HRC AND GRATINGS OPERATIONS MANAGEMENT CONCEPTS

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1 INTRODUCTION

1.1 Purpose

To fulfill the ASC scope of Science Operation of the AXAF High Resolution Camera (HRC), and of the gratings instruments, we are developing a plan to analyze all the requirements and interfaces relevant to the scientific operation of HRC. This plan should then cover, in more detail than appropriate for DR ASC SE06, (science mission operations plan), how the ASC will actually handle the HRC, LETG (Low Energy Transmission Grating), and HETG (High Energy Transmission Grating) science mission operations.

Some of the operations considerations unique to HRC are concern during the initial turn-on of high voltage, reduction and restoration of high voltage in the presence of large fluxes of charged particles, calibration of the position response of the microchannel plates, use of internal blade mechanisms to provide quadrant shutters for focus and tilt measurements, use of internal radioactive calibration sources, the finite count life of the microchannel pores which implies needs to manage the aim point selection for sources and avoid slews across bright sources.

Both gratings experiments are concerned with the fail safe operation of the grating deployment mechanisms, and with calibrations to establish the absolute energy scale and to allow unfolding of higher order spectral lines which will be superposed on the first order dispersed spectrum. Some of the operations considerations unique to LETG are determination of the efficiency of the HRC at the lowest energies (down to 80 eV), saturation of the zero order image on the HRC. Some of the operations considerations unique to HETG are ACIS counting rate limitations. All these are discussed in more detail in sections 2 (HRC) and 3 (gratings).

Both to develop and to carry out the plan, the ASC will work closely with the HRC IPI team at SAO, the LETG team at SRON and MPE, the HETG team at MIT, the MSFC AXAF project, the off-line software system developer CSC, the Mission Operations Lab and On-line system elements, and the TRW Flight Operations Team (FOT) to ensure reliable, flexible and efficient operations.

This document is intended as a prose description of our ASC HRC and gratings operations concepts. It provides a tutorial description of what are the constituent elements of HRC operations. We intend to identify all internal ASC requirements and all interfaces which must be analyzed, and to describe our current operational concepts for HRC. Text enclosed in [brackets] flags issues and questions which need to be addressed as we complete our plans and operational capabilities relative to HRC. The milestones and schedules for development of the required operations capabilities will be defined to support the Integrated Operations Schedule, document AMO-1001. This specific issue is intended as draft suitable for circulation among the elements of the ASC concerned with HRC and gratings, to solicit comments and corrections on our concepts for scientific management of HRC. We expect the operational aspects of HRC to remain volatile, as the instrument undergoes final assembly and test prior to delivery in late 1996.

1.2 Top Level Functions

The ASC management of HRC and gratings operations must include execution of the following functions:

1. Initial activation of the instrument on-orbit, initial configuration, and performance verification during the Orbital Verification (OV) phase.

2. On-orbit calibrations, including those performed as part of OV or immediately thereafter. These calibrations will include measurements of celestial sources, of the HRC on-board radioactive sources, and of background levels through analysis of blank sky data and data in the stowed position. [The ASC calibration group will develop the on-orbit calibration concepts, scenarios, and plan, within the Science Operations Team (SOT).]

3. Perform scientific observations as specified by the IPI/IDS/TS guaranteed time observers (GTO) and by general observers' (GO) peer reviewed proposals. Provide a limited set of standard choices to define the aim point, define suitable ACIS modes specific to gratings, and support assessment of event pile-up limits and operational work arounds.

4. Monitor the performance of HRC and gratings over time. Predict performance trends, identify needs for calibrations, changes to data processing, and changes to mission planning and scheduling of HRC or gratings, detect anomalies, and support resolution of all anomalies.

5. Reconfigure HRC following performance degradations; e.g., redefine standard aim points if parts of the microchannel plate become "burned out," (actually, reduced in their gain) due to high count exposure.

6. Perform maintenance operations, TBD.

7. Provide information for the Science User community, via the ASC User Support Group.
8. Interact with the Flight Operations Team (FOT) on HRC and grating scheduling issues, and review and iterate those schedules which the FOT produces.

HRC and gratings operations management does not include direct User Support functions, nor Data System functions such as data reduction and generation of data products, or validation of the data reduction.

1.3 Applicable Documents

Science Instrument Team Documents

HRC DR SOP 01, Science Instrument Operations Handbook, Version TBD

HRC DR SSE10, IP&CL

LETG SOP 01, Science Instrument Operations Handbook, Version TBD

HETG SOP 01, Science Instrument Operations Handbook, Version TBD

MSFC Documents

ASC/OCC ICD

AMO-1001, Integrated Operations Schedule

ASC Documents

ASC Science Instrument Notebook (SIN)

ASC SE06, Science Mission Operations Plan

ASC SE03, Data system Requirements

ASC (internal documentation), detailed requirements for the monitoring and trends analysis software.

ASC (internal documentation, in preparation), Science Operations Team development plan.

ASC (internal documentation, draft 29 March, 1996) ACIS Science Operations Management Concepts

ASC (internal documentation, in preparation), Spacecraft and Aspect Science Operations Management Concepts

ASC (internal documentation, 26 October 1995), Mission Planning and Scheduling list of SI considerations affecting the off-line scheduling system:
WWW file `/proj/asc/MP/DOCUMENTS/html/ascii/si_rules.txt`

ASC Mission Planning and Scheduling list of observing scenarios (27 September 1995):
WWW file `/proj/asc/MP/DOCUMENTS/html/ps/axaf_obs.ps`

TRW Documents

TRW OP03b, Standard operations procedures

TRW OP05, Operations Constraints, Restrictions, and Limitations (CARD)

TRW OP16, On orbit activation requirements

TRW OP17, On orbit activation timeline

2 HRC OPERATIONS CONSTITUENTS

2.1 On-orbit Activation and Verification

The ASC will work with TRW to provide appropriate inputs to and review of OP16 and OP17. Those documents will provide the definitive requirements and timeline of HRC activities in this mission phase. The OV phase has been divided conceptually into phase 1, defined as prior to opening the ACIS door, and phase 2 subsequent to opening the door. We briefly describe here the OP16 plans for these phases. A description of the check-out of one major HRC component, the HRC-S high energy x-ray suppression filter, is not included in this section; it will be covered in the gratings on-orbit activation section.

2.1.1 Phase #1

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 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. There is no constraint imposed by the HRC on how early in the mission this can occur. The initial turn on requires a sequence of discrete hardware commands and serial digital commands. Discrete hardware commands are used to configure the primary and redundant sides of the electronics and activate the power bus. Serial digital commands to the HRC instrument are used to configure it to a known initial state. The serial digital commands will be used to turn on the HRC low voltage power supplies, enable or disable various circuits, and set each of the on-board HRC discriminators to their nominal value. We will verify that the HRC low voltage power supplies are generating the expected voltages and currents and that the HRC has the expected temperatures at its different components. Voltage, current, temperature and instrument status values appear in the housekeeping portion of the HRC science data telemetry, sampled every 2.05 seconds when the HRC is in observing mode (every 32.8 seconds in next-in-line mode).

Once we have turned on the HRC instrument and verified its nominal performance, the HRC on-board electronic pulse generation system can be used calibrate the end-to-end gains and off-sets of its amplifier chains. Voltage pulses are applied to the bottom electrode of the bottom MCP and capacitively couple to the crossed grid charge detector position readout. The pulse rate is $\sim$100 events s^{-1} and is synchronized to the spacecraft timing signals. 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 60 amplifiers along each axis of the HRC-I, the forced coarse position command for each axis must be issued 60 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 chain.

The anti-coincidence shield PMT HV can be activated anytime after the HRC instrument has been initialized. (Note: there is no constraint on how low the pressure must be before the PMT HV can be turned on.) 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 promptly sense it and issue the commands to shut off the HV. Activation of the PMT HV consists of a sequence of serial commands: one to turn on the HV and several 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 2.05 second interval in observing mode.

The HRC MCP high voltage power supplies must not 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 OP16 places 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 HRC detector housing door must be opened to allow residual gas within the HRC detector housing to escape before either MCP HV supply is activated for the first time; this will be done 1 day (TBR) before HV turn on. In order to minimize potential contamination of the HRC MCPs and to enable the MCPs to view the internal calibration source, the door will be closed but not sealed prior to switching on the HV.

The MCP HV initialization process for both the HRC-I and HRC-S sets the initial HV levels of the top and bottom MCPs to their minimum levels; as a precaution these commands will be re-issued prior to turning on the HV power supply. Turning on the MCP HVPS is a critical command and should only be issued after the operators have verified that the HRC and its environment are safe for HV activation. The HV to the top and bottom MCP will be ramped to their operational levels through serial commands raising the level one step at a time alternating between the top and bottom MCP HVPS. If the number of steps are not equal for the top and bottom plate, the extra steps will come at the end of the sequence. During the initial HV activation for both the HRC-I and HRC-S, at each step there will be a pause to verify proper MCP operation. Only one of the detectors, HRC-I or HRC-S, may have HV on at any given time. The HVPS must be commanded off before switching between detectors. To switch off the MCP HVPS the HV levels are commanded to the lowest value and then the HVPS commanded off.

The HRC-I MCP HV is activated first and instrument housekeeping and MCP event rate data are monitored to verify nominal instrument performance.

Once the MCP HV levels are set to their operating levels, a detector background measurement will be performed. The expected total background event rate is $\sim$0.25 counts cm^{-2} s^{-1} or roughly 25 counts s^{-1} for the HRC-I. Much of this expected background is due to cosmic rays, which are flagged by the HRC anti-coincidence shield and can be rejected by enabling the anti-coincidence vetoing; with active anti-coincidence the expected background rate is $\sim$0.05 counts cm^{-2} s^{-1} or $\sim$5 counts s^{-1} for the HRC-I. The background is measured without active anti-coincidence rejection and with the HRC having observing mode telemetry; events that are coincident with shield events are flagged in a veto status word enabling event rejection during ground processing. A six hour background measurement is required to determine the non-anti-coincidence background rate to 0.3% and the background on 1 cm scales to 3%. The background will be measured with next-in-line mode telemetry using active anti-coincidence shield rejection [and without?].

At the conclusion of the background measurement on HRC-I, the internal calibration source will then be used to illuminate it with x-rays. Observing mode telemetry will be required for this measurement. Assuming the source is bright enough to produce an event rate comparable to the maximum observing mode telemetry rate of $\sim$184 counts s^{-1} or approximately 2 counts cm^{-2} s^{-1} [how strong is the source?], then a six hour (TBR) exposure will provide a 0.5% statistical uncertainty on the measurement of the detection efficiency over 1 cm scales. Before commanding the calibration source back to its stowed position, the center blanking and edge blanking function can be verified; 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.

Once HRC-I MCP operational verification is finished HRC-S can begin. 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. Since the illumination pattern of the internal calibration source on the HRC-S is different at different exposure time is required to achieve the same statistics.

After both the HRC-I and HRC-S have been through the initial operational verification described above (i.e. use of the internal calibration source is complete), the HRC vacuum housing door can be opened [are there other constraints, such as the level of outgassing, to when the door may be opened]. The HRC MCP HVPS should be commanded off prior to opening the housing to avoid possible damage to the MCPs by discharges caused by trapped gas escaping during motion of the mechanism.

After the HRC housing door is open, the HRC-I HV is activated [do we need to do this with a real time contact?]. Additional background measurements will be performed using the HRC-I; these are repeats of the measurements made with the housing door closed. At this point the HRC will not be at the aimpoint of the HRMA; it will be viewing the "fixed" part of the SIM translation table. [What will the stray light environment be at this SIM position? If the stray light level is high it may be necessary to reduce the MCP HV to zero (i.e. no background measurement with the door open).] Additional background measurements will be made with the HRC-S also.

During the phase #1 period of orbital activation and checkout, the AXAF altitude will go below 60,000 km. These times will be predicted and the HRC detector HV will be commanded to its lowest level at the time the observatory is expected to descend to 60,000 km. The HV level will be commanded to ramp back up to its operating level at the time the observatory is expected to ascend to 60,000 km.

2.1.2 Phase #2

After about 25 days on-orbit, the rate of outgassing is expected to be low enough to proceed with opening the contamination covers. We plan to open the ACIS door first, then the HRMA aft contamination cover (ACC). [Do we reduce the MCP HV to zero during the first motion of these mechanisms (ACIS door, ACC, sun shade door, SIM focus and translation mechanisms) because of the potential release of trapped gas?] We need to spend about 2.5 days (TBR) using ACIS to measure the radioactive sources inside the HRMA front cover, which establish a transfer standard from ground (at end of XRCF calibration) to orbit. The ACIS Operations management concepts (and, in more detail, OP16 and OP17), describe the initial sequence of activities using the ACIS. After focus and boresight measurements of the ACIS-S and ACIS-I detectors, we then return the SIM to bring the ACIS-S to the HRMA axis, and make observations with the HETG in the optical path [ASC CAL group to specify targets and observation times.]

The phase #2 dividing line is not clearly defined in HRC activities; some of the activities described in the phase #1 section could be accomplished after the ACIS door is open. The greatest limitation on activities may be the allocation of observing mode telemetry. During most [all] of the ACIS on-axis activities we expect the HRC to be in next-in-line telemetry mode. The phase #2 activities listed here are those that begin with the translation of the SIM to put the HRC-I at the aim-point of the HRMA.

Once the HRC-I is positioned at the aim point of the telescope, many 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. ACIS activation activities should give us a good initial guess at focus and boresight. FPSI/SIM/Spacecraft integration measurements should provide a value for departure from co-planarity of the FPSIs; this defocus will not be removed prior to focus test but rather will be looked for in the results. 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 two shutter blade positions are set by serial commands. All four quadrants are selected in turn [is there a particular sequence that should be used?]; the sequence should be repeated many times during the test to account for effects caused by long-term drifts. The position of best focus is found by determining the differences in the centroids of the light distribution coming from the different quadrants. In order to determine the focus position to within 25 microns, TBD counts [a crude model says 3000; need simulations] are required from each quadrant; the exposure time required to accumulate this number of counts depends on source selection. [ASC CAL group to specify targets and observation times.] A source with a low-energy or steep spectrum will provide the cleanest determination of the best focus. [Do we observe sources with different overall spectra at this point or wait and do this as a calibration?] At the end of the focus test the shutters are moved back to their stowed positions. 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. [ASC CAL group to specify targets and observation times.] 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. The SIM focus position will be changed only if necessary to bring the HRC-S to the proper off-set from the best imaging focus.

2.2 Mechanism Operation

The HRC instrument contains four moving mechanisms:

- Vacuum housing door
- +Y focus shutter
- −Y focus shutter
- Calibration source arm

Each of these mechanisms will be used throughout the mission. All of the mechanisms have redundant electronic control systems and all but the door mechanism have fail-safe systems. While all mechanism designs have been ground tested to several thousand cycles, mission activities will be scheduled to minimize the operation of each of the mechanisms. We will plan for no more than several hundred cycles per 10 years on orbit.

2.3 Data Queues

In the normal data mode for HRC, telemetering the event coarse position, the amplitudes of 6 position taps, the total electron signal, event flags, and a time-tag, allows for 184.39 events per second; in next-in-line mode this rate drops to 3.72 events per second. For bright, extended or multiple sources, where the average event rate exceeds the allowed telemetry rate, the detailed information on some of the events is lost. The HRC maintains an event data buffer that can hold the information for 64 events. Once the buffer is full it the full event information is lost; the information from an event must be read from the buffer before another event can be loaded. The net effect is an increase in instrument deadtime. The HRC telemetry also contains data from two MCP event counters: one for the number of MCP event triggers per second (total event rate) and another for the number of MCP event triggers which pass the enabled discrimination tests (valid event rate). These counters will register events that do not have detailed event information in the telemetry stream either because the HRC electronics were busy processing a valid event or because the data buffer was full. Using these rate data we expect to be able to determine the effective deadtime of the HRC when the telemetry is saturated.

2.4 Command Logs

All commands issued to the HRC are executed upon receipt. Every serial digital command sent to the HRC has a telemetry verifier in the HRC science housekeeping data; these verifiers appear every 2.05 seconds in observing mode telemetry (32.8 seconds in next-in-line mode). Verification of the receipt and execution of commands to the HRC requires the receipt of telemetry from AXAF and decommutation of the HRC housekeeping telemetry. We will maintain a HRC instrument configuration model that captures the expected state of the HRC based on the command load sent to the observatory. Command verification will be accomplished via comparison of the actual state as determined from telemetry verifiers with the configuration model.

2.5 Command Macros

Command macros are a FOT concept, in which multiple commands which are repeatedly used in an exact sequence are identified with a single name. The actual detailed sequence might be loaded into the spacecraft flight computer, or it might only reside in the ground Operations Data Base and be uploaded whenever used. Activity descriptions are a mission planning and scheduling (MPS) concept in which major scheduled activities can be described. Activity descriptions also provide a mechanism through which a sequence of commands or command macros can be passed the necessary command parameters for expansion into the desired command sequence load.

One specific use for command macro sequences is for support of OV, orbital verification phase, in which orbital activation and checkout take place, and for standard internal calibration measurements for which it is desirable to exercise the exact same HRC configuration over the mission duration.

We expect to have command macros for at least the following:

- Select primary/redundant side electronics
- Instrument power-up/initialization
- Turn-on MCP HV and set level
- Open/close HRC housing door
- Configure observing mode
- Configure next-in-line mode
- Switch from HRC-I to HRC-S
- Switch from HRC-S to HRC-I
- Position focus shutters
- Position internal calibration source
- Perform electronic gain calibration
- Respond to EPHIN trigger
- Recovery from safe-mode

The HRC uses a macro sequence stored in the flight software of the spacecraft on-board computer to respond to a trigger from the radiation monitor; this sequence reduces the MCP HV to its lowest level [or should it turn off the HVPS]. We will also consider defining macro sequences to reconfigure HRC after eclipse or perigee passage.

2.6 Calibration Data

There are two primary sources of calibration data: Observations of astronomical objects and data taken with internal radioactive calibration sources.

Astronomical targets are used for measurement of focus, boresight, plate scale, relative quantum efficiency, and HRMA response characteristics. These are scheduled via the OR process. Targets intended for calibration only (i.e., not as part of a scientific investigation by GTO or GO), will undergo a request and evaluation process [TBD] within the ASC, and such data goes immediately into the public domain. In addition, all data used in any scientific observation might also be used to help the calibration process, provided this can be done without compromising the exclusive scientific data rights of the observer.

Data taken with the internal radioactive X-ray source primarily are used to diagnose changes in the HRC alone; these include efficiency, gain, variations in efficiency or gain, and spectral resolution. Calibrations using the internal source are expected to be infrequent and follow a regular schedule. Some internal source calibrations will be requested as a result of performance changes identified through trends analysis. Any of these calibrations may be scheduled either through ER or OR. In order to use the internal calibration source the HRC housing door must be closed and the HRC must have observing mode telemetry. A convenient time to schedule the use of the internal calibration source may be during ACIS bakeouts. At these times ACIS will be at the aim-point of the HRMA but in a state in which it cannot make useful science observations. The HRC can have observing mode telemetry while not at the HRMA aim-point with no impact on science observation time. [During ACIS bakeout do we always want to close the HRC door? If the door isn't closed, do we have to turn down the MCP HV?]

On orbit, HRC UV/Ion shield transmissions cannot be calibrated or monitored completely independent of MCP QE. Systematic trends in changes in transmission as a function of energy, such as those caused by water or organic contamination or the loss of material form the UV/Ion shield, may be identified through the use of the gratings observations of celestial sources with the HRC as the readout. Observations of sources with different spectra without the gratings may also be useful in identifying possible transmission changes. An appropriate set of celestial sources will be selected for repeated observation with and without gratings to monitor possible changes in transmission.

The HRC has no internal mask that will permit a direct measurement of its spatial resolution. Observations of celestial sources determine the combined HRMA, PCAD and HRC spatial resolution. Multiple observations, using the HRC to view a variety of sources at different off-axis angles and using ACIS, must be jointly analyzed to disentangle the HRC specific components of the calibration. Possible changes in spatial resolution will be monitored by repeated observations of selected sources. GTO and GO observations will be examined regularly for possible changes in spatial resolution as part of monitoring and trends analysis.

The HRC position calibration will be determined and monitored based on analysis of observations of celestial sources of known locations, analysis of the location of photocathode "splotchos" around the perimeter of the HRC-I and HRC-S detectors, and electronic calibration of the gains and off-sets of the CGCD amplifiers. Observations of celestial sources determine the combined HRMA, PCAD, SIM and HRC position calibration. Multiple observations, using the HRC to view a variety of sources at different off-axis angles, using different SIM positions, and using ACIS, must be jointly analyzed to disentangle the HRC specific components of the calibration. As discussed above, either special calibration observations or regular science observations of celestial sources may be used for this calibration. The photocathode "splotchos" provide fixed reference points on the detector for determining position calibrations. Using internal calibration source observations or observations of large, bright extended sources, the enhanced QE in the region of the "splotchos" produces "sources" whose locations in detector coordinates are known. Electronic calibrations that inject a known charge into the CGCD amplifier chains will be performed during orbital activation and checkout and at scheduled times during the mission. The gains and off-sets of the amplifier chains will be incorporated in ground processing of the position signals to account for differences between amplifier chains. Changes in the gains and off-sets will require changes to the parameters for ground processing.

When the HRC is not positioned at the HRMA aim-point it will collect data which is potentially useful for background calibration. We need to manage which of HRC-I and HRC-S will have high voltage applied. As a baseline [TBR], the instrument which has been observing will continue to have high voltage (exclusive of radiation belt passage) for half of the time period not at the aim-point, and similarly the unit which is to be placed at the aim-point will have high voltage applied for the remaining half of the time prior to moving. We will plan HV turn on to include a ground contact before moving to the aim-point. In case the same unit is used in two successive periods at the aim-point we will plan whether to exercise the alternate units HV during the time not positioned at the aim-point.

[ISSUE]. Based on the definition of useful observing modes, we must define a set of standard modes in which calibration is to be performed.

2.7 Housekeeping Data

HRC housekeeping data comes in two varieties: instrument health and safety housekeeping (appearing in the 8 kbps "engineering" telemetry stream) and science housekeeping (appearing in the 24 kbps "science" telemetry stream or the 0.5 kbps next-in-line data); both varieties contain instrument voltage, current, temperature, and configuration data. The items that are telemetered cannot be changed by ground operations. The instrument health and safety housekeeping data is monitored by the FOT and the FOT will have a pre-determined responses to anomalies in this data, which will safe the instrument. The SOT will monitor both varieties of housekeeping data. The science housekeeping provides additional instrument configuration data. In particular, the telemetry verification of the serial commands sent to the HRC instrument appear in science housekeeping; this data will be compared to expected values, based on the planned command loads, to verify proper functioning of the instrument. Housekeeping data on the thermal behavior of the HRC within the thermal environment provided by the SIM will be examined for operating conditions (observatory attitude, ACIS operating mode,...) that must be avoided or might impact the quality of the science data. Information on these conditions will be fed back to MPS for inclusion in scheduling constraints.

2.8 Monitoring and Trends Analysis

The internal ASC requirements and specifications for HRC Monitoring and trends will be specified in internal ASC document [TBD]. Briefly, we expect that a monitoring pipeline will be run autonomously with the receipt of any new real-time or near real time (NRT) telemetry data to perform routine monitoring functions, database updates, reporting, and alerts. A few trends analysis pipelines will be run using telemetry and standard data products, at some regular intervals [TBD as part of the MTA software design] appropriate to the quantities being analyzed. Special case analysis will take place in response to flags or alarms produced by those pipelines, or as identified by the data validation or calibration functions, or in response to possible anomalies identified by any means. SOT Scientists will also run additional interactive analyses of HRC scientific performance on a level of effort basis. HRC data will also be used for MTA of HRMA and aspect system performance.

2.9 Eclipse Operations

There are no special operations that are required by the HRC in response to eclipse passages other than those that are dictated by overall AXAF operations. AXAF operations currently require that the HRC instrument be turned off prior to eclipse passages as part of load-shedding. Before every eclipse [TBR] the HRC instrument will be powered off [Is it absolutely necessary to power off for every eclipse?]; after eclipse egress, when spacecraft loading permits, the HRC will be powered on and placed into a configuration determined from the current observing schedule.

2.10 Radiation Belt Operations

During perigee passages the AXAF will enter the earth's radiation belts; the HRC MCP HV must be reduced to avoid damage to the MCPs caused by radiation induce high event rates. Mission scheduling will determine the times during which the AXAF is in the radiation belts; for planning purposes we will take this to be altitudes below 60,000 km. We plan to explore the possibility of operating the HRC MCP HV at altitudes below 60,000 km. The HV for the active HRC detector, HRC-I or HRC-S, will be reduced to its minimum value at the time AXAF is expected to descend to 60,000 km. The HV for the active detector will be commanded to ramp up to its operational voltage at the time the AXAF is expected to ascend to 60,000 km. Both of these actions will usually be accomplished via stored command sequences.

2.11 Maintenance Operations

During high levels of particle radiation, HRC will receive a "TRUE" for the value of the radiation monitor High Level flag. The data originates from the EPHIN (electron, proton, helium instrument) detector, and is processed by the OBC to see if it exceeds specified rates in specified EPHIN particle and energy channels, for a minimum time duration. The HRC anti-coincidence shield is an alternate source of the high rate flag. ASC will specify to the FOT the proper commands to be stored in the OBC and any new sequences to be sent to HRC to modify the shutdown logic if necessary. Also, the ASC will identify necessary modifications to the EPHIN trigger levels at which the OBC is to send the flags.

In order to avoid a high total event dose in any one spot on the HRC detectors, the selected aim point of the telescope on the HRC will be changed regularly. The SOT will maintain map of the extracted charge, determine the appropriate aim point location, and specify the location to the FOT.

Over time, the HRC gain may drop and improved instrument response can be obtained by raising the MCP HV operating level. The SOT will supply to the FOT the proper command sequences for the new HV settings.

It may be that special HRC operations must be executed in order to allow proper SIM thermal control.

2.12 Anomaly Resolution

Anomaly resolution proceeds as outlined in SE06. The core team for anomaly resolution involving HRC is the internal ASC/HRC team consisting of individuals from D&OSS, Calibration, and Science Data Systems. We expect those individuals, M. Juda, H. Donnelly, J. Drake, A. Dobrzycki, to remain as the core team for anomaly resolution, independently of their other future organizational assignments. This team will be called on in case of an HRC anomaly, and also in case of other anomalies (e.g. HRMA or aspect system) for which HRC can provide diagnostic data. The core team will be supplemented with other resources and managed at a level appropriate to the apparent complexity or seriousness of the anomaly, and by a person with expertise appropriate to the apparent nature of the anomaly.

In addition to FOT and SOT monitoring, we expect the data processing verification and validation function and the User Community to be an important potential source for alerting the existence of HRC anomalies.

2.13 User Support

Within the ASC, the SOT will interface with the User Support Team to define a menu of standard choices to offer as defaults to the Science Observers. The SOT will also work with User Support to assess the feasibility of any special HRC observing mode which is proposed, and to implement any special mode required by an accepted observation.

Standard mode choices for HRC observations may involve either selection of an HRC configuration, or of a spacecraft configuration. We expect the HRC configuration to be fixed and standard, but there might be trade-offs of high voltage setting to try to get some energy resolution information out of the charge amplitude. Examples of HRC configuration settings are on-board veto selection and center/edge blanking. An example of a special HRC configuration would be to position one of the focus shutters to block x-rays from an extremely bright source that would be within the field of view during the observation of a faint source. Examples of spacecraft configuration choices are the location of the aim points, definition of a dither mode, and telemetry allocation of either the 24

Kbps or the next-in-line mode rate of 500 bps. These issues are discussed in the Spacecraft and Aspect Science Operations Management Concepts document, currently under preparation.

These standard choices must be defined prior to XRCF calibration, so that HRC can be calibrated in the modes in which it will actually be used most often for flight observations. Aim points for imaging will be chosen near the centers of HRC-I and HRC-S, and we will also define points near the edge of HRC-I to serve for observations where it is more important to look a greater distance from the center than to cover the field symmetrically about the center.

The HRC microchannel pores take a relatively long time, tens of milliseconds, to recharge following an event. Because the HRMA image is essentially all within a single region of 3 x 3 MCP pores, only relatively weak point sources (5 to 25 counts per second) can be observed in-focus without pileup degrading the spatial resolution and accurate flux measurement. Standard choices will include off-axis and out of focus observations to alleviate this limitation.

3 GRATINGS OPERATIONS CONSTITUENTS

Issues common to both gratings include establishing the energy scale, proper calibration to allow unfolding of higher order spectra, prevention of grating deployment in case the other grating is not stowed, prevention of accidental use of the fail safe grating removal mechanism.

3.1 On-orbit Activation and Verification

On-orbit activation for the HRC was discussed above; for ACIS it is described in the ACIS Science Operations Management Concepts document.

3.1.1 Phase #1

There is no grating activity in phase 1.

3.1.2 Phase #2

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. The grating insertion mechanisms are not to be operated until after the ACIS has observed the flight contamination monitor sources which verifies that the aft contamination cover has successfully opened. The first operation of a grating insertion mechanism will come only after we have performed ACIS checkout of both the ACIS-S and ACIS-I arrays with celestial sources. 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. Checkout using the HETG/HRC-S and LETG/ACIS-S configurations will be deferred to the period following orbital activation as a calibration task. Grating verification will consist of observing celestial targets and analyzing the data from the FPSI for the expected performance.

The HETG/ACIS-S checkout will be performed at a single nominal aim point on the ACIS-S array. The LETG/HRC-S checkout will use each of the three nominal locations on the HRC-S: the center, in the thick Al strip region, in the high energy x-ray suppression filter region. [Do we need to use multiple aim point locations with the "Drake" flat because of the dependence in position of the reflected rays and high energy suppression efficiency on the aim point?]

3.2 Calibration Data

Astronomical targets, as detected and telemetered with either the HRC or ACIS, are the only source of calibration data on-orbit.

Astronomical targets are used for measurement of focus, boresight, plate scale, relative and absolute energy scale, relative diffraction efficiency as a function of energy and diffraction order, and detector and HRMA response characteristics. These are scheduled via the OR process. Targets intended for calibration only (i.e., not as part of a scientific investigation by GTO or GO), will undergo a request and evaluation process [TBD] within the ASC, and such data goes immediately into the public domain. In addition, all data used in any scientific observation might also be used to help the calibration process, provided this can be done without compromising the exclusive scientific data rights of the observer.

Calibration of the response of the gratings in conjunction with the use of the high energy x-ray suppression filter will require the use of multiple aim points in the filter region. Special dither patterns (small motion in the Z axis direction) will be required for the most effective high energy suppression.

[ISSUE]. Based on the definition of useful observing modes, we must define a set of standard modes in which calibration is to be performed.

3.3 Housekeeping Data

The grating instruments generate no housekeeping data. All inferences must be made by analysis of grating performance, as measured with either HRC or ACIS, or by analysis of HRMA and telescope data, including a temperature monitor on the yoke that holds each grating in its insertion mechanism. The latter in particular will serve to define the thermal environments of the stowed and deployed gratings.

3.4 Monitoring and Trends Analysis

The internal ASC requirements for grating monitoring and trends analysis will be specified in internal ASC document [TBD]. Briefly, we expect that a monitoring pipeline will be run autonomously with the receipt of any new real-time or near real time (NRT) telemetry data to perform routine monitoring functions, data base updates, reporting, and alerts. Since the gratings themselves do not generate telemetry data, these are all done with either HRC or ACIS experiment telemetry. A few trends analysis pipelines will be run using telemetry and standard data products, at some regular intervals [TBD as part of the MTA software design] appropriate to the quantities being analyzed. Special case analysis will take place in response to flags or alarms produced by those pipelines, or as identified by the data validation or calibration functions, or in response to possible anomalies identified by any means. SOT Scientists will also run additional interactive analyses of grating scientific performance on a level of effort basis.

3.5 Maintenance Operations

TBD. (For example, might we require the grating deployment mechanisms to be exercised at some minimum frequency?)

3.6 Anomaly Resolution

Anomaly resolution proceeds as outlined in SE06. The core team for anomaly resolution involving gratings is the internal ASC/grating team consisting of individuals from D&OSS, Calibration, and Science Data Systems. We expect those individuals, M. Juda, H. Marshall, J. Juda, J. Drake, D. Huenemoerder, to remain as the core team for anomaly resolution, independently of their other future organizational assignments. This team will be called on in case of a grating anomaly, (which must initially be diagnosed via HRC or ACIS telemetry data). The core team will be supplemented with other resources and managed at a level appropriate to the apparent complexity or seriousness of the anomaly, and by a person with expertise appropriate to the apparent nature of the anomaly.

In addition to FOT and SOT monitoring, we expect the User Community to be an important potential source for alerting the existence of grating anomalies.

3.7 User Support

Within the ASC, the SOT will interface with the User Support Team to define a menu of standard choices to offer as defaults to the Science Observers. The SOT will also work with User Support to assess the feasibility of any special grating observing mode, and to implement any special mode required by an accepted observation. These modes actually refer only to the science instrument and SIM configurations, since the gratings have no other degrees of freedom once they are deployed into the converging X-ray beam. Specific FPSI configuration issues are the selection of ACIS operating mode and the selection of the aim point and dither pattern on the HRC-S. Special observations might include for example: an observer request for an ACIS image and non-dispersive spectrum prior to an HRC-S/LETG observation, or an observer may want a specific off-axis angle for an ACIS-S/HETG observation to control which wavelengths are covered by FI or BI CCDs.