AXAF Science Center

Harvard–Smithsonian
Center for Astrophysics

MEMORANDUM

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To: Distribution

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Subject: Overview of ASC Orbital Verification Plans

1 Introduction

The purpose of the memo is to describe the ASC plans for science instrument performance verification during orbital verification phase. The contents of the memo are an expansion of the presentation made 1995 January 4 by the ASC to the AXAF Technical Support Team; the viewgraphs from that presentation were distributed to the ASC.

The purpose of orbital verification is defined as a demonstration of the overall scientific performance of AXAF. This activity involves several functions. We must verify science instrument operation, the ability to acquire celestial targets, the ability to position the specified science instrument at HRMA focus, the ability to acquire images and spectra, and we must determine focus and boresight. The ASC is coordinating with the science instrument IPIs in developing our planned activities. Our plans will also include the other scientific subsystems of AXAF, such as the aspect system and clock.

1.1 Constraints

There are a few constraints imposed on the activities, some of which have schedule impact. The observatory will be operated only in the expected on-orbit configuration: this means for example that systems will be powered from only the primary side, systems will not be intentionally driven to operational temperature extremes, and we expect the telemetry to be in a "science" format a majority of the time. Many of the planned activities require the telescope sunshade door to be open which limits activities prior to this event to verifying FPSI operation. Most significant among these limitations is that the science instrument module must not be translated prior to opening the sunshade door and the objective transmission grating (OTG) insert and retract mechanism must not be operated until the time of OTG verification, which in turn requires the observation of a science target.

The sequence of science instrument tests at the focus of the telescope is:

- ACIS-S

- ACIS-I
- ACIS-S/HETG
- HRC-I
- HRC-S
- HRC-S/LETG

1.2 Correlated Observatory Operations

There are several other aspects of the operation of AXAF that concern systems other than the science instruments and which impact its overall scientific performance. The observatory must achieve thermal stability, have its celestial location determined, be able to acquire aspect stars, and establish pointing control. We must be able to reconstruct images based on data from the science instruments and from the PCAD system. In order to operate independently, the observatory must demonstrate the ability to execute stored command loads autonomously. We must also be able to retrieve on-board recorded telemetry. The ASC expects to monitor progress in these areas and provide input to the lead disciplines responsible for the particular observatory subsystem. A mechanism must be in place for the ASC to concur on the adequacy of the performance of these subsytems for the science mission.

2 Science Instrument OV Phase Activities

The AXAF mission is a science mission and as such verifying the proper performance of the science instruments is a key function during orbital verification. The schedule of activities is constrained by when it is safe to perform some tasks and by time order dependencies between tasks. Many of the verification tasks require the instruments to image the sky, which in turn requires the telescope sunshade door to be open. The sunshade door cannot be opened until the ACIS camera housing door is opened and the forward contamination monitor sources are measured. The ACIS door cannot be opened until the OBA has sufficiently out-gassed and vented overboard. Thus the opening of the ACIS door provides a natural breakpoint in the schedule of activities. In what follows we will refer to the period before the opening of the ACIS door as Period 1 and that after the door is opened as Period 2.

2.1 ACIS Period 1 Activities

The period 1 ACIS activities include the initialization of the instrument, the verification of expected operating conditions, and the verification of the basic functions of the instrument.

The first set of activities will perform the hardware (HW) and software (SW) initializations. The very first command which must be sent to ACIS will turn on the instrument's power supplies. The Back End Processor (BEP) must then be turned on after a stable operating condition of the power supplies has been achieved. ACIS is a fairly intelligent and complicated instrument; it has a BEP which acts as the "brains" of the instrument controlling the communication with the spacecraft and controlling the operation of the

Front End Processors which actually operate the CCDs. Many of the activities to be performed with ACIS will be executed by the flight SW running on the BEPs and FEPs; therefore the BEP and FEPs must be turned on before preceding with the initialization. After turn on, the BEP will be commanded to dump the flight SW to telemetry. We want to verify from the outset that the flight SW has not been corrupted. The BEP will then run through a series of checks of its internal memory and its interfaces. The FEPs should be turned on during this stage. We will then establish the capability to send commands to the BEP and verify their execution. Since almost all commanding of the instrument will be done in this fashion, it is critical that we exercise this capability early in the OV phase to identify any unexpected problems.

The next stage of activities will verify the expected operating conditions of the instrument. ACIS has several temperature monitors located on the electronics boxes, the radiators, the camera housing, and the focal plane, and it has one pressure monitor inside the camera housing. It is important to get this information as soon as possible to identify anomalous conditions which may effect the instrument. The sequence of events will be to simply turn on the monitors and immediately start to read them out. We will then use the temperature information to confirm our preflight thermal models.

The HW and SW initialization and the verification of the physical conditions must occur as soon as possible. There may be a delay before the next stage of activities which is the CCD initialization. The first step in this stage is to apply power to the CCD analog electronics and immediately start to clock out the CCDs. The CCDs will start to produce data which must be processed by the FEPs and BEP and sent to telemetry. The first data will be produced in "diagnostic mode" which produces the most useful information for identifying problems. If everything is working, we will configure the CCDs in the timed exposure mode and start collecting data. An important test at the beginning of this data collection will be the bias computation. We will most-likely decide to dump the bias map into telemetry as soon as possible as opposed to trickling it down as planned during normal observations. ACIS has an internal X-ray calibration source which is always on; therefore as soon as we turn on the CCDs, they will be collecting X-ray events. These events will provide useful diagnostic data on the state of the CCDs (specifically, has any contamination built) but the event rate is low enough so as to not adversely effect the bias calculation. After executing in timed-exposure mode, we will load another one of the ACIS onboard parameter blocks and operate in that configuration. We will then load a parameter block from the ground and operate in that configuration. It is crucial to verify both methods of loading parameter blocks because we anticipate both will be heavily used during normal operations.

The next stage is the detailed checkout of the CCD operations. The ACIS flight SW will monitor the signal from the EPHIN detector and turn off power to the CCDs (not the BEP or FEPs) when the signal indicates a high radiation environment. The ACIS flight SW uses a programmable threshold to identify time periods with high radiation. The flight SW then continues to monitor the radiation signal and after a programmable number of low signals, it will turn the CCD power back on. We will verify this performance by manually setting the radiation signal high and then low and observing the flight SW's response. The detailed checkout will also include bias measurements made with different exposure times; these data are particularly useful in characterizing the CCDs' performance. Finally, the detailed checkout will include data collected in timed exposure mode and continuous clocking mode with several configurations to verify the capability to collect useful data in these modes; these data will also be useful in characterizing the CCDs' performance. These measurements will be conducted as normal operations commanded through parameter blocks.

The last activity of the period 1 ACIS activities is the opening of the vent valve door. This is the only activity which we believe could potentially cause irreparable damage to the instrument if not executed properly. The danger lies in opening the vent valve too quickly and creating a large pressure differential across the ACIS optical blocking filter (OBF), which may cause the filter to rupture. This activity should be performed in a real-time contact because the valve is opened with a paraffin actuator. The FOT could monitor the temperature of the actuator and decide to heat it more slowly or more quickly. Inside the ACIS camera housing there is an LED on the opposite side of the OBF from the CCDs. This LED will be turned on before the opening of the vent valve and will be used to check the integrity of the filter. After the operation is complete, the LED may be turned off. Before the valve is opened the ACIS internal pressure monitor will be carefully compared to the SIM pressure monitor. Hopefully, the pressures are close to the expected values and the operation may be executed.

2.2 HRC Period 1 Activities

All the HRC activities during Period 1 are limited to verifying proper instrument operation. While the HRC will not be moved to the telescope optic axis during this period, it is be necessary that for some of the time it is selected as the observing instrument, so that it receives the 24 kbps science telemetry.

The first scheduled activity for the HRC is a hardware initialization. The HRC low voltage will be commanded on and we will verify that the HRC low voltage power supplies are generating the expected voltages and currents. We will also verify that the HRC has the expected temperatures at its different components. The initial turn on requires a sequence of fifteen commands: ten discrete commands to configure the instrument power selection, one discrete command to activate the HRC power bus, and four serial commands to guarantee the HV power supplies are off (even though the HVPS default to off when HRC is powered on). This series of commands can be executed in seconds; however, it will take somewhat longer for the HRC to stabilize when it is first turned on (at CDR, D. Boyd presented simulations showing a 10 hr thermal time constant). Voltage, current, and temperature values appear in the instrument housekeeping portion of the telemetry, sampled approximately every 2 seconds when the HRC is in observing mode.

As the next activity, the complete set of HRC low voltage commands will be exercised and the response of the instrument to each verified. Each of the on-board HRC discriminator values will be set and the returned housekeeping values compared to the commanded levels. Once again the execution of the commands will take only a matter of seconds and the verification of the instrument response will appear promptly in the instrument housekeeping.

The HRC has an on-board electronic pulse generation system that enables a calibration of the end-to-end gains and off-sets of its amplifiers. Once the nominal performance low voltage electrical systems has been verified, the amplifier gain verification can proceed. The amplifier gain verification is accomplished through a sequence of serial commands. First, the electronic pulse inject is enabled (single command); then the voltage amplitude of the pulses is set (single command). For each amplifier, the HRC event processing electronics must be commanded to use a specified coarse position (two commands, one for each axis). Since there are 64 amplifiers along an axis of a detector, the forced coarse position command must be used 64 times to completely sample the electronics. Several different voltage amplitudes must be used to make a determination of both linearity and off-set for each amplifier. At the observing mode telemetry rate only ~ 185 events per second can be telemetered; about one day of data collection is required.

The HRC high voltage power supplies cannot be turned on until the pressure within the detector housing is below 10^{-5} Torr. A cold cathode ionization gauge mounted inside the SIM provides the most direct measure of the pressure. According to estimates in the SI to Observatory ICD, the pressure should reach this level on roughly the seventh day after launch. The draft timeline in the Orbital Verification Activities Requirements document (OP16 dated 11 Oct. 94) placed the date for HV turn on on day 12, this should leave ample margin to allow the pressure to reach a low enough level. The first time any HV system is turned on and raised to its operating level must be performed during a real-time contact. Sustained breakdown or arcing of the HV can damage the MCPs or the PMTs; a real-time contact is necessary as is HRC observing mode telemetry so that in the event of a problem we are able to sense it and issue the commands to shut off the HV. The first HV system that will be activated is for the anti-coincidence shield PMT. Activation consists of a sequence of serial commands: one to turn on the HV and several more to ramp the HV level up by commanding the setting to progressively higher voltages. This activation should not take more than a few minutes. Event rates in the anti-coincidence shield are recorded in the HRC science data, two samples for each$\sim$2 second interval.

The HV for the HRC-I or the HRC-S MCPs is activated through a similar sequence of commands as used for the anti-coincidence shield. Only one of the two detectors may have HV on at a given time. The HRC-I HV is activated first and instrument housekeeping and MCP event rate data are monitored to verify nominal instrument performance. HRC-I detector background is measured first; the expected event rate with active anti-coincidence is approximately 0.05 counts cm^{-2} s^{-1} or roughly 5 counts s^{-1}. A six hour background measurement will permit the total background rate to be determined to 0.3% and the background on 1 cm scales determine to 3%. It may be possible to collect a portion of the background data in next-in-line mode but at least some collection must be done with HRC observing mode telemetry The active anti-coincidence will be disabled using a single serial command and background data collected for $\sim$15 min before the anti-coincidence is enabled again (via a single serial command). Background data collection with active anti-coincidence disabled must be done with HRC observing mode telemetry.

At the conclusion of the background measurements, the internal calibration sources will then be used to illuminate the HRC-I with x-rays. Three calibration sources, mounted on the inside of the HRC housing door, can be positioned so that one at a time can shine through a hole in the calibration source housing; this is accomplished via serial commands to the motor control electronics. First the calibration source motor is selected via a single serial command, next the motor drive is enabled, finally the source is positioned via serial commands to move a specified number of steps or by a pair of serial commands to load a position and a serial command to move to the loaded position. Assuming the sources are bright enough to produce an event rate comparable to the maximum telemetry rate of $\sim$185 counts s^{-1} or approximately 2 counts cm^{-2} s^{-1} then a six hour exposure will provide a 0.5% statistical uncertainty on the measurement of the detection efficiency over 1 cm scales. The HRC-I can be exposed to all three calibration sources in sequence with the total time required for detection efficiency verification of 18 hours. Before commanding the calibration sources back to their stowed position, the center blanking and edge blanking function can be verified. A single serial command is required to select the center blanking function and four serial commands set the low and high boundaries for each of the two axes. A similar set of commands are used to select and configure the edge blanking function. A fifteen minute exposure should be sufficient in each for verification. At the conclusion of the edge blanking verification the calibration source mechanism must be commanded to the stowed position; this can be done with a single serial command. HRC observing mode telemtry is required for these tests.

Once HRC-I MCP operational verification is finished HRC-S can begin. The MCP HV must be shut off before switching from HRC-I to HRC-S. HRC-S MCP operational verification will follow the same steps as outlined above for HRC-I. The times required for the individual tests should be the same with the exception of the internal calibration source total exposure. Because of the HRC-S geometry, there are two locations in the calibration source housing where the sources illuminate the HRC-S. Each source must be used at each hole so the total exposure time is doubled (36 hours).

2.3 ACIS Period 2 Activities

The period 2 ACIS activities will include some of the most dramatic in the OV phase, such as opening the ACIS door, opening the aft and forward contamination covers on the HRMA, opening the HRMA sunshade door and conducting the first astronomical observation with AXAF.

The first activity is the opening of the ACIS door. Unfortunately, a great deal of uncertainty currently exists concerning when it is safe to open the ACIS door. The problem is that no one on the project can accurately predict the outgassing rates of the OBA. Since ACIS is the coldest surface on the satellite (filter ≈ -60 C and CCDs ≈ -120 C), most of the contaminants will eventually freeze out on ACIS. Therefore, it is crucial that the ACIS door not be opened until the OBA has outgassed to an acceptable level. Currently, 25 days has been proposed as the length of time required; however, this is not even an estimate, merely a number chosen on past experience and it may have little bearing on reality. Before opening the ACIS door, the ACIS internal pressure monitor and the SIM pressure monitor will be checked. If the values are significantly different, there is a large problem and corrective action may need to be taken. If they are the same, it may be safe to open the door but it is not guaranteed. The launch-lock position is on the ACIS-S array; therefore ACIS will be configured to collect data with the central 2 chips of the ACIS-S array and the 4 chips of the ACIS-I array. It is not clear at this time if the ACIS door should be opened first or if the HRMA aft contamination cover (ACC) should be opened first. It is possible that there will be some residual outgassing after the ACC is opened; in this case the ACC will be opened first and some time will be allowed for this material to vent overboard. If not, the ACIS door will be opened and data will be collected on the internal background of the satellite. The ACIS door should be opened during a real-time contact since it uses a paraffin actuator which may be monitored during the process. After the ACIS door is opened, data will be collected from the Forward Contamination Monitor (FCM) sources. These data will be used to determine if a contamination layer had built up on the HRMA. The data will be collected in the ACIS timed-exposure mode which will be commanded by an on-board parameter block.

At this point, it is time to open the HRMA sunshade and collect first light with AXAF. AXAF should be positioned on the first target and the sunshade opened. ACIS will be collecting data as the door is opened and we should verify in real-time that operation has executed normally. We will use the ACIS data to verify that the door has opened completely and is not obstructing the optical path. We will also collect bias and diagnostic data to measure any increases in the background rate. Multiple observations will be conducted to find the boresight of the ACIS-S array and the ACA, this will entail changing the pointing direction many times. Multiple observations will be conducted to find the best focus of the ACIS-S array, this will entail moving the focal plane along the optical axis many times. Finally, the plate scale of the ACIS-S array will be measured in two ways. First, a point source will be moved across the field of view by changing the pointing direction and second, an observation with several objects separated by known (but small) distances will be conducted. These observations should all be conducted with normal operating modes commanded through

ACIS parameter blocks.

The SIM will be moved for the first time in the next stage. We will first move the SIM in small steps to keep the HRMA aimpoint on the ACIS-S array. If the operations have been successfully executed and verified, we will then move the SIM so that the HRMA aimpoint falls on the ACIS-I array. We can them move the aimpoint around on the ACIS-I array and further verify the SIM performance. We will then find the boresight, focus and plate scale of the ACIS-I array using the same procedures above. All of these operations will be conducted with ACIS in a normal operating configuration.

The last activity involves inserting the High Energy Transmission Gratings (HETG) and collecting data. The SIM must be translated to place the HRMA aimpoint on the ACIS-S array. The HETG will then be inserting as ACIS is collecting data. We will collect data from several targets to verify the ability to center a target for the gratings and to verify the focus of the ACIS-S array at its outer extremes. After these operations are completed the HETG will be moved out of the way.

Finally, ACIS will be moved to the stow position. The time in the stow position is extremely useful for ACIS because there will be four X-ray calibration sources which will be used for the most detailed performance check of the CCDs. These sources will always be on and ACIS will always see them when in the stow position. ACIS will require the full 24 kbps for some of this time. ACIS will run in a normal operating mode when collecting these data.

2.4 HRC Period 2 Activities

For the initial portion of Period 2 the HRC will not be at the telescope focus and the HRC will be running in next-in-line mode. We expect to open the HRC housing door sometime before the ACIS camera housing door is opened. While the HRC will not be viewing the sky it will be able to take background measurements that we can compare to those taken with the door closed. The HRC-S MCP HV must be commanded off before opening the HRC housing door. The HRC-S HV should be activated and background measurements performed similar to those done during Period 1 as described above. While much of the background collection could be accomplished while in next-in-line mode, at minimum six hours of HRC observing mode should be used for collecting background data from the HRC-S. When active anti-coincidence is disabled, HRC observing mode telemetry must be used in order to handle the expected higher event rates. Roughly half the time between opening the HRC housing door and moving the HRC to the telescope aim point should be devoted to HRC-S verification and half to HRC-I. Once again, the HV must be switched off before switching from HRC-S to HRC-I. As above the HRC-I HV will be activated and background measurements performed with at least six hours of HRC observing mode available.

Once the HRC-I is positioned at the aim point of the telescope, most of the same tests that were performed with ACIS will be done with the HRC. Since this is the first time that the HRC fiducial lights can be viewed by the ACA, check-out of them must be performed prior to any of the imaging tests as knowledge of the aspect is critical to the tests. The first HRC activity to be performed is a focus determination. The implementation of this activity for the HRC is quite different from that for the ACIS. Instead of taking a set of "focus plates", the HRC uses a Foucault shutter out in front of the MCP to block all but a single quadrant of the x-ray beam from the HRMA. The position of best focus is found by determining the differences in the centroids of the light distribution coming from the different quadrants. The two shutter blade positions are set by serial commands. A single command selects shutter Y+, another command enables the motor drive and a series of commands moves the shutter a specified number of steps to the desired position finally the motor drive is disabled. All motors are deselected then a similar set of commands are used to position the Y− shutter. After the first quadrant of data is collected, the Y+ shutter is moved to change which of two quadrants is blocked. After data collection form the second quadrant is complete, the Y− shutter is moved. Finally to open the last quadrant the Y+ shutter is moved back to its previous position. At the end of the focus test the shutters are moved back to their stowed position: for each shutter the motor is selected, motor drive enabled and motion command to move to its limit switch. The duration of this test will depend on the target selected for use during focus determination. Assuming the selected source produces 1 counts s^{-1} in the HRC or 0.25 counts sec^{-1} when all but a single quadrant is blocked, the time required for each quadrant exposure is TBD After analysis of the data a new best focus position may have been found; the SIM focus should be moved to this new position.

Verification of the imaging performance and the determination of the boresight and plate scale will begin after the HRC-I focus determination. These activities will be accomplished through the observation of a variety of different targets. For boresight determination, point sources will be observed at a range of off-axis angles and open star clusters with many known x-ray sources (e.g. the Pleiades) will be observed. The open star cluster observations will also provide data for a plate scale determination. As with the ACIS verification, we will verify that translation of the SIM results in the expected image shifts. To the extent that it is possible, the HRC verification targets will be selected to permit verification of other observatory subsystems.

A similar set of verification tests will be performed with the HRC-S prior to the start of LETG verification. The HRC-I and the center segment of HRC-S are not co-planar, since the HRC-S is set to approximate the Rowland circle of the OTGs. We will use the focus determination to verify the off-set. Since we expect to not be at the best focus, the SIM focus position will not require a change to bring us to focus.

2.5 Grating Activities

Grating verification activities cannot begin until Period 2 and each grating insert and retract mechanism must not be operated until the start of their respective grating verification. We do not anticipate the operational verification of the grating insert and retract mechanism to be more than a single insert and retract; this can be done as part of the grating verification. The HETG verification will be performed only with the ACIS-S; likewise, the LETG verification will only be performed with the HRC-S. Grating verification will consist of observing celestial targets and analyzing the data from the FPSI for the expected performance.