instrument Test and Verification (WBS 1.2.3.4.2).
1.2.3.3	Ground Support Equipment and Proto Models	
1.2.3.3.1	Electrical Proto Model	Includes all costs incurred for the definition, specification establishment, design, fabrication, assembly and test of the optical mechanisms control electronics Electrical Proto Models, as applicable.
1.2.3.3.2	M/T Proto Model	Includes all costs incurred for the definition, specification establishment, design, fabrication, assembly and test of the Mirror and Grating Assemblies Mechanical/Thermal Proto Models.
1.2.3.3.3	Electrical Ground Support Equipment (EGSE)	Includes all costs incurred for the definition, specification establishment, design, fabrication, assembly, test and verification of the mechanism controller EGSE and associated software.
1.2.3.3.4	Mechanical Ground Support Equipment (MGSE)	Includes all costs incurred for the definition, specification establishment, design, fabrication, assembly, test and verification of the integration and test equipment and shipping containers.
1.2.3.3.5	Mock-ups and Simulators	Includes all costs incurred for the definition, specification establishment, design, fabrication, assembly, test and verification of mockups and simulators, as applicable.
1.2.3.4	Systems Engineering and Integration	
1.2.3.4.1	Systems Engineering	Includes all costs incurred by NRL for systems engineering functions with the EIS international design and development team.

Table 7-3. EIS Instrument Components WBS Dictionary (Continued)

WBS	Description	WBS Dictionary
1.2.3.4.2	Instrument Test and Verification	Includes costs incurred by NRL for the EIS Instrument components subsystem level test and verification at NRL. Subsystem tests to include thermal vacuum, thermal cycling, electrical and mechanical functional, acoustic (as applicable) and vibration.
1.2.3.4.3	EIS Integration and Test Support	Includes costs incurred by NRL to support EIS Instrument integration and test both in the UK and Japan.
1.2.3.5	Operations	
1.2.3.5.1	Mission Operations Definition and Planning	Includes all costs incurred by NRL for mission definition and planning during Phases C and D.
1.2.3.5.2	Mission Operations Support	Includes all costs incurred by NRL for the pre-launch preparation and post launch activities under Phase E.
1.2.3.6	Product Assurance	
1.2.3.6.1	Product Assurance	Includes all costs incurred by NRL to establish and maintain a product assurance program to include safety, reliability and quality assurance engineering activities.

A. Resumes

Dr. George A. Doschek. Principal Investigator, Naval Research Laboratory.

Education. B.S., Physics, University of Pittsburgh, 1963; Ph.D., Physics, University of Pittsburgh, 1968.

Background. Dr. Doschek has been Branch Head of the Solar-Terrestrial Relationships Branch in the Space Science Division at the NRL since 1979. Between 1970 and 1979 he was a Research Astrophysicist at NRL, and between 1968 and 1970 he was an E.O. Hulburt Fellow at NRL. He is a member of the American Astronomical Society/Solar Physics Division (AAS/SPD), the International Astronomical Union (IAU), and is a Fellow of the Optical Society of America. He was the 1986-1988 Chairperson of the SPD, and he is a recipient of NRL's highest award for scientific achievement, the E.O. Hulburt Award. He is an author on 242 research papers, most of which are in refereed journals. He has served on NASA advisory and review committees. He was a member of the NASA Solar-B Science Definition team.

Dr. Doschek's research is in the area of high resolution X-ray-EUV-UV spectroscopy of astrophysical and laboratory plasmas. He has developed plasma diagnostic techniques for measurement of plasma temperature, density, emission measure, equilibrium state, and composition, and has contributed extensively to pure spectroscopy. He has produced detailed analyses of spectra from many major solar physics space missions: OSO-4,6 (X-ray spectroscopy), Skylab (EUV and UV spectroscopy), P78-1/SMM/Hinotori (X-ray spectroscopy), Yohkoh, (X-ray spectroscopy), and SOHO (SUMER EUV spectroscopy). He has carried out similar analyses for laser-produced plasmas. In addition, he has participated in the design and construction of spectroscopic instrumentation for both laboratory and astrophysical plasmas. Dr. Doschek was the NRL Principal Scientist for the BCS on Yohkoh, and was a key instrumentation team member in the design and construction of the NRL SOLFLEX BCS flown on P78-1.

EIS Research Interests and Investigation Role.

Dr. Doschek is the Principal Investigator of the US EIS investigation and is therefore responsible for the delivery and successful performance of all US hardware for the EIS investigation. He is also responsible for all other US involvement in the EIS project as specified in the AO. Dr. Doschek's research interests are in investigating the role of magnetic reconnection in solar activity and high energy transient phenomena.

Selected Relevant Publications.

Doschek, G.A. 1999, "The Electron Temperature and Fine Structure of Soft X-ray Solar Flares", Astrophys. J., in press.

Doschek, G.A., and Feldman, U. 1999, "Extreme Ultraviolet Spectral Line Profiles in Quiet Sun Coronal Plasmas at Distances of 1.03 < R < 1.45 Along the Solar Equatorial Plane", Astrophys. J., in press.

Doschek, G.A., Feldman, U., Laming, J.M., Warren, H.P., Schühle, U., and Wilhelm, K. 1998, "The Electron Pressure in the Solar Lower Transition Region Determined from O V and Si III Density Sensitive Line Ratios," Astrophys. J., 507, 991.

Doschek, G.A., Laming, J.M., Feldman, U., Wilhelm, K., Lemaire, P., Schühle, U., and Hassler, D.M. 1998, "The Si/Ne Abundance Ratio in Polar Coronal Hole and Quiet Sun Coronal Regions," Astrophys. J., 504, 573.

Doschek, G.A. 1998, "New Results from Solar Coronal Spectroscopy (SOHO/SUMER)", Proc., the Tenth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, ASP Conf. Ser. 154, edited by R.A. Donahue and J.A. Bookbinder, p. 413 (invited).

Doschek, G.A., Warren, H.P., Laming, J.M., Mariska, J.T., Wilhelm, K., Lemaire, P., Schühle, U., and Moran, T.G. 1997, "Electron Densities in the Solar Polar Coronal Holes from Density Sensitive Line Ratios of Si VIII and S X," Astrophys. J. (Letters), 482, L109.

Doschek, G.A., Mariska, J.T., Warren, H.P., Wilhelm, K., Lemaire, P., Kucera, T., and Schühle, U. 1997, "Determination of the Formation Temperature of Si IV in the Solar Transition Region," Astrophys. J. (Letters), 477, L119.

Doschek, G.A. 1997, "Emission Measures and Electron Densities for the Solar Transition Region," Astrophys. J., 476, 903.

Doschek, G.A. and Feldman, U. 1996, "The Temperature of the Bright Knots at the Tops of Solar Flare Loops," Astrophys. J., 459, 773.

Doschek, G.A., Mariska, J.T., and Sakao, T. 1996, "Soft X-ray Flare Dynamics," Astrophys. J., 459, 823.

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Doschek, G.A., Strong, K.T., and Tsuneta, S. 1995, "The Bright Knots at the Tops of Soft X-ray Flare Loops: Quantitative Results from Yohkoh," Astrophys. J., 440, 370.

Doschek, G.A., et al. 1994, "The 9 November 1991 Flare at 03.2 UT: Observations from Yohkoh," Astrophys. J., 431, 888.

Doschek, G.A., et al. 1993, "The 5 January 1992 Flare at 13.3 UT: Observations from Yohkoh," Astrophys. J., 416, 845.

Doschek, G.A., and Feibelman, W.A. 1993, "An Improved Ultraviolet Spectral Line List for the Symbiotic Star RR Telescopii," Astrophys. J. Suppl., 87, 331.

Doschek, G.A., et al. 1992, "Yohkoh Bragg Crystal Spectrometer Observations of the Dynamics and Temperature Behavior of a Soft X-ray Flare," Publ. of the Astron. Soc. of Japan, 44, L95.

Doschek, G.A., Dere, K.P., and Lund, P.A. 1991, "Relative Abundances in the Lower Solar Transition Region," Astrophys. J., 381, 583.

Dr. Charles M. Brown. Co-Investigator (Instrument Scientist), Naval Research Laboratory.

Education. B. A. Mathematics, Southern Illinois University, 1965; Ph. D. Chemical Physics, University of Maryland, 1971.

Background. The bulk of Dr. Brown's research has been in the area of experimental high-resolution spectroscopy. His experiments have been performed at wavelengths ranging from the visible, through the ultraviolet to the EUV and X-ray region. He conducts laboratory experiments at NRL and with facilities at other research institutions such as the NOVA laser, the NIKE facility, the NSLS synchrotron at Brookhaven National Laboratory, and the Electron Beam Ion Traps (EBIT). In addition to his laboratory research, Dr. Brown has participated in a number of space flight experiments such as the Bragg Crystal Spectrometer (BCS) on Yohkoh, the Middle Atmosphere High Resolution Spectrograph (MAHRSI) on STS-66 and STS-85, SO82A and SO82B on SKYLAB, and has made contributions to a number of balloon and rocket experiments.

Dr. Brown's early work was on high-resolution spectra of atoms and molecules, mostly in the vacuum ultraviolet region. Major contributions from that work were studies of high temperature absorption spectra of many atoms and their Rydberg states. Dr. Brown and his co-workers were among the first to apply Multichannel Quantum Defect Theory to the analysis of these spectra. Other work in this era were analyses of SO82B spectra from SKYLAB and identification of many spectral lines therein, most notably Si I and O_2. Work with Dr. C. E. Moore and R. Tousey produced an atlas of solar UV spectral lines from a high-resolution echelle spectrograph. As part of the laboratory spectroscopy effort, a UHV beam line was constructed at the NIST SURF-II synchrotron and the NRL 6.6-m vacuum spectrometer was installed there.

More recently, Dr. Brown has fielded a number of experiments at high power laser facilities to study laser heated plasmas. Both spectra and images were obtained and analyzed. High-resolution XUV spectra were obtained for many highly charged ions at the OMEGA laser and the NOVA laser using a 3-m grazing incidence spectrometer. Cylindrical and spherically bent crystals were used to obtain both spectra and monochromatic high-resolution images of the laser plasmas. In a joint effort with NIST scientists an NRL-NIST EBIT facility was constructed. Dr. Brown has conducted a number of spectroscopic studies of highly charged ions using the EBIT.

EIS Research Interests and Investigation Role.

Dr. Brown leads the optical design effort and shares the mechanical and engineering work. Instrument layout and raytracing studies of optics, laboratory working in assembly, focusing, vacuum, calibration, and testing are generally Dr. Brown's contributions to the EIS construction. As a team member, Dr. Brown contributes to flight operations and data analysis.

Formal Recognition and Selected Relevant Publications. Dr. Brown is a fellow of the Optical Society of America and has served on the NRC Committee of Line Spectra of the Elements. Dr. Brown is author or co-author of over 125 scientific publications. The following is a short list of relevant publications.

Longmire, M.S., Bartoe, J.-D. F., Brown, C.M., Brueckner, G.E., and Tousey, R., "Measurements of Spectrally Integrated Atmospheric Transmittance in the O2 Schumann-Runge Bands and Derived Oxygen Column Densities: 76 km to 102 km," Geophys. Res. 84, 1277 - 1558 (1978).

Moore, C.E., Tousey, R., and Brown, C.M., "The Solar Spectrum 3069A - 2095A from the Echelle Spectrograph flown in 1961 and 1964. An Extension of Rowland's Preliminary Table of Solar Spectrum Wavelengths," NRL Report 8653, (Naval Research Laboratory, Washington, D. C. 1982), 169pp.

Behring, W.E., Underwood, J.H., Brown, C.M., Feldman, U., Seely, J.F., Marshall, F.J., Richardson, M.C., and Underwood, J.H., "Grazing incidence technique to obtain spatially resolved spectra from laser heated plasmas," Applied Optics, 27, 2762 - 2766 (1988).

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Culhane, J.L., Hiei, E., Doschek, G. , Cruise, A.M., Bentley, R.D., Bowles, J.A., Brown, C.M., Feldman, U., Fludra, A., Guttridge, P., Lang, J., Lappington, J., Magraw, J., Mariska, J., Ogawara, Y., Payne, J., Phillips, K., Sheather, P., Slater, K., Towndrow, E., Trow, M., and Watanabe, T. , "The Bragg Crystal Spectrometer for Solar-A," Solar Physics 136, 89 - 104 (1991).

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Aglitskiy, Y., Lehecka, T., Obenschain, S., Bodner, S., Pawley, C., Gerber, K., Sethian, J., Brown, C.M., Seely, J.F., Feldman, U., and Holland, G., "High resolution monochromatic X-ray imaging system based on spherically bent crystals," Applied Optics 37, 5253-5261 (1998).

Conway, R., Stevens, M., Brown, C.M., Cardon, J., Zasadil, S., and Mount, G., "Middle Atmosphere High Resolution Spectrograph Investigation," J. Geophys. Res., 104, 16327-16348 (1999).

Dr. Joseph M. Davila. Co-Investigator, NASA Goddard Space Flight Center.

Education. B.S., Mechanical Engineering, Lamar University, 1972; B.S., Physics, University of California, Irvine, 1978; Ph.D., Astronomy, University of Arizona, 1982.

Background. Dr. Davila is a member of the American Astronomical Society, the American Geophysical Union and the International Astronomical Union. Dr. Davila has published more than 40 papers in refereed journals on subjects such as the linear and non-linear theory of hydromagnetic waves, hydromagnetic instabilities due to energetic particle beams, resonance absorption in inhomogeneous plasmas, the acceleration of high speed wind streams in solar and stellar coronal holes, and plasma heating in closed magnetic structures. Dr. Davila has also published research on the acceleration of cosmic rays, the transport of energetic particles within the Galaxy, the modulation of galactic cosmic rays by the solar wind and the propagation of solar cosmic rays in the interplanetary medium.

Dr. Davila has been the Principal Investigator for the SERTS sounding rocket program since 1990, where he has pioneered the use of multilayer optical coatings for spectroscopy, and been instrumental in the continued development of intensified CCD detectors for spectroscopy. Dr. Davila has used SERTS data to conduct extensive research into the structure and dynamics of the solar corona.

EIS Research Interests and Investigation Role.

Dr. Davila will coordinate the multilayer coating for all EIS optical components at GSFC, and will provide the spectrometer slit. Dr. Davila will be responsible for the SERTS sounding rocket calibration effort. In collaboration with the UK and NRL EIS teams, he will participate in development of the data processing and analysis software. After launch, he will participate in science operations in Japan and pursue his research interests in the observational study of solar coronal dynamics and structure.

Selected Relevant Publications.

Keski-Kuha, R.A.M., Thomas, R.J., and Davila, J.M. 1991, "Rocket Flight of a Multilayer Coated High-Density Toroidal Grating," in Proceedings of the SPIE, 1546, 614.

Davila, J.M. 1994, "Solar Tomography," Astrophys. J., 423, 871.

Ofman, L. and Davila, J.M. 1995, "Alfven Wave Heating of Coronal Holes and the Relation to the High-Speed Solar Wind," JGR, 100, 23414.

Brosius, J.W., Davila, J.M., Thomas, R.J., and Monsignori-Fossi, B.C. 1996, "Measuring Active and Quiet-Sun Coronal Plasma Properties with Extreme-Ultraviolet Spectra from SERTS," Astrophys. J. Suppl., 106, 143.

Brosius, J.W., Davila, J.M., Thomas, R.J., Saba, J.L.R., Hara, H., and Monsignori-Fossi, B.C. 1996, "The Structure of Solar Active Regions and Quiet-Sun Areas Observed in Soft X-rays with Yohkoh/SXT and in the Extreme-Ultraviolet with SERTS," Astrophys. J., 477, 969.

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Brosius, J.W., Davila, J.M. and Thomas, R.J. 1998, "Calibration of the SERTS-95 Spectrograph from Iron Line Intensity Ratios," Astrophys. J. (Letters), 497, L113.

Dr. Kenneth P. Dere. Co-Investigator (Mission Scientist), Naval Research Laboratory.

Education. A.B., Physics, Cornell University, 1969; M.S., Physics, Cornell University, 1971; Ph.D., Physics, The Catholic University of America, 1980.

Background. Dr. Dere's research interests have largely centered on the use of X-ray, EUV, UV, and visible light spectroscopic diagnostics of high temperature solar plasmas as a means to understand their basic physical processes. He has been involved in the analysis of Solar Radiation (SOLRAD) X-ray observations of solar flares, Skylab S082A slitless EUV spectrograph observations of solar flares and active regions, HRTS UV spectrograph observations of the dynamics of the quiet and active sun, and SOHO LASCO and EIT observations of coronal mass ejections. Currently, he is helping to lead an international consortium in constructing the CHIANTI atomic database for the analysis of astrophysical spectra. This research has resulted in over 100 scientific papers authored or co-authored by Dr. Dere.

Dr. Dere is a member of the American Astronomical Society and its Solar Physics and High Energy Astrophysics Divisions. He is also a member of the American Geophysical Union and has served as an associate editor of JGR-Space Physics. He is currently secretary of IAU Commission 10 on Solar Activity. He was a member of the NASA Solar-B Science Definition Team.

EIS Research Interests and Investigation Role.

The overall function of the EIS Mission Scientist is to serve as the point of contact for EIS science issues. The responsibilities include developing the science goals for EIS; ensuring that the instrument is capable of accomplishing these goals; preparing relevant NASA documents; developing scientific interfaces to the other Solar-B experiments such as through the planning of joint science observing programs and organizing EIS/Solar-B science meetings. The observations obtained with EIS will allow Dr. Dere to continue the study of topics addressed in the past, such as the role of sub-resolution structure in coronal heating, the use of explosive events as diagnostics of coronal heating, spectroscopic diagnostics of the physical conditions in coronal plasmas, and the initiation of coronal mass ejections.

Selected Relevant Publications.

Dere, K.P., Mason, H.E., Widing, K.G., and Bhatia, A.K. 1979, "XUV Electron Density Diagnostics for Solar Flares," Astrophys. J. Suppl., 40, 341.

Dere, K.P., and Cook, J.W. 1979, "Decay of the 1973 August 9 Flare," Astrophys. J., 229, 772.

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Dere, K.P., et al. 1997, "EIT and LASCO Observations of the Initiation of a Coronal Mass Ejection," Sol. Phys., 175, 601.

Dere, K.P., et al. 1998, "LASCO and EIT Observations of Helical Structure in Coronal Mass Ejections," Astrophys. J., submitted.

Dr. Clarence M. Korendyke. Co-Investigator (Project Scientist), Naval Research Laboratory.

Education. B.A., Physics and Math, Kalamazoo College, 1984; M.A., Physics, University of Maryland, 1988; Ph.D., Physics, University of Maryland, 1992.

Background. Dr. Korendyke's central area of interest is in the development, construction, and operation of space flight instrumentation to observe solar and heliospheric plasmas. As assistant project scientist, he played a central role in the development of the LASCO instrument. This instrument, successfully operating on the SOHO, produces panoramic images of the solar corona from 1.1 to 30 solar radii. The LASCO instrument is a significant improvement over previous instrumentation in field of view, dynamic range, and sensitivity and has set a new standard of excellence for coronagraph instrumentation. Analysis of the LASCO panoramic images has produced a number of significance scientific findings. A result of great practical importance is the real time identification of earth-directed coronal mass ejections 60-80 hours prior to earth impact using the LASCO and EIT data. An important astrophysical result is the direct measurement of slow solar wind velocities from 2 to 30 solar radii using small tracers.

For the last decade, Dr. Korendyke has also carried out the HRTS sounding rocket program as project scientist under the direction of the principal investigator, Dr. Guenter E. Brueckner. He has supervised and launched four successful HRTS sounding rockets. Since 1992, these launches correspond to 1/4 of the total solar physics sounding rocket launches. The HRTS 7 launch successfully observed a flaring neutral line in a solar active region. The spectra obtained are the only existing EUV slit spectra of a solar flare with arc-second spatial resolution. The HRTS 8 launch successfully observed an active region at the limb and obtained the first high cadence spectroheliograms of a C IV surge at the limb. The HRTS 9 launch obtained spectra and spectroheliograms of a solar active region. The spectroheliograms in C IV are dominated by cool loops lying above a neutral line. These loops were found to be consistent with the Noci and Antiochos model. The HRTS 10 payload was launched to examine conditions in the quiet sun in conjunction with SOHO. Subarcsecond resolution spectroheliograms revealed the complex evolution of solar structures within supergranules on the disk; above the limb, C IV movies show the rapid evolution and dynamics of higher altitude transition region structures at the pole.

EIS Research Interests and Investigation Role. Dr. Korendyke will serve as the EIS Project Scientist for the NRL portion of the investigation. He will supervise and coordinate the NRL EIS technical program under the guidelines established by the Principal Investigator. After launch, he will participate in the initial commissioning of the EIS instrument and in operational activities.

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Korendyke, C.M., and Socker, D.G. 1993, "Measured Optical Performance of Three Fabry-Perot Interferometers for use in a Tunable Ultraviolet Filter," Optical Engineering, 32, 2281.

Dr. John T. Mariska. Co-Investigator (Data Coordination Scientist), Naval Research Laboratory.

Education. B.A., Physics, University of Colorado, 1972; A.M., Astronomy, Harvard University, 1973; Ph.D., Astronomy, Harvard University, 1977.

Background. Dr. Mariska's main area of interest is the observational and theoretical study of the structure, dynamics, and radiating properties of the solar transition region and corona. Among his contributions have been studies of transition-region emission measures, density diagnostics, and mass motions, as well as investigations of the nonthermal broadening of emission lines formed in the solar transition region and its implications for models of coronal heating. He has also conducted theoretical examinations of the generation and maintenance of steady flows in magnetic flux tubes under solar conditions, performed numerical studies of solar prominence formation and the early phases of solar flares, and has analyzed UV, EUV, and X-ray data on the features that comprise the outer layers of the solar atmosphere.

Dr. Mariska has been a PI or Co-I on numerous NASA- and Navy-sponsored research efforts. He is currently the PI on a Navy-funded program for dynamical modeling of the solar atmosphere and on a NASA-sponsored program for analysis of SOHO observations. As a participant on the NRL BCS experiment on the Yohkoh mission, Dr. Mariska was responsible for supervising the development of the production BCS data reduction and analysis software. He is currently responsible for maintaining Yohkoh software and data at NRL.

Dr. Mariska is the author or co-author of more than 80 articles in the refereed literature and of one book. He is a member of the American Astronomical Society and was secretary of its Solar Physics Division from 1986 to 1988. He is also a member of the International Astronomical Union, where he serves as secretary of Commission 12 (Solar Radiation and Structure); the American Geophysical Union; and the American Association for the Advancement of Science. Dr. Mariska also serves as a Scientific Editor for The Astrophysical Journal.

EIS Research Interests and Investigation Role. Dr. Mariska will serve as the Data Coordination Scientist for the NRL portion of the EIS investigation. In that role, he will be responsible—in collaboration with the UK EIS team—for translating the EIS science goals into observing sequences for the instrument. Also in collaboration with the UK EIS team, he will participate in development of the data processing and analysis software. After launch, he will be participate in science operations in Japan and pursue his research interests in the observational study of solar transition-region and coronal dynamics.

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Mariska, J.T. 1987, "Solar Transition Region and Coronal Response to Heating Rate Perturbations," Astrophys. J., 319, 465.

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Warren, H.P., Mariska, J.T., Wilhelm, L., and Lemaire, P. 1997, "Doppler Shifts and Nonthermal Broadening in the Quiet Solar Transition Region: O VI," Astrophys. J. (Letters), 484, L91.

Warren, H.P., and Mariska, J.T., and Wilhelm, K. 1997, "Observations of Doppler Shifts in a Solar Polar Coronal Hole," Astrophys. J. (Letters), 490, 187.

Dr. John F. Seely. Co-Investigator, Naval Research Laboratory.

Education. B.S., Physics, North Carolina State University, 1968; Ph.D., Physics, University of Tennessee, 1973.

Background. Dr. Seely is presently the Head of the UV and X-Ray Spectroscopy Section in the NRL Space Science Division. He has done work in the areas of EUV and X-ray spectroscopy of solar and laboratory plasmas with applications to the diagnosis of these plasmas. His work on solar flare plasmas includes the analysis of spectra and images from the Yohkoh, Skylab, and P78-1 spacecraft. Recent work on SUMER spectra has involved determining the line widths and non-thermal broadening in coronal streamers. His work on laboratory plasmas includes the study of high-resolution EUV spectra from laser-produced and tokamak plasmas. Dr. Seely has led a program for the design and implementation of multilayer-coated gratings and mirrors for the EUV and soft X-ray regions and has studied the optical properties of materials in these regions. Dr. Seely is the author or co-author of over 170 papers in refereed scientific journals.

Dr. Seely has been the PI or Co-I on many projects funded by NASA, DOE, DoD, and DTRA. He presently manages projects, with a total budget of $1.1M per year, for the development of multilayer gratings for flight instruments, high resolution X-ray and EUV imaging and spectroscopy diagnostics for hot plasmas, and the development of hard X-ray and neutron sources for medical and defense applications.

Dr. Seely is a Fellow of the Optical Society of America. He is a member of the American Physical Society, American Astronomical Society, Sigma Xi, and the American Association for the Advancement of Science. He serves as a referee for Physical Review Letters, Physical Review, Applied Optics, Review of Scientific Instruments, and other journals. Dr. Seely has been awarded four patents and has received three NRL Technology Transfer Awards as well as a Research Publication Award.

EIS Research Interests and Investigation Role.

Dr. Seely will have primary responsibility for the multilayer coatings on the grating and telescope mirrors. He will write the specifications for the grating and mirror substrates, interact with the vendors, and monitor the delivery schedules. Dr. Seely will characterize the grating and mirror substrates using Atomic Force Microscopy. He will measure the efficiencies of the multilayer gratings and the reflectances of the multilayer mirrors using the NRL beamline at the Brookhaven Synchrotron. After launch, he will participate in the science operations in Japan and will analyze the spectra recorded by the EIS instrument, particularly the line widths and non-thermal broadening.

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Seely, J.F. and Brown, C.M. 1993, "Multilayer-Coated Grating Spectrometer Operating in the Extreme Ultraviolet Region and Based on the Seya-Namioka Mount," Appl. Optics, 32, 6288.

Barbee, T.W., Rife, J.C., Hunter, W.R., Kowalski, M.P., Cruddace, R.G., and Seely, J.F. 1993, "Long-Term Stability of a Mo/Si Multilayer Structure," Appl. Optics, 32, 4852.

B. Letters of Endorsement

C. Statements of Work for the EUV Imaging Spectrometer Investigation

This appendix contains a summary of the Statement of Work (SOW) between the National Aeronautics and Space Administration (NASA) and the Naval Research Laboratory (NRL) for conduct of the development of the EIS Instrument Components for the Solar-B mission as described in AO 98-OSS-05. SOWs are included for the Naval Research Laboratory (NRL) and Goddard Space Flight Center (GSFC). During Phae A, detailed SOWs were submitted for Phase B and Phase C/D.

C.1 Naval Research Laboratory SOW.

C.1.1 Phase B—Preliminary Design. During Phase B, NRL will lead the EIS Instrument Components preliminary design effort. NRL will hold a Preliminary Design Review at the end of Phase B.

a. Internal and external interfaces will be established and documented.

b. Preliminary design of the Front Filter Assembly (FFA), primary Mirror Assembly (MIR), Slit/Slot Assembly (SLA), Spectrometer Entrance Filter Assembly (SFA), Grating Assembly (GRA), and associated optical mechanisms will be completed.

c. Preliminary design of the mechanical and electrical GSE will be completed.

d. Commence time-phased procurement of selected long-lead flight components.

e. Provide systems engineering support to the international EIS preliminary instrument design. Support will include providing assistance in the development of the EIS Interface Control Documents and participation in EIS Instrument engineering meetings.

f. Establish preliminary plans for the NASA EIS Education and Public Outreach (E/PO) program.

g. Provide support to continued EIS science and mission planning activities. Support will include participation in EIS Instrument and Solar-B science meetings as applicable.

h. Provide deliverables defined in Table C-1.

C.1.2 Phase C—Detailed Design. During Phase C, NRL will develop the EIS Instrument Components detailed design to a level permitting fabrication. NRL will hold a Critical Design Review at the end of Phase C.

a. Detailed design of the FFA, MIR, SLA, SFA, GRA, and associated optical mechanisms will be completed.

b. Detailed design of the mechanical and electrical GSE will be completed.

c. Remaining long-lead items will be ordered and fabrication will begin upon approval of detailed designs.

d. Provide systems engineering support to the international EIS detailed instrument design. Support will include participation in EIS Instrument engineering meetings.

e. Detailed plans for the NASA EIS E/PO program will be developed.

f. Provide support to continued EIS science and mission planning activities. Support will include participation in EIS Instrument and Solar-B science meetings as applicable.

g. Provide deliverables defined in Table C-2.

C.1.3 Phase D—Implementation. During Phase D, NRL will lead the EIS Instrument Components development, fabrication, integration, and test effort and participate in the EIS instrument and spacecraft integration, test, and calibration. Phase D will end one month after launch.

a. Assembly and test of the development model for the MIR and GRA assemblies will be conducted.

b. Assembly and test of the flight FFA, MIR, SLA, SFA, GRA assembly, and associated optical mechanisms will be conducted.

c. Assembly and test of the mechanical and electrical GSE will be conducted.

d. Provide systems engineering support to the international EIS detailed instrument development. Support will include participation in EIS Instrument engineering meetings.

e. Participate in the EIS Instrument integration, test and calibration in the UK.

f. Provide support to continued EIS science and mission planning activities. Support will include participation in EIS Instrument and Solar-B science meetings as applicable.

g. Participate in the spacecraft-to-EIS integration and test in Japan.

h. Support the Solar-B pre-launch and launch activities in Japan.

i. Implement the NASA EIS E&PO program.

j. Provide deliverables defined in Table C-3.

Table C-1. Phase B Deliverables and Schedule

Data Deliverables		
DRD No.	Document Title	Initial Submission Date and Frequency
874CM-001	Configuration Management Plan	December 16, 1999; Update as needed
874CM-002	EIS Component Specification	Fifteen days before PDR
874CM-003	Preliminary Design Review Package	Fifteen days before PDR
874CM-004	Interface Control Documents	Fifteen days before PDR
874MA-001	Project Management Plan	December 31, 1999; Update as needed
874MA-002	Monthly Progress Report	Due no later than 15th of each month
874MA-003	Financial Management Report	Due no later than 10 working days after contractor's accounting month
874MA-004	Work Breakdown Structure	December 1, 1999
874MA-005	Risk Management Plan	January 17, 2000
874MP-001	Contamination Control and Implementation Plan	Fifteen days before PDR
874QE-001	Product Assurance Plan	January 31, 2000
874SE-001	System Error Budget	Fifteen days before PDR
874SW-001	Software Management Plan	Not Applicable
874VR-001	Verification Plan	December 31, 1999
Program Reviews		
Preliminary Design Review (PDR)		March 15, 2000 (TBR)

Table C-2. Phase C Deliverables and Schedule

Data Deliverables		
DRD No.	Document Title	Initial Submission Date and Frequency
874MA-002	Monthly Progress Report	Due no later than 15th of each month
874MA-003	Financial Management Report	Due no later than 10 working days after contractor's accounting month
874CM-xxx	Critical Design Review Data Package	Fifteen days prior to CDR
Program Reviews		
Critical Design Review (CDR)		March 15, 2001 (TBR)

C.1.4 Phase E—Mission Operations and Data Analysis. During Phase E, NRL project personnel will provide missions operations and data analysis and archiving support.

a. Support mission operations, data reduction, and data analysis activities at ISAS, NRL, and other Co-I facilities.

b. In conjunction with the UK and Japanese partners on the EIS team, NRL personnel will work at ISAS throughout the duration of the Solar-B mission to support mission operations and data analysis.

c. In proportion to its share of operational responsibility within the EIS team, NRL will provide workstations to support mission operations and data analysis at ISAS. Additional workstations and data archiving equipment for use at NRL will be supplied.

d. As part of the EIS team, NRL will participate in constructing observing timelines and the resulting instrument command loads to achieve the EIS scientific observations, monitor the health and safety of the instrument, and verify its performance.

e. Working with both the EIS team and the other instrument teams, NRL will participate in collaborative data reduction and analysis. Results will be presented at scientific meetings and published in appropriate scientific journals.

f. Prepare education and public outreach materials to communicate EIS results beyond the scientific community.

Table C-3. Phase D Deliverables and Schedule

Data Deliverables		
DRD No.	Document Title	Initial Submission Date and Frequency
874MA-002	Monthly Progress Report	Due no later than 15th of each month
874MA-003	Financial Management Report	Due no later than 10 working days after contractor's accounting month
Program Phase D Milestones		
Milestone		Delivery Date
Electrical Proto-Model Delivery		December 2000
Mechanical/Thermal Proto-Model Delivery		April 2001
Electrical GSE		June 2001
Mechanical GSE		March 2001
EIS Instruments Components for Flight Model Delivery		October 2002
EIS Instrument Flight Model for Integration to Spacecraft		August 2003
Launch		August 2004

C.2 Goddard Space Flight Center SOW. This SOW describes Goddard Space Flight Center's (GSFC) participation in the EUV Imaging Spectrometer (EIS) program, as proposed by the Naval Research Laboratory (NRL) E.O. Hulburt Center for Space Research (Space Science Division) submitted in response to NASA's AO 98-OSS-05.

C.2.1 Phase B—Preliminary Design. GSFC will support NRL's efforts to perform the preliminary design for the EIS Instrument Components. GSFC will help specify the multilayer coatings for EIS optical components, along with the necessary optical devices to apply the coatings; the spectrometer slit assembly; and will carry out an independent verification of all optical raytracing done at NRL.

C.2.2 Phase C/D—Implementation. GSFC will support NRL's efforts to develop and fabricate the EIS Instrument Components. Efforts under this activity include assisting in finalizing designs of the optical components; the fabrication of the slit wafer assembly; test and calibration support for the flight components; and software development for EIS observing programs.

C.2.3 Phase E—Mission Operations and Data Analysis. GSFC will support NRL's MO&DA efforts. This may include a SERTS rocket flight after launch for a calibration test at no cost to the EIS program. It also includes full participation in the EIS science mission by providing scientific expertise to plan EIS observing programs and participation in analysis of EIS data after launch.

C.2.4 Deliverables. GSFC will provide informal reports and publications in scientific journals.

D. Relevant Experience and Past Performance

D.1 Large Angle and Spectrometric COronagraph (LASCO). The LASCO instrument is one of 11 instruments included on the joint NASA/ESA SOHO (Solar and Heliospheric Observatory) spacecraft. SOHO was launched on 2 December 1995 at 0808 UT (0308 EST) from the Kennedy Space Center, Cape Canaveral, Florida. The LASCO instrument is a set of three coronagraphs that image the solar corona from 1.1 to 32 solar radii. It is convenient to measure distances in terms of solar radii. One solar radius is about 700,000 km, 420,000 miles or 16 arc minutes. A coronagraph is a telescope that is designed to block light coming from the solar disk, in order to see the extremely faint emission from the region around the sun, called the corona. The instrument has produced panoramic images of the solar corona from solar minimum through the rising phase of the solar cycle and continues to operate successfully.

❒ *Cost and Schedule Performance:* Final program value of $35M for the US hardware contribution.

❒ *Point of Contact:* Dr. Russell A. Howard, NRL Code 7660

D.2 Bragg Crystal Spectrometer (BCS). The BCS is one of the instruments that make up the scientific payload of the Yohkoh mission. The spectrometer employs four bent germanium crystals, views the whole sun and observes the resonance lines of Fe XXVI, Fe XXV, Ca XIX, and S XV with high resolving power and high sensitivity. It observes the 10 – 50 million degree plasmas generated in solar flares with high cadence. It is particularly suited for observing the impulsive phase of flares. The spectrometers measure the electron temperature, emission measure, nonthermal velocities, and bulk plasma flows in solar flares and active regions. The international consortium that built the BCS contains the same key groups responsible for the EIS spectrometer.

❒ *Cost and Schedule Performance:* This was a low cost program. The US contribution was supported by internal NRL science funds. The development phase was four years from initiation to launch. The instrument was delivered on schedule for an August 1990 launch. The MO&DA phase has been in operation for over eight years. Final US program value is about $3M.

❒ *Points of Contact:* Dr. G. A. Doschek, NRL Code 7670, US PI, Prof. J. L. Culhane, MSSL, UK PI.

D.3 Upper Atmosphere Research Satellite (UARS). The UARS platform (launched in 1991) provides simultaneous, coordinated measurements of atmospheric internal structure (trace constituents, physical dynamics, radiative emission, thermal structure, density) and measurements of the external influences acting upon the upper atmosphere (solar radiation, tropospheric conditions, electric fields). NRL provided and operates the Solar Ultraviolet Spectral Irradiance Monitor. The instrument has reliably measured the solar ultraviolet output of the sun with high precision and long term accuracy throughout the UARS mission.

❒ *Cost:* Final program value of $12M for the hardware contribution.

❒ *Points of Contact:* Dr. Dianne Prinz, NRL, Code 7668

D.4 Very high Angular resolution ULtraviolet Telescope (VAULT). VAULT is a new spectroscopic imaging instrument for the study of the very fine-scale structures of the solar atmosphere in the UV. VAULT can obtain images of the solar chromoshere with the unprecedented resolution of 0.25" (<200 km) in the Lyman α line (1216 Å). VAULT is flown as a sounding rocket payload. The first VAULT launch took place on May 7, 1999 at White Sands Missile Range.

❒ *Cost and Schedule Performance:* Final program value of $1.5M with a development period of four years.

❒ *Points of Contact:* Dr. C. M. Korendyke, NRL Code 7662K

D.5 Middle Atmosphere High Resolution Spectrometer Investigation (MAHRSI). MAHRSI is a high spectral resolution (0.018 nm) imaging spectrometer sensitive in the wavelength region from 190nm to 320 nm. MAHRSI's primary objective is to measure limb intensity profiles of the resonance fluorescent scattering of sunlight by hydroxyl (OH) in the altitude region from 38 to 90 km, and by Nitric Oxide (NO) in the region from 48 to 160 km. From these intensity profiles, global vertical density profiles of OH and NO with a vertical resolution of 2 km and a downtrack resolution of 8 - 12 degrees are inferred. By measuring Rayleigh scattering intensity profiles, the experiment also provides precise knowledge of the neutral density and temperature in the mesosphere. MAHRSI was designed and developed by the Upper Atmospheric Physics Branch UAP, within the Space Science Division of the U.S. Naval Research Laboratory (NRL). MAHRSI flew in November 1994 on the German Space Agency's Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere/Shuttle Pallet Atmosphere Satellite (CRISTA/SPAS), as part of NASA's flight of the Atmospheric Laboratory for Applications and Science ATLAS-3. The CRISTA/SPAS satellite was deployed from the Space Shuttle Atlantis STS-66 on November 4, 1994 for 8 days of free flight. During these 8 days the MAHRSI instrument observed latitudes from 53° S to 63° N, and acquired 80 orbits of OH profiles, composing nearly 5 global maps, and 24 orbits of NO profiles. MAHRSI flew again successfully on Space Shuttle Discovery STS-85 in August of 1997.

❐ *Cost and Schedule Performance:* MAHRSI completed two complex shuttle missions on schedule. The total value of the Mission was $15M.

❐ *Point of Contact:* Dr. R. Conway, PI, NRL Code 7641

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