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X-RAY BACKGROUND SURVEY SPECTROMETER (XBSS)

W. T. Sanders, Principal Investigator
R. J. Paulos, Program Manager

Space Science and Engineering Center
University of Wisconsin-Madison
1225 West Dayton Street
Madison, WI 53706

FINAL REPORT
NASA Contract NAS 8-38664

August 30, 1996

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1. Summary

The objective of this investigation was to perform a spectral survey of the low energy diffuse X-ray background using the X-ray Background Survey Spectrometer (XBSS) on board the Space Station Freedom (SSF). XBSS obtains spectra of the X-ray diffuse background in the 11–24 Å and 44–84 Å wavelength intervals over the entire sky with 15° spatial resolution. These X-rays are almost certainly from a very hot ($\approx 10^6$ K) component of the interstellar medium that is contained in regions occupying a large fraction of the interstellar volume near the Sun. Astrophysical plasmas near 10^6 K are rich in emission lines, and the relative strengths of these lines, besides providing information about the physical conditions of the emitting gas, also provide information about its history and heating mechanisms.

2. Background

The X-ray Background Survey Spectrometer (XBSS) was proposed in 14 November 1988 in response to NASA Announcement of Opportunity (AO) for Space Station Attached Payloads, AO OSSA 3-88, dated 22 July 1988. The AO was directed specifically to soliciting proposals for externally attached payloads that could operate productively during the assembly phase of the Space Station, with the first capability for mounting attached payloads to the Space Station expected to be available in 1995. Notification of selection was received on 29 June 1989, and negotiations were begun toward a contract for a definition study to establish the compatibility of XBSS with the Space Station and its schedules, the validity of the XBSS cost estimate, and the availability of Space Station facilities, and to prepare the necessary implementation phase management and technical plans. The selection was however termed a "partial selection," because the investigations selected oversubscribed the resources then planned to be available for Space Station Attached Payloads during the Space Station assembly phase.

A contract for $99,787 was negotiated with a start date of 13 June 1990 and an end date of 31 October 1990 for an investigation entitled "X-ray Background Survey Spectrometer" Definition Tasks. On 5 November 1990 Dr. L. A. Fisk, AA of OSSA, sent a letter informing us that OSSA must defer indefinitely its Space Station attached payloads program due to Space Station program budget reductions in FY 1991 and beyond. The XBSS contract end date was extended on 12 February 1991 to 30 September 1991 (Mod. 2). On 31 July 1991, Dr. Fisk sent a letter deselecting XBSS from any further study consideration for flight assignment effective 30 September 1991. The XBSS contract end date was extended on 10 December 1991 to 30 September 1992 (Mod. 3); on 16 July 1993 it was extended to 31 December 1993 (Mod. 4); and on 9 March 1994 it was extended to 30 June 1994.

3. Description of XBSS

XBSS consists of two large area Bragg X-ray spectrometers to cover the wavelength range 11 - 24 Å using thallium acid phthalate (TAP) Bragg crystals, and two similar spectrometers to cover the wavelength range 44 - 24 Å using lead stearate (PbSt) Bragg crystals. The spectrometers are of a novel design and have a very large area-solid angle product, so as to permit measurement of the wavelength spectrum of the soft diffuse cosmic background X-ray radiation with good spectral resolution. Each spectrometer consists of a curved panel of Bragg crystals mounted above a position-sensitive proportional counter. The spectrum is dispersed across the counter and all portions of the spectrum are measured at the same time. This eliminates the serious problem in conventional Bragg spectrometers of false spectral features being introduced by time-varying background. On the other hand, while all wavelengths are measured at the same time, the various wavelengths come from different directions in the sky. The spectrometers must therefore be rocked back and forth about an axis perpendicular to the dispersed direction. Spectral resolution is sufficient to resolve the more prominent lines for both the TAP and PbSt spectrometers. Spatial resolution is 15°.

Figure 1 illustrates the original concept of the XBSS payload mounted upon a NASA-supplied Attached Payload Accommodation Equipment (APAE), called a deck carrier, which was then mounted to the -Z (anti-earth) face of the Space Station main truss. The detectors scan perpendicular to the orbit plane. The ram baffle necessary to prevent residual atmospheric oxygen from hitting the crystal panels is not shown in this view. Figure 2 shows the XBSS payload field of view. The total field of view of the XBSS detectors is an arc on the sky 30° wide by 154° long. The detector pairs, facing in opposite directions, compliment X-ray wavelengths observed by each other from the same part of the sky. Figure 3 shows the XBSS payload layout on the deck carrier.

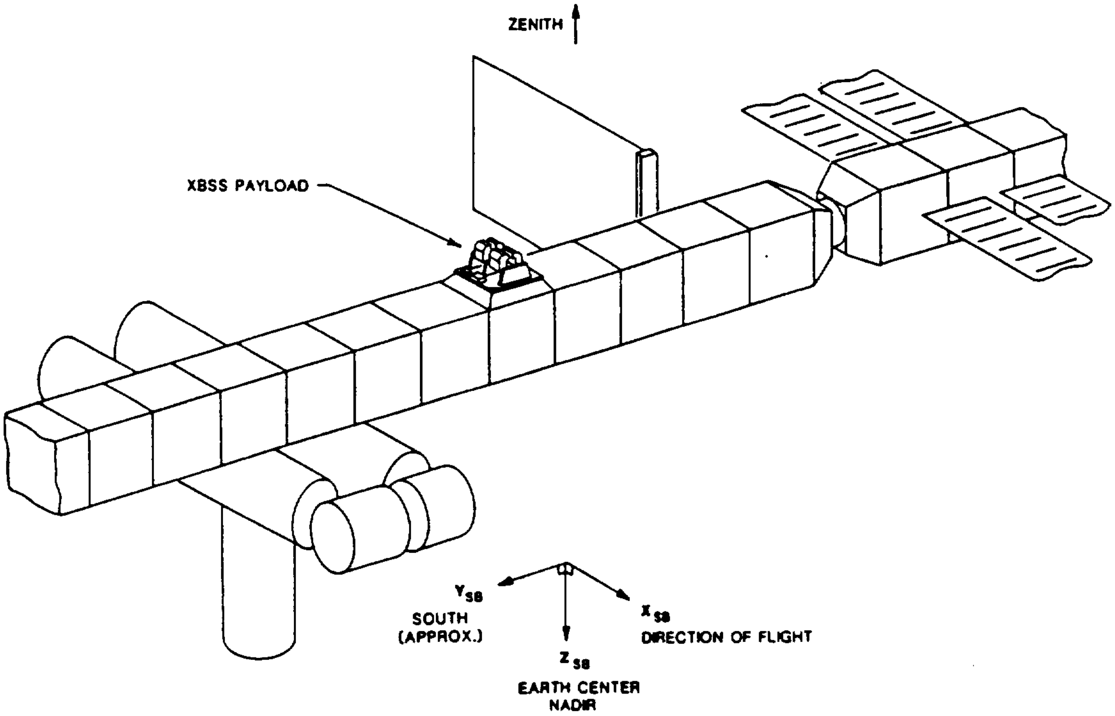


Figure 1 – XBSS Payload Mounted on Space Station Main Truss

Two spectrometer units (both with PbSt crystals) were built and flown in sounding rocket investigations, but were hampered by the very short observation times (less than 200 s each). The sounding rocket proportional counters were subsequently incorporated into Bragg spectrometers that flew on the Diffuse X-ray Spectrometer (DXS) attached Shuttle payload in January 1993 on the STS-54 mission. The DXS mission covered only the 44 - 84 Å wavelength region, and obtained only 60,000 s observing time, which provided coverage of ~ 5% of the sky. DXS consisted of two identical PbSt Bragg crystal spectrometer instruments that were mounted one on either side of the Shuttle cargo bay. Figure 4 shows the layout of one DXS instrument. Each instrument, Port and Starboard, had a detector assembly that employed a large area cylindrical array of PbSt Bragg crystals with a 2d spacing of 101 Å. This 2d spacing and the geometry of the detector constrain the instrument sensitivity to the 44 – 84 Å range. The XBSS PbSt spectrometers are intended to be the same units that flew on DXS, while the design of the TAP spectrometers must be modified somewhat because of the different crystals, the different 2d spacing and the different wavelength range covered.

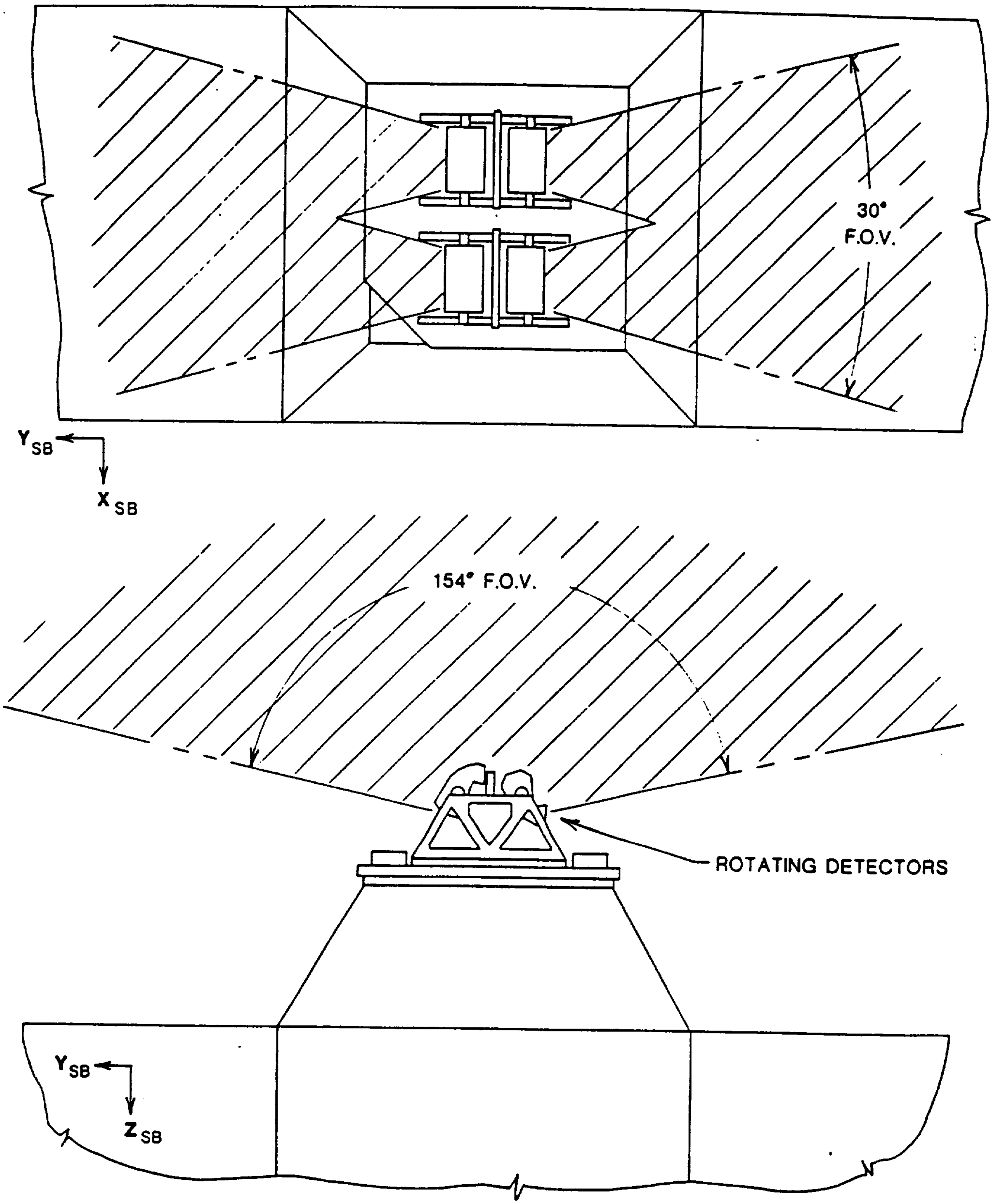
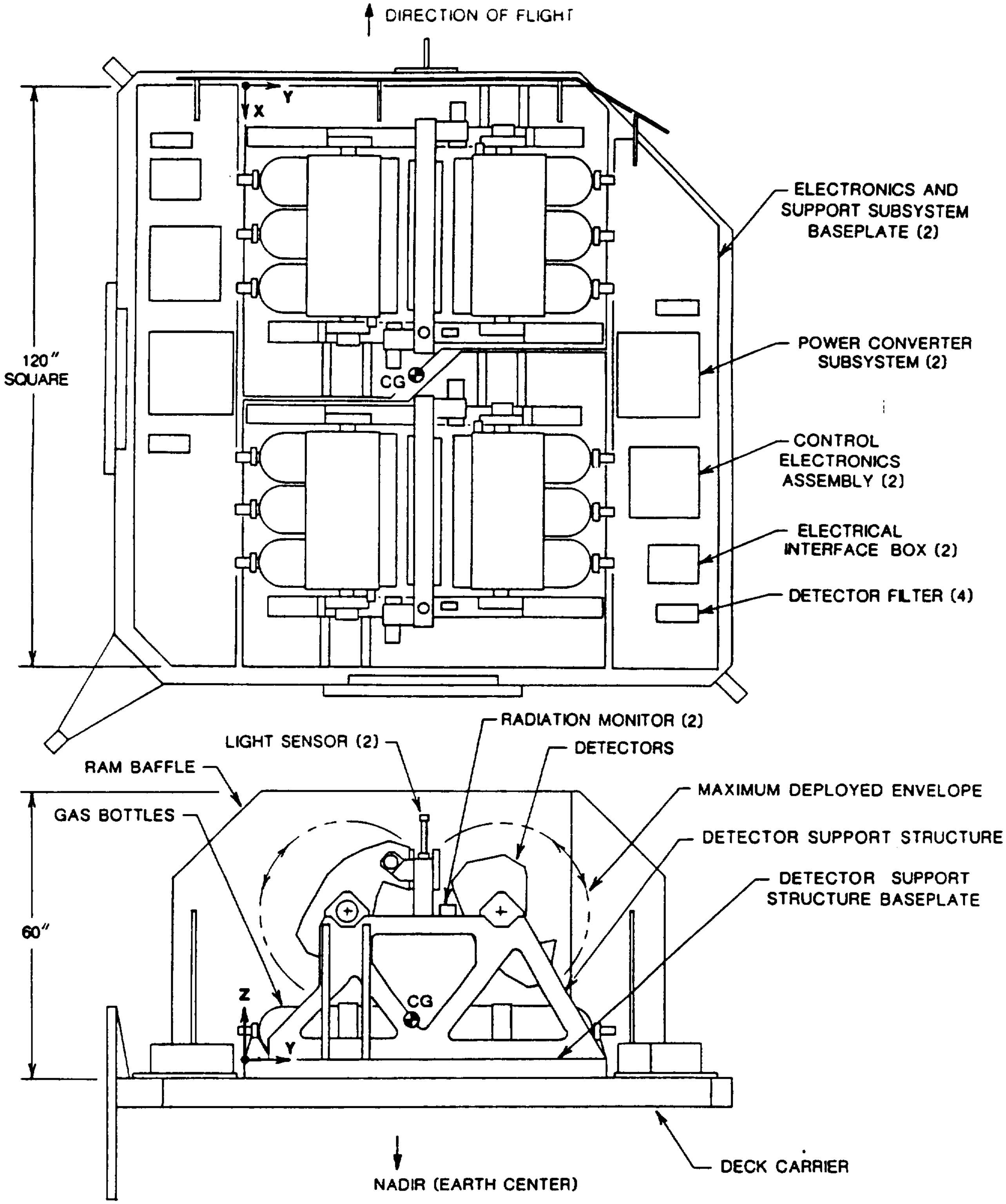


Figure 2 – XBSS Field of View



NOTE: CG-OFFSET MOMENT = 60,185 IN-LBS
AS MEASURED FROM THE CENTER OF THE DCI.

Figure 3 – XBSS Layout on Deck Carrier APAE

X-rays enter the XBSS detector assembly through an entrance aperture, are Bragg-reflected from the crystal panel, and pass through a collimator and thin window into a proportional counter that is position-sensitive in the dispersed direction. The curvature of the crystal panel assures that at any particular time, different regions of the proportional counter view different regions of the sky at different Bragg angles (i.e., they "see" different wavelengths). When collecting data, the detectors are scanned back and forth so that x-rays from each wavelength interval are collected from a 150° arc on the sky every two minutes. For the January 1993 DXS mission, that arc was along the galactic plane from galactic longitude 150° – 300°. The PbSt is destroyed by solar ultraviolet radiation and also by atmospheric oxygen atoms hitting it at the Shuttle orbital velocity. To counter these effects, XBSS is operated only during orbit night and must be oriented so that the atmospheric oxygen is blocked from hitting the crystal panel.

Magnets are mounted at the XBSS entrance aperture to reject low energy ($E < 20$ keV) electrons, because the pulses generated in the proportional counter by low energy electrons can mimic low energy x-ray events. The XBSS collimator restricts the field of view of any position on the proportional counter to a 15° x 15° (FWHM) sky resolution element. The collimator supports a 100 line-per-inch nickel mesh, which in turn supports the proportional counter thin window against the P-10 counting gas at a pressure of one atmosphere. Each counter has a large-area entrance window made of Formvar and the UV-absorbing agent, UV24, with a total mass thickness of about 90 μg cm^{-2}. The proportional counter has a front layer, where the x-rays of interest are absorbed, and a back-plus-side veto layer that is operated in anticoincidence with the front layer to reject counts that arise from penetrating particles (cosmic rays). Each layer contains anode wires at $\approx$ 1700 V. Between the two layers is a plane of wires that are at ground potential and oriented perpendicular to the plane of the x-ray trajectory. The distribution of induced electrical charges among these ground plane wires allows the determination of the position of the incident x-ray across the counter, the dispersion direction of the Bragg crystals. The spatial resolution of the proportional counter is about 0.5 mm, but the ~ 2 – 3 Å energy resolution of the spectrometer is determined by the 15° acceptance angles of the collimator. A more complete description of these instruments is found in Sanders et al. (1992).

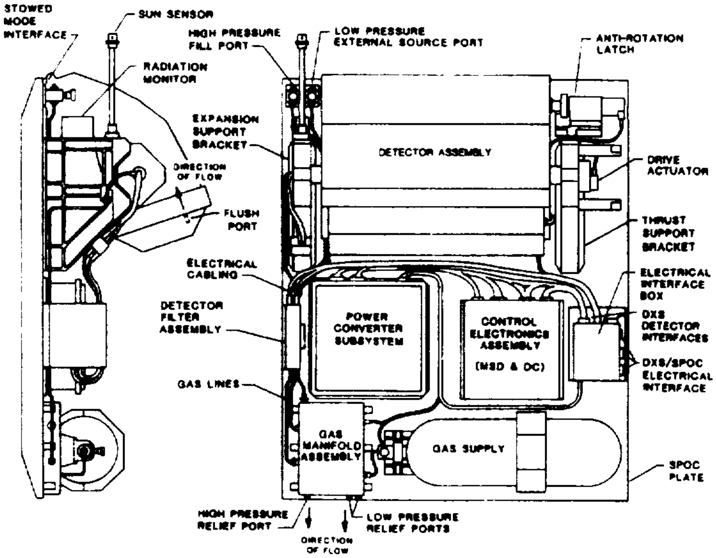


Figure 4. – Layout drawing of one DXS instrument

4. Early Definition Phase XBSS Tasks

The goal of the definition phase was to advance the design of XBSS.

During the first few months of "early definition phase," work was focused on the following tasks:

(1) refining the science objectives,
(2) defining the system data management plan and electrical ground support equipment and ground system requirements,
(3) advancing the TAP detector mechanical design,
(4) defining an approach for planning documents,
(5) developing the XBSS instrument performance specifications, and
(6) supporting a NASA Headquarters status review in the fall of 1990.

After the decision by the Office of Space Science to defer indefinitely its Space Station attached payloads program, the work of this contract was focused on defining the modifications of the initial XBSS plan, in which it was to be attached to SSF via the NASA-provided Attached Payloads Accommodations Equipment (APAE), to a design that allowed XBSS to be flown on the SSF by being mounted on the Japanese Experiment Module (JEM).

The furtherance of the science goals of XBSS was pursued by attendance at scientific meetings to present papers describing the importance of the XBSS measurements to our understanding of the physics of the interstellar medium.

After the flight of the DXS payload on the Shuttle in January 1993, additional modifications of the XBSS design were investigated, wherein the XBSS payload consisted of the two flight-qualified DXS instruments and their associated electronics.

4.1. XBSS Science Objectives

At x-ray energies in the band between 0.1 and 0.28 keV, there is a measurable and rather large intensity of diffuse x-rays in all directions. Nearly all of the detected diffuse x-ray flux in this energy band is of Galactic origin and most of it originates closer than ~ 100 pc. In some high latitude, low-neutral-matter directions (e.g., Draco, Ursa Major, Eridanus) ROSAT observations indicate that there is an additional contribution to the 1/4 keV x-ray diffuse background from the galactic halo. The fraction of the detected flux that is of halo origin is unclear, but is at most 50% in a few directions and is negligible over the large solid angle at low galactic latitudes. Halo emission contributes only a small fraction of the total x-ray background seen at this energy.

For the past two decades, the low energy x-ray diffuse background has been interpreted as thermal emission from a million-degree plasma in the interstellar medium. This interpretation prevailed because (a) candidate non-thermal mechanisms could be ruled out, (b) the shape of proportional counter pulse-height distributions of the detected x-rays was consistent with theoretical predictions of the emission from a million-degree plasma, and (c) there should be hot plasma in the interstellar medium deposited by supernovae. DXS observations indicate that the emission is indeed thermal, although even the relevant temperature is still uncertain.

4.1.1. The Hot Interstellar Medium and the Soft X-ray Background

The appearance of the soft X-ray background can be seen in the all-sky maps produced by several experiments (McCammon et al. 1983, Marshall and Clark 1984, Garmire et al. 1992, Snowden 1993, Snowden et al. 1995) in the C band or the 1/4 keV band. The post-ROSAT general picture is the following. The finite intensity of the soft X-ray background seen in the plane of the Galaxy requires that there be a "local" component, closer than the closest 10^{20} cm^{-2} of neutral material. The local ISM is known to be relatively empty out to 50 - 100 pc, so this local cavity is a natural place for the local X-ray background component to originate. In at least one direction (MBM 12, G154-34) the local component is known to originate closer than 65 pc from the Earth (Snowden, McCammon, and Verter 1993). Some directions, generally at high galactic latitudes, are brighter than other directions, generally at low galactic latitudes, because the local emission component extends farther *out* of the galactic plane than it does *in* the galactic plane, and because there is a galactic halo emission component that provides up to 50% of the total in some high latitude directions. There are other interstellar cavities (e. g., Orion/Eridanus, Monoceros/Gemini, Scorpius/Centaurus) that also contain soft X-ray emitting regions that are seen from Earth. Sanders (1995) presents schematic diagrams of some major features of the local interstellar medium relevant to the emission of the soft X-ray background.

4.1.2. Previous Spectral Observations of the Hot ISM

Before the flight of DXS, the only spectral information about the diffuse background was obtained from the distribution of pulse heights recorded by proportional counter detectors. The observations with the best spectral resolution were those of Inoue et al. (1979), who used a gas scintillation proportional counter. These pulse height distributions were typically found to be consistent with the X-ray spectrum predicted to be emitted by a plasma in collisional ionization equilibrium with normal cosmic abundances at a temperature near 10^6 K, plus or minus about 30%, independent of the particular plasma model that was used. In addition to the detailed pulse height distributions, the ratios of counting rates from one pulse height band to another also were consistent with million degree plasma. Since no viable non-thermal mechanisms could be identified, and since supernovae were perfectly acceptable thermal mechanisms, the "standard" interpretation became that the source of the low energy X-ray diffuse background was a 10^6 K collisional plasma in the interstellar medium.

4.1.3. Results from the Diffuse X-ray Spectrometer

DXS obtained spectra of the diffuse background with 2 - 3 Å spectral resolution over the 83 - 44 Å range. The field of view was mechanically collimated to 15°, and it scanned an arc along the galactic plane that covered the longitude range 150° - 300°. Thus, it obtained spectra from the local hot bubble component of the diffuse x-ray background, but not from the halo component. The DXS scan path covered well-known features of the diffuse x-ray sky, such as the Monoceros-Gemini enhancement, which is possibly a fossil supernova remnant, and the Vela supernova remnant, as well as more "typical" unenhanced regions along the galactic plane in Auriga, Puppis, and Crux. Figure 5 shows the spectrum DXS obtained from the Puppis region, longitudes 213° - 252°. The solid line shows the data, with one sigma error bars, while the dotted line shows the best fit single temperature Raymond & Smith model. The best-fit temperature is 1.16 x 10^6 K, with an emission measure of $n_e^2 d = 0.0026$ cm^{-6} pc. These are reasonable values, roughly the same as those found by previous experiments (McCammon and Sanders 1990), but in detail the fit is not acceptable. Most noticeable is the 61 Å - 75 Å region, where the data exceed the model substantially. Also quite apparent are the region near 76 Å, where the Mg VIII line of the model does not stand out in the data, and the 54 - 55 Å region, where the Si IX and S IX lines of the model are not prominent in the data.

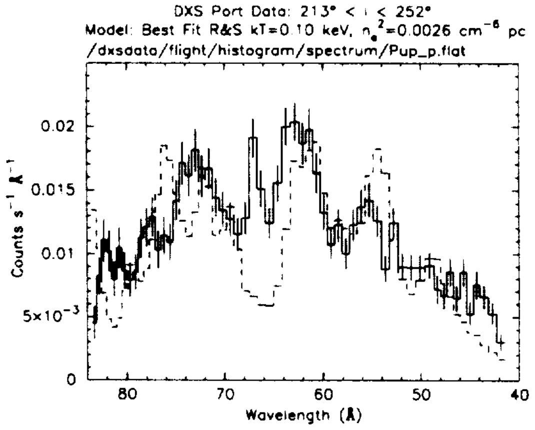


Figure 5 – DXS spectrum from Puppis (solid line) and best-fit single temperature coronal plasma model from Raymond & Smith (dashed line).

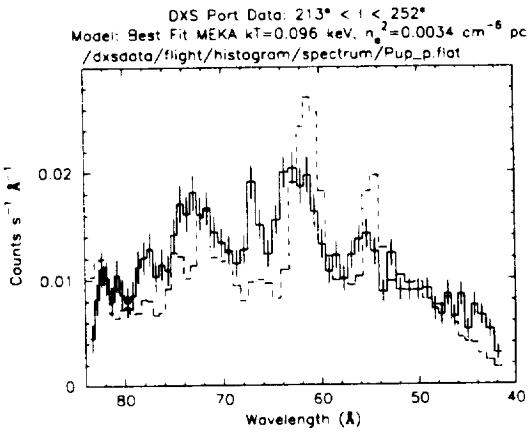


Figure 6 – Best-fit single-temperature Mewe & Kaastra model (dashed line) compared to the DXS data (solid line)

In Figure 6, the solid line shows the same spectrum obtained from the Puppis region, while the dotted line shows the best fit single temperature Mewe & Kaastra model. The best-fit temperature is 1.14 x 10^6 K, with an emission measure of n_e^2d = 0.0034 cm^{-6} pc. These are again reasonable values, but the fit again is not acceptable. Most noticeable is that in the 63 – 79 Å regime the data exceed the model, but it is not as discrepant in the 64 – 68 Å regime as the RS model is. Also apparent are the region near 61 – 62 Å, where the Si VIII line of the model strongly exceeds the data, and the region near 55 Å, where the Si IX line of the model strongly exceeds the data. Note that this is the same Si IX line that Raymond & Smith have at 54.5 Å and that Liedahl has at 55.5 Å (see Figure 3).

Two-temperature fits were examined, and looked promising with one temperature near one million degrees and the other near 2.5 x 10^6 K, but the required emission measure of the higher temperature component over-produced X-rays in the 0.5 - 1 keV range by a factor of 5. Various NEI models were also examined, blast wave and cooling plasmas, as well as depleted abundance plasmas, but all without success. Abandoning fits with the standard models, we next tried the approach of fitting the spectra of individual ions, with the goal of setting upper limits on the column density of individual ions. In doing this however, we discovered that there are significant differences between the synthetic spectra generated by the Raymond & Smith code versus those generated by the Mewe & Kaastra code. When the differences between the synthetic spectra generated by the RS code and those generated by the Mewe & Kaastra code became apparent, it was unclear which code to use. D. A. Liedahl of Lawrence Livermore National Laboratories, using the HULLAC atomic physics package, recently calculated improved atomic data for selected ions of Si and S and Mg, and from these obtained the emission spectra of those ions at a temperature, kT = 100 eV, appropriate for the DXS data analysis. Spectra of selected ions of iron at kT = 200 eV were also calculated.

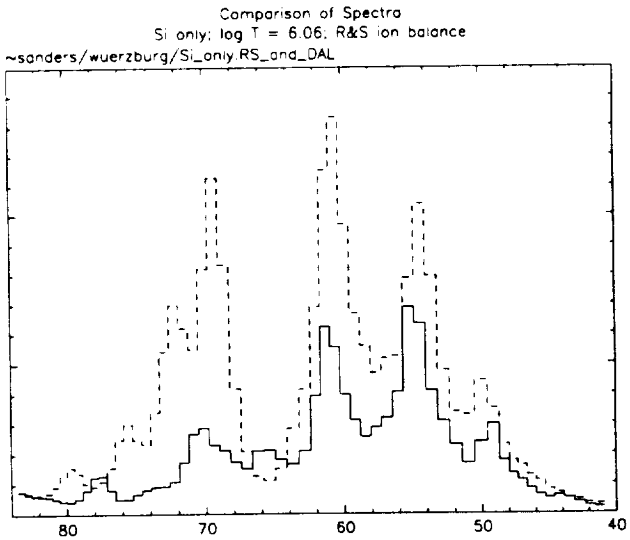


Figure 7 – Si spectrum at log T = 6.06 calculated using RS model (dashed line) and a Si spectrum at log T = 6.06 calculated using HULLAC (solid line)(arbitrary normalization).

In Figure 7, the dashed line shows the spectrum of Si at kT = 100 eV (T = 1.16 x 10^6 K) calculated from the RS code, folded through the DXS response function, and plotted with an arbitrary normalization. The solid line shows the spectrum of Si at kT = 100 eV, obtained from the individual ion spectra calculated by HULLAC and the ionization balance calculated by the RS code, folded through the DXS response function and plotted with an arbitrary normalization. The shapes of these two spectra are significantly different - enough so that future work must incorporate the HULLAC results.

Currently 18 ionic spectra (Mg VII – X; Si VII – XII; S VII – X; Fe XIII – XVI) have been calculated at one temperature each (kT = 200 eV for Fe; kT = 100 eV for the others) using HULLAC. We anticipate that the spectra of the above ions, and possibly a few others, at a number of temperatures in the range of interest will be calculated soon. In the meantime, we have tried fitting the DXS Puppis and also the Monoceros-Gemini data using only the 18 single temperature ionic spectra that we have. The reduced chi-squares are still too large to consider these acceptable fits, but large improvements over the plasma code models are already apparent. We think that we will be able to make significant progress in fitting the DXS spectra after the results of additional calculations using HULLAC become available.

4.1.4. Refined XBSS Science Objectives

The XBSS science team formulated a refined statement of the XBSS science objectives: *The XBSS science objective is to use the information contained in the emission lines in the 11-84 Å wavelength range of the spectrum of the x-ray background to determine the properties of the hot interstellar gas and its role in the dynamics and evolution of the Galaxy.* The method of achieving this objective is by obtaining spectra of the X-ray diffuse background in the 11 –24 Å and 44 – 84 Å wavelength intervals over the entire sky with 15° angular resolution. For the version of XBSS studied after the DXS flight, the objective was achieved by obtaining spectra of the X-ray background in only the 44 – 84 Å range over the entire sky with 15° angular resolution.

4.2. Define Electrical Ground Support System

Preliminary work was accomplished regarding the system data management plan and electrical ground support equipment (EGSE) and ground systems requirements. This task began in the early definition phase and was expected to continue into the main definition period.

4.3. Advance the Design of the TAP Detector

The TAP detector design was advanced to the layout stage. Figures 8 shows the TAP detector layout and Figure 9 shows the sectional view A-A from Figure 8. Fundamental concepts for crystal mounting and the stowed mode interface were evaluated and integrated into the detector layout. Figure 10 shows the TAP detector aperture sealing (stowed mode interface) concept, and Figure 11 shows the crystal mounting scheme. Work on this task was expected to continue into the main definition period.

4.4. Define Approach for Planning Documents

Work was begun on defining a preliminary description of the approach for satisfying reporting in the areas of Performance Assurance, Configuration Management, and Experiment Checkout Equipment. A preliminary plan has been generated that includes our approach for all of these areas. This plan is attached to the end of this report as Attachment A.

4.5. Develop the XBSS Instrument Performance Specification

Preliminary work was begun on developing an instrument performance specification. This specification was to include the major XBSS subassemblies and was to be consistent with the measurement requirements stated in the XBSS science objectives. A preliminary instrument performance specification was to be generated during the main definition phase, based in part on work performed on this task during the early definition phase. This preliminary instrument performance specification was not generated because the XBSS project was not extended to the main definition phase, and because the XBSS platform concept changed during the course of the early definition phase from that of a Deck Carrier APAE mounted on the main Space Station truss, to using the Exposed Facilities of the Japanese Experiment Module (JEM-EF), to using the Unpressurized Berthing Adapter (UBA) attached to the Station truss.

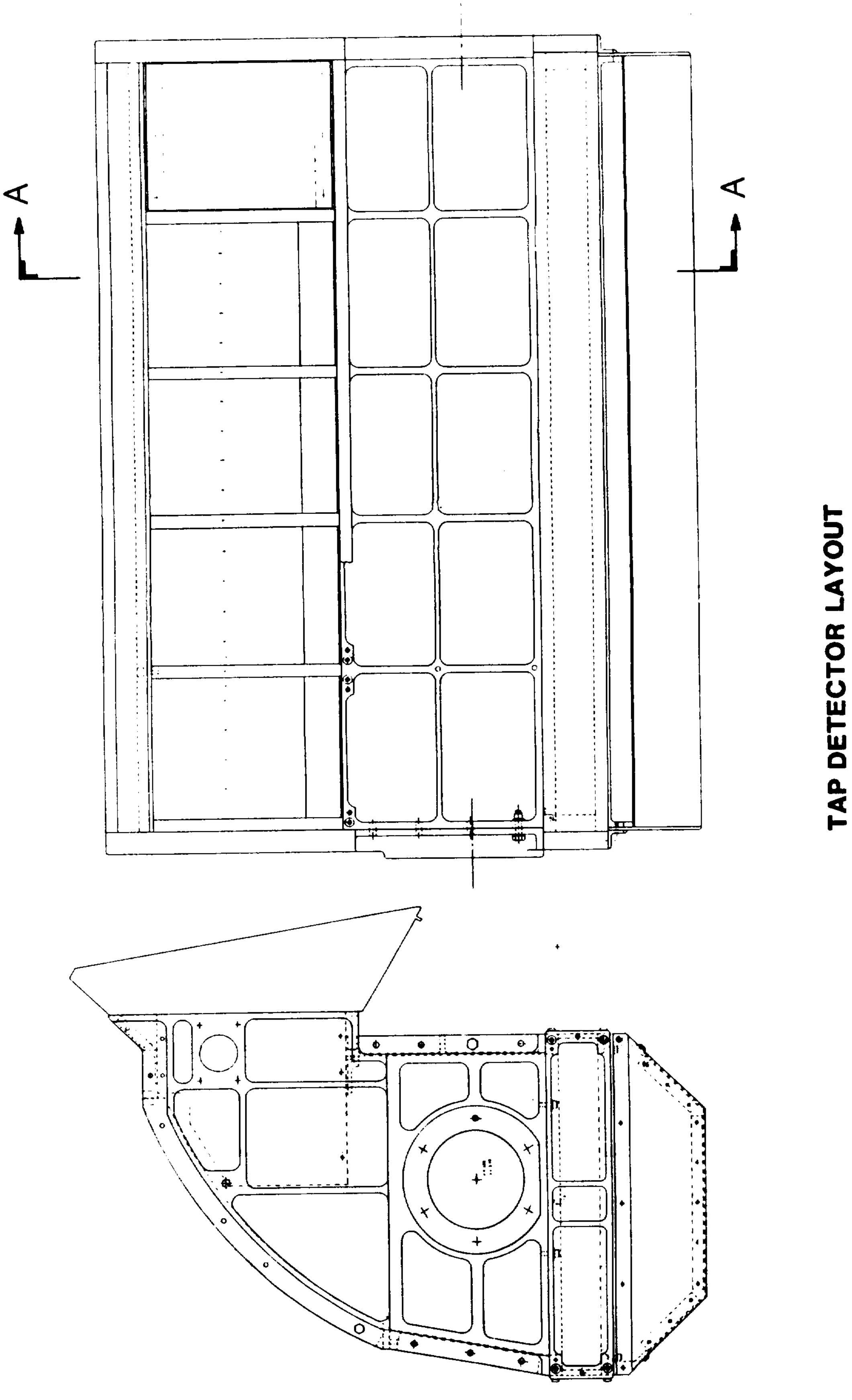


Figure 8 – XBSS TAP Detector Layout

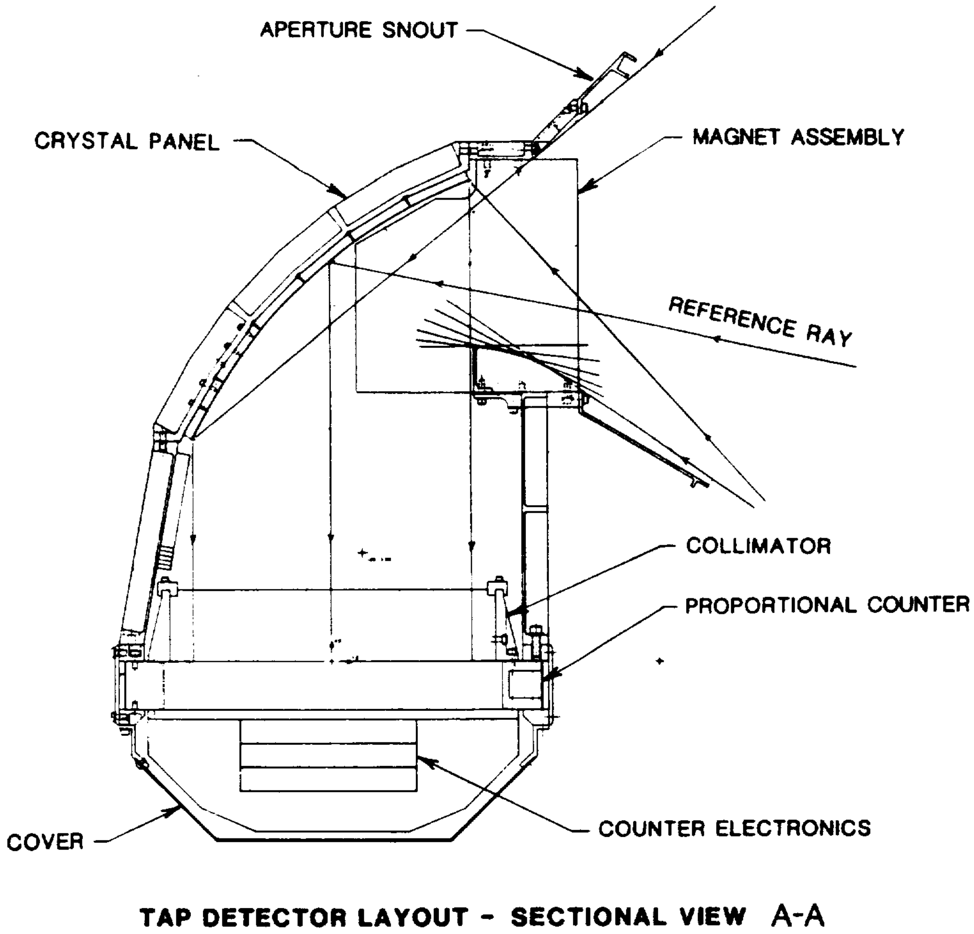


Figure 9 – XBSS TAP Detector Layout - Sectional View A-A

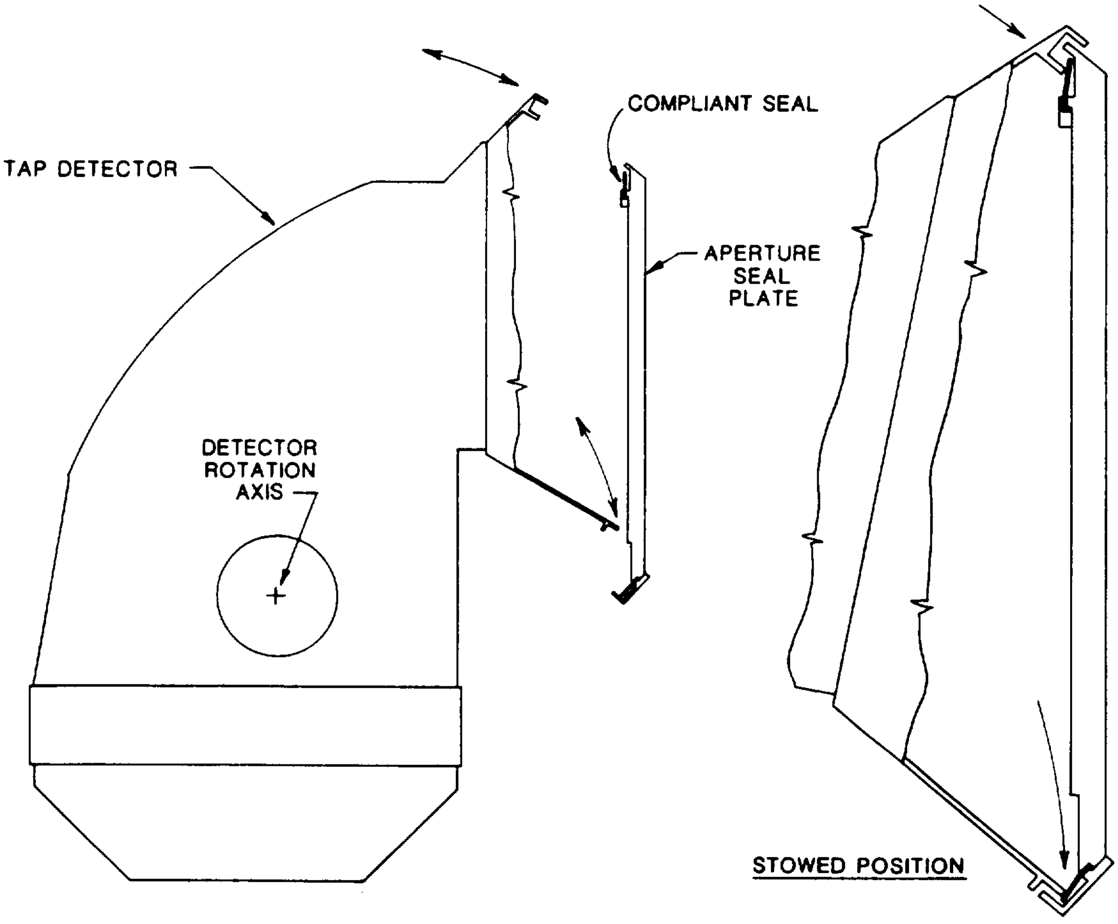


Figure 10 – XBSS TAP Detector Aperture Sealing Concept (Stowed Mode Interface)

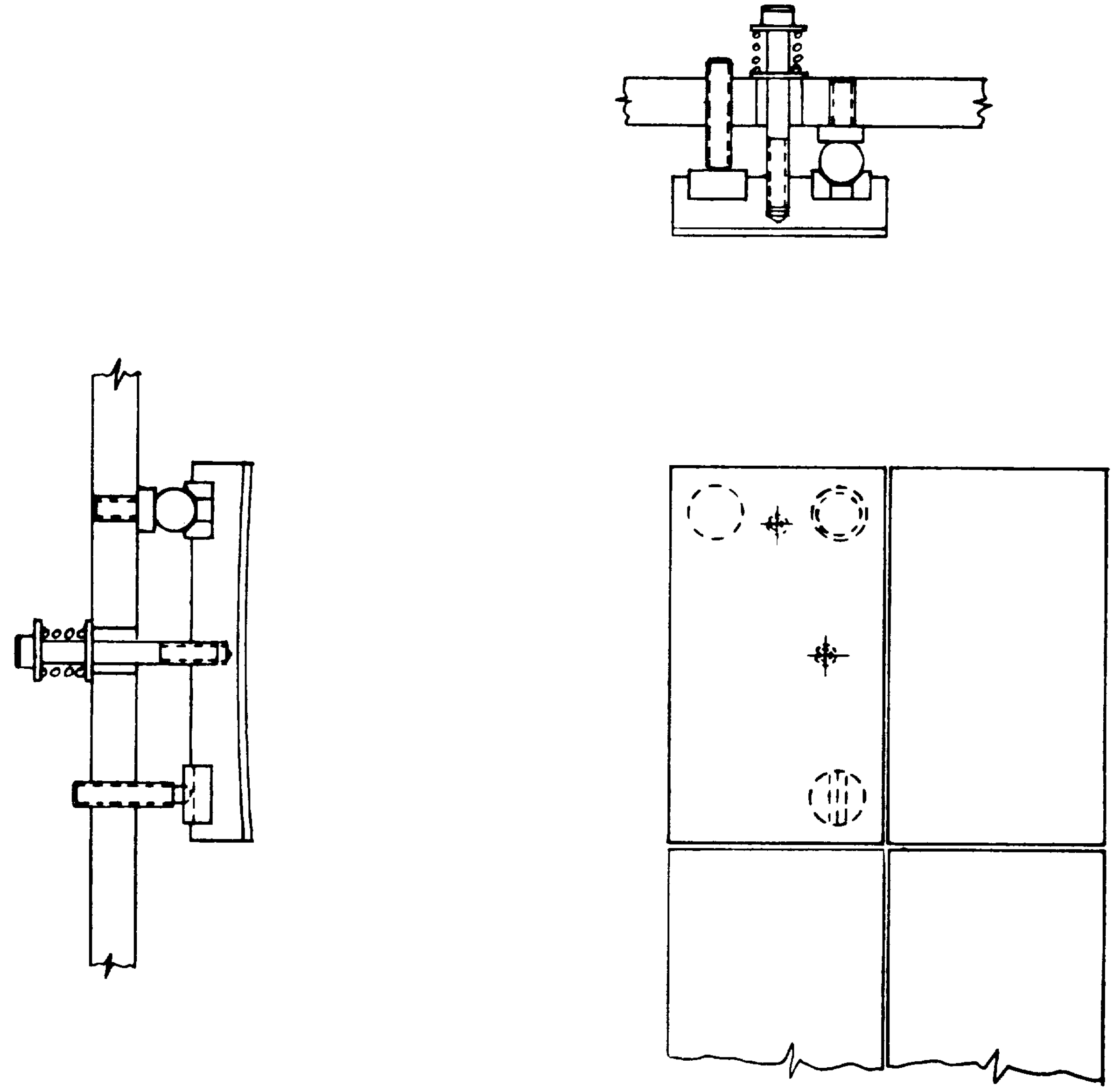


Figure 11 – XBSS TAP Detector Crystal Mounting Concept

4.6. NASA Headquarters Status Review

A NASA Headquarters status review had been anticipated for September 1990, but was not held. An XBSS Headquarters briefing was made on November 20, 1990, not by members of the University of Wisconsin XBSS science team, but by our MSFC technical officer with input from the UW science team. Headquarters was pleased that we still had resources remaining to pursue the XBSS science goals, and confirmed that additional funds ($300,000 for FY91; $300,000 for FY92) were no longer available for the main XBSS definition phase.

4.7. Modifications of XBSS Design to Allow Mounting on JEM

Earlier work in reducing the XBSS footprint on the Deck Carrier (from the original 100 ft^2 to 60 ft^2 easily and to 50 ft^2 with some effort) was utilized in defining XBSS configurations for possible flight on the Space Station Japanese Experiment Module Exposed Facility (JEM-EF).

The originally proposed XBSS was as an Attached Payload ("AP configuration") mounted on NASA-supplied Attached Payload Accommodation Equipment (APAE) mounted on the truss assembly of the transverse boom of the Space Station. In the original AP configuration, all four spectrometers are mounted on one platform; they have independent gas supplies but share some electronics. The XBSS JEM-EF configurations make use of one, two, three or four of the payload Equipment Exchange Unit (EEU) positions on the JEM-EF. Each individual payload consists of one spectrometer with its own gas bottles and its support electronics. Each payload is totally independent of the other XBSS payloads. The XBSS JEM-EF Configuration #1 attempts to repeat the results of the AP configuration. It requires a smaller spectrometer than the AP configuration in order to fit inside the payload envelope, but the spectrometer field of view scans the sky in the same way relative to the Space Station. Four such payloads with no obstructions of their fields of view would provide sky exposure similar to the AP configuration, although reduced because of their smaller size. The XBSS JEM-EF Configuration #2 keeps the spectrometer the same size as that of the AP configuration, but the direction of the scan is *in* the orbit plane. This reduces the amount of the sky from which spectra can be obtained, but increases the quality of the spectra obtained. In this configuration, good spectra may be collected without mechanically rotating the spectrometer; the orbital motion of the Station accomplishes the rotation. Other configurations are possible, but these were considered most likely to achieve the XBSS science goals, and these were the alternatives presented at the 12th Space Station Utilization Workshop in Japan, 29-30 January 1991. A copy of the presentation is attached to this report as Attachment B.

4.8. Scientific Presentations

The furtherance of the science goals of XBSS was pursued by attendance at scientific meetings to present papers describing the importance of high spectral resolution measurements of the low energy X-ray background to our understanding of the physics of the interstellar medium. Presentations were made at the XIth Moriond Astrophysics Meeting in Les Arcs, Savoy, France during the week of 10-17 March 1991 (Sanders et al 1991, Attachment C), and at a Workshop on the X-ray Background held in Laredo, Spain 11-13 September 1991 (Sanders & Edgar 1992, Attachment D).

4.9. Reduced XBSS Design - Reflight of DXS Instruments

After the flight of the DXS payload on the Shuttle in January 1993, additional modifications of the XBSS design were investigated, wherein the XBSS payload consisted of the two flight-qualified DXS PbSt instruments and their associated electronics. We were told that NASA was restoring one node on the Space Station truss for attached payloads using the Unpressurized Berthing Adapter (UBA) and an entirely new electrical signal interface. Attachment E contains 4 presentation charts that give the experiment overview, a drawing of the two-detector layout on a plate, the general experiment requirements, and the experiment status.

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Attachment A

Preliminary XBSS Performance Assurance Plan

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Preliminary XBSS Performance Assurance Plan

1. Introduction

The University of Wisconsin Space Science and Engineering Center (SSEC) has developed a performance assurance program that has successfully supported several spaceflight instrument programs for many years. The overall approach has been to develop a program to assure the reliability, quality, and mission success of the flight instrument while meeting all contractual requirements in the simplest and most straightforward manner possible. Forms, procedures, documents and other tools of the program are designed to be simple, understandable, and easy to use. The program is also designed to function in an environment where there are multiple spaceflight programs in various phases of their development operating with shared personnel simultaneously. It is therefore advantageous to use, insofar as possible, the same methods and procedures for all programs to minimize confusion and maintain simplicity and clarity. It is our intent to apply existing performance assurance methods to XBSS as much as possible. The present SSEC performance assurance program for spaceflight instruments is based on the program developed for the Orbiting Solar Observatory 8 Soft X-Ray Instrument which has evolved and was used on the Pioneer Venus Net Flux Radiometer, the Hubble Space Telescope High Speed Photometer, the Diffuse X-Ray Spectrometer, the Galileo Net Flux Radiometer, and other programs.

2. General Performance Assurance

The University of Wisconsin Space Science and Engineering Center's performance assurance program covers quality assurance, reliability, configuration management, and safety. It has been designed to be responsive to the NASA NHB series of requirements documents to the extent appropriate for small spaceflight instrument development programs. The fundamental purpose of the performance assurance program is to assure the instrument meets or exceeds its mission objectives and that all contractual requirements are met.

2.1 Organization

The performance assurance manager has overall responsibility for the implementation of the performance assurance program. The performance assurance manager will be the designated performance assurance representative for the XBSS program. All performance assurance, quality assurance, and configuration management personnel report to the performance assurance manager. The performance assurance manager reports directly to the Executive Director of the Space Science and Engineering Center thus giving the performance assurance program an independent reporting channel to Center management.

2.2 Performance Assurance Plan

This preliminary performance assurance plan, submitted as part of the final report, will be revised and updated as needed over the life of the program. All performance assurance functions unless otherwise noted are performed at the University of Wisconsin Space Science and Engineering Center. Some test equipment calibration activities, material non destructive testing, environmental testing, and procurement quality activities are performed at outside facilities under our direction. A fundamental feature of the performance assurance program is that it is an integral part of the total program, not a separate activity. While there are some features that are in the nature of an audit function, most are basic to the design, fabrication, and test process. For example, the choice of materials for the instrument structure is heavily dependent on performance assurance considerations. It is important that the performance assurance functions be planned and scheduled with the related program activities so that the program is properly supported.

2.3 Status and Facility Reviews

Performance assurance program reviews are a standard part of all internal and contract required program status and design reviews. From time to time separate reviews will be held as needed. It may be necessary to schedule a review for a particular topic or problem in order to agree on a resolution plan. The NASA technical officer will be promptly notified of all such reviews.

2.4 NASA Participation in Inspections and Tests

NASA will be have the opportunity to participate in all inspections, tests, audits, surveys, and other performance assurance activities at University of Wisconsin facilities and those of contractors and suppliers. Because it is a policy of the University that there is no classified activity, there are no difficulties for reasons of security. Contractors and suppliers will be required to provide access to University of Wisconsin, US government source inspection, and NASA personnel. Any exceptions must be agreed upon by both the University of Wisconsin and NASA. NASA will be notified of all activities of interest in a timely manner to facilitate NASA planning and logistics.

2.5 Performance Assurance Progress Reporting

The progress of the performance assurance program is included in the normal periodic program progress reports. The performance assurance section highlights problems, concerns, resolutions, required and pending actions, and the status of the various performance assurance activities. Lists of performance assurance submissions (parts, materials, process lists, non conformance reports, waiver requests, test procedures, etc.) are included for tracking purposes.

3. Quality Assurance

The quality assurance program is designed to assure the flight hardware, software, ground support equipment, and documentation meets all requirements and that mission performance will be as intended. The quality assurance program is based on the requirements of the NASA NHB series of documents.

3.1 Mandatory Inspection Points (MIPs)

All fabrication and assembly is planned and documented on a manufacturing record (MR). The manufacturing record is numbered with the prefix "MR" followed by the drawing number of the assembly drawing of the item being fabricated. All fabrication steps are detailed including inspection points for University of Wisconsin, customer, and government inspectors. For each step, the applicable drawing number (procedure if a process) and revision level is noted. The person who performs the step signs and dates the MR when the step is completed. Inspection points are included and are signed and dated when completed. Mandatory inspection points are clearly denoted. The manufacturing flow is clearly shown on the MR. A copy of the MR, called the "traveler" accompanies each item through the various steps. At the lowest assembly level, the first step is usually parts kitting. A "unit history configuration record" records the part traceability information required (part numbers, manufacturers, lot numbers, screening lot numbers, serial numbers if parts are serialized). The status of each in process item is therefore always clear by inspection of the traveler Travelers are attached to travelers of the next higher assembly and so forth through the building of larger subsystems. The final top level unit documentation package includes the documentation for the included subassemblies. The final step in the manufacturing is the acceptance tests and inspection.

3.2 Test Witnessing

Test procedures are prepared for each test, from in-process tests (such as test select procedures) to final qualification and acceptance tests. The test procedure includes test data sheets to make clear the information required. If witnessing is required, it is noted on the manufacturing record for that test. NASA will be notified in advance of each test. Test procedures will be provided for review in advance.

3.3 Logbooks and Manufacturing & Assembly Records

Subsystem and subassembly records are completely contained in their manufacturing records, travelers, unit history configuration records, and test data sheets as described above. Once the subsystem has completed acceptance or qualification testing, subsequent operations are documented in the instrument level logbook which begins with integration of the various subsystems. The integration operations, tests, operators, problems, references to non conformance reports, failure reports, and references to related documentation are recorded in the logbook.

3.4 Materials, Processes, Selection, and Control

All materials used in the flight instrument must be reviewed, approved, and incorporated in the instrument approved materials list. The factors to be considered in selection of materials include (but are not limited to): suitability for use in the intended application, history of use in spaceflight hardware, outgassing properties, stress corrosion properties, strength, production variability of key parameters, magnetic properties, hazard aspects (both in the material itself and in operations performed on it), and contractual requirements.

For outgassing properties, the first level screening criteria are the standard total mass loss of less than 1% and condensed volatile condensable materials less than 0.1% in the standard test. However, it is important to note that the temperature profile of the mission must be carefully considered to assure that conditions encountered in flight are not more severe than the standard outgassing screening test. The amount of material used is also an important consideration because large amount of material meeting the outgassing criteria may produce more contamination than a small amount of material exceeding the criteria. NASA Reference Publication 1124 is used as a guide for initial selection of materials for outgassing properties.

Stress corrosion selection is based on MSFC-SPEC-522B. All materials used are from Table I. No Table III materials are used.

Metallic machined parts to be used in structural or safety critical applications are subjected to non destructive testing (dye penetrant inspection) to assure there are no cracks greater than the specified acceptable size. Non-metallic machined parts are given a 1x visual inspection for cracks.

Procedures are required for all manufacturing processes involving multiple steps or needing special process controls to assure the resulting item meets requirements. The step, required controls, and inspections are detailed in the procedure. These procedures are available for review by NASA.

All materials and processes used in the flight instrument will be listed in the Materials and Processes List. The list will indicate approval status. The first issue of the list will be included in the Instrument Baseline Design Review. The list will be updated as needed and at each project design review.

3.5 Cleanliness Control

XBSS is not particularly sensitive to contamination, either particulate or condensed volatile materials. The driving contamination requirement is therefore the need not to be a source of contamination. Particulate contamination is a concern in the assembly of thin windows to counters. Besides the selection of materials for low outgassing properties, minimizing to the extent possible the use of outgassing materials, and containing materials subject to outgassing, the contamination control program is designed to keep the instrument clean as early as possible in the fabrication and assembly phase.

All parts will be carefully cleaned to remove manufacturing contamination (oils, chips) before being assembled into the instrument. When the basic structure has been assembled, it will be cleaned and baked out to removed volatile materials. Later assembly and test operations will be performed in the University of Wisconsin Space Science and Engineering Center clean room.

The SSEC clean room is located on the fifth floor of the Space Science and Engineering Center. It is a 10 by 30 foot room having a positive pressure HEPA filtered non-laminar flow air supply. There are several class 100 laminar flow work benches in the room. Access to the clean room is strictly limited to those with a need to be inside. Large windows provide a vantage point for personnel needed for test witnessing or casual observers. All personnel entering the room must be trained in the proper procedures for clean room operations including garments required for entry. Garment required are a one piece coverall, hood, beard cover, knee length booties, and gloves. Garments are regularly cleaned by a certified clean room laundry. Equipment not absolutely needed in the clean room, such as EGSE, is kept outside and connected through ducts from a nearby room. Communication from test equipment operators to the clean room is via headset.

3.6 Non-Conformance Control

Whenever any item fails to meet requirements either in inspection, test, or at any other time an anomalous condition is noted, a non-conformance report is initiated. The form is in three parts and is based on the non conformance control system requirements of the NHB series of documents.

The first part describes the non-conformance. The non-conforming item name, part number, serial number is noted. The description of the non-conformance and the governing requirement document number and paragraph is noted. The top portion is signed and dated by the individual reporting the non-conformance.

The second part of the form is filled out by quality assurance. The QA disposition is noted. The possible dispositions are: return for rework or completion (used when standard procedures will correct the non conformance as in the case of a skipped step, for example, a connection not soldered), scrap, return to vendor, or submit to Material Review Board (MRB). The performance assurance manager signs and dates the second part of the form.

The third part of the form is used to record the MRB disposition. The possible dispositions are rework, repair, return to vendor, scrap, use as is, and request customer approval. For rework, the item can be brought into conformance using standard procedures. For repair, the item can be made functional through non-standard procedures but there may be some evidence of a non standard procedure at the end. In both cases, the steps are detailed in the MRB disposition. The item may also be scrapped or returned to the vendor by the MRB. If the non conformance is judged to be minor, the MRB may decide to use as is. If the non conformance affects interface or ICD requirements, or can be considered major, the MRB is submitted to the customer for approval with a recommendation from the MRB.

All non conforming material is segregated from other material and kept in bonded stores pending disposition.

3.7 Software Quality Assurance

Software design requirements documents are written for all elements of flight application software and firmware code. Those requirements are reviewed in a manner similar to hardware specifications and requirements documents. Software code is written in modular form using good computer science design practice. Revisions to software are controlled and documented such that changes are identified and the revision level used for any test activity is documented. Software configuration management is implemented by SCCS (Source Code Control System).

3.8 Reliability

A Failure Modes, Effects, and Criticality Analysis (FMECA) will be performed and included with the baseline design review. The FMECA will be updated as needed and presented at each program review.

3.9 Component Quality Assurance

Parts are selected from the GSFC preferred parts list, MIL-STD-975, and other NASA flight program lists. If a part is needed that is not on a preferred list, a non standard parts approval request will be submitted stating the need for the part, the reliability status of the requested part, and the plan to qualify it for the flight instrument. Parts will be selected that will withstand the radiation environment requirements of the mission.

All parts used in the flight instrument will be listed on the Declared Component List which will include the part name and number, manufacturer, specification, and screening requirements.

All flight parts are inspected upon receipt, sent for screening if required, and kept in bonded stores segregated from non flight parts until needed for assembly.

A database file of GIDEP alerts is kept up to date so that parts can be checked against any outstanding alerts. As new alerts are received, the flight parts database is checked to see if the alert is applicable to any parts in the inventory or any already assembled into flight hardware.

4. Configuration Management and Control

The configuration management system has been designed to assure that all elements of the program are properly and completely documented and that there is a one to one correspondence between the item and the documentation. The configuration management and control system has been developed and used for several space flight instrument programs over many years. It is designed to be simple, effective, reliable, and common to all flight programs at SSEC.

4.1 Configuration Management

The major features of the configuration management system are as follows:

All drawings and documents are named according to a standard convention which includes the name of the program, the name of the item, and the kind of drawing. Each drawing is assigned an eight digit identification number. The first four digits identify the program and the next four are assigned in sequence. Each drawing must include information indicating where it is in the hierarchy ("used on" and materials lists).

Before formal release, the originator need only assure that the drawing have a proper name and number and that the program drawing list accurately indicate the date of the latest version. All copies of such drawings must be stamped "Preliminary - Information Only".

Release of a drawing requires signatures of both program management and performance assurance in addition to the originator. Distribution of released drawings is by a controlled list. All copies are stamped "Controlled Drawing - Copy number ____" and are numbered. One time copies may be issued but are stamped "Uncontrolled Copy".

Revisions of released drawings are done only by Engineering Change Notice which are reviewed and approved by the program manager and performance assurance before the drawing is revised and reissued.

All program documentation is listed on the program "Drawing List" which is updated and issued as needed.

Deviation and waiver requests arising either from the drawing revision process or the non-conformance disposition process, including material review board actions, are reviewed by the program manager and the performance assurance manager before submittal to the customer.

4.2 Configuration Baselines

Configuration baselines are established at the performance and interface levels at the instrument design reviews. Baselines at lower levels are established when documentation is put under control and released. Configuration identification lists are maintained throughout the program so that the configuration of the instrument and all subsystems is known at all times. The configuration is reported at all design reviews and whenever there are significant changes.

4.3 Contractor and Supplier Configuration Management

Requirements for supplier configuration management are included in procurement documents and enforced so that procured items will have the same information as items produced in house.

4.4 Acceptance Review, Acceptance Data Package

Before each delivery, a review is held to assure the configuration of the as built equipment is as indicated in the documentation, the test and inspections are complete and satisfactory, all paperwork has been satisfactorily dispositioned, and that any non-flight items are properly documented. In addition, plans for subsequent handling and testing are reviewed to assure readiness to ship.

5. Checkout Equipment

The XBSS checkout equipment, sometimes referred to as GSE (ground support equipment) or EGSE (electronic ground support equipment) or MGSE (mechanical ground support equipment) shall be designed, built, tested, and maintained in accordance with the provisions of the XBSS Performance Assurance Plan. The plan will specifically address what provisions apply to the checkout equipment. In general, configuration management, safety, and other provisions that affect the integrity of the XBSS flight instrument or safety of personnel apply to the checkout equipment. Since it is readily repairable, the grade of parts used need not be as high as those used in the flight instrument. Reliability of the checkout equipment is important and is considered in the design and logistics such that overall program cost is kept as low as possible.

Attachment B

Presentation at the 12th Space Station Utilization Workshop in Japan

Tokyo, Japan
29-30 January 1991

THE
X-RAY BACKGROUND
SURVEY SPECTROMETER EXPERIMENT
(XBSS)

W. T. Sanders
R. J. Edgar
University of Wisconsin
Madison, Wisconsin
USA

12th Space Station Utilization Workshop in Japan

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29-30 January 1991

ABSTRACT

The X-Ray Background Survey Spectrometer (XBSS) experiment was selected for definition phase study as an attached payload for the Space Station Freedom. In this presentation, the proposed XBSS configuration is presented, as well as several alternative configurations suitable for attachment to the JEM-EF.

XBSS Science Overview

• X-ray Astronomy	Study x-rays emitted by the Sun, stars, supernova remnants, hot interstellar gas, galaxies, quasars, etc.
• X-ray Background	Between the localized sources of x-rays, the x-ray sky has a diffuse background glow in all directions.
• Low Energy X-ray Background	The low energy diffuse background x-rays, wavelengths 12-120 Å, come from "nearby" interstellar space, the region of our Galaxy closer to us than a few hundred light years.
• Spectrometer	The low energy x-ray diffuse background intensity is known for the whole sky, but detailed spectra are lacking. Models predict the x-ray spectrum to contain numerous emission lines in the 12-120 Å wavelength range of the spectrum. From the intensities and wavelengths of the lines in the spectrum, we can learn about the emitting gas: its temperature, ionization states, elemental abundances, the history of the gas, etc.
• Survey	XBSS can obtain spectra in the 11-84 Å wavelength range (See Figure 1) from the whole sky, with 15° x 15° resolution, in ≈ 9 months on SSF.
• Science Objective	To use the information contained in the emission lines in the 11-84 Å wavelength range to determine the properties of the hot interstellar gas and its role in the dynamics and evolution of the Galaxy.

XBSS Spectrometer Description

- The XBSS experiment consists of a set of four Bragg crystal spectrometers.

- Each spectrometer has a large-area cylindrically-curved Bragg crystal panel that reflects the entering x-rays into the detector, a position-sensitive collimated proportional counter. (See Figure 2)

- The Bragg crystal layer spacings are selected so that two of the spectrometers are sensitive to 42 - 84 Å x-rays and two of them are sensitive to 11-24 Å x-rays.

- Due to the properties of Bragg reflection and the geometry of the spectrometer, each segment of the proportional counter receives only x-rays of a particular wavelength.

- At any time, the different wavelength x-rays arriving at the detector came from different directions of the sky within the spectrometer field of view.

- To obtain a complete spectrum from any one direction of the sky, the spectrometers must be rotated about an axis parallel to the center of curvature of the crystal panel.

- The proportional counter collimators are 15° x 15° , its window is ≈90 μg cm^{-2} Formvar, and the gas is P-10 (90% argon; 10% methane) at 1 atmosphere pressure. The gas is supplied to each proportional counter from three high pressure (3000 psi) bottles.

Possible XBSS Configurations

- The originally proposed XBSS was as an Attached Payload ("AP configuration") mounted on NASA-supplied Attached Payload Accommodation Equipment (APAE) mounted on the truss assembly of the transverse boom of the Space Station Freedom. See Figures 3, 4 and 5 for the layout and field of view.

- In the original AP configuration, all four spectrometers are mounted on one platform; they have independent gas supplies but share some electronics.

- The XBSS JEM-EF configurations make use of one, two, three or four of the payload EEU positions on the EF (See Figure 6). Each individual payload consists of one spectrometer with its gas bottles and its support electronics. Each payload is totally independent of the other XBSS payloads.

- The XBSS JEM-EF Configuration #1 (Figure 7) attempts to repeat the results of the AP configuration. It must have a smaller spectrometer than the AP configuration to fit inside the payload envelope, but the spectrometer field of view scans the sky in the same way. Four such payloads with no obstructions of their fields of view would provide sky exposure similar to the AP configuration, although reduced because of their smaller size.

- The XBSS JEM-EF Configuration #2 (Figure 8) keeps the spectrometer the same size as that of the AP configuration, but the direction of the scan is in the orbit plane. This reduces the amount of the sky from which spectra can be obtained, but increases the quality of the spectra obtained. In this configuration, good spectra may be collected without mechanically rotating the spectrometer; the orbital motion of the Station accomplishes the rotation.

- Many other variations are possible, but if there are serious problems with either of these, please inform me.

XBSS Special Considerations

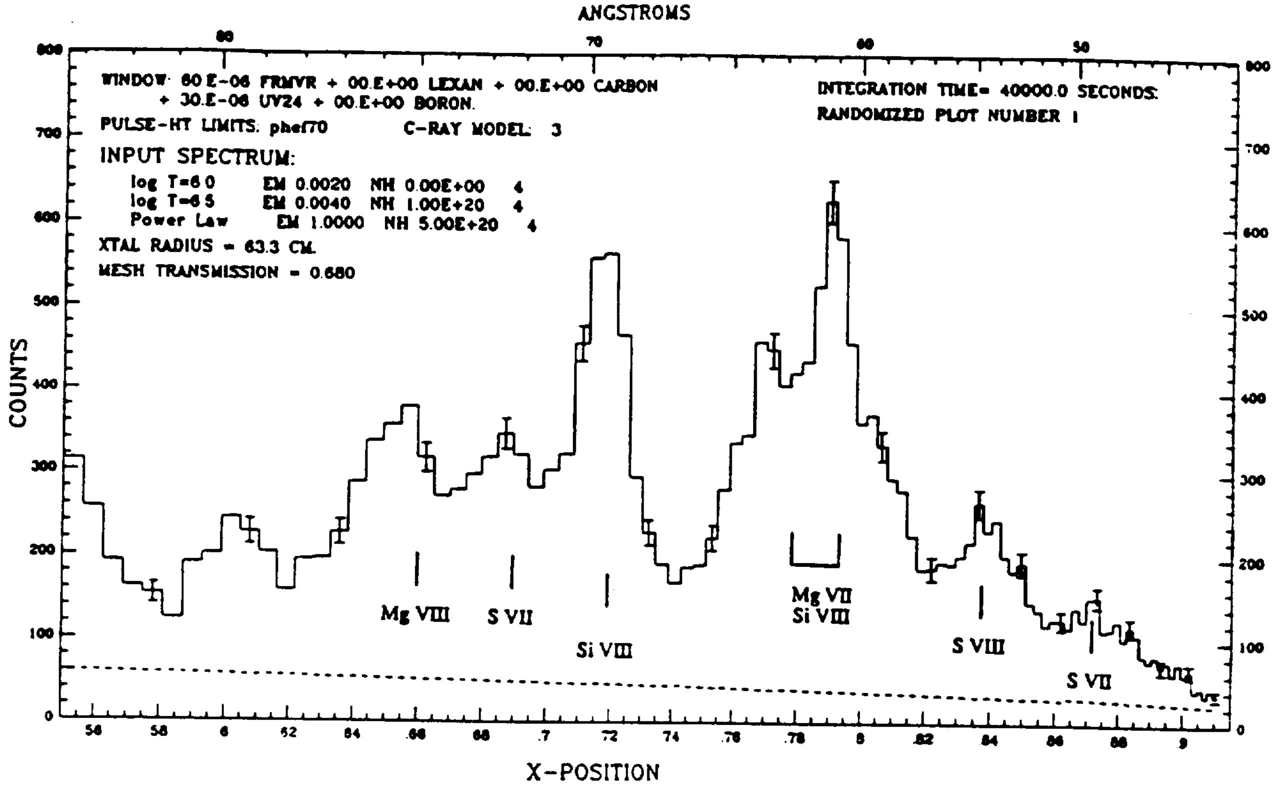
- Solar UV radiation destroys the XBSS crystals, so the spectrometers are sealed in the daytime part of the orbit; data is collected only at night.
- Atmospheric atomic oxygen "ram" destroys the XBSS crystals, so observations must be not be towards the direction of flight and "ram" shields are probably needed.
- Space Station elements in the XBSS field of view obscure the view of the sky and scatter atomic oxygen onto the crystal panel, so the field of view must be selected to avoid other SSF elements. This may constrain the positions where the XBSS payloads can be mounted; it may require additional XBSS shields; or XBSS may have to reduce its scan angles.
- Molecular contaminants may coat the crystals and reduce their efficiency, so the spectrometers must be sealed when there is a likelihood of contaminants being present.

XBSS Status

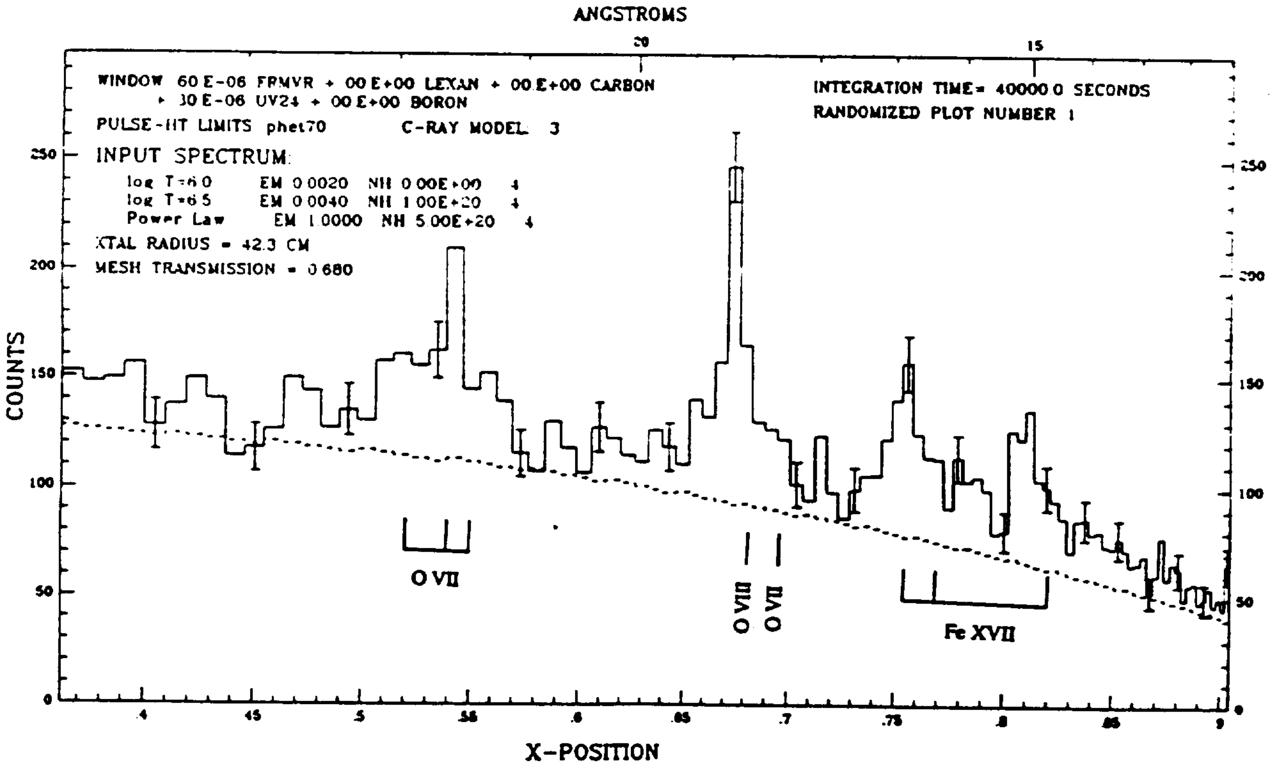
- XBSS design is very similar to that of the Diffuse X-ray Spectrometer (DXS) experiment - an attached Shuttle payload manifested for August 1992.
- DXS is built, calibrated and tested (vibration, EMI, thermal vacuum)

Questions

- What are constraints on the mass and the mass moment for JEM-EF payloads? One XBSS payload currently has mass ≈ 250 kg. Is this too large?
- What are constraints on power for JEM-EF payloads? One XBSS payload currently requires ≈200 Watts. Is this too large?
- What are telemetry constraints for JEM-EF payloads? One XBSS payload requires ≈100 kbps downlink and less than 1 kbps uplink. Are these too large?
- Is the payload envelope absolute at all times, or may it be violated under some circumstances? If so, what are the circumstances?
- How are the payloads attached to the ELM-ES during launch? Have the details been established?
- What is the current status of the PIU?
- What errors have we made concerning JEM-EF?



PbSt model spectrum. Time = 40,000 s; log T_1 = 6.0; log T_2 = 6.5; solar abundances.



TAP model spectrum. Time = 40,000 s; log T_1 = 6.0; log T_2 = 6.5; solar abundances.

Figure 1. - An example of the predicted data that XBSS would return, assuming one particular model spectrum of the low energy diffuse x-ray background.

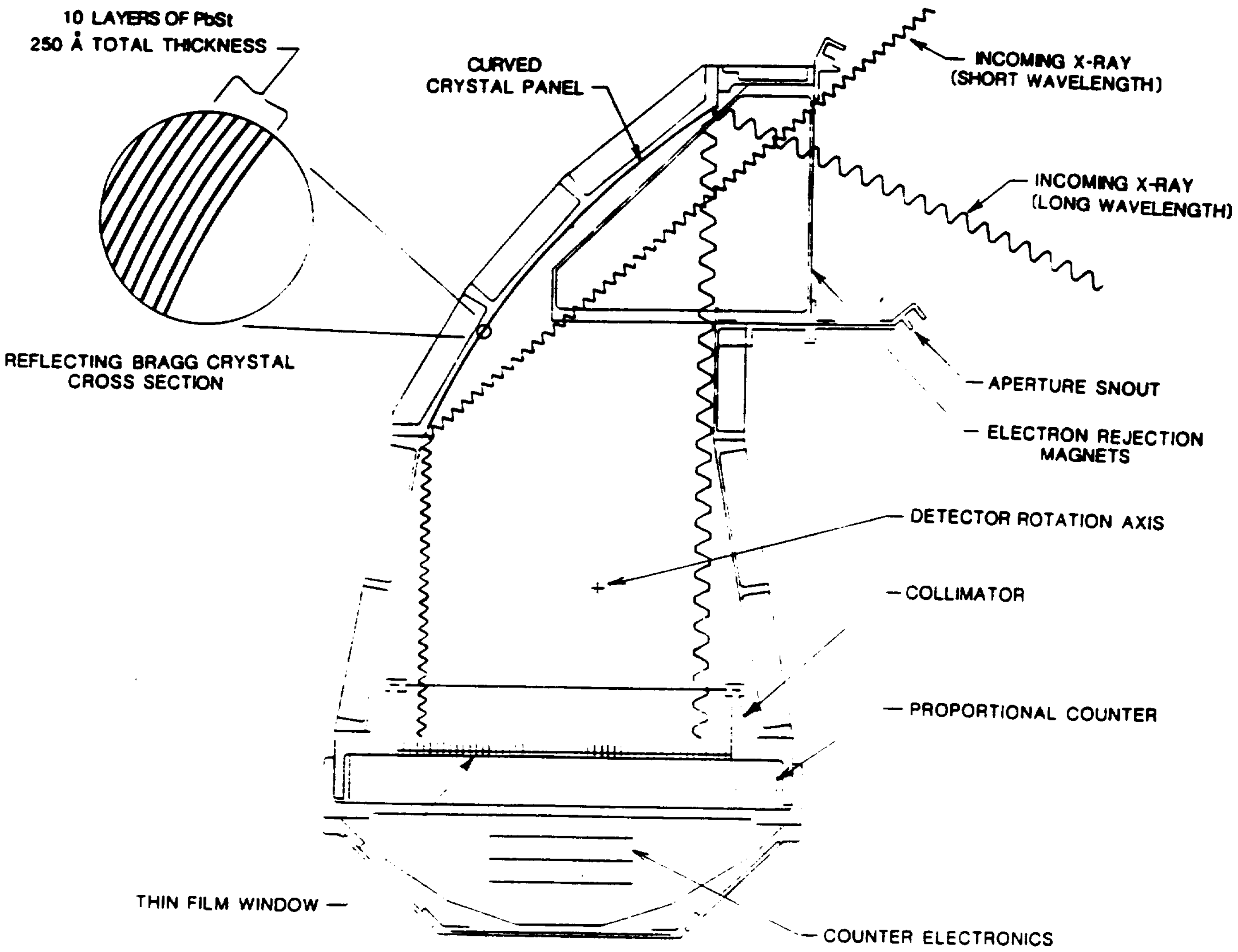


Figure 2.- As x-rays enter the opening of a long wavelength (42-84 Å) XBSS spectrometer, they strike the curved Bragg surface which is made up of approximately 200 layers of lead stearate. The alternating thin and thick layers serve as a grating that reflects the x-rays, at the same angle as the angle of incidence, into the proportional counter. Since short wavelength x-rays are Bragg-reflected at small angles only, they always enter the proportional counter at the crystal panel (back) side. Conversely, long wavelength x-rays are reflected at large angles only and must enter the proportional counter at the opposite (front) side.

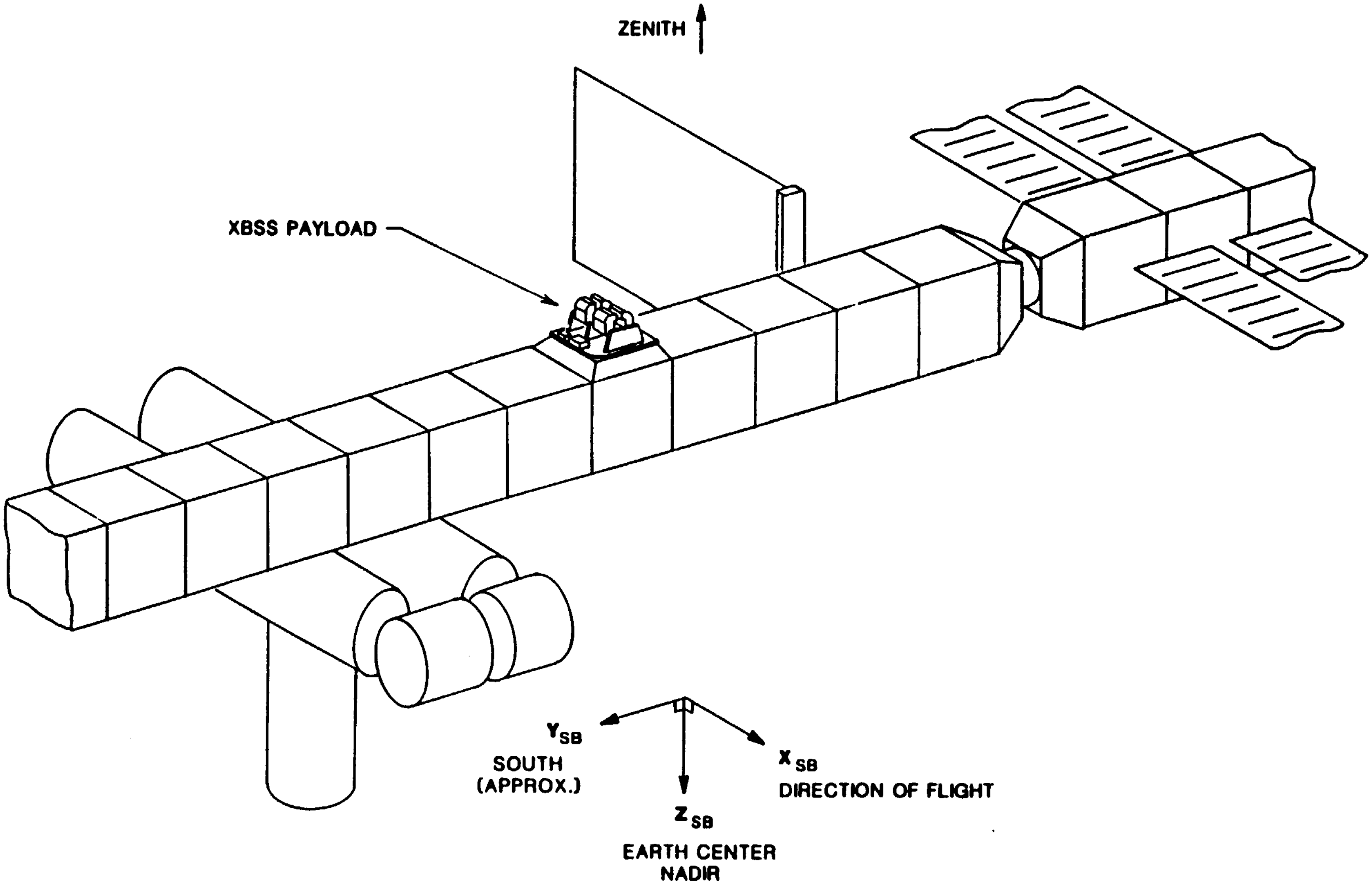


Figure 3.- The XBSS experiment on the Space Station Freedom (SSF) as a USA "Attached Payload."

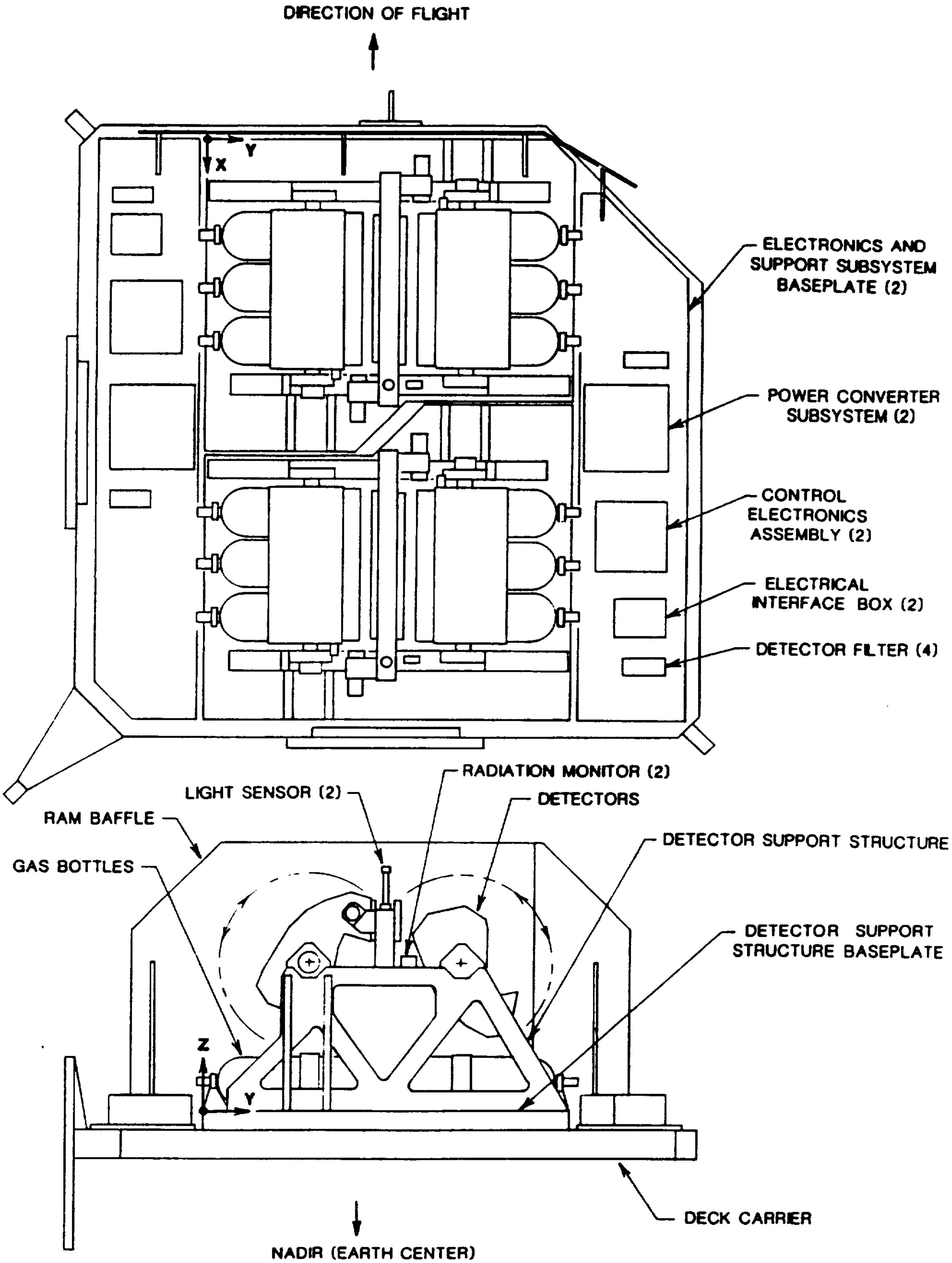


Figure 4.- The XBSS layout on a "Deck Carrier" APAE in the "Attached Payload" configuration.

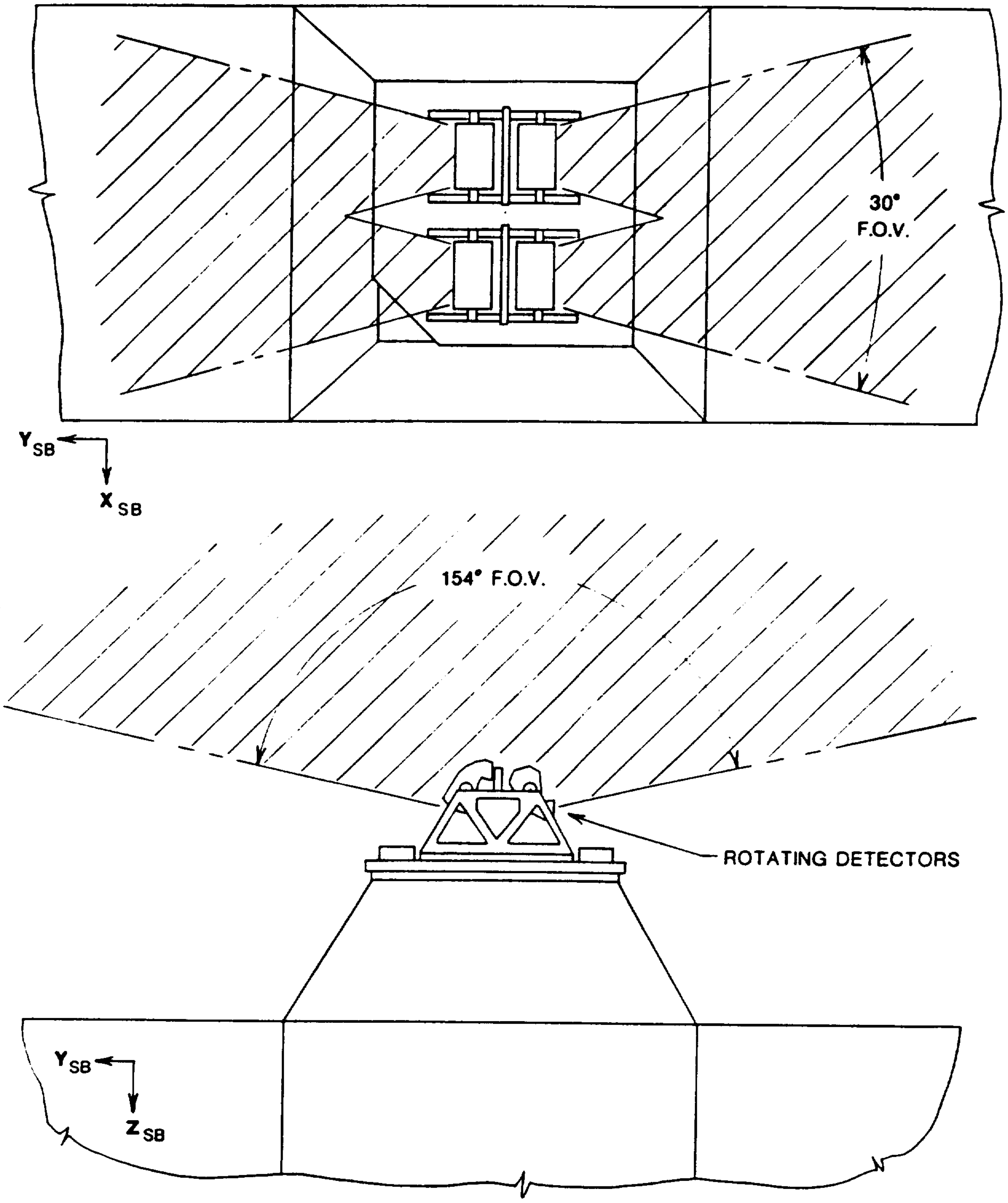
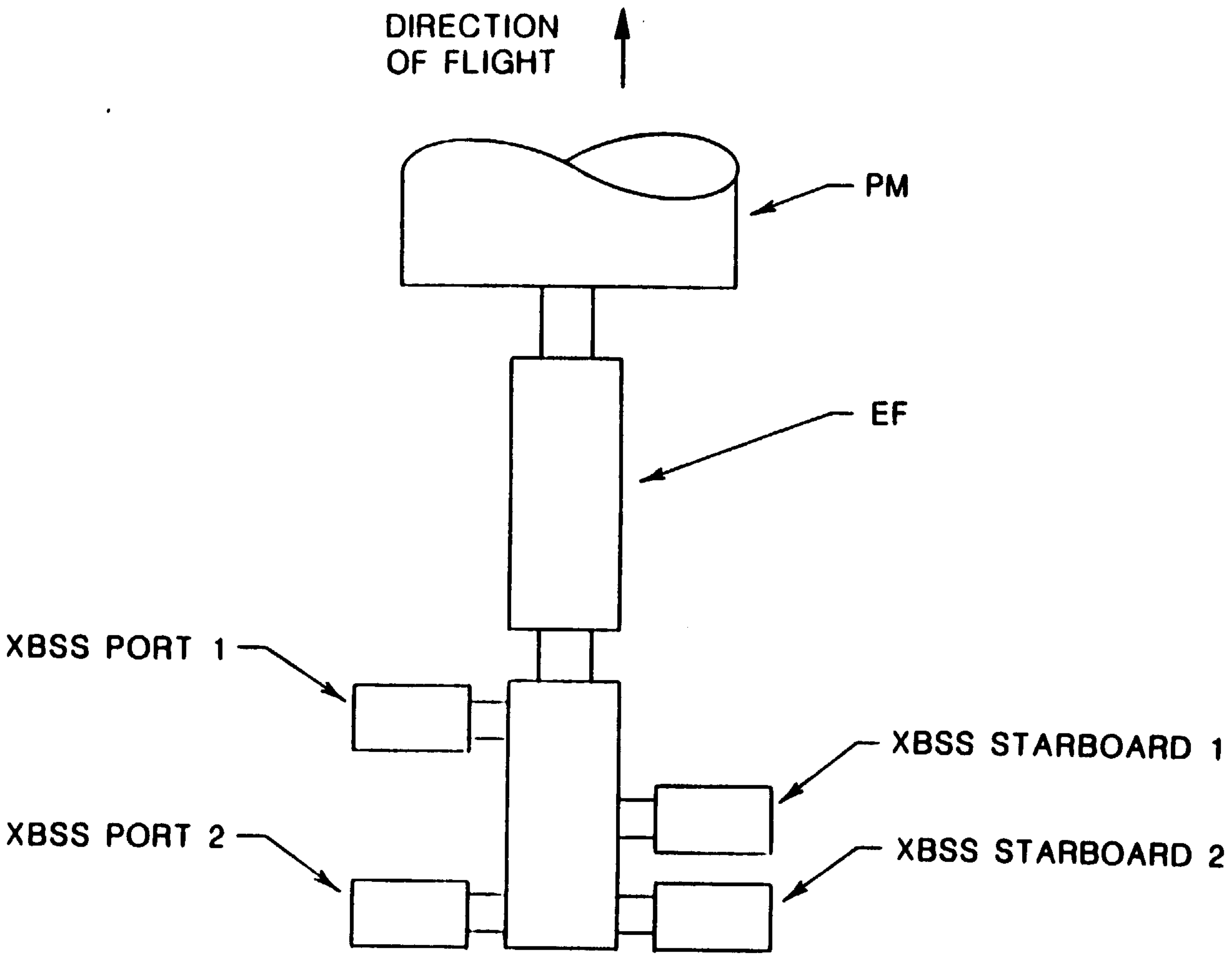


Figure 5.- The XBSS effective field of view in the "Attached Payload" configuration. The field of view (including allowance for spectrometer rotation) is centered on the zenith and extends ± 15° in the SSF XZ-plane and ±77° in the SSF YZ-plane.



XBSS JEM INSTRUMENT LOCATIONS

Figure 6.- Possible locations for the 4 XBSS spectrometers if they were all to be flown as JEM-EF instruments.

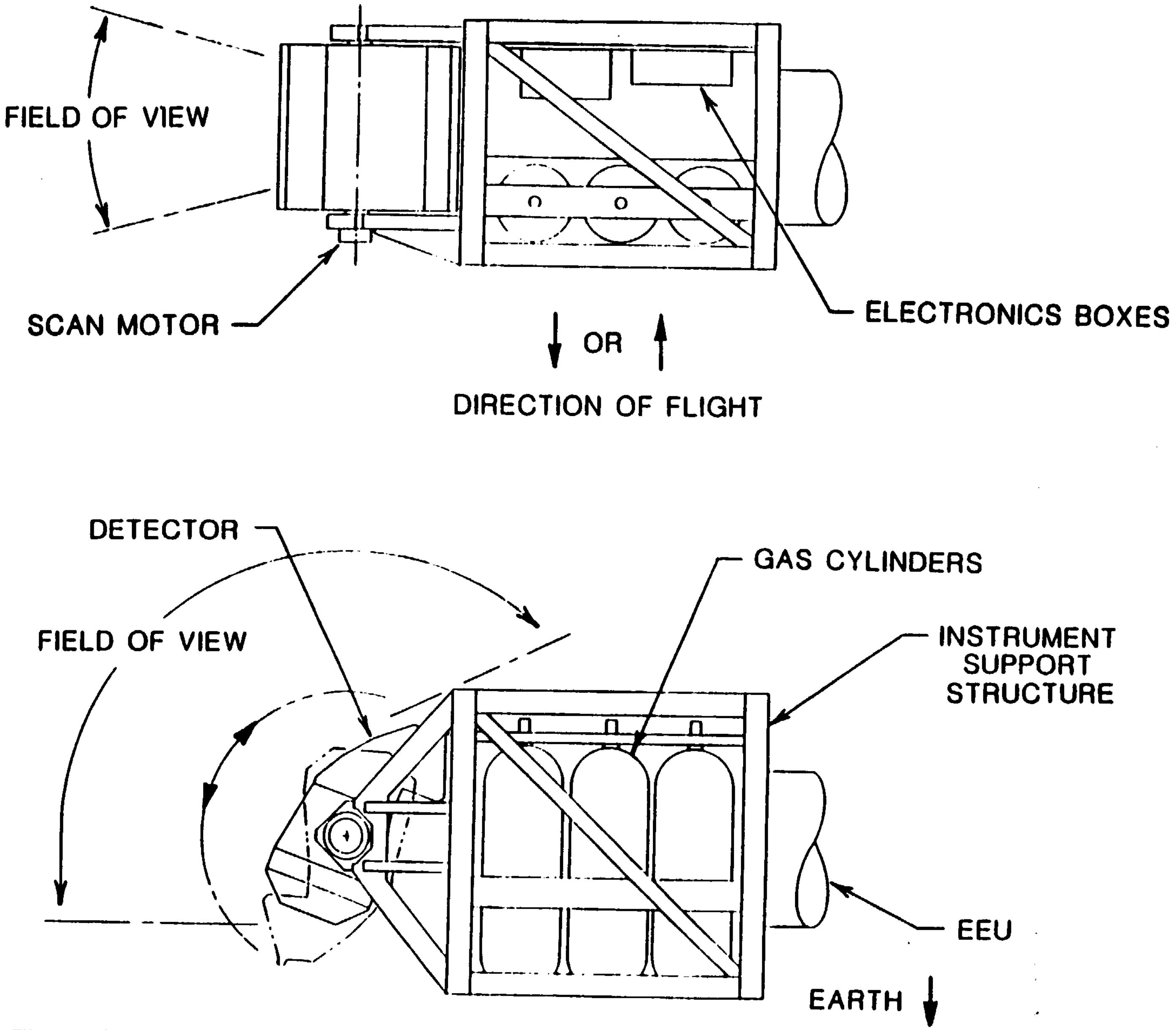


Figure 7.- The XBSS JEM-EF Configuration #1 possibility: the spectrometer rotation scans the field of view perpendicular to the orbit plane and the scan angle may be adjusted to some value in the range 120°-150°. A 150° field of view (including allowance for spectrometer rotation) is indicated here.

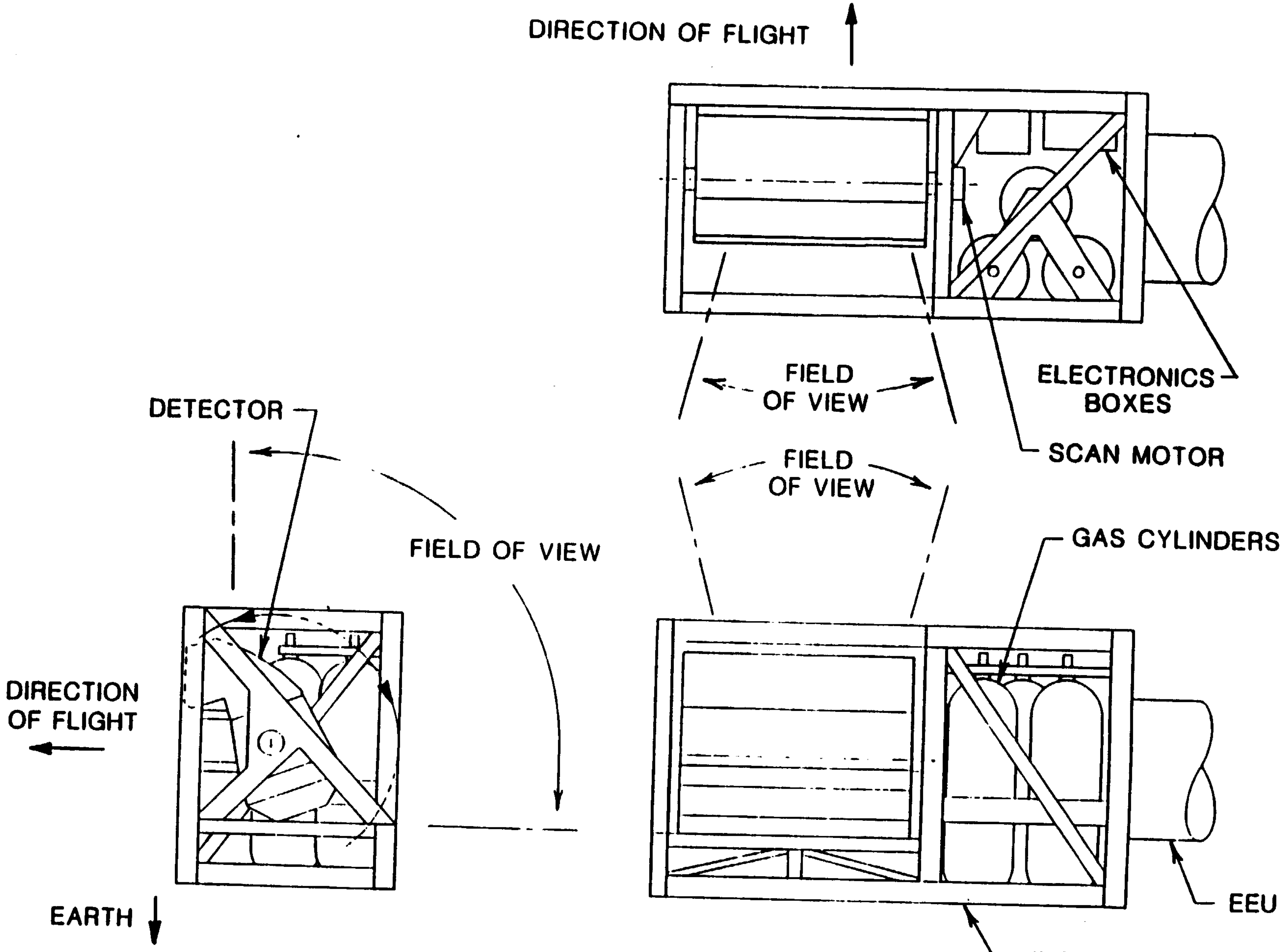


Figure 8.- The XBSS JEM-EF Configuration #2 possibility: the spectrometer rotation scans the field of view <u>in</u> the orbit plane and the scan angle may be adjusted to some value in the range 0°-120°. A 90° field of view (including allowance for spectrometer rotation) is indicated here.

Attachment C

Presentation at the XI th Moriond Astrophysics Meeting

Les Arcs, Savoy, France
10-17 March 1991

HIGH SPECTRAL RESOLUTION SURVEYS OF THE X-RAY BACKGROUND

W. T. Sanders
R. J. Edgar, M. Juda, D. McCammon, P. Plucinsky, C. Snedeker,
J. Zhang
Department of Physics
University of Wisconsin - Madison
Madison, WI 53706
USA

ABSTRACT

Following an overview of the observations of the 0.1 - 10 keV x-ray diffuse background and their current interpretation, future experiments to observe the x-ray background with high spectral resolution are discussed. In the 1990s, we plan to survey the x-ray diffuse background using detectors with much higher spectral resolution (≈ 5 eV) than previously obtainable. The Diffuse X-ray Spectrometer (DXS) experiment uses a Bragg crystal spectrometer to obtain spectra over the 0.1 - 0.3 keV range on a Space Shuttle flight and the X-ray Background Survey Spectrometer (XBSS), an attached payload on the Space Station, uses similar detectors over the 0.1 - 1.1 keV range. Another kind of detector is an x-ray quantum calorimeter that will observe the diffuse background in the 0.1 - 2 keV range on a sounding rocket flight next year (1992). The latter detector is also a candidate for a small Explorer satellite later in the 1990s.

1. Introduction

Figure 1, from the recent review article by McCammon and Sanders 1), summarizes the observations of the x-ray background in the 0.1-10 keV range. At energies greater than 3 keV, the x-ray background is isotropic and generally believed to be of extragalactic origin, although the source is not certain. The integrated emission from active galactic nuclei probably contributes significantly to it and perhaps accounts for all of it. A 40 keV thermal bremsstrahlung spectrum provides an excellent fit to the observed data from 3 to 50 keV 2). At energies less than 0.3 keV, the x-ray background is quite anisotropic and generally anticorrelated (but not in detail) with the ga-

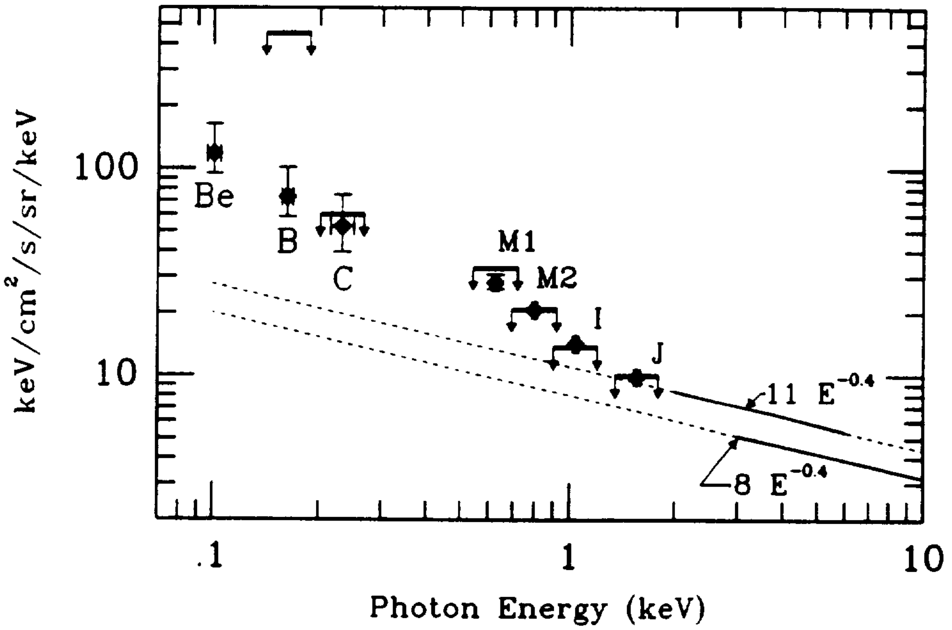


Figure 1. Average observed diffuse background intensity vs. energy. The plotted points are the all-sky averages (with certain non-typical regions excluded). The upper "error bar" is the average for $|b| > 60°$, while the lower "error bar" is for $|b| < 20°$. Be-band points assume that the unobserved part of the sky also tracks the B band. The intensities are plotted for an assumed E^{-1} power-law spectrum. The correct effective energy for each point is sensitive to the assumed spectral index: The horizontal error bars show the effect of a ±0.5 change. The heavy bars represent the best upper limits that can be placed at each energy for the flux incident on the Galaxy from an extragalactic or halo source.

lactic neutral hydrogen. The spectrum is consistent with that calculated by Raymond 3) for a million degree thermal plasma. It is generally thought to arise from a high temperature component of the interstellar gas in our Galaxy, and most of it originates within a few hundred parsecs of the Sun.1) Any halo or extragalactic x-rays in this energy range to reach the earth must survive absorption by several optical depths of interstellar matter (unit optical depth for 0.2 keV x-rays corresponds to $N_H \approx 10^{20}$ cm^{-2}). At intermediate energies, 0.5 - 3 keV, it is not yet clear just how much of the x-ray background is galactic or extragalactic. There are background features that are identified with galactic objects (such as the North Polar Spur or Eridanus fossil supernova remnants), but at high galactic latitudes the majority of the intermediate energy background is probably extragalactic.1)

At energies less than 0.3 keV, it now seems likely that very little of the observed x-ray background originates outside the Galaxy. But in determining the upper limit on the extragalactic component, corrections must be made for the opacity of the interstellar gas along a line of sight out of the Galaxy. In addition to the opacity correction inferred from the neutral galactic hydrogen, account must also be taken of the opacity associated with the ionized galactic hydrogen component, which has a scale height of ~ 1 kpc and a total column density averaging ~ $1 \times 10^{20} \csc(b)$ cm^{-2}.4) Even toward the galactic poles the opacity correction is large. The resulting extragalactic upper limits are comparable to the maximum observed intensity, about four times more than a power-law extrapolation of the extragalactic spectrum 1) (see Figure 1), but after galactic absorption, the detected flux of x-rays with an extragalactic origin is at most 13% of the total observed flux (in the direction of the SMC) with a best fit value of 5%. It should be possible to improve this limit by about a factor of 7 using the ROSAT x-ray telescope to look for shadows of the extragalactic flux cast by galactic clouds.

In the 0.5 - 1 keV range, the present best upper limits to the extragalactic flux are 2-3 times more than the power-law extrapolation of the extragalactic spectrum. It should also be possible to improve these limits with high-resolution observations of dense clouds. If the galactic emission is thermal, 99% of the photons will be in lines and it may be possible to to look between the lines for an excess continuum due to an extragalactic component if sufficiently high spectral resolution can be used. From 1 to 3 keV, the observed diffuse flux is probably mostly extragalactic, but it may be 25-30% higher than an extrapolation of the 3-10 keV spectrum. This excess could have implications for models of AGN contributions to the diffuse background if it is extragalactic.1)

The remainder of this talk describes several experiments that our research group at Wisconsin plans to fly in the next few years to observe the x-ray background with high spectral resolution. These involve two fundamentally different types of detectors: Bragg crystal spectrometers and x-ray quantum calorimeters, but with either detector we obtain much higher spectral resolution (< 10 eV) than was previously obtainable for the diffuse background.

2. Bragg Crystal Spectrometers

Bragg crystal spectrometers are used to obtain spectra of the diffuse x-ray background by the Diffuse X-ray Spectrometer (DXS) experiment on a one-week Space Shuttle flight and by the X-ray Background Survey Spectrometer (XBSS) on a year-long Space Station mission. Each spectrometer (see Figure 2) has a large-area cylindrically-curved Bragg crystal panel that reflects the entering x-rays into the detector, a position-

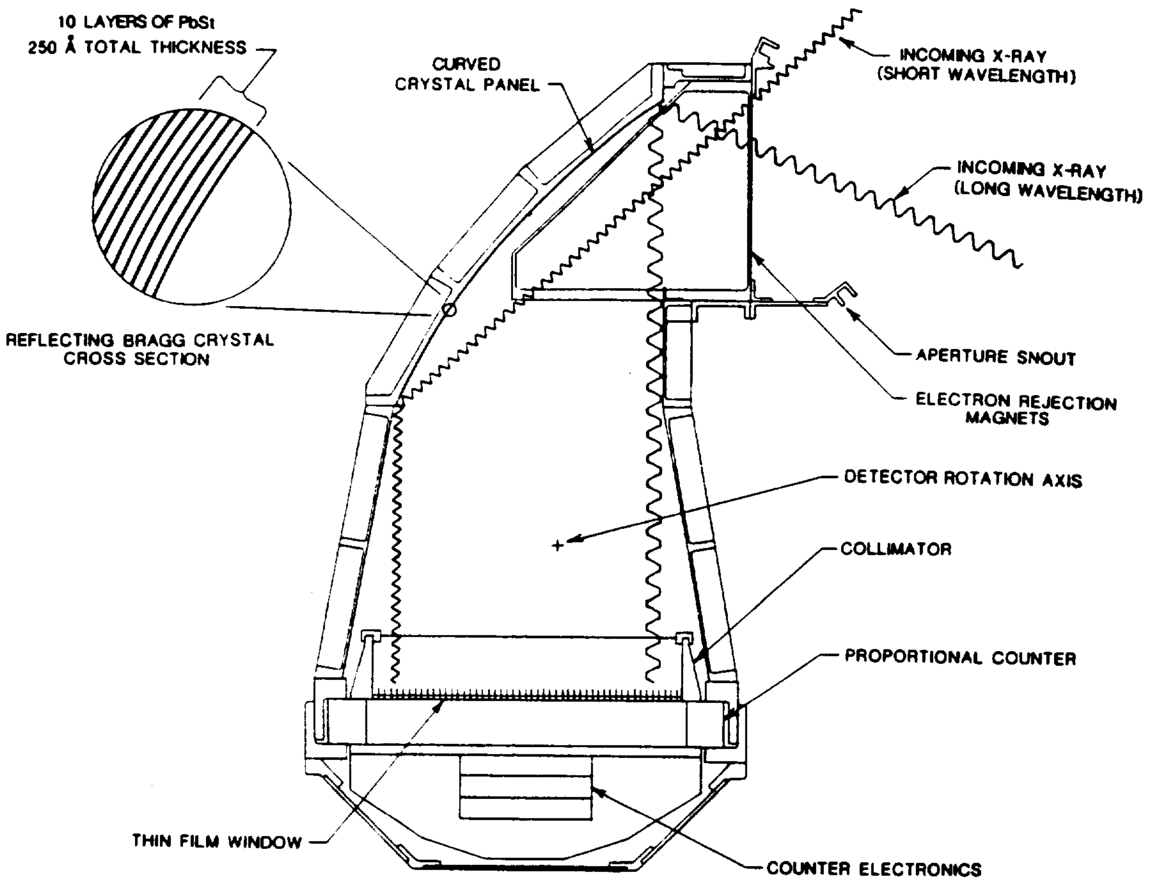


Figure 2. X-rays enter the DXS (or XBSS) detector through an entrance aperture at the upper right and are Bragg-reflected by the curved "crystal". The proportional counter is position sensitive (resolution ≈ 0.5 mm) in one dimension - the dispersion direction of the crystal panel. Because the proportional counter has a collimator before it, each positional element of the counter "sees" a different limited segment of the crystal panel. Due to the panel curvature, different counter elements "see" the crystal at different angles of incidence. By the nature of Bragg reflection, $n\lambda=2d\sin\Theta$, different counter elements thus "see" different wavelength x-rays that originated from different directions on the sky. Rotation of the spectrometer is necessary to obtain a complete spectrum from one direction.

sensitive collimated proportional counter. The proportional counters use 15° x 15° collimators, 90 $\mu g\ cm^{-2}$ Formvar windows and P-10 gas (90% argon, 10% methane) at one atmosphere.

The DXS has two such spectrometers; each uses lead stearate "crystals" to provide sensitivity ($\approx 0.02\ cm^2\ sr$) over the 0.148-0.295 keV (42-84 Å) range. During four days of data collection, DXS obtains spectra from each of ten 15° x 15° sky elements with resolution $\Delta E \approx 5-10$ eV. The DXS is built and tested, and currently undergoing safety-mandated modifications. The launch data is currently in early 1992.

The XBSS has four spectrometers, two identical to those of DXS and two additional ones with TAP (thallium acid phthallate) crystals to provide sensitivity ($\approx 0.005\ cm^2\ sr$) over the 0.52-1.1 keV (11-24 Å) range. During nine months of data collection, XBSS obtains spectra from the whole sky in 15° x 15° resolution elements. The spectral resolution of the TAP detectors is limited by the collimators to $\Delta E \approx 40$ eV. XBSS is currently in a Phase A/B study. Its mission start date is currently "in the late 1990s or early 21st century."

3. X-ray Quantum Calorimeters

The x-ray quantum calorimeter is a device that measures the energy of a single x-ray by measuring the temperature rise of a silicon slab attached to an x-ray absorber. In principle, the measurement uncertainty can be made very small, making the devices potentially useful for high resolution non-dispersive x-ray spectroscopy.5) If there were no noise in the thermalization of the x-ray, resolution better than 1 eV would be possible for detectors operating at 0.1 K. Thus a thermal detector operating at cryogenic temperatures can offer the high efficiency of a solid state detector and resolution comparable to that of dispersive spectrometers.5)

Our research group has been working with the x-ray group at the NASA/Goddard Space Flight Center to develop x-ray quantum calorimeters (XQC) for space flight applications. We are currently constructing a sounding rocket payload that is designed to obtain high resolution spectra of the x-ray diffuse background over the energy range 0.06-2.0 keV. We have recently obtained in the laboratory a resolution of 7.1 eV for 5.9 keV x-rays. In order to obtain a reasonable number of counts from the diffuse background during a 200 s sounding rocket flight, we need an area-solid angle product of at least 1 cm^2 sr. We obtain this using a 1 sr field of view and a detector with an area of 1 cm^2. But to keep the energy uncertainty small, the heat capacity of the detectors must be kept low and instead of one large calorimeter, we are using an array of 25 calorimeters each 2 mm on a side. The detectors will be cooled during the flight by an on-board adiabatic demagnitization refrigerator to an operating temperature of 0.07 K. The XQC payload is currently being assembled and a flight is planned for the spring of 1992. Figure 3 is a Monte Carlo simulation of the results we expect with a 200 s sounding rocket flight.

The XQC is also an obvious candidate for a small Explorer satellite, if such an opportunity is available later this decade. A 1 cm^2 detector array as described above, with a 10° field of view, could obtain a 500 s exposure of each of the 100 square degree resolution elements on the entire sky in six months. Such a mission would replace the XBSS mission, because it could return better quality data sooner and cheaper.

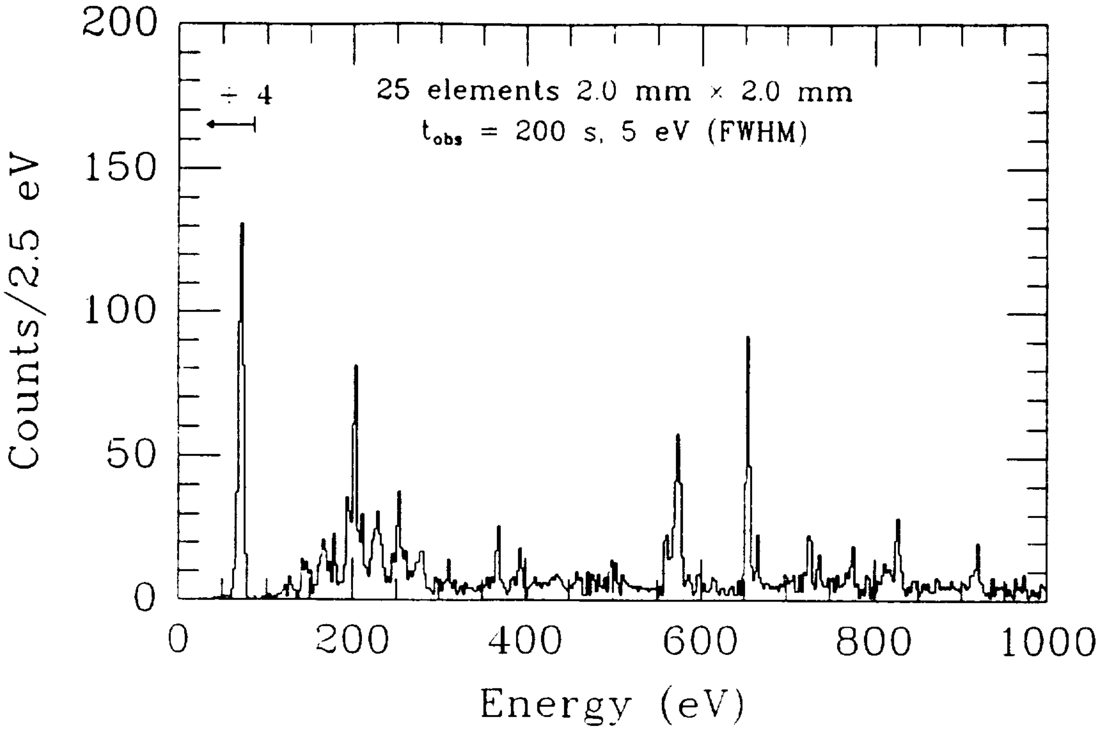


Figure 3. Monte Carlo simulation of the spectrum expected from a 200 s sounding rocket flight.

Acknowledgements

This work was partially supported by NASA contracts NAS8-39664 and NAS5-26078.

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Attachment D

Presentation at the Laredo Workshop on the X-ray Background

Laredo, Spain
11-13 September 1991

The Diffuse X-Ray Spectrometer Experiment

W. T. SANDERS and R. J. EDGAR

University of Wisconsin - Madison

1 INTRODUCTION

The Diffuse X-ray Spectrometer (DXS) experiment is designed to obtain medium resolution spectra ($\Delta E \approx 0.01$ keV) of the soft x-ray diffuse background in the energy range 0.15 - 0.28 keV. The soft x-ray diffuse background is discussed by D. McCammon (this volume) and was reviewed by McCammon and Sanders (1990). The DXS field of view is 15° x 15° (FWHM) and it will measure the spectrum of ten independent regions of the sky. DXS is to be flown as an attached payload aboard NASA's Space Shuttle in 1992.

2 EXPERIMENT DESCRIPTION

The DXS experiment consists of two Bragg crystal spectrometers, one mounted on each side of the Shuttle cargo bay. Each spectrometer has a detector assembly that uses a large area (≈ 30 cm x 60 cm) array of lead stearate (PbSt) Bragg "crystals" to disperse incident x-rays across the face of a position-sensitive proportional counter. The spectrometers communicate with the Shuttle and the ground through the SPOC (Shuttle Payload of Opportunity Carrier) Avionics electronics package mounted on the starboard side of the Orbiter, next to the starboard DXS instrument. Figure 1 shows a DXS detector assembly mounted on a SPOC plate, which is then attached to the Shuttle. Other major assemblies are: the Control Electronics Assembly, the Power Converter Subsystem, the high pressure P-10 gas bottle, the detector latch, the radiation monitor (turns the proportional counter high voltage off and on when the count rate exceeds or falls below an adjustable threshold), the sun sensor (keeps the detector stowed when the experiment is in sunlight), the aperture seal (prevents sunlight from shining on the crystal panel when the detector is stowed), and the rotation motor (to scan the spectrometer field of view across the sky).

A cross sectional view of the spectrometer's detector assembly is given in Figure 2. The assembly extends more than 60 cm perpendicular to the plane of the page. X-rays enter the detector assembly through the aperture, are Bragg-reflected off the crystal panel, and pass through the collimator and thin window into the proportional counter, which is position-sensitive in one dimension. The magnets are to reject low energy (E < 20 keV) electrons. The Bragg crystal panel is a thin plastic sheet whose inner surface is coated with 200 layers of PbSt, producing a one-dimensional pseudo-crystal. The reflecting layers of lead have spacing 2d=101 Å. The PbSt may be destroyed by solar ultraviolet radiation and by atmospheric oxygen atoms hitting it at the Shuttle orbital velocity.

The DXS collimator is of a simple crossed slat design and restricts the field of view to 15° x 15° (FWHM), although at any one time x-rays are typically received from 4 or 5 different resolution elements. It supports a 100 line-per-inch nickel mesh, which supports the proportional counter thin window against the P-10 counting gas at a pressure of one atmosphere. Each counter has a large-area entrance window made of Formvar and a UV-absorbing agent, UV24, with a total mass thickness of about 90 μg cm^{-2}. The proportional counter has a front layer where the x-rays of interest are absorbed, and a back-plus-side veto layer, operated in anticoincidence with the front layer. Each layer contains an anode whose high voltage ($\approx$ 1700 V) is turned off whenever the orbiter is in the South Atlantic Anomaly (SAA). Between the two gas volumes is a plane of wires running perpendicular to the plane of the page and maintained at ground potential. The distribution of induced electrical charges among these ground plane wires allows the determination of the position of the incident x-ray across the counter, which is the dispersion direction of the Bragg crystals. The spatial resolution of the detector is about 0.5 mm, but the energy resolution of the spectrometer is determined by the 15° acceptance angle of the collimator.

3 EXPERIMENT OPERATION

The operation of the detector is as follows. Any one ground plane segment is constrained by the collimator to receive x-rays that are reflected from a particular segment of the crystal panel. The x-rays that are Bragg-reflected from that segment of the crystal panel have a particular angle of reflection, equal to their angle of incidence, θ, and a particular wave-

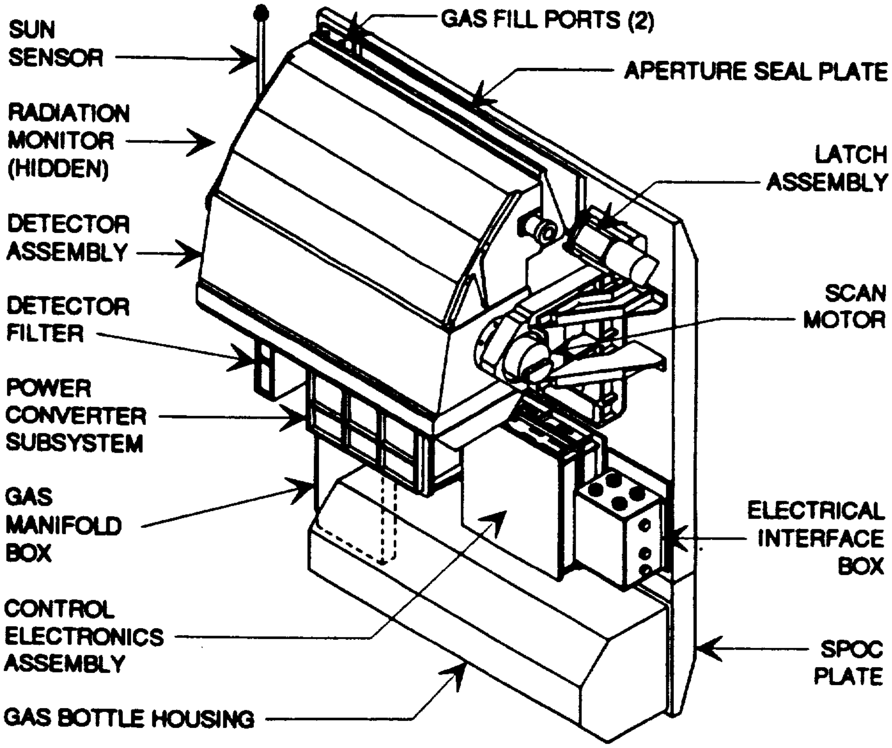

Figure 1 -- Isometric drawing of one of two DXS Bragg crystal spectrometers

length that satisfies the Bragg condition, $\lambda = 2d \sin\theta$. Given the position across the counter of a detected x-ray, both its wavelength and direction of origin on the sky are determined. The spectrum of the diffuse background is dispersed across the proportional counter at all times, but x-rays of different wavelengths come from different regions of the sky.

To get a complete spectrum from a single region of the sky, the detector assembly must be rotated through an angle ≈ 60°. As the detector assembly is rotated, additional partial spectra are obtained from the adjacent sky regions, and as the rotation is extended beyond 60°, complete spectra from additional regions are obtained. Ideally, this instrument would be flown on a spinning satellite, continuously collecting data while rotating through 360°. Since DXS is Shuttle-mounted, the best it can do is rotate back and forth with a 157° view of the sky.

From our computer modeling, we find that the *minimum* useful exposure per 15° x 15° resolution element is 5000 seconds (and more than that is desirable). For ten resolution elements, DXS requires 50,000 seconds of good observing time during which the Shuttle maintains the same inertial attitude. Furthermore, these 50,000 seconds must be obtained

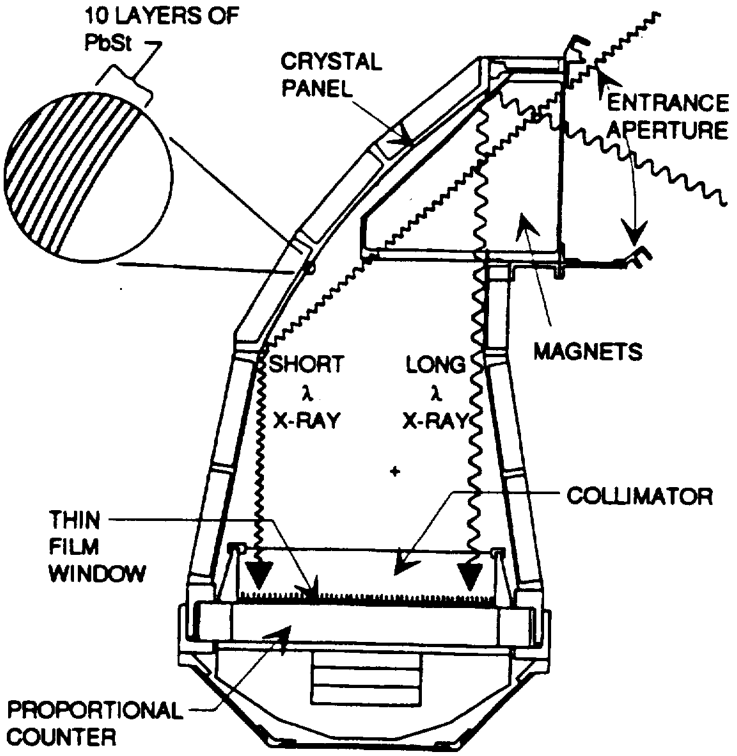

Figure 2 -- Cross sectional view of a DXS detector assembly

(a) at night so that the sunlight does not destroy the crystals, (b) when atmospheric oxygen is not directed into the detector aperture so the atomic oxygen won't erode away the crystals, and (c) when the Shuttle is not in the SAA, which is much larger for low energy x-ray instruments than it is for higher energy ones. Approximately 5 days on orbit are required to obtain the DXS data.

During the time that DXS is on-orbit, the science team operates out of a Payload Operations Control Center (POCC) at Goddard Space Flight Center, uploading time-tagged commands to the instruments and monitoring the data, which is telemetered to the ground in near real time. The proportional counters collect data for 10-20 minutes each orbit and the proportional counter gain is periodically checked by an on-board Al Kα X-ray tube.

The detector response function, including PbSt crystal geometry and efficiency, collimator effects, and mesh and window transmission is shown in Figure 3. When a typical diffuse background spectrum, a 10^6 K thermal plasma (Raymond & Smith 1977, 1987; hereafter RS) plus an absorbed ($N_H = 10^{20}$ cm^{-2}) 3 x 10^6 K (RS) plasma and an absorbed (N_H = 5 x 10^{20} cm^{-2}) 11 $E^{-1.4}$ ph cm^{-2} s^{-1} sr^{-1} keV^{-1} spectrum, is modeled with this response function, integrated for 10^4 seconds, and randomized assuming Poisson statistics, the result is as shown in Figure 4. The wavelength resolution is 2-3 Å, corresponding to about 0.01 keV, with a variation of a factor of three across the DXS bandpass. The

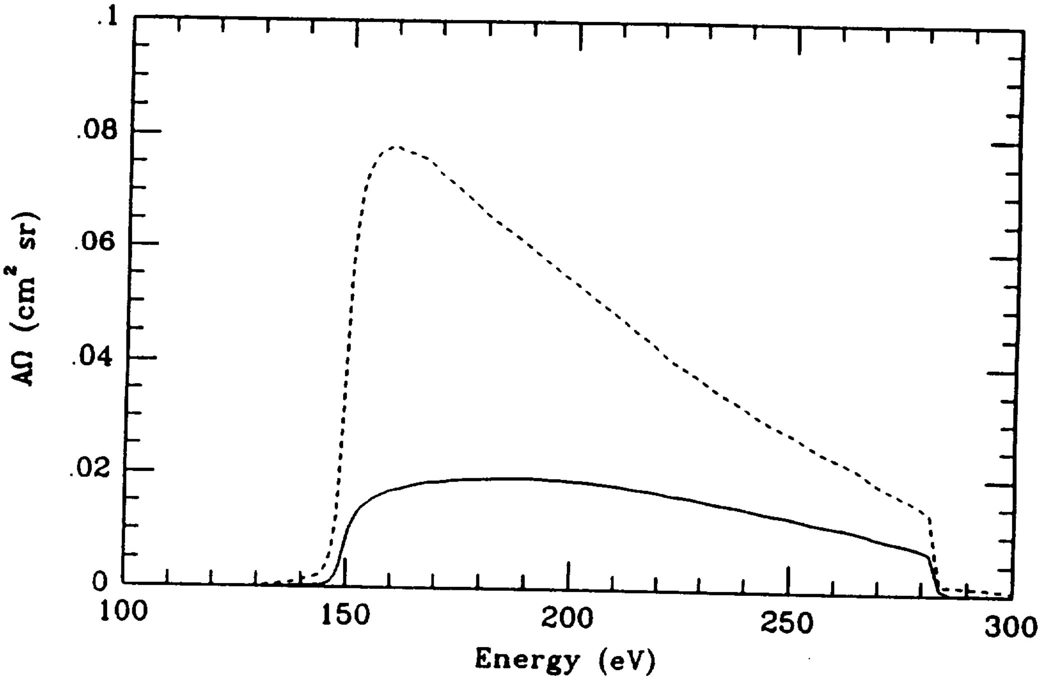

Figure 3 -- Response function for one DXS as a function of photon energy (solid line); not including window transmission (dashed line)

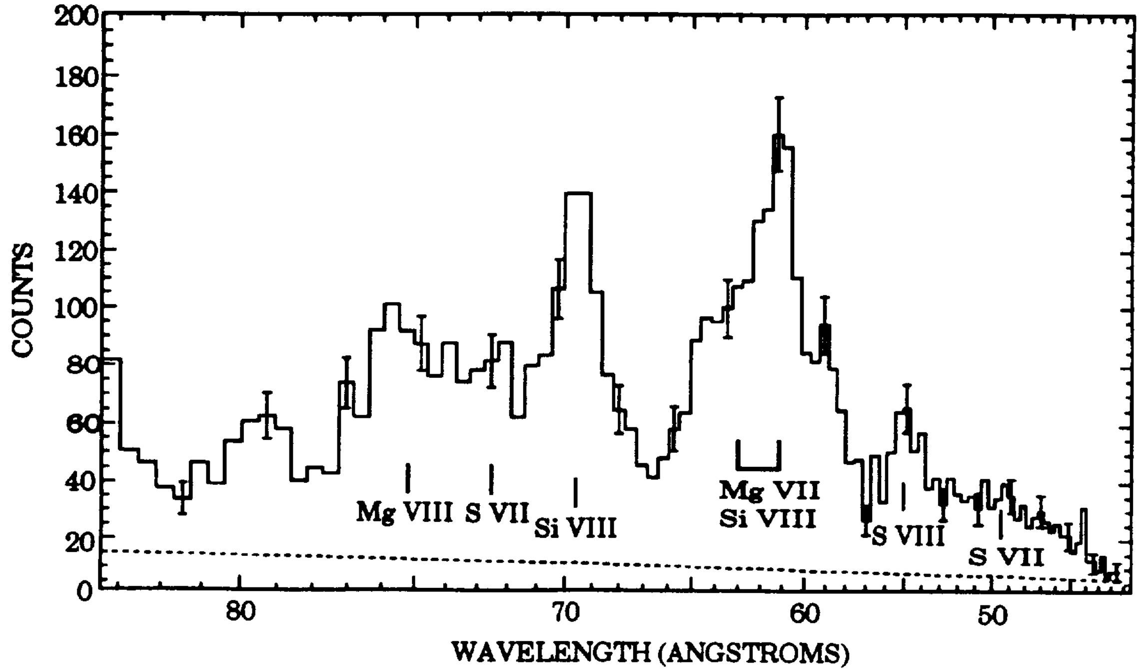

Figure 4 -- Diffuse background model spectrum folded through the DXS response function

minimum detectable line in this spectrum has about 100 counts, corresponding to a sensitivity of 0.5 ph $cm^{-2} s^{-1} sr^{-1}$.

Until recently, NASA also planned to fly a set of instruments similar to DXS on the Space Station. This mission was called the X-ray Background Survey Spectrometer (XBSS) and was designed to obtain spectra of resolution similar to that of DXS, but from the whole sky and over a broader bandpass, 0.15 - 1.1 keV. However, in August 1991, XBSS was "deselected" as a Space Station payload.

DXS was proposed by W. L. Kraushaar in 1978 and he has guided it since its inception. The design and construction of the proportional counters were the work of Dan McCammon and Kurt Jaehnig. Steve Snowden, Jeff Bloch and the staff of the University of Wisconsin-Madison's Space Science and Engineering Center have contributed greatly to the progress of DXS. This work was supported by NASA contracts NAS 5-26078 and NAS 8-38664.

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Attachment E

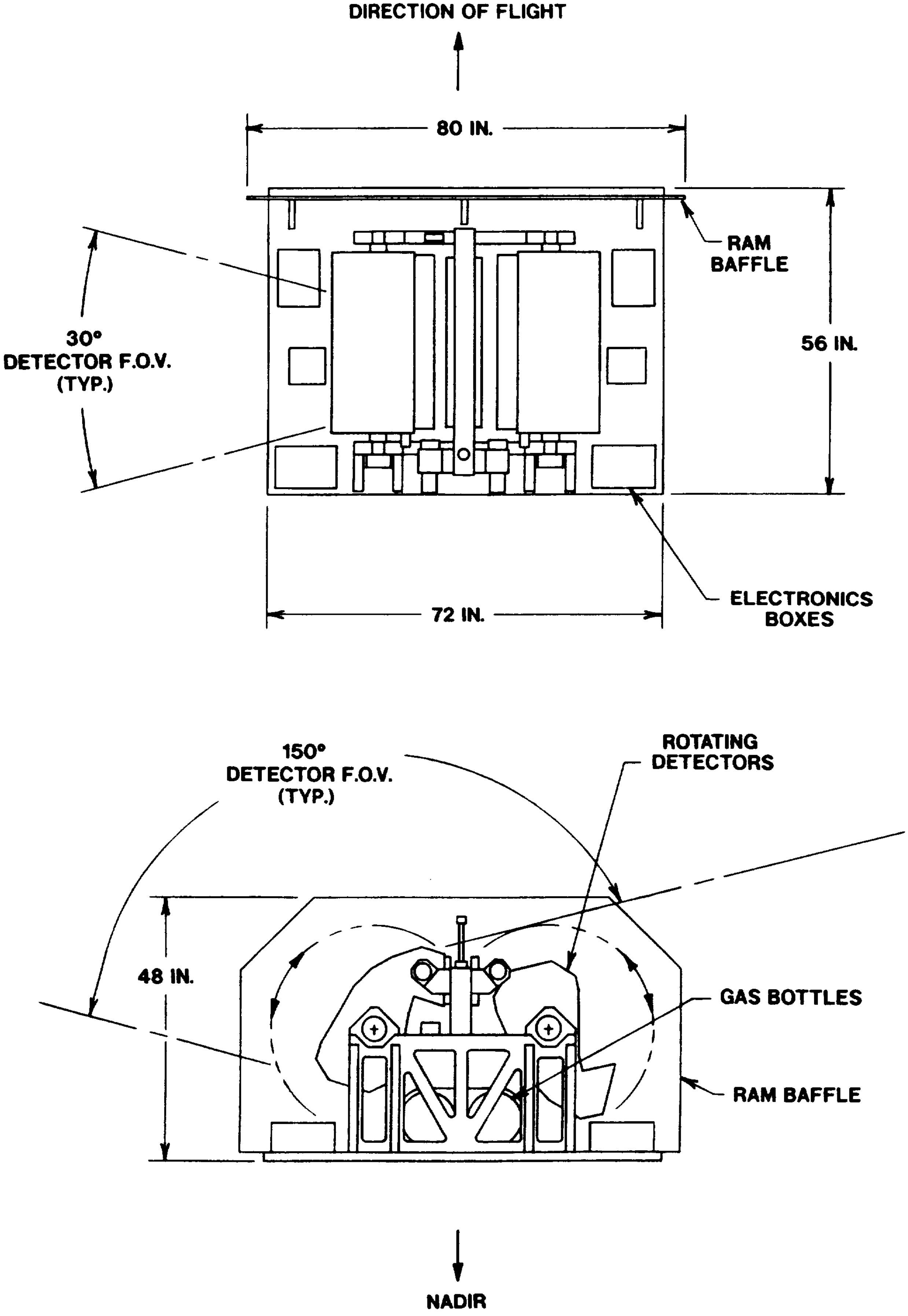
Presentation Charts for Reduced XBSS Experiment using DXS Flight Hardware

23 July 1993

X-ray Background Survey Spectrometer
University of Wisconsin

Experiment Overview:

- The XBSS payload consists of two Bragg crystal x-ray spectrometers and associated electronics
- Each XBSS detector consists of a crystal panel and a position-sensitive proportional counter
- Data are collected during orbit night by rotating the detectors; during orbit day the detectors are stowed
- The XBSS detectors were flown as part of the DXS attached Shuttle payload in January 1993
- XBSS views deep space to observe x-rays originating in our galaxy beyond the solar system
- The objective of the XBSS is to perform a spectral survey of the low energy diffuse x-ray background
- Spectra will be obtained of the diffuse x-ray background in the 44-84 Å wavelength interval with 15° angular resolution
- The emission spectra allows determination of the temperature of the emitting plasma as well as the elemental and ionic abundances
- Commands are uploaded several times per day and data are received by telemetry in near real-time



XBSS

July 23, 1993 #2

X-ray Background Survey Spectrometer
University of Wisconsin

Requirements:

Mass	900 lbs.
Power	315 W (average)
Overall Dimensions	80 in. x 56 in. x 48 in.
Data Rate	200 Kbps
Commands	1000 bytes per orbit
Field of View	150° x 30°
Pointing	-ZLV (Knowledge of Station attitude within ±2°)
Thermal Limits	-40°C to 40°C
Mission Duration	9 - 18 months

July 23, 1993 #3

X-ray Background Survey Spectrometer
University of Wisconsin

Status:

- The XBSS payload uses hardware from the DXS experiment that was flown on the STS-54 mission
- The XBSS payload utilizes existing detectors and other support hardware
- The DXS payload will be modified to accommodate the MDM interface for XBSS
- The DXS payload will be modified to accommodate Station power interface for XBSS
- The S6 spacer/face D truss location is ideal for achieving the XBSS science goals
- The DXS hardware is currently located at the University of Wisconsin
- The XBSS experiment could support an FY98 flight
- The XBSS payload is compatible with recent Station design changes