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Performance Report:

A Timeline for the Synchrotron Calibration of AXAF

Prepared in accordance with DRD# 784MA-002

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1.0 Introduction

In order to establish plans for the completion of the AXAF synchrotron calibration, we have developed a timeline for specific measurements to be made at the synchrotron. We have approached this task by developing a plan for full-detailed calibration of a single flat, and calculated from an estimate of the available beam time and operational overheads the number of such flats which may be calibrated to this degree of detail. This number of flats is slightly less than an independent estimate of the minimum number which must be calibrated, but is not significantly different compared to the accuracy of the time estimate.

Presented herein are the known elements of the timeline for synchrotron reflectance calibrations of HRMA witness samples (Section 2). In Section 3, lists of measurements to be done on each witness flat are developed. The elements are then arranged into timelines for the three beamlines we expect to employ in covering the full 50-12,000 eV energy range (Section 4). (Although the required AXAF operational range is only 0.1-10 keV, we must calibrate the extent to which radiation just outside this band may contaminate our in-band response.) In Section 5, we describe the working relationships which exist with each of the beamlines, and estimate the time available for AXAF measurements on each. From the timelines and the available time, we calculate the number of flats which could be measured in full detail over the duration of the program for each beamline. A suggestion is made regarding a minimum required baseline of witness flats from each element coating run or qualification run to be used in the calibration. We intend that this suggestion open discussion of the issue of witness flat deployment.

As presented in the Feasibility Study (SAO-AXAF-90-032), the synchrotron calibration will *require* three beamlines to allow full coverage of the 50-12000 eV energy range. This is because no single or pair of beamlines could be found which would be available to AXAF for this calibration, and which could cover that energy range. Hence, each flat for which a full-range calibration is needed must be measured on each of the three beamlines, implying that it must be cycled through the reflectometer at least three times on three separate beamline runs.

Furthermore, data runs are no more than three to six weeks in duration. As we shall show, numerous data runs on each beamline will be required to measure even a simple majority of the synchrotron-designated witness flats to be produced in the coating process. Therefore, the calibration will proceed over the entire period between coating completion and the Launch Date.

The beamlines to be used are located at the National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY. They are Beamline X8C (5000-20000 eV), Beamline X8A (2030-6200 eV), and Beamline U3A (40 - 2100 eV). The procedures for the three beamlines are different, and so a different specific timeline for a single mirror calibration will be developed for each beamline, and a separate calculation of the number of flats to be completely measured will be made.

2.0 Timeline Elements

We proceed by specifying the elements which compose the timelines. Each element or set of elements includes a sample flow diagram whence estimates of the duration of the element are derived. Written procedures will be derived from these flow diagrams. For some of these elements, actual run-time experience has confirmed the durations. For others, so indicated, only preliminary estimates exist. Some elements vary from one beamline to another. No run-time confirmations exist for elements specific to Beamline U3A, because that line is currently under construction. Timelines are based on the general algorithm illustrated in Fig. 1. This algorithm is for the execution of one calibration run on one beamline. Approximately five runs on each beamline will be required for AXAF. The algorithm includes a looping portion for these runs, corresponding to the number of separate energy sub-ranges required to cover the beamline's full range. These sub-ranges will be discussed in Section 3.

In general, angle scans precede the energy scans for each energy range. The angle scans are used to establish the alignment of the reflectometer to the beam, and to establish the sample position which will be taken as 0°00′ 00″, from which subsequent grazing angles will be set.

2.1. Sample installation

Figure 2 shows the flow of the sample installation. The sample is unpacked on a clean bench located near the reflectometer test station (RTS). It is opened to the filtered atmosphere and inspected briefly. Any obvious changes are recorded in the flat's exposure log. The sample is then moved into the exchange compartment of the RTS clean/dry box. The exchange compartment is purged with filtered nitrogen gas. Once inside the clean/dry box, the mirror is loaded into the sample holder. The holder is then mounted within the interchange chamber. The chamber is then evacuated to 1.0 x 10-7 torr.

2.2. Energy range setup

Figure 3 shows the energy range setup. Monochromator adjustments and foil filter changes are required in some cases before energy and angle scans in a particular range of energies may be performed. Rocking curves of the second monochromator crystal or tilts of the second crystal for alignment purposes may be required. Adjustments of the lift table vertical tracking may be required after rocking curves and tilt alignments are completed. Foil filters, which absorb second-order and/or ultraviolet contaminants from the beam, are ordinarily specific to a particular energy sub-range.

2.3. Normalizations

Normalizations are cross-calibrations of the monitor diode (hereafter "monitor") and the reflected flux detector diode ("detector") at specific energies or over ranges of energies. The configuration requires that the mirror be removed from the beam using a vacuum-feed-through lifting rod. The detector to be normalized is then moved into the beam path. If the detector has a limiting slit to eliminate scattered energy from the mirror, a detector scan precedes the normalization for precise detector positioning. These are done frequently to allow immediate evaluation of variations in diode detector efficiencies. Ordinarily the detectors are identical to within one percent. The error budget allows only 1% net uncertainty in each reflectance data point. (See SAO-AXAF-DR-93-035, "An Error Budget for the Synchrotron Calibration of AXAF HRMA Witness Coupons", D. Graessle, June 1993.) Immediate normalizations can limit normalization uncertainty to the 0.2% level or below.

2.3.1. Fixed energy. Fixed energy normalization is shown in Fig. 4. For scans of reflectance versus angle, at fixed energy, a brief measurement of the cross-calibration of monitor and detector is all that is needed. However, the statistics in the normalization can be reduced by taking multiple points once the configuration is established for this measurement. Typically 15 data points (monitor and detector) are taken.

2.3.2. Energy scan. Energy scan normalization is shown in Fig. 5. For energy scans, the monochromator is moved through a sequence of energies at which (usually single) data points are taken for each energy. The goal is to duplicate the sequence which will be taken with the witness flat in place. Because the monochromator does not rest for long periods of time between moves (as it does for a fixed energy-normalization) there is a possibility that the normalization at a particular energy will be different for an energy scan than for a fixed-energy normalization. The effects at issue are the thermalization and mechanical stabilization of the monochromator elements immediately after the energy is changed, which may result in flux variations with time at the 1% level or greater.

2.4. Sample lower

The sequence to lower the mirror sample is shown in Fig. 6. When installed, the witness flat and the sample holder are screwed onto the end of the sample lifting rod, which feeds through a double o-ring seal into the interchange chamber. Lowering the sample requires opening the large gate valve isolating the interchange chamber from the reflectometer chamber (the vertical gate valve or VGV), lowering the sample holder to the kinematic mounting plate, and unscrewing and retracting the lift rod. Various vacuum safety steps are taken to protect the beamline and the storage ring from vacuum accidents which might occur during manipulations within the RTS vacuum.

2.5 Angle scans and alignment correction

While the primary focus of the AXAF synchrotron calibration program is to obtain sufficient energy detail in the HRMA calibration for spectroscopic observations, significant emphasis must be placed on scans of reflectance versus grazing angle at fixed energies. These angle scans are necessary to assure the accurate beam alignments and angular certainty required for the energy scans which will follow. They also provide information about the coating roughness and thickness, which are used as fixed parameters when fitting the energy scan data for the optical constants as a function of energy.

Fig. 7 gives a symmetric angle scan with an open (i.e., unslitted) detector. Energies for these scans are selected to be in the middle of the currently set energy scan subregion. The open detector scans allow for correction of the beam alignment because there is no slit to block rays passing the sample without striking it. Fig. 8 describes the angle scan with the slitted detector. By accepting less of the scattered rays, interference effects due to reflection from different mirror coating interfaces are seen more clearly, giving data useful for determining the iridium coating thickness and roughness.

2.6 Energy scans

The energy scan is illustrated in Fig. 9. The sample is positioned at the desired angle and the energies scanned according to the prescribed sequence. Because the energy scans will be analyzed with the parameters derived from slit-detector angle scans, a slit must be used on the detector for these scans. Hence a scan of the slit across the reflected ray must be done to locate the detector. An intermediate energy point is selected to minimize any error that may occur due to beam motions caused by the monochromator. After the detector is scanned and located, the monochromator (energy) scan data are taken.

2.7 Sample lift

The sequence to lift the mirror from the beam path is shown in Fig. 10. This is used to permit normalizations, or removal of the sample from the chamber. The VGV is opened and the lift rod is lowered and threaded into the sample holder lift bar again. Then both rod and sample holder are retracted up into the interchange chamber. The VGV is then closed, isolating the sample, rod, and interchange chamber from the reflectometer vacuum. Safety procedures preceding and following the lift are similar to those of the sample lowering procedure described in Section 2.4.

2.8 Renormalization of energy scans

Because of the thermalization processes and possible mechanical irregularities occurring in the monochromator during energy scans, the normalizations may change with time for some energies. While this is undesirable, it may be unavoidable. Therefore a second normalization scan is done for each energy range after the energy scans are completed, according to the procedure discussed in Section 2.3.2.

2.9 Sample removal and repack

The interchange chamber, after vacuum precautions are taken, must first be vented so that its access port into the clean/dry box may be removed. Once opened into the dry box, the sample and holder may be removed from the interchange chamber lift rod, and taken into the dry box. The witness flat is then removed from the sample holder for inspection and repacking. Fig. 11 shows this sequence.

3.0 The Required Measurements

The listing of the full detailed measurements for each of the beamlines may be found in Tables 1, 2, and 3. Included are the angle scans set to allow angular corrections as well as provide modeling details for analysis of the energy scan data. The energy scan data in turn provide details of the features of the mirror efficiency versus energy with less angular detail. Particular emphasis is placed on regions with absorption edges for iridium, as well as oxygen and carbon (possible contaminants).

The Tables 1a, 2a, and 3a compile the energy scans required for each of the three beamlines, and Tables 1b, 2b, and 3b the angle scans required. Operationally, at least one symmetric angle scan is included for each range of energies, to insure that the reflectometer is appropriately aligned for the energy scans which will follow in that range. While some of the energies designated for angle scans correspond to specific absorption features, a majority are designated solely for the purpose of alignment of the reflectometer to the beam at an intermediate point of the energy scan range which is to be measured following the angle scan. For the energy ranges above 2000 eV, corresponding to beamlines X8A and X8C, angle scans at the extremes of the energy sub-ranges are also included in order to detect trends in the beam position and angle as the energy is varied within each sub-range. By this means, we expect to be able to recover the angle accuracy versus energy should they vary by more than 0.9 arc seconds, the precision with which the angle may be set.

Energy scans are taken at angles dependent on the energy range of the measurements; however the four mean grazing angles of the HRMA nest are always included, namely 51.865, 41.746, 36.850, and 27.382 arc minutes. The immediate reflectances at these points, plus interpolation therefrom might allow the HRMA to be modeled directly from reflectances, rather than from optical constants. The optical constants are preferred to raw reflectances because they are independent of angle. Hence the baseline program includes derivation of optical constants for each flat measured.

A key factor contributing to the duration of each timeline is the detail of the scans, i.e. the step size interval of the parameter being scanned. The energy increment used in an energy scan depends on (1) the behavior of the reflectance curve in the region being scanned, and (2) the smoothness of the monochromator throughput versus energy. We discuss these in turn.

The two most important contributions to the reflectance versus energy are absorption features (i.e. anomalous dispersion) and the critical angle cut-off. In that absorption edges are frequently irregular and with steep slopes, they require the smallest step sizes. The critical angle effect is regular and predictable, and it does not occur at angles of interest to AXAF except above 5000 eV. Most of these measurements are to be made on Beamline X8C.

The quantitative criterion for setting a maximally allowed energy increment in any given region based on the shape of the reflectance in that region must be so as to maintain an overall uncertainty of HRMA response at an arbitrary energy not greater than 1%, including energy interpolation errors resulting from an acceptable algorithm. This interpolation criterion establishes the minimal degree of detail with which absorption features and reflectance cut-offs must be scanned to describe their intrinsic shapes. Step sizes as great as 200 eV may be derived from this criterion in regions of high reflectance far below the critical angle. In the iridium M-absorption edge regions, these step sizes may be as small as 0.5 eV.

The smoothness of the beamlines' monochromatic intensity versus energy, and the smoothness of the normalization curves versus energy, become important when considering energy increments greater than 10 eV. These factors are found experimentally to be dependent to some degree on the size of the energy increment. We find that at certain specific energies within a scan region, a monitor or detector reading may be widely skewed from the trend indicated by surrounding points. The positions of these scattered points are not predictable from run to run, but are repeatable in energy during a particular run period. While the cause of this is still under investigation, the effect may be as high as 2-3% deviations from a smooth reflectance versus energy curve. The result is that several points along a scan may be displaced from the smooth curve traced by the surrounding points. Such an effect is not due to the test mirror, but due to fluctuations in the normalization at those particular energy points. What we have found is that by limiting the step size in some regions, we may either reduce this effect, or we may exclude from the calibration these badly scattered points, without sacrificing the requirements of the interpolation criterion above. Experimentally, we find that step sizes no larger than 50 eV are best on Beamlines X8C and X8A, above 4 keV. Optimal performance for both speed and detail is found with 25 eV steps, and hence we have at this point budgeted the timelines for 25 eV increments as an operational upper limit above 4 keV. Studies continue at the synchrotron to increase the step size while maintaining the point-to-point accuracy.

The scan segments for each energy range are shown in column 3 of Tables 1a, 2a, and 3a. An explanation for each table follows.

3.1 Beamline X8C measurements

Table 1 gives the specific measurements required for the 5-12 keV energy range to be covered by Beamline X8C. The energy range is divided into two segments, 5-8.5 keV, and 8-12 keV, providing 500 eV of overlap. A considerable time is spent using angle scans to determine and correct the alignment to the beam on this line, because the critical angles are smaller here than in any other energy range. Hence the minimal reflectance angle, determined by the sample size, beam width, and the alignment, must be smaller here than on the other beamlines. At least three sets of symmetric angle scans are done for each of the two energy ranges. This approach allows alignment at an intermediate energy within the range, and a check of the trend in the beam position within the reflectometer from the low extreme to the high extreme in each case. This will allow verification of 1 arc-second accuracy in the sample angle as a function of energy. The intermediate energy angle scans are done with an open detector to correct the alignment. The symmetric scans at the endpoint energies are done with slit detectors, since no correction is to be done the alignment from them. In addition, there are angle scans at each 1000 eV to provide checks and corrections to angle scan data at those values.

It is in the X8C energy range that contributions to the effective area of the outer shells of the HRMA decay to insignificance with increasing energy. Only the innermost shell has any significant contribution to the calibration at 10 keV and above (Figs. 12 and 13, effective areas derived from tabulated optical constants[1]). Hence the effective area of the HRMA as a whole decays with energy as the outer shells of the nest drop out. The detailed shape of this effect, shown in Fig. 12, will be developed from the reflectances of witness flats measured on Beamline X8C. The interpolation criterion described above is satisfied with steps of 100 eV in this range. The 25 eV operational limit is therefore employed for the step sizes.

Most of the energy scans are traversed in the full 25 eV steps, because there are no absorption features to be found in iridium mirrors over the 5-11 keV range. The L-III edge at 11,215 eV is a reasonably strong feature, but not at angles relevant to the AXAF calibration, and need not be calibrated in detail. We traverse the edge in 1 eV steps in order to locate the exact position of the edge, and use that as an energy reference at that point, to monitor the monochromator energy calibration over time.

The grazing angles selected for the energy scans include and encompass the average grazing angles of the shells of the HRMA for which there remain at least 5% reflectance. For example, there is no need to acquire data for 51.865 arc minutes over the 8-12 keV range, because the reflectance of the elements in this outermost shell has decayed to less than 5% in that energy range. It cannot contribute significantly to the HRMA response in that range, and can be ignored in the calibration. More interesting data can be taken and smaller angles than the innermost shell. We have added scans at 6 and 9 arc minutes in the 8-12 keV range to replace the 51.865 and 41.746 arc minute scans where the contributions from the latter become small.

3.2 Beamline X8A measurements

Table 2 gives the list of required measurements for the 2030-6200 eV range covered by Beamline X8A. This beamline covers the Iridium M-edges, shown in Fig. 14. The point density varies as the 2030-3200 eV range is scanned, to collect the detail of these edges fully.

The region is broken up into four subregions with some overlap at the endpoints. We have 2030-2400 eV, 2200-2900 eV, 2800-4000 eV, and 3900-6200 eV. The 3500-6200 eV range is covered in 25 eV steps for the reasons outlined in Section 3.0. The M-edge region is scanned in steps as small as 0.5 eV, particularly in the M_{III} region, because the trough is very sharp and narrow. This edge is deepest for the largest AXAF mirror pair P1/H1 (see Fig. 12), meaning that its effect on the total effective area is significant (~6%).

The angles to be measured are 8-fold, including the four mean grazing angles of the nest, and additionally 85, 65, 21, and 15 arc minutes. These will give adequate definition to the optical constants to

1. B.L. Henke, E.M. Gullikson, and J.C. Davis, "X-ray Interactions: Photoabsorption, Scattering, Transmission and Reflection at E=50-30000 eV, Z=1-92", in Atomic Data and Nuclear Data Tables, 54 (2), p. 181 (1993).

be derived as a function of energy from these data, with several detailed angle scans at fixed energies to provide the parameters to be used in the models.

The angle scans taken are to

1. correct the alignment and zero angle at an intermediate energy (symmetric, open detector),
2. determine the angular trend within the sub-range at the endpoints (symmetric, slit detector),
3. collect data for fitting purposes, to place limits on roughness and thickness parameters in the model, or,
4. obtain data at or near the troughs of the several M-edges.

In number 4 above, we are attempting to address the steep slopes of the reflectance curves, which may affect our models for fitting the data through this region. We are unable to include sufficient scans to bracket the edge minima with two or more additional energies, which might be useful for the model; we will rely on test mirror measurements to supplement the scheduled angle scans, if such measurements prove necessary to produce an adequately detailed derivation of the optical constants versus energy in this region.

3.3 Beamline U3A measurements

In the 50-2000 eV range, the reflectance for the AXAF mirrors is high, typically above 80% for all four of the mean grazing angles of the nest. We must include sufficiently large grazing angles in the energy scans to allow determination of optical constants with more careful precision than the four AXAF angles will allow. Specifically, we require overdetermination of the optical constants in order to verify their validity, and the least-squares fit requires data beyond the critical grazing angle in order to be well-conditioned.

We therefore include the four AXAF angles in all energy ranges, but add an additional four angles at larger values, varying with the energy range, in order to cover the critical angle region at all energies. Angle scans are included, but not in as great a number, due to the relative insensitivity of the angles at these energies. (Knowledge of the grazing angle to arc-second accuracy is not required over the 50-2100 eV energy range).

The energy ranges are selected by the band-pass ranges of the respective foil filters employed to remove unwanted UV radiation as well as harmonic contaminants. Foils of seven different materials will be used, specifically aluminum L and K, beryllium K, boron K, carbon K, titanium K, chromium L, and nickel L. Nine separate energy ranges are selected to optimize performance of the beamline for beam purity, timeliness, and monochromator adjustments such as reflection grating selection. Scanning the monochromator past the absorption edge of the filter will provide instantaneous energy calibration for each scan region.

We include significant detailing of the carbon-K and oxygen-K edges, which are likely to be present to some extent in the data. These contaminants will be present in varying amounts on the surfaces of the witness flats. Efforts will be made to *eliminate* any additional molecular contamination of the flats at the synchrotron. We currently believe no change in the response versus time need be allowed for any mirror due to exposure at the synchrotron laboratory. The HRMA itself has a less strict programmatic standard for molecular contamination after coating. The degree of contamination must be determined using several dedicated flats to be stored with the HRMA, and then taken to the synchrotron at different times. This initiative is beyond the scope of this report, and still in the planning stages.

4.0 Timelines for Full-Detail Calibrations

At this point, the procedures of Section 2 may be arranged into timelines for each beamline, so as to produce the required measurements in Section 3. The procedural elements are assembled in accordance with the flow diagram given in Fig. 1. Tables 4, 5, and 6 include the individual timelines for a single flat on the respective beamlines. All elements include a duration in minutes; most durations are confirmed by real-time testing. Estimated durations (untested) are indicated by "(e)". These estimates are totalled into a figure to which operator and storage ring overheads are added. We have assumed a typical operator overhead to be 15% of the running time. The storage ring overhead is taken to be 25% of the sum of the procedure duration and operator overhead estimates for X8A and U3A. A larger overhead

(40%) is chosen for X8C, because of the need to realign more frequently after new injections to the storage ring. These figures are derived from experience at the synchrotron laboratory, where we have found that about 75% (60% for X8C) of the wall time is useful for data acquisition during a typical run. The results are combined into a "total days per flat" figure at the conclusion of each table, where 1 day equals 24 hours.

All three timelines include some estimated durations, and no timeline has been executed fully or repeatedly to confirm the days-per-flat estimates. The total days-per-flat for each beamline represents an estimate of the average amount of time required to take the maximal amount of data that will be required from any single witness flat on that beamline. As presented, each timeline may be used as a procedure stacking list for calibration of a flat. A series of such procedure stacks would constitute a full procedure for a data run.

4.1 Beamline X8C, 5000-12000 eV

The shortest of the three timelines is that for Beamline X8C (Table 4). The lack of any significant absorption features in this range, except for the unimportant iridium L-III edge at 11,215 eV, is the reason for this brevity. Since no edges must be explored in detail, energy scans with 25 eV step sizes may be employed. Furthermore, the full energy range may be covered in two energy sub-ranges, so that energy range setups must be done only twice for each flat.

The energy setup includes a rock curve, a lift table tracking adjustment, and a check of the energy calibration at some energy within the energy range. Calibration of the energy consists of placing a foil EXAFS filter in the beam path and observing the monitor signal variation on a short energy scan through the absorption edge of the material in the filter. These foils may include (but are not necessarily limited to) Mn-K at 6.539 keV for the 5000-8000 eV range, and Cu-K at 8.979 keV and Pt-L at 11.564 keV for the 8000-12000 eV range.[2] The absorption features of these foils have been calibrated using double crystal spectrometers in transmission tests to determine the energy positions of their extended x-ray absorption fine structure (EXAFS) components by the manufacturer of the foils; transmission curves for these foils have been compiled and are included in a data booklet accompanying the foils at the beamline. Comparing these curves with their calibrated EXAFS with those measured in real time on X8C during mirror calibrations allows fast calibration (or correction thereof) of the energy scale.Appropriate attention must be paid to the uncertainty in the grazing angle, which is more sensitive on X8C than on any other beamline because of the energy range. At 10 keV and above, the angular accuracy required at the critical angle is one arc second to insure uncertainty in reflectance of less than 1%. (See the error budget report SAO-AXAF-DR-93-035.) Symmetric angle scans are therefore taken in the middle of each energy range to set the alignment, and at both of the upper and lower extremes to detect trends in the grazing angle versus energy. This adds a significant amount of time in the production of energy scan data with a claim of 1% accuracy, particularly over 8-12 keV. These checks of the angular accuracy will be sufficient for the error budget.

The total time required for a single flat, including overheads, is found to be 3.1 days.

4.2 Beamline X8A, 2030-6200 eV

The timeline for Beamline X8A, perhaps the most important of the three beamlines because of the detail required in the M-edge region, is shown in Table 5. Grazing angle accuracy is not as critical as for X8C, however the measurement precision allows detection of systematic errors as small as 0.2% (via testing results), and these systematic are frequently due to angular errors. Horizontal beam motion during energy scans contributes most of this error, and the degree of beam motion must be restricted. Verifications must be completed which confirm acceptable degrees of motion over an energy scan range; therefore a significant number of symmetric angle scans are required in the procedures. Energy calibrations are not necessary on X8A. These have already been done as part of separate experiments by SAO/AXAF, and the calibration in this energy range is stable to within an eV or better. The results of the

2. J.A. Bearden and A.F. Burr, "Reevaluation of X-ray Atomic Energy Levels," *Rev. Mod. Phys* **39**, 125 (1967).

X8A energy scale calibrations will be reported in separate documents currently in preparation.

For the necessary measurements from Table 2, the total time required per flat on X8A is 4.06 days.

4.3 Beamline U3A, 40-2100 eV

The timeline for U3A is given in Table 6. We have compiled the most efficient procedural approach to this calibration derivable from the available operational information for U3A, which is still under construction and testing. No mirror measurements have been made at this beamline to date. Low energy measurements have been made on U3C, a fourth beamline belonging to Los Alamos. These were found to be contaminated by stray light; furthermore the time available on U3C is not adequate for AXAF. Efforts will proceed as rapidly as possible to test this timeline before the start of AXAF witness flat calibrations in the Summer of 1995.

As indicated in Table 6, the total time estimated for each flat is 3.9 days for a full-detail calibration.

5.0 Beamline Time Allocation

The availability of operation time on a given beamline depends on the relationship established with that beamline by SAO/AXAF. Up until now the program has been oriented toward the establishment of the appropriate level of participation for the time that will be required for the measurements in each energy sub-range covered by each beamline. SAO/AXAF has become a direct participant in the program of two of the beamlines, to insure that enough time will be available for calibrations on those lines. For the third beamline, SAO will participate as an outside user, provided enough time can be had in this mode of operation.

The project has been man-loaded to include measurements at the synchrotron for 154 days (22 seven-day weeks) per year. Some of this time (24 days) is absorbed in the setup and takedown periods, and maintenance periods, which will be necessary to complete the work efficiently. The remaining 130 days are to be distributed appropriately for the calibration measurements. We have divided this time into two 50-day allotments for U3A and X8A; 30 days remain for Beamline X8C and some margin for flexibility.

A breakdown of the timelines according to the activities in the flow in Figure 1 is shown in Table 7. This table in turn presents the number of flats which can be measured at each beamline given the time allotted to that beamline. The following paragraphs give an explanation of the allocations and the number of flats thereby derived for each beamline.

5.1 Beamline X8C

Beamline X8C is heavily subscribed by many inside and outside users. AXAF will apply for time as an official outside user and attempt to secure 27 days per year for the calibration program over 1995 through 1998. Time allocation in this mode is set by the NSLS General User Oversight Committee, which has responded favorably to the program as presented in our initial General User proposal. Subsequent proposals will determine the allocation available to AXAF, and a review of the sufficiency of the time will be necessary at that time. AXAF may elect to discontinue as a General User if time allocated is not adequate, and proceed to negotiate for more usage time with the Participating Research Team of X8C.

The available beam time on X8C as a General User will be maximally around 27 days per year. Table 4 indicates that 3.2 days are necessary for each flat, given the substantial operational overhead we have estimated. Hence 30 flats may be measured on this beamline in full detail over the life of the program. These flats will have to be selected judiciously. This corresponds to roughly four flats per HRMA element. However, as noted in Section 3.1, only the P6/H6 elements contribute over the full range, and our actual measurement strategy will utilize this simplification.

5.2 Beamline X8A

SAO/AXAF has become a member of the Participating Research Team for Beamline X8A, which entitles AXAF to negotiate a fair share of the total PRT user time. (The PRT user time equals 75% of the full available time on the beamline.) Approximately 220 days per year are available on this beamline in total. The PRT allotment is then 165 days. AXAF shares the PRT allotment with two other parties, but the division is not necessarily equal. Recently AXAF has been able to acquire significantly more than 25% of these 165 days for testing purposes. However, even if AXAF were confined to one-third of the total, we would then have at least 55 days per year. SAO/AXAF has proposed to use 50 days per year during the calibration period. Hence we expect to be able to calibrate 43 mirrors on this beamline, as derived in Table 5. This corresponds to five flats per HRMA element.

5.3 Beamline U3A

SAO/AXAF has secured permission from Los Alamos National Laboratory to assemble, implement, and test U3A for use in the AXAF synchrotron calibration. SAO/AXAF is a PRT member on this beamline, as with X8A. The assembly is under way, and hence the duration of some of the timeline elements is uncertain. We have agreed to use no more than 16 weeks per year on this beamline for AXAF and AXAF-related purposes. In Table 6, we have budgeted 50 days per year to work on AXAF witness flats, as on Beamline X8A. We therefore estimate that 44 flats may be calibrated in full on U3A over the life of the program. Again, this is five flats per HRMA element.

6.0 The Coating Configuration and Selection of Calibration Flats

The coating configuration is shown in Fig. 15.[3] The shaded flats are 6"x 2"x 1" flats, some of which will be designated for synchrotron measurements. The "off-end" flats (A0, B0, C0, A6, B6, and C6) will be present for both the qualification run and the production run for each HRMA element. At least 50 of these flats are to be delivered by MSFC EB-23 Laboratory, with specifications strictly established for synchrotron calibrations. Some of the flats will be designated for HRMA contamination monitoring, and will not be part of the spatial calibration. (An additional 100 flats are to be procured by OCLI to serve as witness flats, but as of this date it is not certain that the optical surfaces of these will be both made and measured to sufficient precision to meet the error budget requirements of the synchrotron measurements.)

As an introduction of the AXAF community to the issue of selection of these flats for calibration we suggest that flats A0, A3, and A6 for all qualification runs, and flats A0 and A6 for the production runs, be selected for calibration at the synchrotron, in full detail according to the timelines given in Tables 4, 5, and 6. In particular, we will evaluate whether to measure additional qualification run flats either axially or azimuthally displaced along the HRMA surface (such as A1, A5, B3, or C3). Decision to do so requires evaluating the deletion of a full synchrotron measurement sequence for the second "off-end" sample from either the qualification or coating run. The remaining flats would be held in reserve for possible future measurements if the spatial uniformity of the HRMA becomes suspect. In the event that all mirrors are found to be identical within the error budget requirements, it will be unnecessary to measure all of the shaded flats to full detail.

The first period of calibration after the coatings have begun may be diverted to the study of all available flats from a single element coating process, because not all of the others will be available at that time (April-May 1995 according to the current coating schedule.) Rapid tests may be done to determine what if any variation exists across the entire array of flats from the first qualification run. If a set of such flats may be made available before this period, such a test could be completed before the start of the calibration. Any changes which must be made to the scheduling or selection of the flats may be made after testing such an array of flats on a single beamline. Thereafter, calibrations must be completed in a strict and timely fashion adhering to the established selection of flats.

We invite any discussion concerning the scheduling of measurements and the disposition of calibration time at the synchrotron as the AXAF community may have. The above allocations for these resources are intended to establish a baseline for the program from which to conduct such trade studies as may ensue.

3. Figure from OCLI Critical Design Audit -- Coating Station presentation, 5 April 1994, OCLI-55033-0066, Drawing number AX-0718.

7.0 References

1. B.L. Henke, E.M. Gullikson, and J.C. Davis, "X-ray Interactions: Photoabsorption, Scattering, Transmission and Reflection at E=50-30000 eV, Z=1-92", in Atomic Data and Nuclear Data Tables, 54 (2), p. 181 (1993).
2. J.A. Bearden and A.F. Burr, "Reevaluation of X-ray Atomic Energy Levels," *Rev. Mod. Phys* 39, 125 (1967).
3. OCLI Critical Design Audit -- Coating Station presentation, 5 April 1994, OCLI-55033-0066.

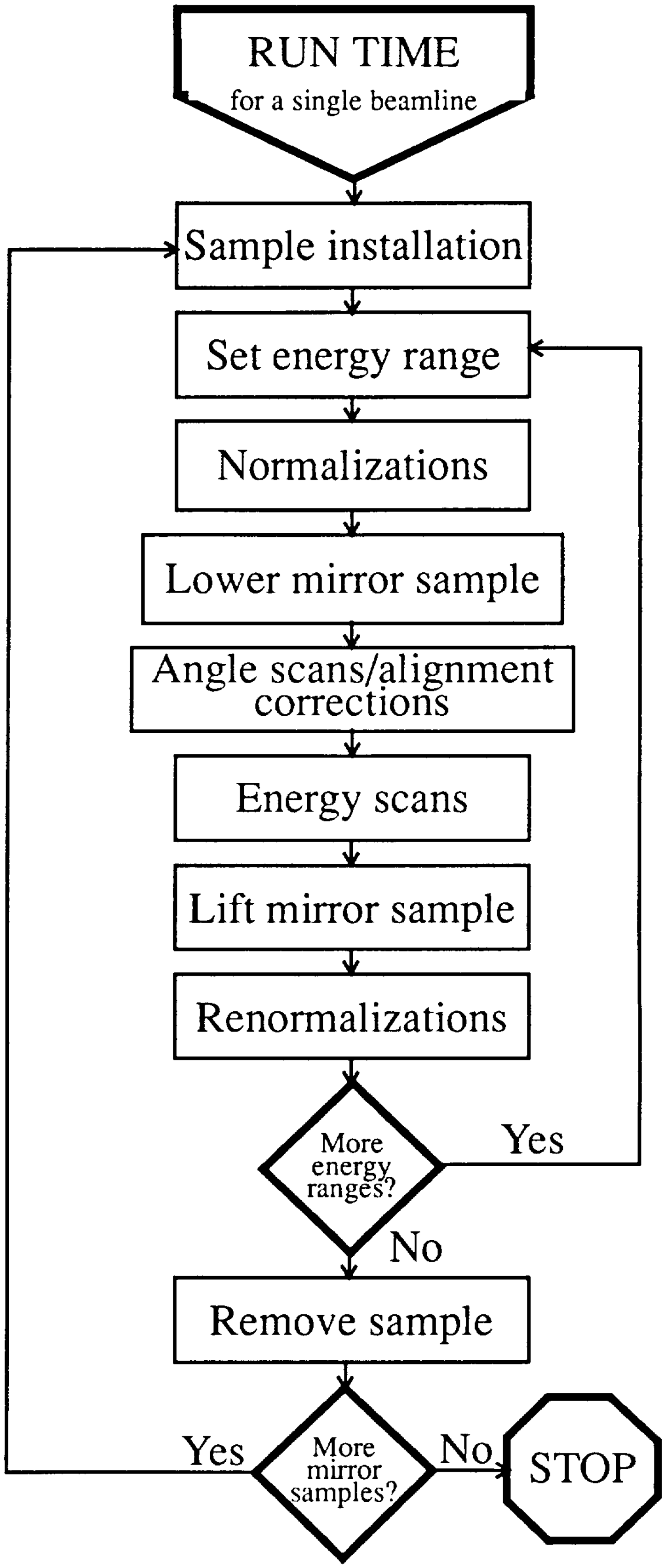

RUN TIME
for a single beamline
Sample installation
Set energy range
Normalizations
Lower mirror sample
Angle scans/alignment corrections
Energy scans
Lift mirror sample
Renormalizations
More energy ranges?
Yes
No
Remove sample
More mirror samples?
Yes
No
STOP

Fig. 1

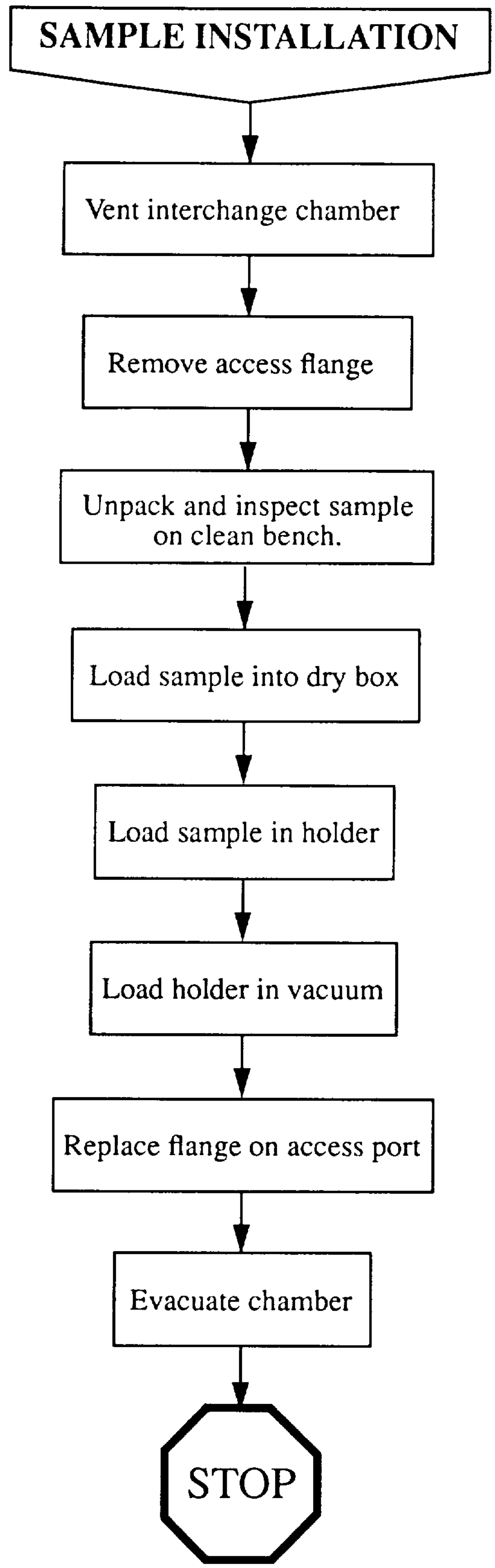

SAMPLE INSTALLATION
Vent interchange chamber
Remove access flange
Unpack and inspect sample on clean bench.
Load sample into dry box
Load sample in holder
Load holder in vacuum
Replace flange on access port
Evacuate chamber
STOP

Fig. 2

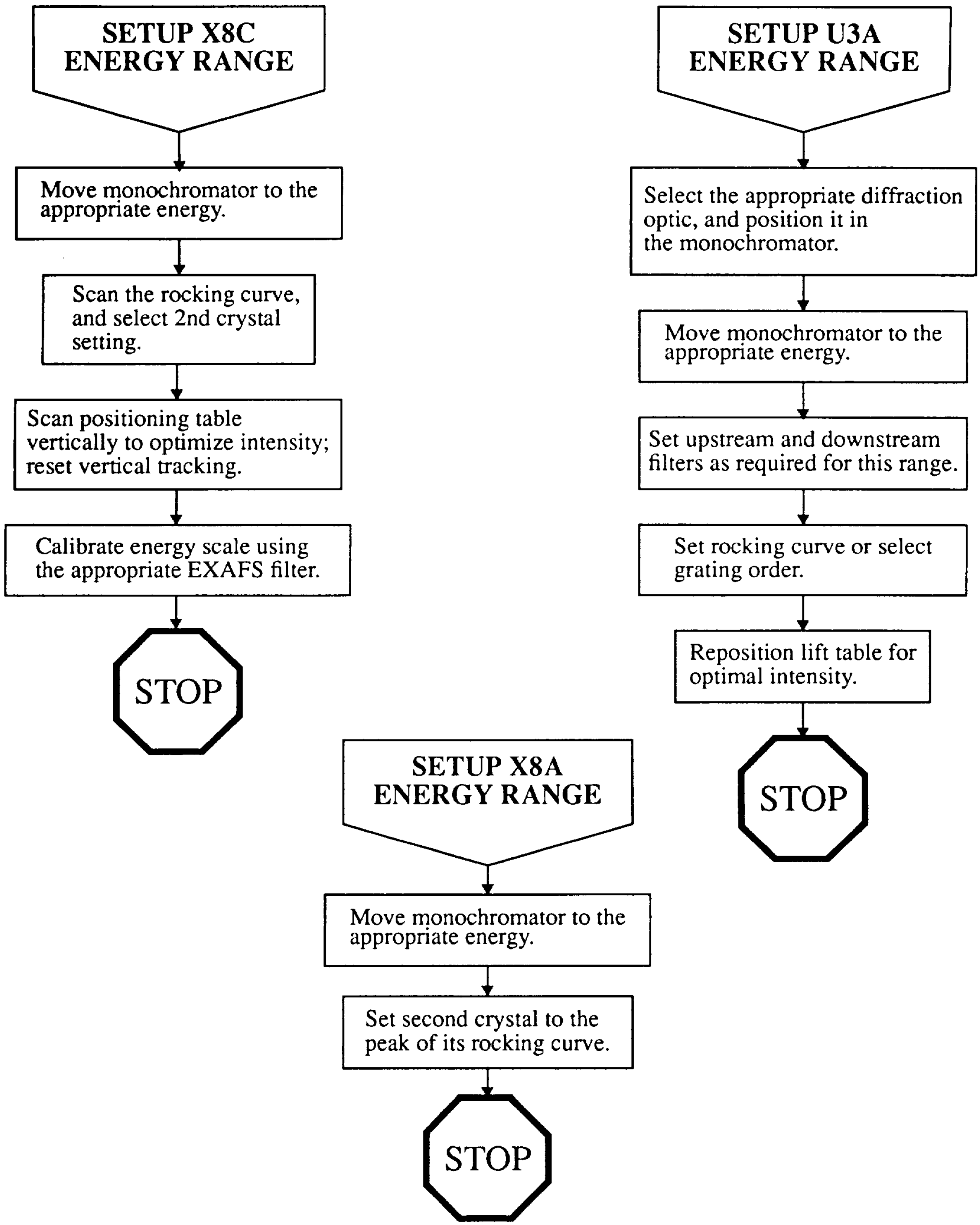

SETUP X8C ENERGY RANGE
Move monochromator to the appropriate energy.
Scan the rocking curve, and select 2nd crystal setting.
Scan positioning table vertically to optimize intensity; reset vertical tracking.
Calibrate energy scale using the appropriate EXAFS filter.
STOP
SETUP U3A ENERGY RANGE
Select the appropriate diffraction optic, and position it in the monochromator.
Move monochromator to the appropriate energy.
Set upstream and downstream filters as required for this range.
Set rocking curve or select grating order.
Reposition lift table for optimal intensity.
STOP
SETUP X8A ENERGY RANGE
Move monochromator to the appropriate energy.
Set second crystal to the peak of its rocking curve.
STOP

Fig. 3

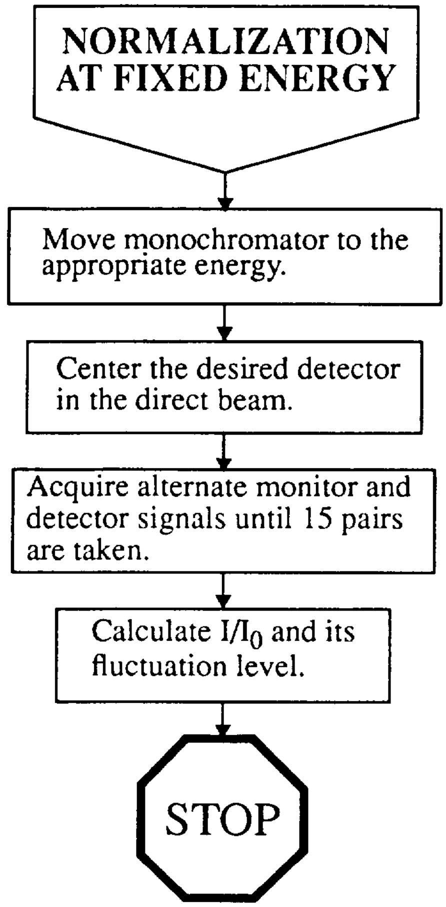
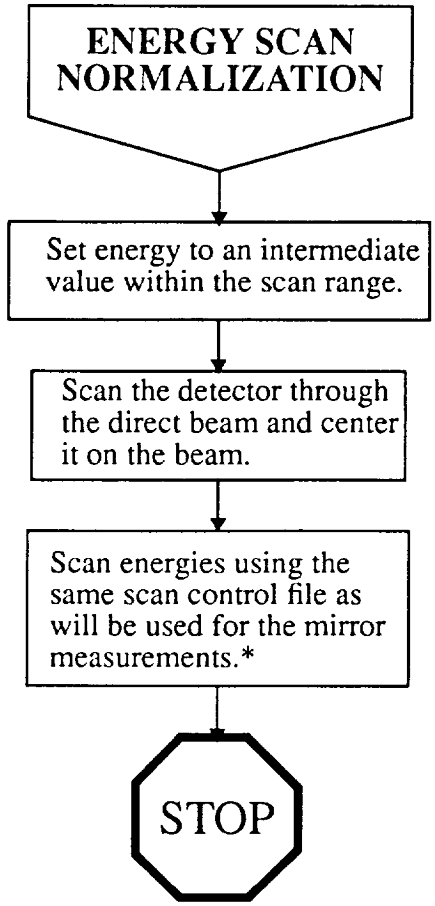

NORMALIZATION AT FIXED ENERGY
Move monochromator to the appropriate energy.
Center the desired detector in the direct beam.
Acquire alternate monitor and detector signals until 15 pairs are taken.
Calculate I/I_0 and its fluctuation level.
STOP

Fig. 4



*This means that the same points, timings, and step intervals will be used in the normalization scan and the reflectance scans, which insures normalization consistency.

Fig. 5

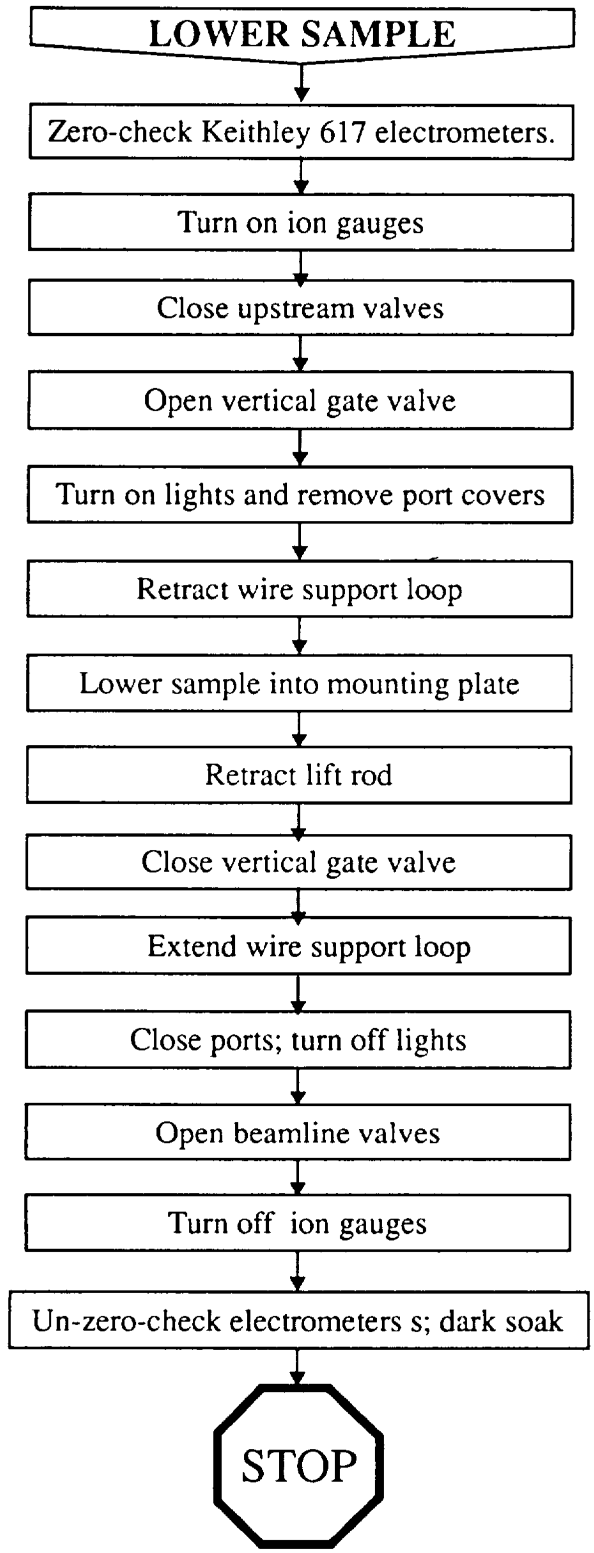

LOWER SAMPLE
Zero-check Keithley 617 electrometers.
Turn on ion gauges
Close upstream valves
Open vertical gate valve
Turn on lights and remove port covers
Retract wire support loop
Lower sample into mounting plate
Retract lift rod
Close vertical gate valve
Extend wire support loop
Close ports; turn off lights
Open beamline valves
Turn off ion gauges
Un-zero-check electrometers s; dark soak
STOP

Fig. 6

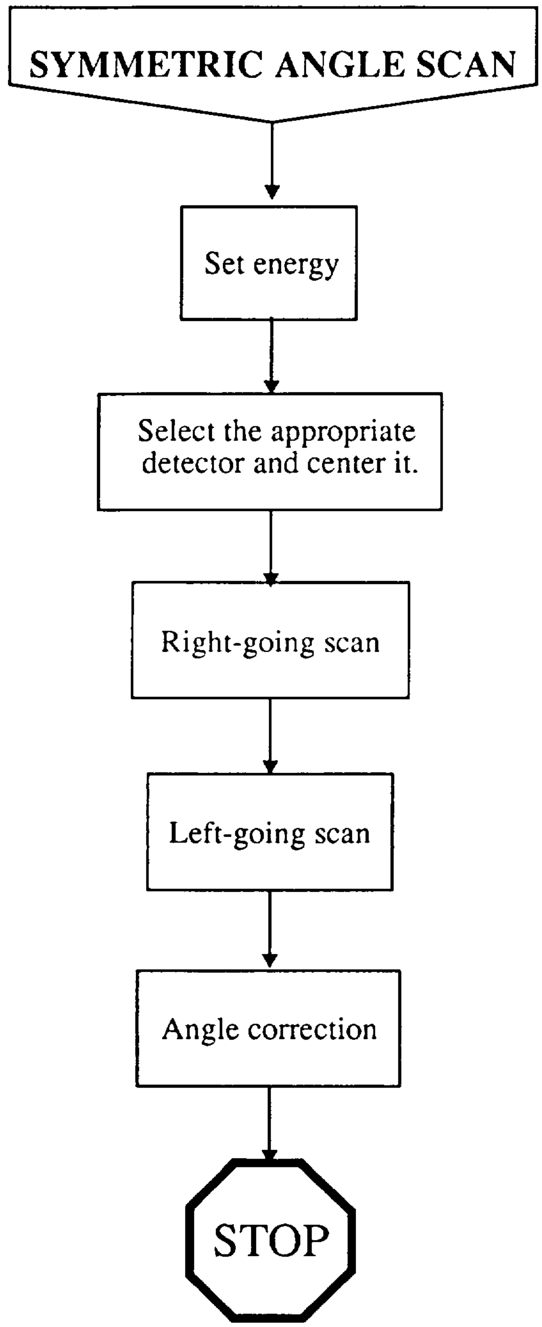

SYMMETRIC ANGLE SCAN
Set energy
Select the appropriate detector and center it.
Right-going scan
Left-going scan
Angle correction
STOP

Fig. 7

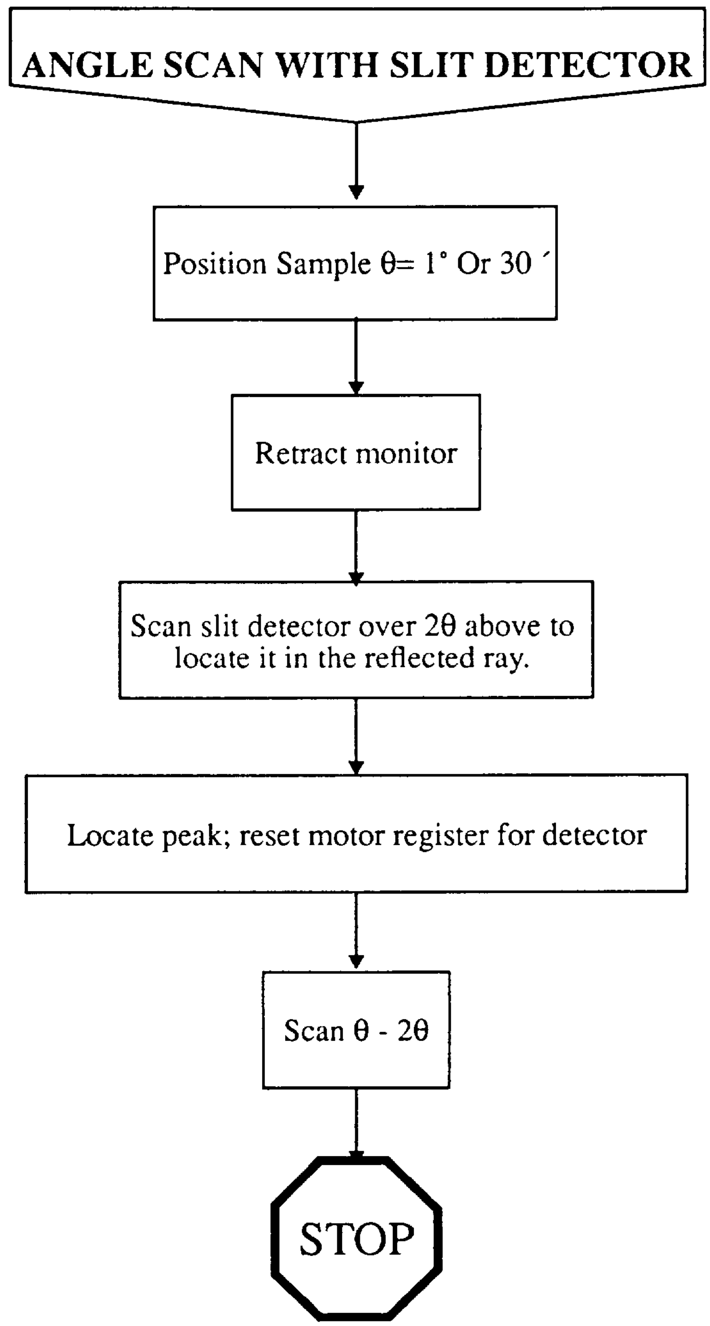

ANGLE SCAN WITH SLIT DETECTOR
Position Sample θ= 1° Or 30 ′
Retract monitor
Scan slit detector over 2θ above to locate it in the reflected ray.
Locate peak; reset motor register for detector
Scan θ - 2θ
STOP

Fig. 8

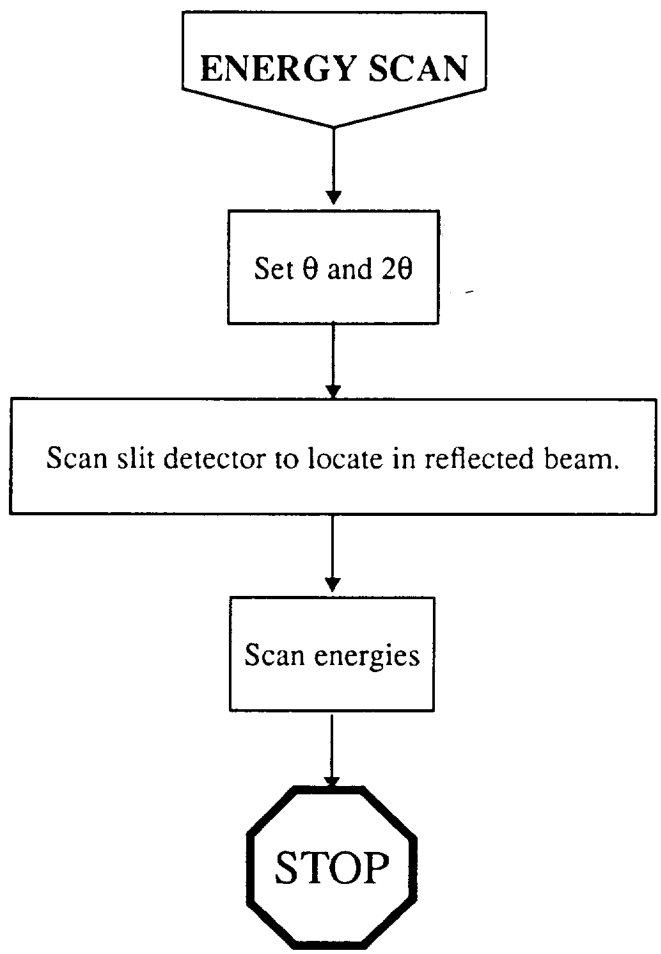

ENERGY SCAN
Set θ and 2θ
Scan slit detector to locate in reflected beam.
Scan energies
STOP

Fig. 9

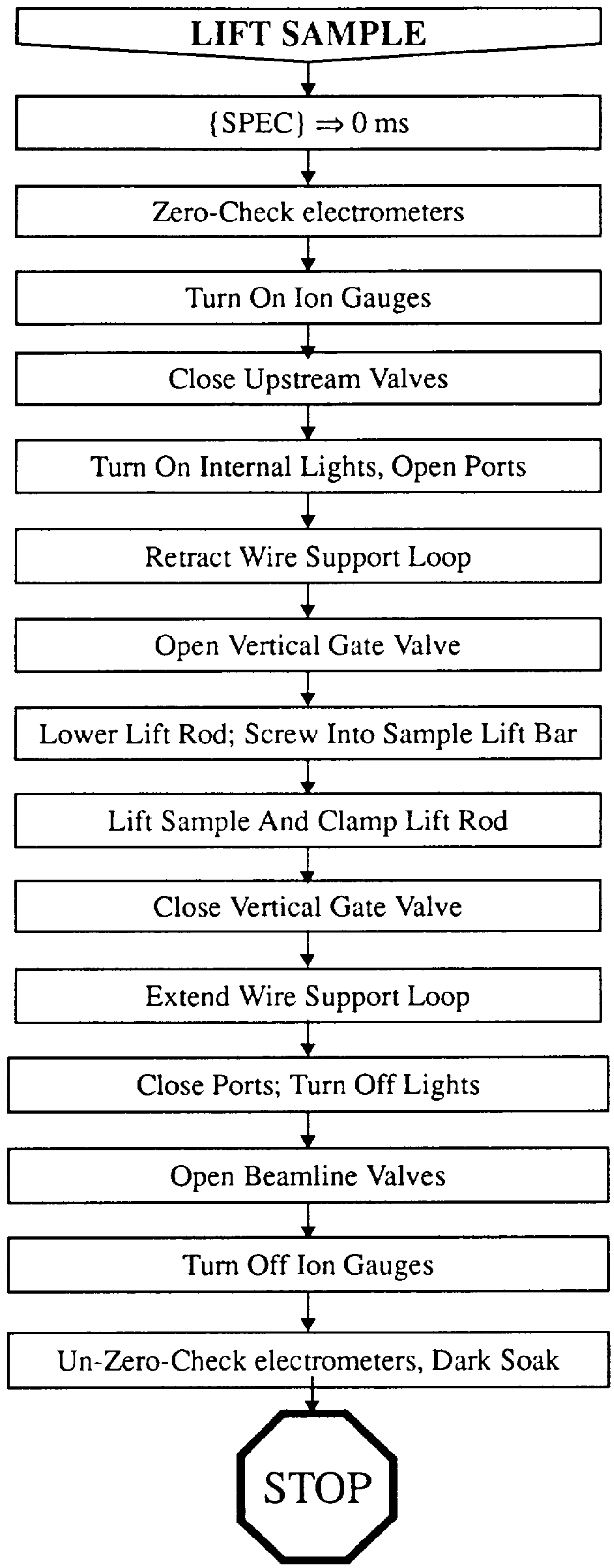

LIFT SAMPLE
{SPEC} ⇒ 0 ms
Zero-Check electrometers
Turn On Ion Gauges
Close Upstream Valves
Turn On Internal Lights, Open Ports
Retract Wire Support Loop
Open Vertical Gate Valve
Lower Lift Rod; Screw Into Sample Lift Bar
Lift Sample And Clamp Lift Rod
Close Vertical Gate Valve
Extend Wire Support Loop
Close Ports; Turn Off Lights
Open Beamline Valves
Turn Off Ion Gauges
Un-Zero-Check electrometers, Dark Soak
STOP

Fig. 10

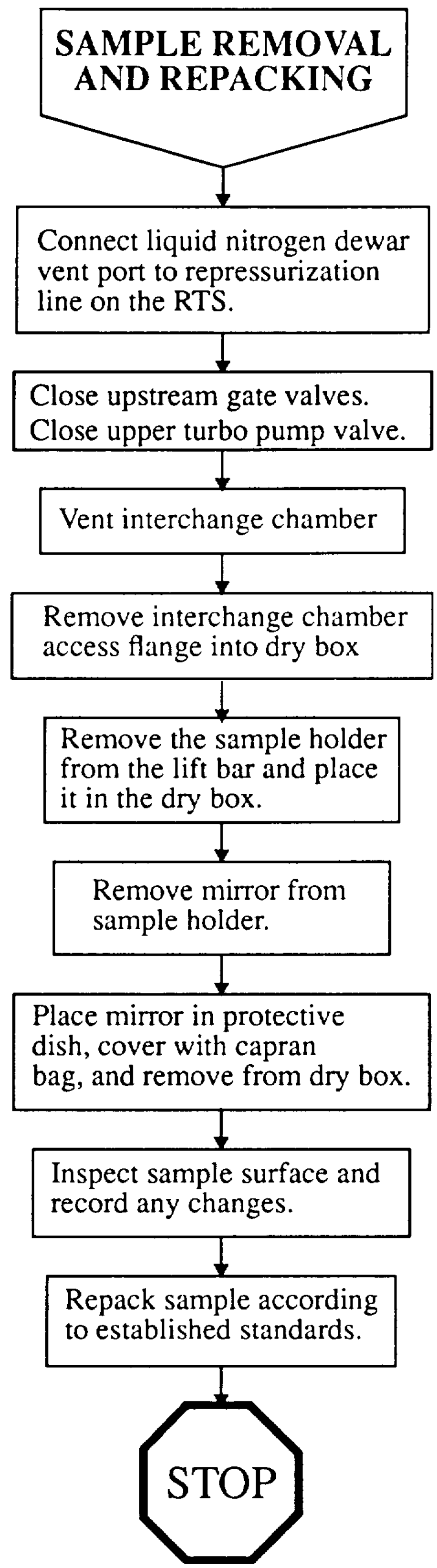

SAMPLE REMOVAL AND REPACKING
Connect liquid nitrogen dewar vent port to repressurization line on the RTS.
Close upstream gate valves. Close upper turbo pump valve.
Vent interchange chamber
Remove interchange chamber access flange into dry box
Remove the sample holder from the lift bar and place it in the dry box.
Remove mirror from sample holder.
Place mirror in protective dish, cover with capran bag, and remove from dry box.
Inspect sample surface and record any changes.
Repack sample according to established standards.
STOP

Fig. 11

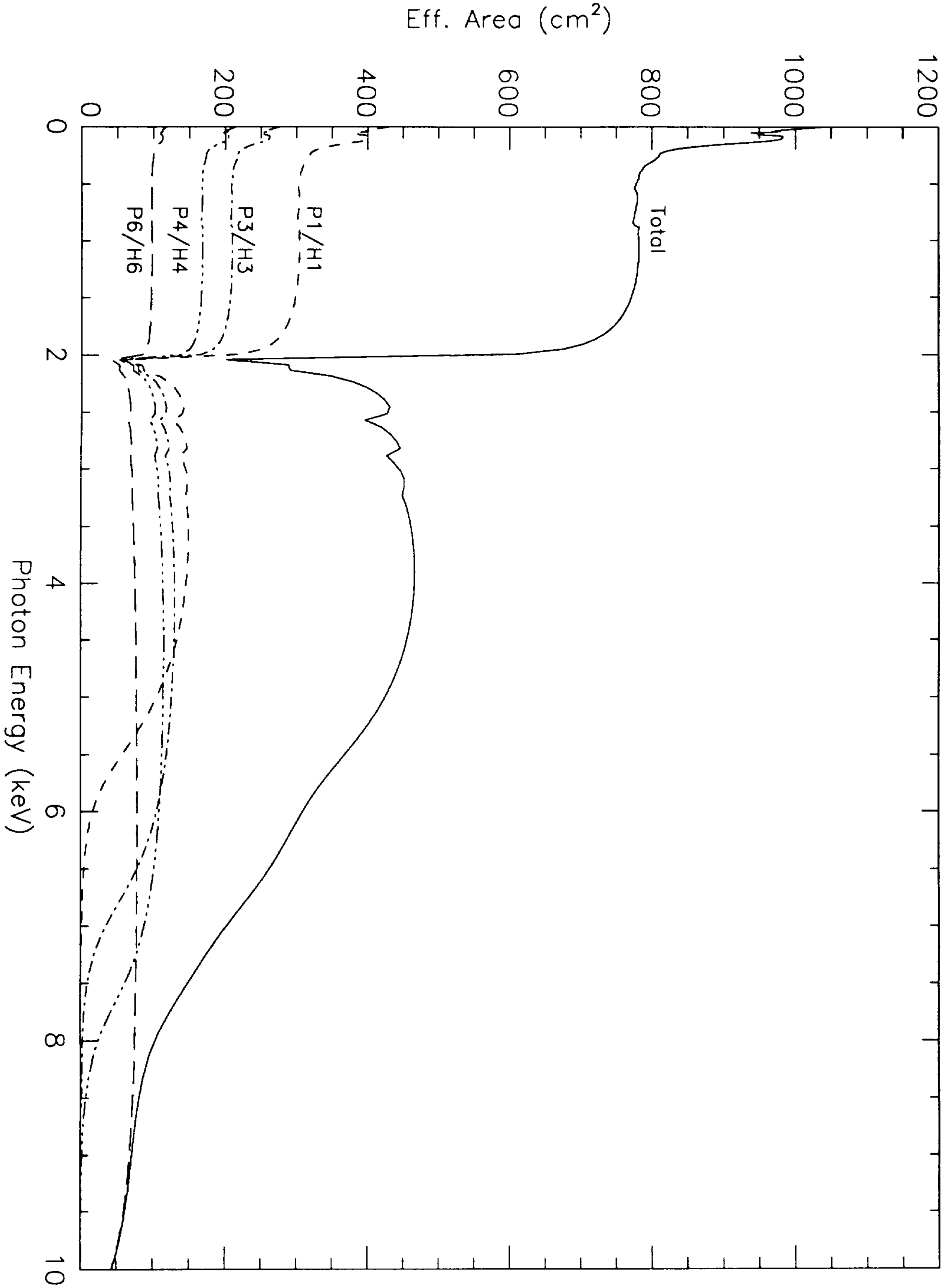

Eff. Area (cm^2)
Photon Energy (keV)
Total
P1/H1
P3/H3
P4/H4
P6/H6
0
200
400
600
800
1000
1200
2
4
6
8
10

Fig. 12

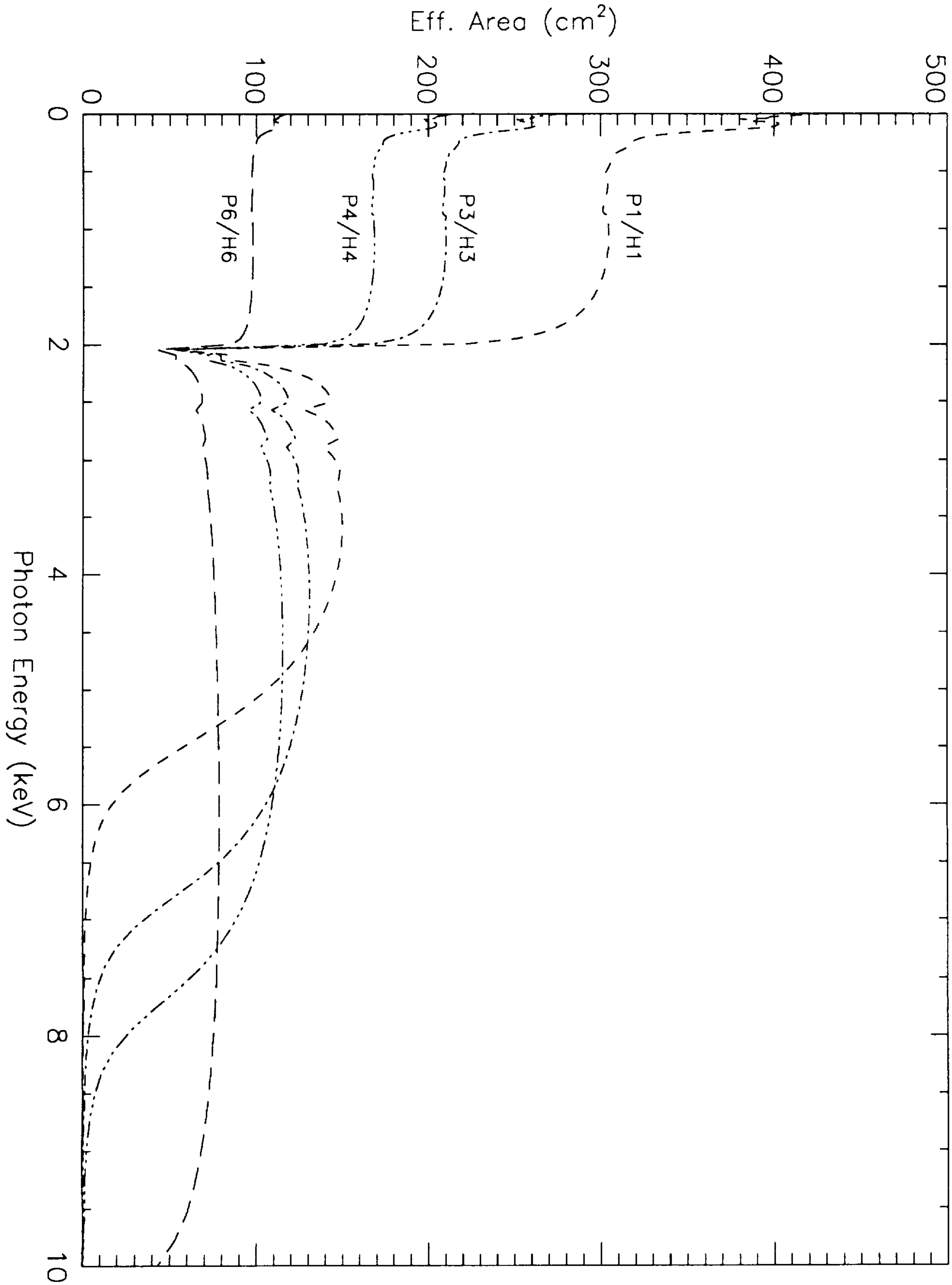

Eff. Area (cm^2)
0
100
200
300
400
500
Photon Energy (keV)
0
2
4
6
8
10
P1/H1
P3/H3
P4/H4
P6/H6

Fig. 13

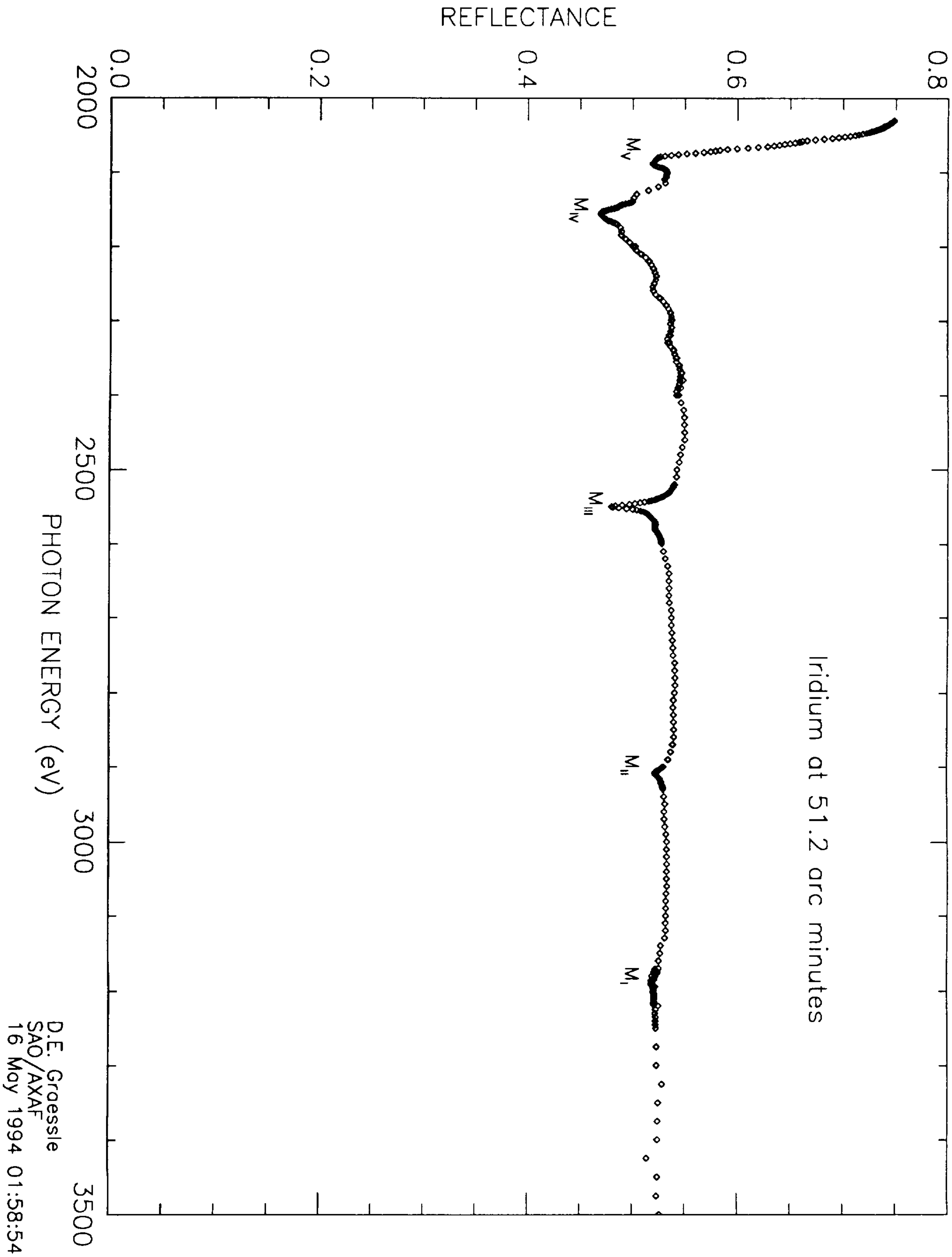

REFLECTANCE
0.0
0.2
0.4
0.6
0.8
2000
2500
3000
3500
PHOTON ENERGY (eV)
Iridium at 51.2 arc minutes
M_V
M_{IV}
M_{III}
M_{II}
M_I
D.E. Graessle
SAO/AXAF
16 May 1994 01:58:54

Fig. 14

SAO REFLECTANCE WITNESSES

AXAF-I

17 WITNESS CONFIGURATION
(Valid./Verif. Run & Prelim. Qual. Runs)

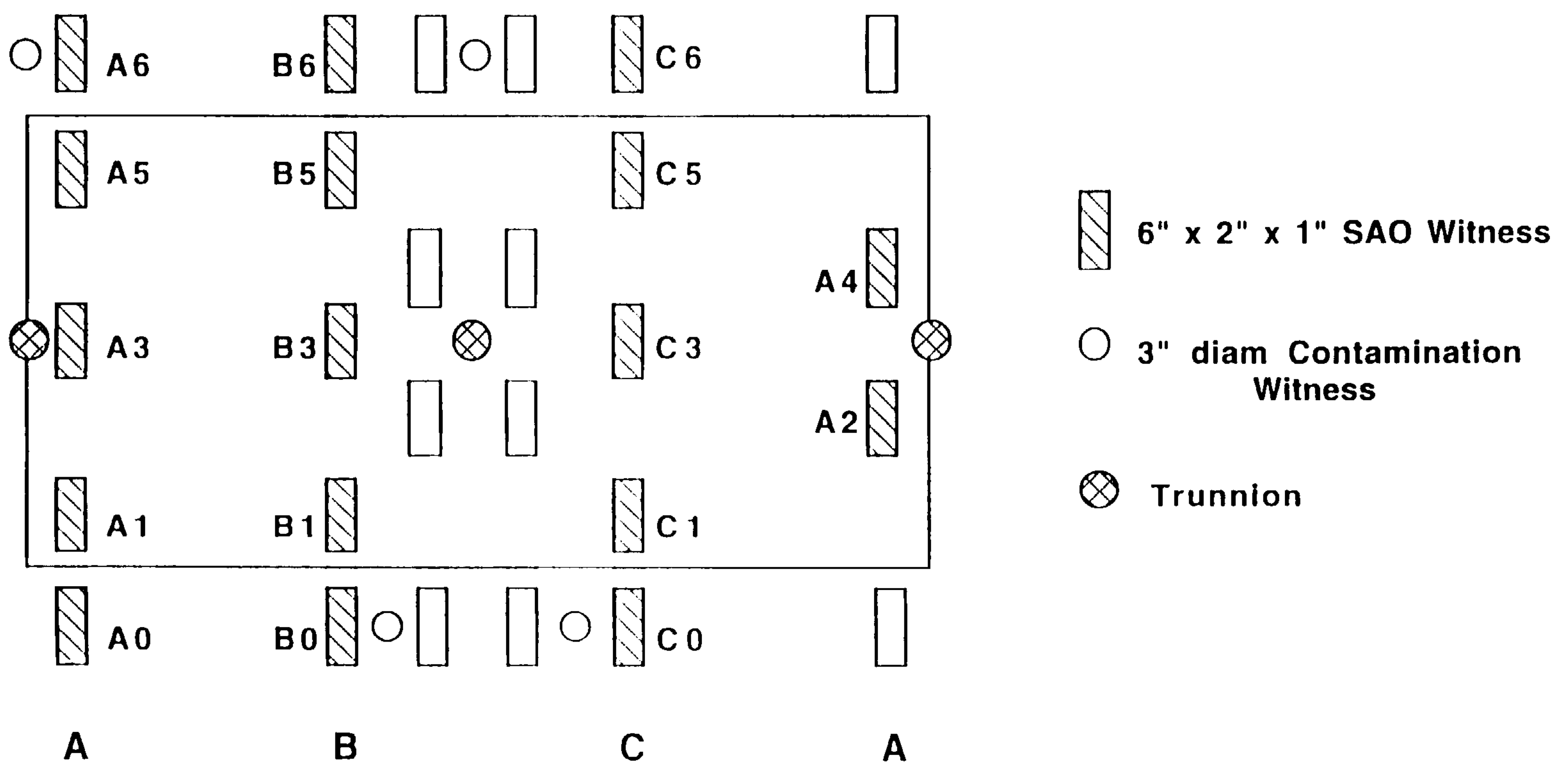


Fig. 15

AX-0718

Table 1a: Energy scans needed, high energy beamline (X8C)

ENERGY RANGE (eV)	ANGLES (arc minutes)	SEGMENTS (eV)	STEP SIZE (eV)
5000 - 8500	27.382, 36.850, 41.746, 51.865, 21, 15, 9, 31.7	5000-8500	25
8000 - 10000	51.865	8000-10000	25
8000 - 11000	41.746	8000-11000	25
8000 - 12000	27.382, 36.850, 31.7, 21, 15, 9	8000-11010	25
		11010-11025	1
		11025-12000	25

Table 1b: Required angle scans, X8C

ENERGY (eV)	Detector aperture	Symmetric?	Alignment?	Verification needed?
7000	open	Y	Y	Y
7000	slit	Y	N	N
5500	slit	Y	N	N
6000	slit	N	N	N
8500	slit	Y	N	N
10000	open	Y	Y	Y
10000	slit	Y	N	N
12000	slit	Y	N	N
8148	slit	Y	N	N
11000	slit	N	N	N
9000	slit	N	N	N

Table 2a: Energy scans needed, intermediate energy beamline (X8A)

ENERGY RANGE (eV)	ANGLES (arc minutes)	SEGMENTS (eV)	STEP SIZE (eV)
2030 - 2400	27.382, 36.850, 41.746, 51.865, 65, 85, 21, 15	2030-2110	1
		2110-2140	5
		2140-2170	1
		2170-2400	5
2200 - 2900	27.382, 36.850, 41.746, 51.865, 65, 85, 21, 15	2200-2520	10
		2520-2600	1
		2600-2900	10
2800 - 4000	27.382, 36.850, 41.746, 51.865, 65, 85, 21, 15	2800-2900	10
		2900-2930	1
		2930-3170	10
		3170-3220	1
		3220-3250	5
		3250-4000	25
3900 - 6200	27.382, 36.850, 41.746, 51.865, 65, 85, 21, 15	3900-6200	25

Table 2b: Required angle scans, X8A

ENERGY (eV)	Detector aperture	Symmetric?	Alignment?	Verification needed?
2156	open	Y	Y	Y
2156	slit	Y	N	N
2030	slit	Y	N	N
2089	slit	N	N	N
2400	slit	Y	N	N
2550	open	Y	Y	Y

Table 2b: Required angle scans, X8A

ENERGY (eV)	Detector aperture	Symmetric?	Alignment?	Verification needed?
2550	slit	Y	N	N
2900	slit	Y	N	N
2200	slit	Y	N	N
3174	open	Y	Y	Y
3174	slit	Y	N	N
4000	slit	Y	N	N
2909	slit	N	N	N
2900	slit	Y	N	N
5000	open	Y	Y	Y
5000	slit	Y	N	N
6200	slit	Y	N	N
3900	slit	Y	N	N

Table 3a: Energy scans needed, low energy beamline (U3A)

ENERGY RANGE (eV)	ANGLES (arc minutes)	SEGMENTS (eV)	STEP SIZE (eV)
40 - 80	27.382, 36.850, 41.746, 51.865, 350, 700, 1000, 1400	40-80	2
60 - 120	27.382, 36.850, 41.746, 51.865, 350, 700, 1000, 1400	60-120	2
100 - 196	27.382, 36.850, 41.746, 51.865, 250, 500, 750, 1000	100-196	2
175 - 295	27.382, 36.850, 41.746, 51.865, 120, 240, 480, 600	175-295	2
250 - 470	27.382, 36.850, 41.746, 51.865, 80, 120, 240, 480	250-280	2
		280-315	1
		315-470	5
430 - 580	27.382, 36.850, 41.746, 51.865, 100, 200, 300, 400	430-530	5
		530-550	2
		550-580	5
530 - 860	27.382, 36.850, 41.746, 51.865, 100, 200, 300, 400	530-860	5
800 - 1580	27.382, 36.850, 41.746, 51.865, 80, 120, 200, 300	800 - 1580	10
1500 - 2100	27.382, 36.850, 41.746, 51.865, 80, 100, 130, 160	1500-2030	10
		2030-2100	2

Table 3b: Required angle scans, U3A

ENERGY (eV)	Detector aperture	Symmetric?	Alignment?	Verification needed?
50	open	Y	Y	Y
100	open	Y	Y	Y

Table 3b: Required angle scans, U3A

ENERGY (eV)	Detector aperture	Symmetric?	Alignment?	Verification needed?
150	open	Y	Y	Y
220	open	Y	Y	Y
284.2	slit	N	N	N
350	open	Y	Y	Y
500	open	Y	Y	Y
700	open	Y	Y	Y
1200	open	Y	Y	Y
1200	slit	N	N	N
1800	open	Y	Y	Y
1800	slit	N	N	N

Table 4: High energy (X8C) timeline

Item	Grazing angle	Det. aperture	No. Data Pts	Duration
Unpack sample				10
Load sample in Interchange Chamber				10
Evacuate I.C.				30
Rock curve 5500 eV				15
Lift table tracking adjustment				10
Energy calibration Ni XAFS filter				40
Energy calibration Pt XAFS filter				40
NORMALIZATIONS:				
5500 eV		slit	15	15
6000 eV		slit	15	15
7000 eV		open	15	15
7000 eV		slit	15	15
8500 eV		slit	15	15
5000 - 8500 eV		slit	140	70
Lower sample				15
7 keV Symmetric angle scan/alignment correction		open	55	60
7 keV symmetric angle scan/check		open	55	45
7 keV symmetric slit angle scan		slit	55/110	60
6 keV angle scan		slit	110	40
5.5 keV symmetric angle scan		slit	55/110	60
8.5 keV symmetric angle scan		slit	55/110	60
ENERGY SCANS:				
5000 - 8500 eV	51.865'	slit	140	70
5000 - 8500 eV	41.746'	slit	140	70
5000 - 8500 eV	36.850'	slit	140	70
5000 - 8500 eV	27.382'	slit	140	70
5000 - 8500 eV	21.0'	slit	140	70
5000 - 8500 eV	15.0'	slit	140	70
5000 - 8500 eV	9.0'	slit	140	70
5000 - 8500 eV	31.7'	slit	140	70
Lift sample				15

Repeat norm scan 5000 - 8500 eV	slit	140	70
Rock curve 10,000 eV			15
Lift table tracking adjustment 10 keV			10
Energy calibration check Ni XAFS filter			40
Energy calibration check Pt XAFS filter			40
NORMALIZATIONS:			
12,000 eV	slit	15	15
11,000 eV	slit	15	15
10,000 eV	open	15	15
10,000 eV	slit	15	15
9000 eV	slit	15	15
8048 eV	slit	15	15
8000 - 12,000 eV	slit	200	85
Lower sample			15
10 keV Symmetric angle scan/alignment correction	open	55	60
10 keV symmetric angle scan/check	open	55	45
10 keV symmetric slit angle scan	slit	55/110	60
12 keV symmetric angle scan	slit	110	60
11 keV angle scan	slit	110	35
9 keV angle scan	slit	110	35
8148 eV symmetric angle scan	slit	110	60
ENERGY SCANS:			
8000 - 10000 eV 41.746’	slit	70	45
8000 - 11000 eV 36.850’	slit	120	60
8000 - 12000 eV 31.7	slit	200	85
8000 - 12000 eV 27.382’	slit	200	85
8000 - 12000 eV 21.0’	slit	200	85
8000 - 12000 eV 15.0’	slit	200	85
8000 - 12000 eV 9.0’	slit	200	85
8000 - 12000 eV 6.0’	slit	200	85
8000 - 12000 eV 24.0’	slit	200	85
Lift sample			15
Repeat norm scan 8000 - 12000 eV	slit	200	85
Repeat 12000 eV normalization	slit	15	15

Repeat 10000 eV normalization	slit	15	15
Repeat 8048 eV normalization	slit	15	15
Vent Interchange Chamber			20
Repack sample			10

Compiled total	2,810.0
+15% operator overhead	+ 421.5
Subtotal	3231.5
+ 40% overhead due to beam dumps	+ 1292.6
Total time per flat	4524.1
Total days per flat	3.1d

Table 5: Intermediate energy (X8A) timeline

Item	Grazing angle	Det. aperture	No. Data Pts	Duration
Unpack sample				10
Load sample in Interchange Chamber				10
Pump down I.C.				30
Set filter to 1.0 micron Ti				5
Rock curve for 2800 eV				15
Lift table tracking adjust 2100 eV				10
NORMALIZATIONS:				
2030 eV		slit	15	10
2089 eV		slit	15	10
2156 eV		open	15	7
2156 eV		slit	15	10
2400 eV		slit	15	10
2030-2400 eV		slit	164	74
Lower sample				15
2156 eV symmetric angle scan, align corr.		open		60
2156 eV symmetric angle scan, verification		slit		65 (e)
2030 eV symmetric angle scan		slit		65 (e)
2089 eV angle scan		slit		35
2400 eV symmetric angle scan		slit		65
ENERGY SCANS:				
2030-2400 eV	51.865'	slit	164	74
2030-2400 eV	41.746'	slit	164	74
2030-2400 eV	36.850'	slit	164	74
2030-2400 eV	27.382'	slit	164	74
2030-2400 eV	65.0'	slit	164	74
2030-2400 eV	85.0'	slit	164	74
2030-2400 eV	21.0'	slit	164	74
2030-2400 eV	15.0'	slit	164	74
Lift sample				15
Repeat norm scan 2030-2400 eV		slit	164	74
Lift table tracking adjust 2550 eV				10

NORMALIZATIONS:				
2550 eV		open	15	7
2550 eV		slit	15	10
2900 eV		slit	15	10
2200 eV		slit	15	10
2200-2900 eV		slit	144	65
Lower sample				15
2550 eV symmetric angle scan, align corr.		open		60
2550 eV symmetric angle scan, verification		slit		65 (e)
2900 eV symmetric angle scan, verification		slit		65 (e)
2200 eV symmetric angle scan, verification		slit		65 (e)
ENERGY SCANS:				
2200-2900 eV	51.865'	slit	144	65
2200-2900 eV	41.746'	slit	144	65
2200-2900 eV	36.850'	slit	144	65
2200-2900 eV	27.382'	slit	144	65
2200-2900 eV	65.0'	slit	144	65
2200-2900 eV	85.0'	slit	144	65
2200-2900 eV	21.0'	slit	144	65
2200-2900 eV	15.0'	slit	144	65
Lift sample				15
Repeat norm scan 2200-2900 eV		slit	144	65
Rock curve 3400 eV				15
Lift table tracking reset 3400 eV				10
NORMALIZATIONS:				
2800 eV		slit	15	10
2909 eV		slit	15	10
3174 eV		open	15	7
3174 eV		slit	15	10
4000 eV		slit	15	10
2800-4000 eV		slit	152	69
Lower sample				15
3174 eV symmetric angle scan, align corr.		open		60
3174 eV symmetric angle scan, verification		slit		65 (e)

4000 eV symmetric angle scan		slit		65 (e)
2909 eV angle scan		slit		35
2800 eV symmetric angle scan		slit		65 (e)
ENERGY SCANS:				
2800-4000 eV	51.865’	slit	152	69
2800-4000 eV	41.746’	slit	152	69
2800-4000 eV	36.850’	slit	152	69
2800-4000 eV	27.382’	slit	152	69
2800-4000 eV	65.0’	slit	152	69
2800-4000 eV	85.0’	slit	152	69
2800-4000 eV	21.0’	slit	152	69
2800-4000 eV	15.0’	slit	152	69
Lift sample				15
Repeat norm scan 2200-2900 eV		slit	152	69
Rock curve 5000 eV				15
Lift table tracking reset 5000 eV				10
NORMALIZATIONS:				
5000 eV		open	15	7
5000 eV		slit	15	10
6200 eV		slit	15	10
3900 eV		slit	15	10
3900-6200 eV		slit	93	44
Lower sample				15
5000 eV symmetric angle scan, align corr.		open		60
5000 eV symmetric verification		slit		65 (e)
6200 eV symmetric angle scan		slit		65 (e)
3900 eV symmetric angle scan		slit		65 (e)
ENERGY SCANS:				
3900-6200 eV	51.865’	slit	93	44
3900-6200 eV	41.746’	slit	93	44
3900-6200 eV	36.850’	slit	93	44
3900-6200 eV	27.382’	slit	93	44
3900-6200 eV	65.0’	slit	93	44
3900-6200 eV	85.0’	slit	93	44

3900-6200 eV	21.0'	slit	93	44
3900-6200 eV	15.0'	slit	93	44
Lift sample				15
Repeat norm scan 2200-2900 eV		slit	93	44
Vent interchange chamber				20
Repack sample				10

Compiled total	4,068.0
+ 15% operator overhead	+ 610.2
Subtotal	4678.2
+ 25% overhead due to storage ring	+ 1169.6
Total time per flat	5847.8
Total days per flat	4.06d

Table 6: Low-energy (U3A) timeline

Item	Grazing angle	Det. aperture	No. Data Pts	Duration
Unpack sample				10 min
Load sample in Interchange Chamber				10 min
Pump down I.C.				30 min
Set filter to Al-L				5 min
Tune monochromator to 40-80 eV range				20 min
NORMALIZATIONS:				
50 eV		open		7 min
40-80 eV		open		8 min (e)
Lower sample into chamber				15 min
50 eV symmetric angle scan, alignment		open		60 min
50 eV symmetric angle scan, verify				50 min (e)
ENERGY SCANS:				
40-80 eV	27.382'	open	20 pts	8 min (e)
40-80 eV	36.850'	open	20 pts	8 min (e)
40-80 eV	41.746'	open	20 pts	8 min (e)
40-80 eV	51.865'	open	20 pts	8 min (e)
40-80 eV	1000'	open	20 pts	8 min (e)
40-80 eV	350'	open	20 pts	8 min (e)
40-80 eV	700'	open	20 pts	8 min (e)
40-80 eV	1400'	open	20 pts	8 min (e)
Lift Sample				15 min
Repeat energy norm scan 40-80 eV		open		8 min
Change foil filter to Be-K				5 min
Tune monochromator to 60-120 eV range				20 min (e)
NORMALIZATIONS:				
100 eV		open		7 min
60-120 eV		open	30 pts	13 min (e)
Lower sample into chamber				
100 eV symmetric angle scan, alignment		open		60 min
100 eV angle scan, symmetric, verify		open		50 min
ENERGY SCANS:				

60-120 eV	27.382'	open	30 pts	13 min (e)
60-120 eV	36.850'	open	30 pts	13 min (e)
60-120 eV	41.746'	open	30 pts	13 min (e)
60-120 eV	51.865'	open	30 pts	13 min (e)
60-120 eV	350'	open	30 pts	13 min (e)
60-120 eV	700'	open	30 pts	13 min (e)
60-120 eV	1000'	open	30 pts	13 min (e)
60-120 eV	1400'	open	30 pts	13 min (e)
Lift Sample				15 min
Repeat energy norm scan 50-120 eV		open	30	13 min
Reset filter to B-K				5 min
Tune monochromator to 100-196 eV range				20 min (e)
NORMALIZATIONS:				
150 eV		open	15 pts	7 min
100-196eV		open	48 pts	20 min (e)
Lower sample				15 min
150 eV symmetric angle scan, alignment		open		60 min
150 eV symmetric angle scan, verify		open		50 min
ENERGY SCANS:				
100-196 eV	27.382'	open	48 pts	20 min (e)
100-196 eV	36.850'	open	48 pts	20 min (e)
100-196 eV	41.746'	open	48 pts	20 min (e)
100-196 eV	51.865'	open	48 pts	20 min (e)
100-196 eV	250'	open	48 pts	20 min (e)
100-196 eV	500'	open	48 pts	20 min (e)
100-196 eV	750'	open	48 pts	20 min (e)
100-196 eV	1000'	open	48 pts	20 min (e)
Lift sample				15 min
Repeat energy norm scan 100-196 eV		open	48 pts	20 min (e)
Reset filter to C-K				5 min
Tune monochromator to 175-295 eV range				20 min (e)
NORMALIZATIONS:				
220 eV		open	15 pts	7 min
175-295 eV		slit	60 pts	25 min (e)

Lower the sample				15 min
220 eV Symmetric angle scan, alignment correctionopen				60 min
220 eV symmetric verification		open		50 min
ENERGY SCANS:				
175-295 eV	27.382'	open	60 pts	25 min (e)
175-295 eV	36.850'	open	60 pts	25 min (e)
175-295 eV	41.746'	open	60 pts	25 min (e)
175-295 eV	51.865'	open	60 pts	25 min (e)
175-295 eV	600'	open	60 pts	25 min (e)
175-295 eV	120'	open	60 pts	25 min (e)
175-295 eV	240'	open	60 pts	25 min (e)
175-295 eV	480'	open	60 pts	25 min (e)
Lift sample				15 min
Repeat energy norm scan 175-295 eV		open	60 pts	25 min (e)
Reset filter to Ti-L				5 min
Tune monochromator to 250-470 eV range				20 min (e)
NORMALIZATIONS:				
284.2 eV		slit	15 pts	10 min
350 eV		open	15 pts	7 min
250-470 eV		slit	80 pts	34 min
Lower the sample				15 min
350 eV symmetric/alignment angle scan		open		60 min
350 eV verification				50 min
284.2 eV angle scan		slit	60 pts	25 min
ENERGY SCANS:				
250-470 eV	27.382'	open	80 pts	34 min (e)
250-470 eV	36.850'	open	80 pts	34 min (e)
250-470 eV	41.746'	open	80 pts	34 min (e)
250-470 eV	51.865'	open	80 pts	34 min (e)
250-470 eV	80'	open	80 pts	34 min (e)
250-470 eV	120'	open	80 pts	34 min (e)
250-470 eV	240'	open	80 pts	34 min (e)
250-470 eV	480'	open	80 pts	34 min (e)
Lift sample				15 min

Repeat energy norm scan 250-470 eV		open	80 pts	34 min (e)
Reset filter to Cr-L				5 min
Tune monochromator to 430-580 eV range				20 min (e)
NORMALIZATIONS:				
500 eV		open	15 pts	7 min
430-580 eV		open	35 pts	15 min
Lower sample				15 min
500 eV symmetric angle scan, alignment		open		60 min
500 eV symmetric angle scan, verification		open		50 min
543.1 eV angle scan		open		25 min
ENERGY SCANS:				
430-580 eV	27.382'	open	35 pts	15 min (e)
430-580 eV	36.850'	open	35 pts	15 min (e)
430-580 eV	41.746'	open	35 pts	15 min (e)
430-580 eV	51.865'	open	35 pts	15 min (e)
430-580 eV	100'	open	35 pts	15 min (e)
430-580 eV	200'	open	35 pts	15 min (e)
430-580 eV	300'	open	35 pts	15 min (e)
430-580 eV	400'	open	35 pts	15 min (e)
Lift sample				15 min
Repeat energy norm scan 430-580 eV		open	35 pts	15 min(e)
Reset filter to Ni-L				5 min
Tune monochromator to 530-860 eV range				20 min (e)
NORMALIZATIONS:				
700 eV		open	15 pts	7 min
530 - 860 eV		open	66 pts	28 min
Lower sample				15 min
700 eV symmetric angle scan, alignment		open		60 min
700 eV symmetric verification		open		50 min
ENERGY SCANS:				
530-860 eV	27.382'	open	66 pts	28 min (e)
530-680 eV	36.850'	open	66 pts	28 min (e)
530-860 eV	41.746'	open	66 pts	28 min (e)
530-860 eV	51.865'	open	66 pts	28 min (e)

530-860 eV	100'	open	66 pts	28 min (e)
530-860 eV	200'	open	66 pts	28 min (e)
530-860 eV	300'	open	66 pts	28 min (e)
530-860 eV	400'	open	66 pts	28 min (e)
Lift sample				15 min
Repeat energy norm scan 530-860 eV		open	66 pts	28 min (e)
Reset filter to Al-K				5 min
Tune monochromator to 800-1580 eV range				20 min (e)
NORMALIZATIONS:				
1200 eV		open	15 pts	7 min
1200 eV		slit	15 pts	10 min
800-1580 eV		slit	78 pts	38 min
Lower sample				15 min
1200 eV symmetric angle scan, alignment		open		60 min
1200 eV symmetric angle scan, verify		slit		65 min
ENERGY SCANS:				
800-1580 eV	27.382'	slit	78 pts	38 min (e)
800-1580 eV	36.850'	slit	78 pts	38 min (e)
800-1580 eV	41.746'	slit	78 pts	38 min (e)
800-1580 eV	51.865'	slit	78 pts	38 min (e)
800-1580 eV	80'	slit	78 pts	38 min (e)
800-1580 eV	120'	slit	78 pts	38 min (e)
800-1580 eV	200'	slit	78 pts	38 min (e)
800-1580 eV	300'	slit	78 pts	38 min (e)
Lift sample				15 min
Repeat energy norm scan 800-1580 eV		slit	78 pts	38 min (e)
Reset filter to Be-K or C-K				5 min
Tune monochromator to 1500-2100 eV range				20 min (e)
NORMALIZATIONS:				
1800 eV		open	15 pts	7 min
1800 eV		slit	15 pts	10 min
1500-2100		slit	80 pts	40 min
Lower sample				15 min
1800 eV symmetric angle scan, alignment		open		60 min

1800 eV symmetric angle scan, verify		slit		65 min
ENERGY SCANS:				
1500-2100 eV	27.382'	slit	80 pts	40 min (e)
1500-2100 eV	36.850'	slit	80 pts	40 min (e)
1500-2100 eV	41.746'	slit	80 pts	40 min (e)
1500-2100 eV	51.865'	slit	80 pts	40 min (e)
1500-2100 eV	80'	slit	80 pts	40 min (e)
1500-2100 eV	100'	slit	80 pts	40 min (e)
1500-2100 eV	130'	slit	80 pts	40 min (e)
1500-2100 eV	160'	slit	80 pts	40 min (e)
Lift sample				15 min
Repeat energy norm scan 1500-2100 eV		slit	80 pts	40 min (e)
Vent interchange chamber				20 min
Repack sample				10 min

Compiled total	3,948.0
15% operator overhead	+592.2
Subtotal	4540.2
25% storage ring overhead	+1135.0
Total time per witness flat	5675.3
Number of days per flat	3.9d

Table 7: Full Calibration of a Single Flat

Activity	U3A (min)	X8A (min)	X8C (min)
Sample installations	50	50	50
Energy range setup	225	90	210
Normalization scans	314	420	320
Lower mirror sample	135	60	30
Angle scans	1070	1090	680
Energy scans	1768	2016	1260
Raise mirror sample	135	60	30
Renormalization	221	252	200
Remove sample	30	30	30
Subtotal	3,948.0	4,068.0	2810.0
Operator overhead (15%)	+ 592.2	+ 610.2	+ 421.5
Subtotal	4540.2	4678.2	3231.5
Storage ring overhead (25%)	+ 1135.1	+ 1169.6	
Storage ring overhead (40% for X8C)			+ 1292.6
Total for a single flat	5675.3	5847.8	4524.1
Days per flat	3.94d	4.06d	3.08d

Beamline Time Allocations

	U3A	X8A	X8C
Days available on beamline per year	50d	50d	27d
Number of years in program	3.5	3.5	3.5
Number of days in program	175	175	94.5
Number of samples possible in full detail	**44**	**43**	**30**