RECEIVED BY OSTI JUN 11 1985

UCRL 15672

P.O. 4681605

ARACOR

NOVETTE DIAGNOSTIC SUPPORT

LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)
PURCHASE ORDER NO. 4681605

ARACOR FINAL REPORT FR84-270
FEBRUARY 1985

7/1/85

PREPARED FOR

LAWRENCE LIVERMORE NATIONAL LABORATORY
LASER FUSION PROGRAM
LIVERMORE, CA 94550

ATTENTION: MR. HARRY N. KORNBLUM

ADVANCED RESEARCH AND APPLICATIONS CORPORATION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

ARACOR

UCRL--15672

DE85 012937

NOVETTE DIAGNOSTIC SUPPORT

Lawrence Livermore National Laboratory (LLNL)
Purchase Order No. 4681605

ARACOR Final Report FR84-270
February 1985

Prepared by

R. Cirigliano, E. Franco, L. Koppel,
B. Rodrigues, J. Smith

Prepared for

Lawrence Livermore National Laboratory
Laser Fusion Program
Livermore, CA 94550

ATTENTION: Mr. Harry N. Kornblum

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ADVANCED RESEARCH AND APPLICATIONS CORPORATION

1223 E. Arques Avenue • Sunnyvale, California 94086 • (408) 733-7780

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

JSW

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION.....	1
2.0 DANTE X-RAY SPECTROMETER SUPPORT.....	2
2.1 Problem Statement.....	2
2.2 DANTE Novette Support.....	3
2.3 DANTE Prime.....	5
3.0 ELLIPSOIDAL X-RAY OPTIC CHARACTERIZATION.....	48
3.1 Problem Statement.....	48
3.2 Computer Simulation.....	49
3.3 Experimental Procedures and Apparatus.....	68
3.4 Summary of Experimental Data.....	89
4.0 X-RAY LASER END MIRROR PREPARATION.....	90
4.1 Problem Statement.....	90
4.2 LSM Dispersion Simulation Technique.....	92
4.3 Simulation Results.....	93
5.0 X-RAY LASER EXPERIMENTAL SUPPORT.....	103
5.1 Problem Statement.....	103
5.2 Data Reduction Procedures.....	103
5.3 Reduced Data Sets.....	130
6.0 NOVA RHO-R DIAGNOSTICS: NEUTRON TIME-OF-FLIGHT.....	145
6.1 Problem Statement.....	145
6.2 NTOF Instrumentation Options.....	146
6.3 Recommended Instrumentation Approach.....	153
APPENDIX A.....	A-1
APPENDIX B.....	B-1
APPENDIX C.....	C-1

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
Section 2.0	
2. 1 In-band photocathode response changes for DANTE A and H Detectors.....	8
2. 2 Comparison of the original and new calibrations of Channel A4 with original response of H4 (Dashed) and the new cathode model (solid).....	10
2. 3 Gaussian input pulse (3/4 ns FWHM).....	16
2. 4 Gaussian pulse convolved with amplified 7912 impulse response.....	17
2. 5 Impulse response for amplified 7912 channels.....	18
2. 6 Impulse response for direct access 7912 channels.....	19
2. 7 DCON filter parameters.....	20
2. 8 Unfiltered deconvolution of the Gaussian pulse.....	21
2. 9 Super Gaussian noise filter.....	22
2.10 Spectrum of convolved Gaussian input pulse before and after filtering.....	23
2.11 Gaussian pulse after filtering and deconvolution.....	24
2.12 Square pulse used to test for DCON artifacts.....	25
2.13 Triangular pulse used to test for DCON artifacts.....	26
2.14 Deconvolved square pulse.....	28
2.15 Deconvolved triangular pulse.....	29
2.16 Peak enhancement of sample DANTE data by deconvolution.....	30
2.17 Analytical fit to compensate for peak attenuation by DCON low-pass filter.....	31
2.18 Peak factor: peak height adjustment for DANTE data as a function of the FEAF FWHM (amplified 7912s).....	33
2.19 Peak factor: peak height adjustment for DANTE data as a function of the FEAF FWHM (direct access 7912s).....	34

LIST OF FIGURES (con't)

<u>Figure</u>	<u>Page</u>
2.20 Example of present transmission algorithm output. Note that the best fit was achieved for the two lowest calibration energies.....	37
2.21 Flow chart of proposed transmission algorithm.....	42
2.22 Behavior of the primary functions in the proposed transmission algorithm for a 1 e-fold filter.....	44
2.23 Behavior of the primary functions in the proposed transmission algorithm for a 3 e-fold filter.....	45
2.24 Behavior of the incremental mass during convergence.....	46
Section 3.0	
3. 1 Schematic of ellipsoidal x-ray collection optic.....	52
3. 2 Image of off-axis point sources for aligned optical system (continued on next page).....	54-55
3. 3 Base to base PSF width as a function of off-axis point source location.....	57
3. 4 Vertical dispersion of the ellipsoidal optic.....	58
3. 5 Spatial dispersion as a function of off-axis source location and optic location.....	59
3. 6 Images of off-axis point sources located 1 cm aft of focal plane (continued on next two pages).....	62-64
3. 7 Images of off-axis point sources located 1 cm fore of focal plane (continued on next two pages).....	65-67
3. 8 Image of point sources originating from the source focal plane under full optic illumination (continued on next page).....	69-70
3. 9 Image of a point located 1 mm aft of the source side focal plane under full optic illumination.....	71-72
3.10 Image of point located 1 mm aft of the source side focal plane under illumination of a 180° optic sector.....	73
3.11 Image of point located 1 mm aft of the source side focal plane under illumination of a 270° optic sector.....	74

LIST OF FIGURES (con't)

<u>Figure</u>	<u>Page</u>
3.12 Image of point located 3 mm aft of the source side focal plane under full optic illumination.....	75
3.13 Plan-view schematic of the experiment.....	79-80
Section 4.0	
4. 1 Rocking curve of sample 84049-2 at test wavelength $\lambda = 171.4 \text{ \AA}$	94
4. 2 Rocking curve of sample 84049-3 at test wavelength $\lambda = 171.4 \text{ \AA}$	95
4. 3 Spectral passband of sample 84049-2 at normal incidence.....	96
4. 4 Spectral passband of sample 84049-3 at normal incidence.....	97
Section 5.0	
5. 1 LINE SPEC hardcopy output of Henway film density as a function of film position for Novette shot number 0801J5HWZA.....	108
5. 2 LINE SPEC hardcopy output of Henway semi-log plot of fluence as a function of photon energy for Novette shot number 0801O5HWZA.....	109
5. 3 LINE SPEC hardcopy of output of Henway linear plot of fluence as a function of photon energy for Novette shot number 0801O5HWZA.....	110
5. 4 LINE SPEC hardcopy output of Henway plot of the integrated fluence as a function of photon energy for Novette shot number 0801O5HWZA.....	111
5. 5 SPEC PLOT hardcopy output of Henway fluence as a function of photon energy for Novette shot number 0801O5HWZA.....	112
5. 6 MCPIGS II hardcopy output of J-file for Novette shot number 083007.....	119
5. 7 MCPIGS II hardcopy output of E-file for Novette shot number 083007.....	120

LIST OF FIGURES (con't)

<u>Figure</u>	<u>Page</u>
5. 8 MCPIGS II hardcopy output of D1 file for Novette shot number 083007.....	121
5. 9 MCPIGS II hardcopy output of D2 file for Novette shot number 083007.....	122
5.10 MCPIGS II hardcopy output of D3 file for Novette shot number 083007.....	123
5.11 MCPIGS II hardcopy output of R1 file for Novette shot number 083007.....	124
5.12 MCPIGS II hardcopy output of R2 file for Novette shot number 083007.....	125
5.13 MCPIGS II hardcopy output of R3 file for Novette shot number 083007.....	126
5.14 MCPIGS II hardcopy output of W1 file for Novette shot number 083007.....	127
5.15 MCPIGS II hardcopy output of W2 file for Novette shot number 083007.....	128
5.16 MCPIGS II hardcopy output of W3 file for Novette shot number 083007.....	129
 Section 6.0	
6. 1 Schematic representation of FASTBUS TDC using component level electronics for neutron TOF instrumentation.....	148

LIST OF TABLES

<u>Table</u>	<u>Page</u>
Section 2.0	
2.1 DANTE XRD sensitivity changes (percent) from before-use calibrations.....	7
Section 3.0	
3. 1 Variation of the minimum magnification of off-axis sources with optic location.....	60
3. 2 Location of central ray image as optic location is varied.....	61
3. 3 Source collimator configurations.....	82
Section 4.0	
4. 1 Physical characteristics of candidate Mo/Si LSM samples.....	90
4. 2 Sensitivity of rocking curve results to variations in F_1 at the test wavelength $\lambda = 171.4 \text{ \AA}$	99
4. 3 Sensitivity of spectral passband results to variations in F_1 at normal incidence $\lambda = 90^\circ$	100
4. 4 Sensitivity of rocking curve results to variations in F_2 at the test wavelength $\lambda = 171.4 \text{ \AA}$	101
4. 5 Sensitivity of spectral passband results to variations in F_2 at normal incidence $\lambda = 90^\circ$	102
Section 5.0	
5. 1 LINE_SPEC processing sequence and user input for the reduction of Henway crystal spectrograph data.....	105-106
5. 2 Data reduction steps for MCPIGS (Note: MMDDNN file descriptor left off file names included in this table)....	114-117
5. 3 Summary of hardcopy output from MCPIGS data reduction.....	118
5. 4 ARACOR reduced Novette XRL Henway data.....	131
5. 5 MCPIGS I July XRL data.....	132
5. 6 MCPIGS I August XRL data.....	133
5. 7 MCPIGS II June XRL data.....	134

LIST OF TABLES

<u>Table</u>	<u>Page</u>
5. 8 MCPIGS II July XRL data.....	135
5. 9 MCPIGS II August XRL data.....	136-137
5.10 MCPIGS II July XRL wavelength reduced data.....	138
5.11 MCPIGS II August XRL wavelength reduced data.....	139-140
5.12 XRL shot summary.....	141

Section 6.0

6. 1 Cost breakdown of single hit direct timing option using OTS and component-level electronics.....	151-152
--	---------

1.0 INTRODUCTION

This report describes the work performed by Advanced Research and Applications Corporation (ARACOR) in support of Lawrence Livermore National Laboratory's Laser Fusion Experiments Program. The effort under Purchase Order No. 4681605 covered a variety of diagnostic systems and areas of technology that occurred between December 1983 and February 1985. The primary performance areas were the following:

1. Contribute x-ray diagnostic, experimental, and data reduction and analysis support for the Novette DANTE x-ray spectrometer experiments. This effort was expanded to improve the overall quality of the Novette database.
2. Experimental and calculational characterization of the x-ray imaging properties of an ellipsoidal x-ray collection optic serving as a sensitivity enhancing component of the Transmission Grating Streak Spectrometer.
3. Performance simulation of the x-ray dispersion properties of candidate x-ray laser cavity, normal incidence end-mirror optics.
4. Contribute x-ray diagnostic, experimental, and data reduction and analysis support for the Novette Henway crystal spectrometer and the MCPIGS microchannel plate intensified grazing incident spectrometer experiments.
5. Perform a technical performance vs cost evaluation of commercially available hardware required to perform the NOVA neutron time-of-flight experiments.

2.0 DANTE X-RAY SPECTROMETER SUPPORT

2.1 Problem Statement

This section describes the work performed by ARACOR in support of the DANTE x-ray spectrometer. In general, these tasks were structured around ARACOR assuming responsibility for DANTE x-ray spectrometers and data reduction. The period of performance was from December 15, 1983, to February 1, 1985. The areas of effort can be divided in two general categories:

1. DANTE Novette Support
2. DANTE Prime

During the Novette experimental series, ARACOR personnel became responsible for the day-to-day operation of the DANTE spectrometer. In fulfilling this oversight responsibility, ARACOR identified a number of areas where the overall quality of the Novette database could be improved. The database improvement effort involved the following tasks:

1. Recalibrate DANTE x-ray detectors and evaluate the response changes since the previous calibrations. Install the results in the Fusion Energy Analysis Facility (FEAF) database;
2. Develop an algorithm to compensate signal amplitudes for DANTE channel temporal responses and scope calibrations;
3. Develop an improved filter transmission algorithm;
4. Generate updated response functions to replace DAIM02, DHIM03, and DH8402; and
5. Reprocess DANTE data accumulated between August 1983 and April 1984.

Their subsequent implementation is described in Section 2.3 DANTE Prime.

2.2 DANTE NOVETTE Support

ARACOR took diagnostic responsibility for the DANTE spectrometers from December 1983 to April 1984. This effort required a period of familiarization with the instrument and data procedures; the day-to-day support of experiments and data reduction; attention toward assuring readiness and maintenance of the spectrometers; providing access to past and present data for members of the Laser Fusion Experiments Program and other LLNL staff members; and evaluating the quality of the data and making recommendations for improvements.

2.2.1 DANTE Familiarization. The accumulated techniques, experience, and lore from the previous diagnostic physicist, Dr. Glen Tirsell were transferred to ARACOR personnel. These techniques can be categorized as follows:

1. Instrument Characteristics and Physics

- o Familiarization with the physical components (XRDs, mirrors, filters, optics), their characteristics and design features.
- o Spectral Characteristics -- The channel spectral response and how these responses are obtained from the calibrated filters, cathodes and mirrors. Considerations that went into the choice of design parameters. Documentation of the data characterizing the individual components.

2. Data Handling

- o Procedures involved in processing the raw 7912 data, unfolding the spectra, outputting the results and archiving the data. Operation of the UNSPEC code.

3. Shot Setups

- o Extrapolation of previous data to determine appropriate oscilloscope settings for new experimental parameters.

4. LTSS Familiarization

- o Use of the essential utility routines to provide flexible response for sundry data requirements. These routines included XPORT, U, Trix-AC, SOCKITTOME, LRLTRAN, MATHSYN and DCON.

2.2.2 Experimental Support. This task comprised the majority of the DANTE support effort. It consisted of daily attention to assure that the DANTE spectrometers were available on required experiments with the appropriate scope configurations (shot setup), validating the data as processed through FEEF, performing spectral unfolds, archiving the data on the Octopus system, and providing summary sheets and results to the interested LLNL staff members and the pertinent shot notebooks.

Shot set up procedures were generally straight forward. They required obtaining the experimental parameters (target type and size, beam energy, intensity, and the geometrical configuration) from the shot physicist, finding one or more shots from past Novette experiments which most nearly resemble the prospective shot and extrapolating signal levels as appropriate. Occasionally, however, it was necessary to approximate the shot setup parameters by examining the data generated during the Argus series.

Data reductions varied considerably in the amount of time and effort required. Most of the data unfolds followed standard procedures. The data, which were assembled by the FEEF system, were visually inspected to assure that scope settings were consistent with the setup request and were properly transmitted. Peak heights and widths were checked to assure that the results were meaningful (amplitudes were not too high or low, noise and fiducials did not interfere with data). The data, trial spectrum, channel weights and shot

descriptions were edited into an UNSPEC template. The data was processed by iterating on the trial spectrum so that it closely matched the integral and spectral hardness. Results were archived on LTSS and a hardcopy output obtained from the RJET facility. For one series of shots [940209(05,09,12)] the DANTE H filters had received substantial damage. In this situation, it was necessary to use visual inspection, micrographs, and channel by channel intershot comparisons to interpret the data. In all support was provided for approximately fifty shots equally mixed between classified and unclassified targets.

2.2.3 Instrument Support and Evaluation. In addition to routine shot support, the status of the DANTE spectrometers was maintained. This included specifying the filter replacement and ordering, supervising their calibration, generating their response functions, and monitoring the quality of 7912 data acquisition.

As part of the instrument oversight task, detailed recommendations were made specifying how the overall quality of the Novette database could be improved. These recommendations and their implementations are described in Section 2.3 DANTE Prime.

2.2.4 Data Base Support. This task involved providing access to the DANTE data base for the members of the Fusion Experiments Program or other LLNL staff. Such efforts included supplying copies of reduced data, sample channel waveforms, interpreted numbers, and comparisons of results for Novette and Argus shots.

2.3 DANTE Prime

This portion of the Novette DANTE effort was to improve the overall quality of the Novette data base. In doing so, the DANTE detectors were recalibrated, an algorithm was developed to compensate signal amplitudes through the transient digitizer, and an improved filter transmission algorithm was developed. With the submission of this report, LLNL personnel can determine the effect of the results from the first three task areas on the Novette database. ARACOR is coordinating with the CTM the subsequent implementation of these results on the FEAF system by LLNL personnel. These and other areas are discussed more fully below.

2.3.1 Detector Recalibration. Uncertainties in the photocathode response of x-ray diodes (XRDs) are probably the largest source of error in DANTE spectral measurements. This is due to the sensitivity of the photoemission process to surface effects and the difficulty of experimentally characterizing the spectral yield with a limited number of quasi-monochromatic x-ray sources.

X-ray electron yields are dominated by the emission of multiply scattered secondary electrons. These electrons have kinetic energies of about 5 eV and sampling depths of approximately a hundred angstroms for metal cathodes. Thus, the emission is sensitive to small changes in the surface work function and the unavoidable build up of several molecular layers of residual gasses that will occur in the moderate ($\sim 10^{-6}$ torr) vacuum present in the DANTE spectrometers.

Seventeen of the 20 detectors used on the Novette experiments were calibrated in March 1983. The remaining three detectors assumed calibrations from previous XRD's having the same photocathode material. All 20 detectors were used for the duration of the Novette experiments and were subsequently re-calibrated in May 1984. The changes in cathode response relative to the previous calibration (or assumed calibration) are shown in Table 2.1. These figures were reduced from graphical data and may be off by a few percent. The numbers shown in boldface are near the principal response band of their respective DANTE channel.

This data was used to determine new channel responses and reprocess the actual Novette data in order to accurately evaluate the overall impact of the sensitivity changes. To scope the magnitude of these effects we have estimated the sensitivity change for each detector within its principal response band. These "in-band" changes are shown in Figure 2.1. Typical Novette-DANTE spectra have a maximum at approximately 0.5 keV with most of the energy between 0.3 and 0.8 keV and, thus, the modified response functions will raise the spectra at the lowest and highest energies, suppress the peak, and probably change the total integrated intensity by no more than ± 10 percent.

Table 2.1 DANTE XRD sensitivity changes (percent) from before-use calibrations

			Calibration Energy (keV)								
Detector	Cathode	Principal Band	0.183	0.277	0.510	0.704	0.932	1.49	2.04	2.98	4.95
A1	Al	0.1-0.18	-28	-28	+ 8	- 3	0	-26	-20	-30	-33
H1	Al	0.1-0.18	+ 6	- 7	+20	+ 8	+10	-	-	-	-
A2	Al	0.2-0.3	-20	-25	+28	- 3	- 5	-	-	-	-
H2	Al	0.2-0.3	+ 5	- 9	+35	+17	+13	-	-	-	-
A3	Al	0.33-0.52	-25	-27	+10	- 5	- 3	-	-	-	-
H3	Al	0.33-0.52	+20	- 4	+22	+22	+17	-	-	-	-
A4	Al	0.45-0.57	-55	-63	+17	-15	-15	-34	-36	-28	-38
H4	Al	0.45-0.57	-35	-45	+12	+12	+ 8	-	-	-	-
A5	Al	0.45-0.72	-63	-60	+ 5	-5	-12	-10	-20	-20	-33
H5	Al	0.45-0.72	0	-25	+18	+6	+15	-	-	-	-
A6	Al	0.55-0.77	-42	-45	+ 2	-10	-13	-10	-17	-25	-38
H6	Al	0.55-0.77	- 8	-16	0	0	- 7	0	-5	-28	-
*A7	Cr	0.65-0.93	-	-	-32	-12	- 4	-40	-25	+10	-53
*H7	Cr	0.65-0.93	-	-	-40	-13	-10	-40	-5	-2	-60
*A8	Ni	0.85-1.03	-	-	-35	- 3	-22	-35	-35	-27	-
H8	Ni	0.85-1.03	-	-	-23	-12	-30	-10	-25	-25	-
A9	Ni	1.05-1.30	-	-	-17	-18	-20	-24	-12	-24	-20
H9	Ni	1.05-1.30	-	-	-27	-20	-25	-25	-30	-25	-
A10	Ni	1.1-1.56	-	-	-33	-23	-25	-30	-20	-27	-
H10	Ni	1.1-1.56	-	-	-13	-10	-25	-23	-23	-30	-

*These detectors were not previously calibrated. Sensitivity changes are relative to the nominal values used in UNSPEC.

Figure 2.1 In-band photocathode response changes for DANTE A and H Detectors.

The nature of the cathode contamination and the steps required to appropriately model the response changes can be understood by a close study of Figure 2.2. This figure gives the original "O" and new "N," calibrations for the aluminum-cathode XRD mounted in DANTE A, channel 4 ("A4"). These data have been vertically shifted such that the original data essentially overlay the unfiltered response curve (dotted line) taken from the pre-exposure calibration of channel "H4."

As a rule, the energy dependence of x-ray photoelectric yields can be fitted to a power law (straight line on log-log plots) between absorption edges (Bernstein, M.J. and Smith, J.A., IEEE Trans. Nuc. Sci., NS-26, Dec. 1979, p.4978-4983). Thus, the sharp jumps near 0.5 and 1.5 keV are due to absorption in the oxygen and aluminum k-shells. The most pronounced changes in sensitivity occurred at the two points below 0.3 keV (see Figure 2.2). This drop is due to the buildup of carbonaceous material on the cathode. This effect was seen in all low-energy after-use calibrations. The magnitude of the effect suggests that, particularly for low-energy channels, future calibrations should be performed more frequently.

The structure in the data between 2 and 3 keV was seen only on this cathode and on channel "A5." This is probably due to contamination by gold debris from one of the targets as the gold M-shell occurs principally between these energies. The smaller jump near 800 eV is also seen only on "A4" and "A5" and is probably due to the gold N-absorptions in this region.

In order to handle the carbon contamination, the FEAF routine for modelling aluminum cathode responses (ALCATH.FOR) requires modification to insert the carbon edge. The following steps are recommended:

- 1) Below 0.183 keV -- Retain the present technique which uses the shape of the f₂ absorption parameters to extend the response below the boron and carbon calibration energies.
- 2) 0.183 to 0.283 keV -- Use a power law fit to the boron and carbon calibration points which lie below the carbon-K absorption edge.

Figure 2. 2 Comparison of the original and new calibrations of Channel A4 with original response of H4 (dashed) and the new cathode model (solid).

- 3) 0.284 to 0.531 -- This is an awkward region since only the vanadium (0.511 keV) calibration energy falls between the carbon and oxygen edges. Fit this point with a power law using a slope of -1.90 which corresponds to the more extensive measurements of Day et al. (J.Appl.Phys., 52(II), Nov. 1981, p. 6965-6973). Note that the presence of nitrogen on the surface would add additional structure in this region, however, this would undoubtedly be significantly less pronounced than the carbon and oxygen edges. The present procedure, which interpolates a point at 0.452 keV between the 0.278 and 0.511 keV points, should be discontinued. This step distorts the spectral response if carbon is present on the surface.
- 4) 0.532 to 1.559 keV -- Retain the present technique which fits straight lines (power law) between 0.705 and 1.486 keV. However, use the slope between these two points to extrapolate down to the oxygen edge (0.532 keV) and up to the aluminum edge (1.559 keV). This empirical slope is preferable to the present technique which uses the slope from previous calibrations. The chromium point (0.578 keV) tends to drop significantly below the trend of the higher energy points in most (but not all) calibrations and is not recommended. This is possibly due to oxygen contamination on the Ionac target.
- 5) 1.560 to 2.00 keV -- Use a power law extrapolation to extend below the zirconium (2.04 keV) calibration point. The slope can be taken from the highest and lowest available points.

At this time, it is not necessary to modify the FEAF routines used to produce spectral responses for the chromium and nickel photocathodes. The carbon edge lies well below the usable sensitivity in these channels and no contamination was observed in the post-use recalibrations. Likewise, gold contamination on aluminum cathodes does not affect the spectral response since the principal structure lies above the 2 keV cutoff in the response functions and the interference near 0.8 keV is adequately handled by the current methods.

2.3.2 Temporal Response and Digitizer Calibration Adjustments. Two of the tasks undertaken in upgrading the Novette data involve adjustments to the FEAF recorded amplitude response--corrected sensitivity values for the direct access digitizers and peak height adjustments for the finite bandwidth of the recording channels.

7912 Digitizer Sensitivity Calibrations. The Novette data was recorded using the nominal input sensitivity of the digitizers to convert signal amplitudes into volts. This assumed calibration was quite accurate for the amplified 7912 channels since they were calibrated before use and serviced regularly. However, for direct access channels these nominal sensitivities are generally off by about 15%. Two steps have been taken to improve the accuracy of pulse amplitude recording.

After completion of the Novette operations, the direct access scopes were sent to the Tektronix shop for post-use calibration. The modified sensitivity values will be applied to the previously recorded amplitudes before reprocessing the Novette data (see Section 2.3.5).

In addition, a scope calibration procedure has been initiated wherein all transient digitizers used on the DANTE spectrometers receive pre- and post-use calibrations. A record of these calibrations is presently being maintained by ARACOR in Building 381, Room 1301. From these records it will be possible in the future to know correct amplitude values while the digitizers are active; it will be possible to spot situations where a digitizer has changed sensitivity over its tour of duty; and it will be possible to better understand what an appropriate period of use is for these instruments.

DANTE Temporal Response Deconvolution Algorithm. The x-ray time history closely follows the 1 ns width of the Novette laser pulse. The x-ray pulse is detected by an x-ray diode (XRD) which generates an output signal that is transmitted through a cable to the transient digitizer for that channel. The digitizer transmits this data to the FEAF system where the signal peak height and full-width half-maximum (FWHM) values are extracted. In the process of

detecting and recording the x-ray signal, the peak heights are reduced by the finite bandwidth or temporal response of the channel. This response is determined by the temporal characteristics of the XRD, the signal cables and the analyzing digitizer.

It is often important to know the actual peak height of the incoming x-ray pulse rather than the area under the curve. At present, the method of obtaining the peak height information is through a time consuming pulse by pulse deconvolution of the data. Additionally, to correct for the high frequency noise filters used in the deconvolution code, a filter correction algorithm must be developed. Further, to process the Novette data on the LLNL Octopus computer system, the original data would have to be transferred from storage tape to FEAF and to LTSS via floppy disks.

An alternative method of obtaining the peak height information is to develop an algorithm that uses the FEAF FWHM values to correct the signal peak height. The accuracy of this algorithm should be within the calibration error of the DANTE system that vary from about ± 10 percent at the highest energies to ± 30 percent at the lowest energies. Therefore, if the algorithm is accurate to ± 5 percent it should not affect the overall quality of the final result.

The following approach was used to develop an algorithm for using the FEAF FWHM to correct peak amplitudes.

- 1) Using sample DANTE data, adjust the filter parameters in the deconvolution code (DCON) to minimize noise problems while maintaining maximum pulse shape fidelity.
- 2) Using radical (square and triangle) pulse shapes, verify that unexpected temporal behavior in the data will be reasonably handled by the code.

- 3) Using the channel impulse response and the DCON code unfold three sets of DANTE data (fast, medium and slow). Plot the Peak Factor (defined below) vs. FWHM. This data must still be corrected for peak attenuation by the DCON filter.
- 4) Evaluate the DCON filter attenuation by folding Gaussian pulses of varying widths with the channel impulse response and unfolding the result with DCON. Fit the resulting "filter factor" with an empirical function.
- 5) Determine the peak correction with an empirical fit to the deconvolved data (Step 3) corrected by the filter factor (Step 4).

The filter function used in the DCON code, is designed to filter out high frequency noise generated in the deconvolution of the input signal. The filter function $F(\text{frequency})$ is given by the equation:

$$F(\text{frequency}) = \exp [- (\text{smooth} * \text{frequency}) ** (2 * \text{Nfexp})]$$

The two parameters used in the filter function and the values used in this evaluation were as follows:

PARAMETER	DEFINITION	VALUE
Smooth :	1/e cutoff frequency	1.00
Nfexp :	Steepness of cutoff	2.00

The filter function then becomes:

$$F(\text{frequency}) = \exp [- (\text{frequency}) ** 4]$$

The operation of the DCON code can be understood from the sample runs shown in Figures 2.3 through 2.11 for a 3/4 ns Gaussian pulse folded with an AMP7912 response function. Impulse responses from previous experimental measurements on the DANTE system were used in the DCON code. Figure 2.3 shows the 3/4 ns Gaussian pulse with a peak height arbitrarily set to a value of 1.00. Figure 2.4 shows the pulse after being folded with the AMP7912 response function, using the SOCKITTOME code called FOLD.

Figures 2.5 through 2.7 show the impulse responses for the amplified and direct access 7912 digitizers and the filter parameters used in the DCON code. Figure 2.8 shows the result of deconvolving the input pulse without inserting the low-pass filter. The high noise level is simply due to the finite sampling of the smooth input pulse. The need for additional filtering is evident. Figures 2.9 and 2.10 show the selected filter and its application to the spectrum of the convolved Gaussian pulse.

The filter parameters used were designed to

- 1) Minimize the effects of random noise on the signal by making the filter's cut-off frequency as low as possible.
- 2) Minimize the filter's effects on the amplitude of the deconvolved pulse by using a sharp frequency cut-off.
- 3) Minimize ringing artifacts caused by the sharp filter cut-off.

The effects of the chosen filter parameters can be seen in the final, deconvolved output shown in Figure 2.11. The noise has been suppressed with moderate peak attenuation and mild ringing artifacts.

Since the filter behaves reasonably well for Gaussian data, the next step was to test the limits of our filter. We created a 3-ns square wave and a 1-ns triangular wave pulse. These pulses can be seen in Figures 2.12 and 2.13. Both test pulses were folded with the AMP7912 response then unfolded using the LLNL

3/4 NS GAUSSIAN PULSE
FILES .. HFOTGAUS

Figure 2. 3 Gaussian input pulse (3/4 ns FWHM).

FRAME 2

Figure 2. 4 Gaussian pulse convolved with amplified 7912 impulse response.

FRAME 4

Figure 2. 5 Impulse response for amplified 7912 channels.

Figure 2.6 Impulse response for direct access 7912 channels.

DCON PROBLEM PARAMETERS :

NPTS = 2048

DT = 9.000E-03 TIME 0. TO 1.842E+01

DOMEGA = 5.428E-02 MAX = 5.558E+01

IRTYPE = 99 SIGH = 6.256E-94

CLIP = 1.000E-09 IDBUG = 1

FILTER PARAMETERS

SMOOTH = 1.000E+00 NFIT = 2

LADJUST = 0 LFILTER = 3

ALEVEL = 1.000E-02 NFEXP= 2 IBAND= 0

BAND = 5.000E+00 BAND6L = 2.500E+00 AFREQ = 0.
NFIL= 0

FRAME 6

Figure 2.7 DCON filter parameters.

Figure 2. 8 Unfiltered deconvolution of the Gaussian pulse.

FRAME 10

Figure 2.9 Super Gaussian noise filter.

FRAME 11

Figure 2.10 Spectrum of convolved Gaussian input pulse before and after filtering.

FRAME 14

Figure 2.11 Gaussian pulse after filtering and deconvolution.

Figure 2.12 Square pulse used to test for DCON artifacts.

FILES .. TRIWAVE

Figure 2.13 Triangular pulse used to test for DCON artifacts.

DCON code. Figures 2.14 and 2.15 show the final pulse shapes after the deconvolution routine. Comparison of the deconvolved pulses with the original test pulses shows that the shape of the pulse was reasonably maintained, although there is some ringing near the pulse edges. The deconvolved square wave peak height overshoots the original peak height by about 5 percent. In the case of the triangle wave we see an amplitude loss over the original pulse by about 10 percent. As we shall show later this 10 percent loss can be partly corrected for by the filter correction function. Thus, since severe pulse shapes show approximately 5 percent effects, we can be assured that the data wave forms will not be significantly affected by filter artifacts.

The strategy we used in developing an algorithm to recover peak amplitudes is to first use the best available technique to correct three sets of recorded data, A_R , back to their original amplitude, A_o . Then we fit an empirical function to the ratio A_o/A_R .

Figure 2.16 shows a scatter plot of the ratio A_{RD}/A_R versus T_F where A_{RD} is the deconvolved amplitude of the recorded data and T_F is the FWHM as reported by FEAF. There are several features worth noting. First, the deconvolved data sets follow a consistent trend. In addition, the data scatter about the trend is moderate and without significant outliers. This establishes the viability of the idea that the amplitude corrections can be expressed as a function of T_F without requiring additional pulse shape information.

Included with the data set are points corresponding to the deconvolutions of four Gaussian test pulses (original widths were 1/2, 3/4, 1-1/2 ns) which had been convolved with the DANTE impulse response using the SOCKITTOME routine FOLD. Note that the deconvolved Gaussian amplitudes track well with the rest of the data. This establishes that Gaussian pulses behave substantially like the recorded data.

To finish recovering the original amplitudes of the recorded data, we must remove the effect of the DCON low-pass filter on the deconvolved amplitudes. Figure 2.17 shows the ratio A_G/A_{GD} versus T_F where A_G is the amplitude

Figure 2.14 Deconvolved square pulse.

Figure 2.15 Decorvolved triangular pulse.

Figure 2.16 Peak enhancement of sample DANTE data by deconvolution.

Figure 2.17 Analytical fit to compensate for peak attenuation by DCON low-pass filter.

of the original Gaussian pulse (before convolving with the channel impulse response), T_F is the FWHM of the convolved pulse, and A_G is the amplitude of the deconvolved pulse. The ratio A_G/A_D is the filter factor, i.e., the ratio by which the deconvolved pulses have been attenuated by the low-pass filter. Here we depend on the observed consistency between the Gaussian test pulses and the recorded data and assume that this function will be a good approximation of the correction required for the deconvolved amplitudes, A_D . The filter factor has been fit to the functional form:

$$F_F = [1 + (0.76/T_F)^8]^{-1} \quad (T_F \text{ in ns})$$

As shown in Figure 2.17, this function fits the A_G/A_D ratio within two percent over the range of T_F from 0.85 to 2.0 ns which is quite adequate for our purposes.

In Figure 2.18 the deconvolved data of Figure 2.16 have been adjusted by this filter factor to give our best reconstruction of the original peak heights. The empirical fit for this amplified data is

$$F_A = [1 - (0.63/T_F)^8]^{-1} \quad (T_F \text{ in ns})$$

This function, which we will call the peak factor, fits the reconstructed amplitudes with a standard deviation of 1.4 percent and a worst case of 4.1 percent. The algorithm should be valid within the design goal of ± 5 percent for $T_F > 0.93$ ns which corresponds to an x-ray pulse width about 0.7 ns.

The effects of a direct-access digitizer on an x-ray waveform are substantially milder than that of an amplified digitizer and the Gaussian pulses behaved much like the actual data pulses in the DCON process. Thus, the direct access peak factor, F_D , was derived directly from sample Gaussian data.

Gaussian pulses with FWHM of 0.5, 1.0, and 1.5 ns were folded with the direct access impulse response (Figure 2.6). The ratio of the original divided by the folded amplitude, A_o/A_p , is plotted in Figure 2.19. These data have been fitted to the direct access peak factor:

Figure 2.18 Peak factor: peak height adjustment for DANTE data as a function of the FEAF FWHM (amplified 7912s).

Figure 2.19 Peak factor: peak height adjustment for DANTE data as a function of the FEAF FWHM (direct access 7912s).

$$F_D = [1 - (0.296/T_F)^{2.18}]^{-1.85} \quad (T_F \text{ in ns})$$

The algorithm should be valid for $T_F > 0.7$ ns (x-ray FWHM > 0.5 ns) within the design goal of 5 percent.

2.3.3 Filter Transmission Algorithm. The current model used to determine the areal densities of elements and compounds in a particular filter solves the system:

$$-\ln C_i = \sum_m \mu_{im} (\Delta \rho)_m$$

for values of $(\Delta \rho)_m$ that minimize the residual, R:

$$R = \sum_i [-\ln C_i - \sum_m \mu_{im} (\Delta \rho)_m]^2$$

where C_i is the measured transmission at calibration energy i ; μ_{im} is the mass absorption coefficient of element or component m at energy i ; and $(\Delta \rho)_m$ is the areal density of element or compound m . In other words, the routine selects values for $(\Delta \rho)_m$ such that

$$\frac{\partial R}{\partial (\Delta \rho)_m} = 2 \sum_i \mu_{im} [\ln C_i - \sum_m \mu_{im} (\Delta \rho)_m] = 0$$

$$\text{or} \quad \sum_i \mu_{im} \epsilon_i = 0$$

$$\text{where} \quad \epsilon_i = \ln C_i - \sum_m \mu_{im} (\Delta \rho)_m$$

is the relative error in fitting the calibration point at energy i . In effect the use of this algorithm weights the relative error by μ_{im} . There are several problems with this.

- 1) While tabulated elemental absorption coefficients are the best available approximation to the spectral transmission of a foil, neither the coefficients nor the foil composition are exact.
- 2) Low transmission measurements are likely to have greater experimental errors due to low signals, foil non-uniformity and spectral impurities.

3) By weighting the relative errors and by weighting with μ_{im} the algorithm achieves a close fit to low transmission measurements at the expense of high transmission points. Because of the possible discrepancy between tabulated absorption coefficients and the actual spectral transmission of a foil, it is important to fit the calibration data in the regions of high transmission that contribute the major portion of the signal.

An example of the type of problems encountered with the present algorithm is seen in Figure 2.20. Here the transmission data for a Paralene-N film (mostly carbon) has been fit closely to the two low transmission points while the carbon point (0.28 keV) is substantially off.

The present model further assumes that the calibration energy, i , corresponds to the principle x-ray emission line. Consideration of multiple emission lines indicates that this is a reasonable assumption for thin (~ 1 e-fold) foils since a multicomponent spectra leads to transmissions about 3 percent above those calculated with the principle line. For thicker (~ 3 e-folds) foils this difference increases to about 10 percent. To quantify this effect, accurate data on the relative line intensities are needed. These data, however, are not well known due to uncertainties in the L-shell excitation process and the subsequent fluorescence, Coster-Kronig, and Auger transitions, along with self-absorption by the target material. In spite of this, a capability to treat multicomponent spectra was considered desirable to allow for the evolution of the model as data becomes available and to explicitly represent the x-ray spectrum portion of the transmission model.

The proposed transmission algorithm uses a variation of Newton's method for approximating roots to calculate the areal densities of component material in filters from x-ray transmission data. The primary features of this methodology are

1. unweighted, linear curve fitting and
2. explicit representation of multiline x-ray spectra.

Figure 2.20 Example of present transmission algorithm output. Note that the best fit was achieved for the two lowest calibration energies.

Theory. In general, the transmission through a foil can be expressed by

$$T(S) = \int_0^E S(E) \exp \left[- \int_0^r \mu(E, x) dx \right] dE$$

where

$T(S)$ is the transmission of spectra S through the foil

$S(E)$ is the source spectra

r is the elemental path length

$\mu(E, x)$ is the absorption coefficient.

If the source spectrum is characterized by a negligible bremsstrahlung continuum then the primary contributors to the photon fluence are the multicomponent emission lines. The transmission now reduces to

$$T_i = \sum a_{ij} \exp \left[- \sum \mu_{ijm} (\Delta\rho)_m \right]$$

where:

T_i is the calculated transmission at the i 'th calibration energy;

a_{ij} is the relative intensity of the j 'th emission line of the i 'th calibration energy;

μ_{ijm} is the mass absorption coefficient of the m 'th element at the energy of the j 'th line of the i 'th calibration energy [$\text{cm}^2 \cdot \text{cm}^{-1}$]; and

$(\Delta\rho)_m$ is the areal density of the m 'th element in the foil [$\text{g} \cdot \text{cm}^{-2}$]

The residual, R , can now be expressed as

$$R = \sum_i (C_i - T_i)^2 = \sum_i R_i^2$$

Minimizing R is equivalent to setting

$$\frac{\partial R}{\partial (\Delta \rho)_m} = \sum_i \frac{\partial R_i^2}{\partial (\Delta \rho)_m} = 0$$

As the resulting equations are complex and nonlinear in $(\Delta \rho)_m$, we will find the root to this set of equations iteratively using Newton's method. That is, given a function $F(X)$ and its first derivative, $F'(X)$, then to find the root of $F(X)=0$, select an X_i ("sufficiently" close) and iterate using

$$X_{i+1} = X_i - F(X_i) / F'(X_i)$$

Similarly, the first and second order partial derivatives with respect to $(\Delta \rho)_m$ will be used to estimate the increment in $(\Delta \rho)_m$ that will minimize the residual. That is,

$$\begin{aligned} (\Delta \rho)_m &= (\Delta \rho)_m + \frac{-\partial R / (\Delta \rho)_m}{\partial^2 R / \partial (\Delta \rho)_m^2} = (\Delta \rho)_m + \sum_i \frac{-\partial R_i / \partial (\Delta \rho)_m}{\partial^2 R_i / \partial (\Delta \rho)_m^2} \\ &= (\Delta \rho)_m + \sum_i \delta_{im} \\ &= (\Delta \rho)_m + \delta_m \end{aligned}$$

Hence, for the i 'th calibration energy

$$R_i = (C_i - T_i)^2$$

and the first and second partial derivatives

$$\begin{aligned} \frac{\partial R_i}{\partial (\Delta \rho)_m} &= -2(C_i - T_i) \frac{\partial T_i}{\partial (\Delta \rho)_m} \\ \frac{\partial^2 R_i}{\partial (\Delta \rho)_m^2} &= 2 \left[\frac{\partial T_i}{\partial (\Delta \rho)_m} \right]^2 - 2(C_i - T_i) \frac{\partial^2 T_i}{\partial (\Delta \rho)_m^2} \end{aligned}$$

the areal density increment for the i'th energy is now

$$\delta i_m = \frac{(C_i - T_i) \partial T_i / \partial (\Delta \rho)_m}{\left[\frac{\partial T_i}{\partial (\Delta \rho)_m} \right]^2 - (C_i - T_i) \frac{\partial^2 R_i}{\partial (\Delta \rho)_m^2}}$$

Thus, the problem reduces to calculating the first and second order partial derivatives of the transmission function:

$$\frac{\partial T_i}{\partial (\Delta \rho)_m} = \frac{\partial}{\partial (\Delta \rho)_m} \left\{ \sum_j \alpha_{ij} \exp \left[- \sum_m \mu_{ijm} (\Delta \rho)_m \right] \right\}$$

In matrix notation:

$$\frac{\partial T_i}{\partial (\Delta \rho)_m} = \begin{bmatrix} \mu_{i11} & \mu_{i21} & \dots & \mu_{ij1} \\ \mu_{i12} & \mu_{i22} & \dots & \mu_{ij2} \\ \vdots & \vdots & & \vdots \\ \mu_{i1m} & \mu_{i2m} & \dots & \mu_{ijm} \end{bmatrix} \cdot \begin{bmatrix} T_{i1} \\ T_{i2} \\ \vdots \\ T_{ij} \end{bmatrix}$$

and

$$\frac{\partial^2 T_i}{\partial (\Delta \rho)_m^2} = \begin{bmatrix} 2 & 2 & \dots & 2 \\ \mu_{i11} & \mu_{i21} & \dots & \mu_{ij1} \\ 2 & 2 & \dots & 2 \\ \mu_{i12} & \mu_{i22} & \dots & \mu_{ij2} \\ \vdots & \vdots & & \vdots \\ 2 & 2 & \dots & 2 \\ \mu_{i1m} & \mu_{i2m} & \dots & \mu_{ijm} \end{bmatrix} \cdot \begin{bmatrix} T_{i1} \\ T_{i2} \\ \vdots \\ T_{ij} \end{bmatrix}$$

The incremental areal density of the m'th element at the i'th calibration energy is now

$$\delta_{im} = \frac{-(C_i - T_i) \left(\sum_j \mu_{ijm} T_{ij} \right)}{\left[\sum_j \mu_{ijm} T_{ij} \right]^2 + (T_i - C_i) \left(\sum_j \mu_{ijm}^2 T_{ij} \right)}$$

and the total incremental areal density of the m'th element is

$$\delta_m = \sum_i \delta_{im}$$

Application. The first step in applying this methodology is to enter the suspected or known filter elements in order of importance. Mass absorption coefficients will be calculated at each of the emission lines associated with a transmission measurement. This may be accomplished by the operator entering (or indicating) the calibration energies (or fluorecser material) and having the code extract the multiline spectra associated with that calibration energy from a data file. To a first approximation, simple transition probabilities may be used to estimate the relative emission line intensities. Absorption coefficients can be extracted from the LLNL x-ray interaction coefficient library, CSLOW, by log-log interpolation.

The envisioned flow chart is shown in Figure 2.21. It begins by initializing all areal densities to zero. The operator then selects an appropriate calibration energy to obtain the first estimate of the areal density of the primary element in the foil. The areal density of this element is calculated by:

$$(\Delta \rho)_{m=1} = \frac{1}{\mu_{m=1}} \ln \frac{1}{C_i}$$

where $\mu_{m=1}$ is evaluated at a single energy (either an average or principle emission line) corresponding to the measured transmission of C_i . The code continues by cycling through incremental areal densities, δ_m 's, and calculates

Figure 2.21 Flow chart of proposed transmission algorithm.

the residual for each pass through the cycle. When the absolute values of all m 's are less than a selected minimum, ϵ , this cycling is stopped and the transmission function of the foil, $T(s)$, $(\Delta\rho)m$, and R are sent to output.

To illustrate the behavior of the basic equations, the following figures were prepared. The behavior of the residual first and second derivatives and of the incremental mass were plotted for a single, hypothetical, element and a monoenergetic x-ray energy. The transmission function reduces to

$$T = \exp(-\mu x)$$

and the residual is

$$R = (C - T)$$

The first and second derivatives are

$$\frac{\partial R}{\partial x} = 2(C-T)\mu T$$

and

$$\frac{\partial^2 R}{\partial x^2} = 2(\mu T)^2 - 2(C-T)\mu^2 T$$

and the incremental mass is

$$\begin{aligned} \delta m &= \frac{-2(C-T)\mu T}{2(\mu T)^2 - 2(C-T)\mu^2 T} \\ &= \frac{-(C-T)}{\mu(2T-C)} = \frac{-R}{\mu(2T-C)} \end{aligned}$$

Figure 2.22 shows these quantities for a 1 e-fold filter with a measured transmission, C , equal to 0.386. Figure 2.23 shows the same data for a 3 e-fold filter with a measured transmission equal to 0.05. Figure 2.24 is an expansion showing the behavior of the incremental mass as it approaches the region where the measured transmission, C , is equal to twice the calculated transmission, T . Note that the initial areal densities must be set to zero to assure convergence.

Fig. 1.A RESIDUAL OF 1 E-FOLD FILTER, UNAS. TRIMS. = 0.35, $\Omega = 1.0$
FILES .. DI

Fig. 1.B FIRST DERIVATIVE OF RESIDUAL FOR 1 E-FOLD FILTER
FILES .. DI

Fig. 1.C SECOND DERIVATIVE OF RESIDUAL FOR 1 E-FOLD FILTER
FILES .. DI

Fig. 1.D INCREMENTAL LOSS FOR 1 E-FOLD FILTER
FILES .. DI

Figure 2.22 Behavior of the primary functions in the proposed transmission algorithm for a 1 e-fold filter.

FIG. 2.2 FIRST DERIVATIVE OF RESIDUAL FOR 3 E-FOLD FILTER
FILES .. DR3

FIG. 2.3 SECOND DERIVATIVE OF RESIDUAL FOR 3 E-FOLD FILTER
FILES .. DR3

FIG. 2.4 INCREMENTAL MASS FOR 3 E-FOLD FILTERS
FILES .. DEL3A

Figure 2.23 Behavior of the primary functions in the proposed transmission algorithm for a 3 e-fold filter.

Figure 2.24 Behavior of the incremental mass during convergence.

2.3.4 Response Function Update. The fourth task in the DANTE Prime data base upgrade is the generation of post-use response functions for the DANTE spectrometers. The update will consist of the three subtasks listed below. These subtasks all involve modification and operation of the FEAF software data base--tasks originally intended for execution by LLNL personnel. With the present submission of this report the inputs are available for the three subtasks to proceed.

- A. Generation of Photocathode Response Functions. This task requires the installation of the modified ALCATH.FOR routine discussed in Section 2.3.1. The calibration data obtained in that effort will then be entered into the data base and the response functions generated.
- B. Generation of New Filter Transmissions. This task will require installation of the filter transmission algorithm developed in Section 2.3.3. The updated filter transmissions can then be generated from the filter calibration data already present in the FEAF.
- C. Generation of Updated Response Functions. Upon completion of subtasks A and B, the post-use response functions to replace DAIM02, DHIM03 and DH8402 can be generated using existing routines.

2.3.5 Reprocess of DANTE Novette Data. Upon completion of the response functions update discussed in Section 2.3.4, the Novette data upgrade can proceed. The steps will proceed as outlined below.

- A. Data Corrections. Apply the modified scope calibrations (2.3.2) to the data. Where appropriate, apply the temporal response algorithm (2.3.2) to peak height data.
- B. Reprocess the corrected data with the updated response functions (2.3.4).
- C. Issue revised analysis sheets and a compiled Novette analysis notebook. This data will probably be given in a format showing the data as reduced with before- and after-use response functions. This would provide an estimate of the uncertainties due to photocathode aging.

3.0 ELLIPSOIDAL X-RAY OPTIC CHARACTERIZATION

3.1 Problem Statement

This section describes work accomplished by ARACOR during the experimental and calculational characterization of the x-ray imaging properties of an ellipsoidal x-ray collection optic. The objects studied in this effort were two nominally-identical, cylindrically-symmetric ellipsoidal grazing incidence x-ray mirrors. These mirrors were newly-developed (and the only existing of their type) by LLNL to serve as sensitivity-enhancing components of the Transmission Grating Streak Spectrometer (TGSS), a laser-induced plasma x-ray diagnostic instrument deployed at the LLNL Novette Laser Facility. The characterization of the optics was accomplished in the period January - May 1984, between the times of their first availability and of installation (of one of the two pieces) into the TGSS.

Due to the importance of the optic-enhanced TGSS diagnostic in an imminent Novette x-ray laser series, it was considered mandatory by LLNL that the fitness-for-use of the optics be demonstrated and that their x-ray imaging properties (spatial dispersion, aberrations, and reflection efficiency) be calculationally and experimentally quantified prior to first use at Novette. As the TGSS is a wavelength-dispersive spectrometer, it was particularly important to determine the degree to which each optic achieved the on-axis point-to-point focusing expected of an ellipsoidal mirror. The spectral resolution of the TGSS would be degraded if the optics' point spread function (PSF), the normalized image profile for an on-axis point source, was unduly broad.

The major technical issues addressed in the project were

1. examination of the optics' on-axis, best-focus PSFs for soft x-rays ($C_{K\alpha} = 44 \text{ \AA}$), particularly to determine if significant energy was contained in broad, low-level profile wings;
2. determination of the effective field-of-view and depth-of-focus of the optics, by examination of the PSFs produced by off-axis source points contained both within the source-side focal plane and fore and aft of the focal plane;

3. verification that optic pointing and focusing achieved by observation of optic-formed visible light images corresponded exactly to the alignment achieved through the use of soft x-ray images, this to expedite the TGSS set-up task; and
4. examination of the soft x-ray reflection efficiency ("throughput") of the optics, for photon energies less than 600 eV (actually measured at $C_{K\alpha} = 44 \text{ \AA}$).

The first three issues were resolved both calculationally and experimentally; the fourth issue was examined by experiment only. The experimental results are contained in the 3 volume set of notebooks titled TGSS X-Ray Mirror Characterization located at the x-ray calibration facility.

Section 3.2 describes the use of the ARACOR reflective-optic ray tracing computer code ELLPMIR in this project. The simulation of optic PSF profiles for all source-point locations described above was quickly accomplished. As the experimental phase of the project developed, ELLPMIR simulations were also used to explain both visible light and soft x-ray image patterns produced by a misaligned optic, thereby providing valuable clues as to how to achieve proper alignment experimentally.

Section 3.3 describes the experimental method (procedures and apparatus) used to resolve the project's technical issues. Emphasis will be placed in this section on the Experimental Plan originally developed for the effort and on subsequent modifications of the experimental method that were introduced as more was learned about the process. Section 3.3 also contains recommendations for the upgrade of the experimental system. Section 3.4 is a listing of the best experimental data collected to address the specific issues outlined above.

3.2 Computer Simulation

3.2.1 Ray Trace Computer Code. A reflective optic ray tracing computer code, ELLPMIR, was used to analyze the cylindrically-symmetric ellipsoidal

grazing incidence x-ray mirror. ELLPMIR is based upon a generalized matrix formulation of geometrical optics. The fundamental reflection formula in this code is (see Herzberger, M., Modern Geometrical Optics, Interscience Publishers, Inc., New York, 1958 for the complete derivation):

$$\bar{S}' = \bar{S} - 2 (\hat{n} \cdot \bar{S}) \hat{n}$$

where $\bar{S}'$ is the reflected ray

$\bar{S}$ is the incident ray

$\hat{n}$ is the unit normal of the reflecting surface

The unit normal is calculated by:

$$\hat{n} = \frac{\nabla f(x_m, y_m, z_m)}{|\nabla f(x_m, y_m, z_m)|}$$

where f is the analytical function describing the surface of the optic:

$$f(x_m, y_m, z_m) = \frac{x_m^2 + y_m^2}{B^2} + \frac{z_m^2}{A^2}$$

and ∇ is the vector differential operator, Del. The subscript m signifies that the variables X, Y, Z refer to the mirror coordinates. The constants A and B are equal to 61 cm and 4.345 cm, respectively, resulting in the optic's foci being located at ± 60.845 cm.

The vector describing a ray incident upon the optic was calculated from the geometry of the mirror and the source, for example:

$$\bar{S} = \begin{pmatrix} x_m - x_s \\ y_m - y_s \\ z_m - z_s \end{pmatrix}$$

where the subscript s refers to the coordinates of the source. The configuration of the optical system was obtained from LLNL sketch by D. Carter (dated 12/15/83) and reproduced as Figure 3.1. The mirror was oriented such that the axis of symmetry was aligned with the source and image side foci. This axis was designated as the Z-axis. As shown in Figure 3.1, the X-axis was in the vertical direction and the Y-axis was orthogonal to the X and Z directions. The (0,0,0) location of this optical system was the origin of the ellipse of revolution defining the grazing incidence optic. The azimuthal angle, ϕ , was defined as the angle between the normal at the point of reflection and the X-axis.

The grid on the optic or the number of points of reflection was part of the input. The Z-component was set by entering DELZ such that $DELZ = \Delta Z_m / (Z_m(2) - Z_m(1))$. The incremental azimuthal angle, DELY, is read in directly. For each increment in the Z direction, ΔZ_m , the azimuthal angle is varied through ϕ_{max} by DELY. At each ϕ both X_m and Y_m are calculated from the equation defining the ellipse of revolution and from

$$\phi = \sin^{-1} (Y_m/R)$$

where R is defined by

$$\frac{R^2}{B^2} + \frac{Z_m^2}{A^2} = 1$$

ELLPMIR contains an option to insert an aperture stop. With this option, a ray is launched from the source side focal position (0,0, f_1) and reflected from the mirror center ($X_m, 0, Z_m$). This ray was projected to the image plane (0,0, f_2). A 5-mm diameter aperture stop was placed at $Z = -1$ cm such that this ray passes through the center of the aperture. The distance between the optic and the aperture stop remained constant as the optic location was varied.

ELLPMIR PSFs are normalized to 32000 which is near the largest value that can be represented with an integer variable using a 16 bit word. The PSFs are further renormalized in the plotting routine. The end result is that the PSFs presented in the following section show relative rather than absolute intensities.

Figure 3. 1 Schematic of ellipsoidal x-ray collection optic.

3.2.2 Results. Two sets of simulations were performed with ELLPMIR. The first modeled a grid of point sources (a 10x10 array of 10 μ m holes on 50 μ m centers) projected onto the optic and then passing through the aperture stop. The source grid was placed in the "upstream" focal plane such that the source points closest to the focal plane were located at (25 μ m, 25 μ m), (25 μ m, -25 μ m), (-25 μ m, -25 μ m), and (-25 μ m, 25 μ m). PSFs were calculated for an aligned system and after the optic was moved ± 1 cm of this position. The second set of calculations were performed by illuminating the entire optic, removing the aperture stop, and varying the location of the source. These results are discussed in turn below.

Grid. The on-axis, best-focus PSF appears as a point with all rays originating from the source being focused onto the image side focal point. Off-axis points originating from the source side focal plane show increasing distortion with radial distance. This behavior can be seen from Figure 3.2. These PSFs show the reflection about the vertical axis common to ellipsoidal optics (Howell and Horowitz, Nuc. Inst. and Meth., 125 (1975), p. 225). The location of the images can be predicted from the geometrical magnification of the optic and the relationship given by Howell and Horowitz:

$$X_i = M(X_S \cos 2\phi - Y_S \sin 2\phi)$$

$$Y_i = -M(Y_S \cos 2\phi - X_S \sin 2\phi)$$

where M is the geometric magnification of the mirror and the subscript i refers to the image plane coordinates.

Figure 3.2 gives the optic location (the leading edge of the optic was at Z = -14 cm corresponding to the aligned condition), the grid size of the image plane (5 μ m per division), the location of the source in microns, and the location in the image plane of a ray reflected from the mirror center (the central ray) for the source points shown in the block diagram of source plane. Note that the location of the source should be incremented by 1 μ m. This 1 μ m discrepancy is due to the transformation of double precision values to integer values by truncation. Thus, the point source listed as being at (24 μ m, 24 μ m)

OPTIC LOCATION = - 14.0 cm

$5\mu\text{m/div}$

Figure 3. 2 Image of off-axis point sources for aligned optical system (continued on next page).

OPTIC LOCATION = -14.0 cm

5 $\mu\text{m}/\text{div}$

IMAGE AT -303, 303

-235, 235

Figure 3.2 (concluded)

is actually at $(25\mu\text{m}, 25\mu\text{m})$. The central ray originating from this point is imaged at $(33.6\mu\text{m}, -33.6\mu\text{m})$. The PSFs in Figures 3.2 were generated with a nominal 10° for ϕ , a Z increment of approximately 0.1 mm, and an incremental azimuthal angle of 0.01° .

Note that the PSFs produced by off-axis points in an aligned system are sharply defined and, therefore, it appears that significant amounts of fluence are not contained in broad, low energy wing. The increase in the base to base width of the PSFs with increasing source radial distance, however, implies that a large portion of the fluence may not be collected by the $100\mu\text{m}$ slit (aligned with the r -axis of the image plane) of the streak camera if the lasing reaction occurs off-axis from the source focus. This is shown in Figure 3.3. The abscissa is shown as a function of the source radial distance and as a function of the image radial distance of the central ray. It can be seen that a ray originating at a radial distance of about $37\mu\text{m}$ off-axis in the source-side focal plane, produced a PSF with a base to base width of $20\mu\text{m}$ centered on a radial distance of $50\mu\text{m}$.

As the optic is moved from its aligned position by ± 1 cm, the image undergoes increasing amounts of distortion and magnification. For example, Figure 3.4 is a plot of the vertical location of a ray originating from $(0,0,f_1)$, reflected from the optic center as the optic is moved fore and aft of its aligned position. Howell and Horowitz describe ellipsoidal focusing systems at glancing incidence as being inherently insensitive to longitudinal displacements of the source and image planes. To a first approximation, they describe the displacement, ΔZ_s , of the source out of the upstream focal plane as having the same effect as a displacement in the upstream focal plane of:

$$X_s = \Delta Z_s \tan \Theta$$

where Θ is the glancing angle of incidence. As can be seen from Figure 3.4, this does not hold true for point sources.

The effect of optic location (or source location) on the imaging of the central ray from off-axis points can be seen from Figure 3.5. The magnification

SOURCE AT FOCAL POINT

Figure 3. 3 Base to base PSF width as a function of off-axis point source location.

Figure 3. 4 Vertical dispersion of the ellipsoidal optic.

Figure 3. 5 Spatial dispersion as a function of off-axis source location and optic location.

in these figures is defined as the ratio of the source and image radial distances:

$$\text{MAG} = \frac{\sqrt{x_i^2 + y_i^2}}{\sqrt{x_s^2 + y_s^2}}$$

The origin of the off-axis rays are shown in the block diagrams included with each figure. Note that MAG does not vary symmetrically with movement of the optic about its aligned position. Further, the minimum value of MAG for source points originating within $25\text{ }\mu\text{m}$ of the source focus occurs when the optic is aligned. This minimum corresponds to the geometrical magnification of the optic. Sources further off-axis show a minimum magnification that occurs fore or aft of the aligned optic location ($Z = -14\text{ cm}$) depending upon the quadrant of origin. This minimum magnification is less than the geometrical magnification due to the effect of adding a vertical displacement in the upstream focal plane. Table 3.1 summarizes the minimum magnification observed.

Table 3.1. Variation of the minimum magnification of off-axis sources with optic location.

Source Location (x_s - μm , y_s - μm)	Minimum Magnification	Optic Location* (cm)
225, 225	0.956	-13.8
175, 175	0.981	-13.9
125, 125	0.949	-13.9
75, 75	1.167	-13.9
25, 25	1.346	-14.0
-225, -225	0.968	-14.2
-125, -125	0.956	-14.1
-25, -25	1.346	-14.0
225, -25	0.244	-13.8
125, -25	0.266	-13.9
25, -25	1.346	-14.0

*The system is aligned when the leading edge of the optic is at -14.0 cm . The rays are reflected about the center of the optic where the geometrical magnification is 1.346.

Insight into the imaging properties of this optic can be obtained from the data in Table 3.2 describing the location of the image resulting from the central ray. Note that the Y-location of the image is predicted by the geometrical magnification while the X-location (the vertical location) demonstrates the effect of adding a vertical displacement in the upstream focus.

Table 3.2. Location of central ray image
as optic location is varied.

Source Location ($X_S - \mu m$, $Y_S - \mu m$)	Image Location ($X_i - \mu m$, $Y_i - \mu m$)		
	Z = -13.0 cm*	Z = -14.0 cm*	Z = 15.0 cm*
225, -225	-1400, 293	303, 303	2081, 313
125, -125	-1530, 163	168, 168	1942, 174
25, -25	-1660, 32.5	33.6, 33.6	1862, 34.8
-25, 25	-1725, -32.5	-33.6, -33.6	1733, -34.8
-125, 125	-1855, -163	-168, -168	1594, -174
-225, 225	-1985, -293	-303, -303	1455, -313
$M^\dagger$	1.301	1.346	1.392

*Optic location

$\dagger$ Geometrical magnification at the optic's center

PSFs obtained when the optic was moved to Z = -13.0 cm are shown in Figure 3.6. Note that the PSFs of the points originating in the upper quadrants of the grid show less spreading and are more intense than those originating from the lower quadrants. When the optic is placed at Z = -15 cm, this behavior is reversed as can be seen from Figure 3.7. These figures were generated with the same optic gridding as that used to produce Figure 3.2. The image plane grid size, however, is now $50 \mu m$ per division rather than the $5 \mu m$ per division used before.

Full Optic Illumination. When the full optic is illuminated by rays originating from the source-side focal plane the ray trace calculations resulted in an annular structure. The development of this pattern as the source is moved

OPTIC LOCATION = 13.0 cm

50 $\mu\text{m}/\text{div}$

Figure 3. 6 Images of off-axis point sources located 1 cm aft of focal plane (continued on next two pages).

OPTIC LOCATION = 13.0 cm
 $50 \mu\text{m}/\text{div}$

IMAGE AT
 -1400, -293

224, 224

224, 224

174, 224

174, 224

174, 124

124, 224

124, 224

124, 124

-1530, -163

INCREASING Y

IMAGE OF SOURCE POINT AT
 X, Y = 224, 124 MICRONS

INCREASING X

Figure 3.6 (continued)

OPTIC LOCATION = 13.0 cm

50 $\mu\text{m}/\text{div}$

IMAGE AT
-1985, 293

-1920, 228

-1855, 163

IMAGE OF SOURCE POINT AT
X, Y--224, -124 MICRONS

INCREASING X ---->

INCREASING Y

Figure 3.6 (concluded)

OPTIC LOCATION = 15.0 cm

50 $\mu\text{m}/\text{div}$

IMAGE AT
1872, 104

74. -74

74. -24

1862, 34.8

24. -74

24. -24

24. 24

1733, -34.8

-24. -74

-24. -24

-24. 24

IMAGE OF SOURCE POINT AT
X, Y= 74, 24 MICRONS

INCREASING X ---->

----- INCREASING Y

Figure 3. 7 Images of off-axis point sources located 1 cm fore of focal plane (continued on next two pages).

OPTIC LOCATION

50 $\mu\text{m}/\text{div}$

96

IMAGE AT

2081, -313

224, 224

174, 224

124, 224

224, 174

2011, -244

174, 174

124, 174

IMAGE OF SOURCE POINT AT
X, Y = 224, 124 MICRONS

INCREASING X ---->

INCREASING Y <----

174, 124

1942, -174

124, 124

Figure 3.7 (continued)

OPTIC LOCATION = 15.0 cm

50 $\mu\text{m}/\text{div}$

IMAGE AT
1455, 313

-224, -124

-224, -124

--- INCREASING Y

IMAGE OF SOURCE POINT AT
X, Y = -224, -124 MICRONS

INCREASING X --->

1525, 244

-174, -124

-174, -124

-174, -124

1594, 174

-124, -124

-124, -124

-124, -124

Figure 3.7 (concluded)

along the horizontal axis (the Y-axis) is shown in Figure 3.8. Note that rays originating from the focal point $(0,0,f_1)$, are imaged as a point at $(0,0,f_2)$, the image side focal point. As the source plane is moved -1 mm from the focal plane rays originating from the Z-axis are imaged as an annulus. Rays originating from off-axis points, however, are imaged as a double ring structure as can be seen from Figure 3.9. The inner ring grows outward with increasing distance from the Z-axis.

A partial optic illumination was simulated to determine the portion of the optic that contributes to the development of the inner ring. When ϕ is swept through 180° , the images in Figure 3.10 are formed. Rays originating from $(0,0,f_2)$ image as an 180° arc, while rays originating from off-axis points form an arc greater than 180° . When ϕ is swept through 270° , off-axis source points (see, for example, the pattern from a source point at $X_S = 0\mu\text{m}$, $Y_S = 250\mu\text{m}$ in Figure 3.11) clearly show the development of an inner ring.

As the distance from the focal plane is increased to -3 mm, the image is altered again. As can be seen from Figure 3.12, rays originating along the axis of symmetry form an annulus. Rays displaced by $100\mu\text{m}$ along the horizontal axis are imaged as an annulus with a more intense region corresponding to the location of the central ray. As the displacement increases to $250\mu\text{m}$, the two ring structure appears. The outer ring, however, is of lower intensity relative to the brighter inner ring. The cardoid shape observed during full optic illumination is typical of the image expected for a comatic image from skew rays and a circularly symmetric optic. Nussbaum and Phillips describe this phenomena in detail and provide references for further depth in Chapter 3 of their book Contemporary Optics for Scientists and Engineers (Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1976).

3.3 Experimental Procedures and Apparatus

3.3.1 Experimental Plan Development. The first task addressed in the ellipsoidal optic experimental characterization effort was the development of an Experimental Plan. This document, attached as Appendix B, describes the

5 $\mu\text{m}/\text{div}$

0, 0

10 $\mu\text{m}/\text{div}$

0, 99

25 $\mu\text{m}/\text{div}$

IMAGE OF SOURCE POINT AT

X, Y = 0, 249 MICRONS

Figure 3. 8 Image of point sources originating from the source focal plane under full optic illumination (continued on next page).

99. 0

IMAGE OF SOURCE POINT AT
X, Y= 99, 249 MICRONS

INCREASING X ---->

Figure 3.8 (concluded)

Figure 3. 9 Image of a point located 1 mm aft of the source side focal plane under full optic illumination.

0. 374

0. 499

IMAGE OF SOURCE POINT AT
X, Y = 99. 249 MICRONS

INCREASING X →

Figure 3.9 (concluded)

Figure 3.10 Image of point located 1 mm aft of the source side focal plane under illumination of a 180° optic sector.

Figure 3.11 Image of point located 1 mm aft of the source side focal plane under illumination of a 270° optic sector.

Figure 3.12 Image of point located 3 mm aft of the source side focal plane under full optic illumination.

ellipsoidal optic and outlines the objectives of the experiments, the procedures and apparatus to be used (subject to modification during the course of the experiments), and the responsibilities of LLNL and ARACOR key personnel. A synopsis of the Experimental Plan's technical approach (intended to supplement rather than replace the reader's examination of this document) is given below.

The Experimental Plan specified that the PSF measurements would be obtained by recording on x-ray sensitive photographic film the optic-formed images of an array of microscopic x-ray source points. These points would be created by back-illuminating a multi-aperture collimator plate with the carbon K-series characteristic radiation ($h\nu = 279$ eV, well below the optic's critical energy at about 600 eV) generated by a demountable x-ray tube. The use of a multi-aperture collimator allowed both on-axis and off-axis PSF profile half-widths and relative peak intensities to be measured simultaneously. As it became evident that the extent of the PSF wings could easily exceed the center-to-center spacing of adjacent "pinhole" apertures, the multi-aperture plate was replaced by a single-aperture plate, for observation of the intensity contained in the profile wings.

A single, relatively-large ($\sim 100 \mu\text{m}$ -diameter) source aperture was used for the throughput measurement. With a measured carbon x-ray intensity I_0 incident on the optic and an intensity I_r reflected to the image plane, the reflection efficiency of the optic was calculated as $R = I_r/I_0$, for $h\nu = 273$ eV. Both I_0 and I_r were measured by a thin-window, flowing gas proportional counter, rather than photographic film.

Provision was made to maneuver both the source collimator plate and the ellipsoidal optic within the vacuum chamber. As the x-ray tube anode was of limited transverse extent (seen as a 0.5"-diameter circle at the collimator), transverse translations of the source collimator were required to ensure that the acceptance aperture of the ellipsoidal optic was illuminated by the cone(s) of radiation defined by the collimator. Limited axial collimator motion was accommodated to adjust the angular extent of the cone(s). The proper filling of the optic aperture was confirmed by x-ray photography obtained at the optic station.

Perhaps the most critical factor considered in the Experimental Plan was the requirement that the ellipsoidal optic's axis of cylindrical symmetry (defined as the "optical axis") be maneuverable, so that it could be brought to cross the active region of the source collimator at the optic's forward focal plane. Means for observing the optical axis and for moving it in a well-controlled way were specified in the Experimental Plan.

Control of optical axis motion was obtained by mounting the optic, within the vacuum chamber, on a 5-axis position manipulator. The manipulator, developed for use at Novette as well as in the current experiments, was constructed by coupling in series three commercial optic translation stages and two rotary-motion stages. As a standard optic alignment procedure, movement of the optic to an arbitrary transverse or axial position was followed by aiming the optical axis at the source collimator through pitch and yaw rotary adjustments.

Two different methods were used during the course of the experiments to observe the disposition of the optical axis. The initial method used an autocollimating telescope (positioned behind the film plane to observe all key points in the vacuum chamber--the source and image planes and the optic station) and a maneuverable retroreflector mounted in the bore of the optic. In a separate bench alignment procedure, the central normal of the retroreflector was aligned in coincidence with the visible light optical axis of the ellipsoid (this procedure to be described in the next paragraph). In the vacuum chamber, with the retroreflector stationary within the optic and the alignment telescope axis pre-positioned to intersect the source collimator, the optic was maneuvered in transverse position and in pitch and yaw until the retroreflector was autocollimated with the telescope axis. Confirmation was quickly obtained that the visible light and the soft x-ray optical axes of the ellipsoids were identical.

With this confirmation, the experiments adopted a more direct observation of the proper alignment of the optic by, in essence, transferring the visible light alignment procedure (used initially to set up the retroreflector orientation) from the bench to the x-ray exposure chamber. In this technique, the

image of a visible-light point source (a laser-illuminated fiber optic filament on the bench, a source collimator aperture illuminated by x-ray tube filament light in the exposure chamber) was directly viewed on a screen at the film plane with the assistance of a telemicroscope. The characteristic image pattern produced by a misaligned ellipsoidal optic being known, the optic could be quickly adjusted in pitch and yaw to obtain a point-like focussed image. In the x-ray exposure chamber, coarse adjustments were accomplished at the optic manipulator, with final fine adjustments achieved by small translations of the source collimator.

During all phases of the experiments, the axial positions of the optic and the film plane with respect to the source collimator were closely controlled. Measurement of these distances was obtained mechanically by use of an extendable inside micrometer. Axial movement of the optic was effected by an optic mount translation stage, while the source plane-film plane distance was adjusted by skimming the spool pipe that supported the detector station.

3.3.2 Experimental Configuration. A plan-view schematic of the evacuated exposure chamber used for the ellipsoidal optic PSF and throughput measurements is shown in Figure 3.13. The chamber consisted of three major sections:

1. x-ray source spool
2. optic/manipulator main chamber
3. detector ("film box") spool

A description of the key components of each of these sections follows.

3.3.2.1 X-ray Source Spool. This section contained a demountable soft x-ray ("Palmieri") tube, a gold-foil source collimator plate, and a 3-axis translation manipulator that allowed the collimator plate to be maneuvered across and along the major axis of the experiment. The source spool could be vacuum-isolated from the optic chamber by closure of a gate valve, the gate of which contained a 1"-diameter glass window.

Figure 3.13 Plan-View Schematic of the Experiment

Legend

1. Carbon-coated (aquadog) Palmieri x-ray tube anode; usual potential 1.5-2.0 kv, current 50mA
2. Single or multi-pinhole gold-foil source collimator
3. Source collimator manipulator, 3 axis translation (rotations not used)
4. Source-to-optic gate valve, with 1"-diam. glass window in gate
5. Ellipsoidal optic, within Novette manipulator (3 axis translation, pitch and yaw) and on kinematic mount floor plate
6. Reticule/retroreflector, within "web" manipulator (2 transverse translations, pitch and yaw)
7. Aperture plate, to simulate transmission grating aperture
8. Cryopump and gate valve
9. Optic-to-film gate valve
10. Removable light-tight foil in evacuation maze
11. Film cross-hair mounting station
12. Photographic film (or removable viewing screen)
13. Film-box back cover, with viewing window
14. Alignment autocollimating telescope (or screen-viewing microscope)
15. Removable collimator datum-block

The Palmieri tube anode was formed as an ellipse so that its projection along the experiment's center-line was a circle of 0.5" diameter. The anode was driven by thermionic electrons emitted by a helical tungsten filament located immediately above the anode. The usual gap potential and currents were 1.0 kV and 50 mA.

For these experiments, the original tungsten anode surface was coated to a thickness of several mils with "Aquadag" graphite suspension to create a carbon x-ray source. The carbon film proved durable and was refreshed only once during the course of the experiments to conceal a build-up of tungsten caused by evaporation of the filament.

The normal vacuum regime for x-ray tube operation was pressures less than 1×10^{-5} torr. The tube spool was fitted with two Vac-Ion pumps (15 l/s, 60 l/s) to maintain this pressure during periods when the spool was isolated from the optic chamber, and to assist in pressure-maintenance during normal operation. Spool pressure was monitored by a Varian cold cathode gauge. It was observed that for a given filament temperature, the beam current drawn by the tube was sensitive to the tube pressure, higher currents being drawn for lower pressures. During long film exposures which required constant beam current, it was necessary to allow the pressure to settle to a minimum value before beginning the exposure, a process of about 10-15 minutes duration.

On one occasion during the experiments, the x-ray tube was accidentally vented to atmosphere while being run at usual power. This incinerated the filament and caused all parts of the experiment, including the ellipsoidal optic, to be contaminated with particulate tungsten oxide, a yellow powder. Given the significant clean-up effort required to recover from this accident and the jeopardy in which the optic was placed, a safety mechanism was soon implemented to prevent reoccurrence of the accident. This mitigation consisted of wiring the upper set-point of the source spool cold cathode gauge into the x-ray tube safety interlock circuit. This caused the tube to be shut down at pressures exceeding the set-point, 1×10^{-5} torr. In addition, a sign was attached to the experiment's vent valve to remind operators of the hazard.

Source collimators. A variety of source collimator patterns were used during the course of the experiments. Each collimator consisted of a thin gold foil (thickness: $\sim 1\mu\text{m}$) containing a pattern of circular apertures formed by photolithographic-etching. Table 3.3 identifies the style of aperture pattern used during different experimental phases, ranging from a square array of $10\mu\text{m}$ diameter pinholes on $50\mu\text{m}$ centers, for the initial PSF measurements, to a single $100\mu\text{m}$ -diameter pinhole for the throughput measurements.

TABLE 3.3. Source Collimator Configurations

<u>Configuration</u>	<u>Aperture Diameter</u>	<u>Aperture Spacing</u>
"5x5"	$50\mu\text{m}$	$250\mu\text{m}$
"10x10"	$10\mu\text{m}$	$50\mu\text{m}$
"single 10"	$10\mu\text{m}$	single aperture
"single 100"	$100\mu\text{m}$	single aperture

The source collimators were mounted to the end of a tube whose axis was essentially parallel to the experimental center-line. The mounting tube was in turn supported on the stem of a Huntington 5-axis (3 translations, 2 rotations) vacuum manipulator, only the translations of which were used. As the source collimators were directly illuminated by the x-ray tube filament, it was hoped that the mounting tube end-cap and body would serve as an effective heat-sink for radiant energy incident on the collimators. All collimators except one survived this heat loading, the single failure being manifested as the interconnection of $10\mu\text{m}$ -diameter, $50\mu\text{m}$ -center apertures by stress-induced cracks. The failure occurred despite our best efforts to use minimum clamping force to retain the collimator plate in the mounting tube end-cap. This suggests that intricately-patterned aperture plates should be stress-relief annealed in an unclamped state prior to use.

Source Collimator Manipulator. Two distinct functions were served by the collimator manipulator during the experiments:

1. relatively-coarse positioning of the collimator with respect to the x-ray tube anode, to insure that the back-lit radiation pattern filled the acceptance aperture of the ellipsoidal optic. This condition was confirmed by x-ray photography performed in the optic tank, in a manner to be described in a following section; and
2. extremely-fine maneuvering of single-aperture collimators onto the axis of the ellipsoidal optic prior to PSF x-ray exposures.

The critical second task was accomplished by observing at the experiment's film plane the pattern of visible light that was generated by the filament, passed by the collimator pinhole, and reflected and focused by the optic. As aperture movements as small as $12\mu\text{m}$ proved significant in this process, the collimator manipulator was fitted with dial gauges to measure its transverse position to this accuracy. It was observed that, due to differential temperature distortion of the collimator mounting tube structure, the collimator position was not stable to $12\mu\text{m}$ accuracy until about two hours after start-up of the x-ray tube, necessitating a thermal conditioning of the source spool prior to PSF exposures.

Important dimensions for all of the experiments were the distances between the source collimator and the optic and the film plane. These distances were measured mechanically by use of an extendable inside micrometer. A special plug-in fixture, inserted as a cap on the optic-side end of the collimator mounting tube, provided a reference surface (of known displacement from the collimator) for these measurements. While the critical distances could be adjusted by movement of the collimator in its manipulator, the required adjustments were usually obtained by moving the optic on its translation stage and/or by shimming the detector spool with O-ring spacers ("econo-rings").

Source-spool gate valve. The source-spool isolation valve gate contained a glass window that allowed the collimator, back-lit by filament light, to be observed while the optic chamber and detector spool were at atmosphere.

Initially, it was thought that this would make significantly more efficient the processes of setting up and verifying the major axis alignment of the experiment. It was found, however, that refraction by the gate's glass window displaced the axial line-of-sight to an unacceptable degree. All visual observations of alignment were therefore performed with all chambering at low pressure and with the glass window retracted.

3.3.2.2 Optic/Manipulator Main Chamber. The main chamber of the experiment was a large rectangular vacuum vessel into which the optic/manipulator set, mounted on a kinematically-positioned baseplate, was installed for testing. The chamber (and the source and film box spools if the gate valves were open) was sustained at hard vacuum by a 10-inch cryopump attached to the main chamber through two gate valves.

Optic Manipulator. The ellipsoidal optic was maneuvered by a manipulator assembly consisting of the series coupling of the following stages (in order: from baseplate to optic cradle):

1. axial ("Z") translation
2. horizontal ("X") translation
3. vertical ("Y") translation
4. pitch (" ϕ ") rotation
5. yaw (" Θ ") rotation

The pitch stage was a tilt table that allowed rotations in three senses, only one of which was used. All stages were adjusted by direct access to their micrometers, requiring that the optic chamber be vented for optic positioning.

The sensitivity of all stages used in the manipulator proved adequate, and neither room noise or cryopump vibration disturbed the positioning of the optic. It was noticed, however, that the action of a 6" electropneumatic valve between the cryopump and the main chamber could significantly alter optic pointing in an unpredictable way. A 4" manual gate valve, installed in series with the 6" valve, was relied on to isolate the cryopump when the chamber was at atmosphere.

Optic retroreflector. For the initial PSF measurements, a retroreflector installed within the optic assisted in establishing the alignment of the optical axis. The retroreflector consisted of a lightly-chromed target reticle, retained in a support web. Stand-off set screws allowed the transverse (X,Y) position and pitch and yaw pointing of the web to be adjusted during the bench alignment procedure. The orientation of the retroreflector relative to the optic was not changed once the optic was installed in the main chamber.

Optic collimator. At Novette, the ellipsoidal optic was used to illuminate an x-ray transmission grating whose "ruled" area was contained within a 5 mm-diameter circle. The grating was located 3 cm from the film-plane end of the optic. Hence, an azimuthal arc length only slightly greater than 5 mm contributed to image formation in the streak camera detection plane. This collimation was simulated in the PSF and throughput measurements by placing a drilled-through aperture plate at the appropriate point (the anticipated grating location) behind the optic. During the time that the retroreflector was relied on for optic alignment, the aperture plate was hard-mounted to the optic support cradle. Later, when the optic-formed, visible-light image of the source collimator was used to guide the optic alignment procedure, the aperture plate was attached to an independent rotary motion feedthrough. This allowed the collimator to be removed from the beamline during alignment, and replaced (without disturbing the optic manipulator) for PSF and throughput x-ray exposures.

X-ray detection in the main chamber. X-ray detectors (photographic film, proportional counter) were deployed at the main chamber to obtain two types of measurement:

1. photographic recording of the x-ray beam pattern incident on the optic
2. recording of the throughput measurement incident intensity I_0 , with a proportional counter.

For the beam-mapping task, a 4"x5" film cassette, containing a single sheet of the sensitive Kodak type SB-5 film, was positioned on the optic manipulator immediately ahead of the optic entrance aperture. An aluminized plastic foil (6 μ m polycarbonate with ~ 400 Å aluminum) was installed as a temporary light

shield at the main chamber's forward beam port, retained by a ring mount. A coarse wire cross-hair, aligned on the experiment's center-line, was also installed ahead of the film cassette to cast a position-referencing shadow on the film. The beam-mapping procedure successfully guided the alignment of the source collimator with respect to the x-ray tube anode so that the optic aperture was fully illuminated.

The beam-mapping photography demonstrated that the x-ray emission intensity varied from point to point on the anode. This implied that the throughput I_0 measurement would be accurate only if it interrogated the same cone of radiation that exposed the optic for the I_r measurement. This cone was that defined by the off-center 5mm optic collimator, requiring that (for the I_0 measurement) the proportional counter be mounted outside of the center-line tubulation of the experiment. Thus, a special main chamber near flange was built to accommodate the counter during the I_0 measurement. It was also required that the collimator mounting be independent of the optic manipulator, which was removed from the chamber during I_0 measurements.

A unique source of interference was identified during the I_0 measurements. The main chamber hard vacuum was routinely monitored with a Varian cold cathode gauge, a high voltage ionization gauge. When the main chamber was suffused with methane proportional counter gas (an unavoidable and expected consequence of the use of thin plastic counter windows), the cold cathode gauge became a relatively intense source of carbon K x-rays, visible to the counter in its I_0 geometry. Because the experiment was directed to observe exactly the carbon radiation emitted by the tube anode, it was necessary to remove the interference by turning the cold cathode gauge off during measurements.

3.3.2.3 Film Box Spool. This spool consisted of a 6"-diameter T-pipe section that supported a film box cannister previously built for work with x-ray microscopes.

The film box consisted of a stationary flange, fitted to support a film cassette at the experiment's image focal plane, and a removable cover. The cover was adapted, by installation of a glass window on center-line, so that the

x-ray source collimator (back-lit by filament light) and the optic retro-reflector could be observed through the alignment telescope with the experiment under vacuum and the film cassette removed. This allowed the source collimator/optic co-alignment to be confirmed immediately prior to PSF and throughput measurements. A second cover was adapted to support the proportional counter on-axis during throughput I_r measurements.

The film-box T-pipe spool supported a fixture at which a light-tight foil was temporarily placed across the beam line during PSF film exposures. This foil consisted of a single ply of Sieman's Makrofol, $2\mu\text{m}$ -thick polycarbonate film bearing a thin ($\sim 350\mu\text{m}$) coating of aluminum. The foil mounting fixture provided an evacuation maze that established pressure equilibration across the foil was gained through the normal leg of the T-pipe.

The length of the film box spool was adjustable (in increments of 2.5 mm) by insertion or extraction of "econo-ring" O-ring spacers to the pipe string. This adjustment was relied on to establish the displacement of the film plane from the source collimator during the PSF measurements that addressed the depth-of-focus of the ellipsoidal optics. The spool also contained a nipple through which all sections of the experiment were evacuated by carbon vane and cryosorb roughing pumps.

Photographic film detectors. Two types of x-ray sensitive Kodak film, SB-5 and RAR-2492, were used in the experiments, for beam mapping and PSF measurement. Due to its high soft x-ray sensitivity but coarse spatial resolution, the SB-5 film proved useful only for the beam-mapping task. The RAR-2492 recorded PSF patterns with very low image graininess and background fog, although exposure times of the order of one hour (three times greater than for SB-5) were required by this film. Both films were tray-processed, the RAR-2492 film being developed in D-19 for 8 minutes at 68°F ; the SB-5, in RXR for 6 minutes at 68°F . It was established experimentally that both films were sufficiently insensitive to visible light to allow the use of only marginally opaque light-shielding foils in the experiment.

Proportional counter. The soft x-ray detector relied on during the throughput measurements was a Siemens type F flowing gas proportional counter. This counter is fitted with an O-ring-sealed mounting flange at its entrance aperture, allowing it to be attached externally to experiment tubulation. The methane counter gas, at atmospheric pressure plus a one-pound flow head, was isolated from the experiment vacuum by a Makrofol window foil. The proportional counter was complemented by a Siemens fixed-gain preamplifier/bias isolation unit built into the counter's electrical connector. External spectroscopy amplifier, high voltage power supply, and single channel analyzer NIM units processed the detector signals. A facility oscilloscope and a multi-channel analyzer were used to observe detector pulse shapes and peak voltage distributions, respectively.

For the throughput I_r measurement, the proportional counter was mounted on the experiment axis (but aft of the image focal plane) by attachment to the film box cover. Since the Makrofol counter window was supported by an electroformed stainless steel screen, care had to be taken to insure that the x-ray image radiation entered the counter without obstruction by the screen. To accomplish this, the film box cover (bearing the counter) was shimmed transversely in a stepwise manner while the count rate was monitored. The I_r intensity measurement was obtained at the counter location that yielded the highest count rate.

3.3.3 Recommendations. Our experience with the procedures and apparatus described above recommends the following design features for a permanent x-ray collection optic calibration facility.

1. The ease of setup and geometric stability of the experiment would be improved if the three critical beam-line components (the source collimator, the optic mount, and the film/counter station) were attached to a common optical bench that was kinematically-mounted within the vacuum vessel.
2. External manipulation of the optic position would also greatly increase the efficiency and reliability of the alignment procedure.
3. External installation and removal of the film box light-tight window would improve on the existing situation.
4. A windowless microchannel plate x-ray detector is a viable alternative to the flowing gas proportional counter used in the current experiments.

3.4 Experimental Results

A three volume set of notebooks was generated by ARACOR and LLNL personnel in the conduct of the experimental plan. This set, entitled TGSS X-Ray Mirror Characterization, covers the time period from the beginning of February to the end of September 1984. These experimental notebooks (as of 7/10/84) will ultimately be transferred to the x-ray calibration facility at LLNL. Contact LLNL employees D. Stearns or B. Cook for more details.

In general the best results are in TGSS X-Ray Mirror Characterization notebook #3. The measurement series that obtained the most useful results was performed in June 1984 by LLNL physicist D. Stearns. The following data represent the best measurements performed on the optics:

PSF

1. Photograph #061584-01: Point spread function from 100 μ m pinhole for mirror #3.
2. Photograph #062684-01: Point spread function from 100 μ m pinhole for mirror #1.

Throughput

1. #061584-02: with 1 mm aperture.
2. #061584-03: without 1 mm aperture.
3. #061584-04: with optic removed.
4. #061584-05: high voltage (1.5 keV).
5. #061584-06: straight through measurement (2 keV).

Field of View

1. Photograph #031684-01: performed with 5x5 mm grid.

These data have been analyzed only qualitatively and the results are contained in the experimental notebooks.

4.0 X-RAY LASER END-MIRROR PERFORMANCE CALCULATIONS

4.1 Problem Statement

This section describes work performed by ARACOR in the calculational performance simulation of the x-ray dispersion properties of candidate x-ray laser (XRL) cavity normal-incidence end-mirror optics. This work was performed in the period May-June 1984.

The objects studied in this effort were several samples of layered synthetic microstructure (LSM) x-ray interference mirrors constructed for LLNL by T. W. Barbee, Jr., of Stanford University. Given the successful resolution of several critical issues dealing with the dispersion performance and survivability of the LSMs, one or more of these samples would provide the stock for fabrication of cavity end-mirrors to be installed on XRL targets used at the LLNL Novette Laser Facility. The function of the end-mirrors would be to reflect back into the lasing high-temperature plasma, the monochromatic laser-transition EUV radiation, thereby increasing the XRL stimulated emission gain. Several XRL schemes, involving lasing transitions of photon energy 181 eV or 130 eV, were to be tested at Novette in the June-July 1984 timeframe, providing an immediate opportunity to deploy single-end, normal-incidence cavity reflectors. An ensemble of 12 LSM samples, the physical characteristics of which are given in Table 4.1, were prepared by Barbee in April 1984.

Table 4.1. Physical Characteristics of Candidate Mo/Si LSM Samples.

d - spacing (Å)*							
XRL (A)	Sample	req'd	-1	-2	-3	-4	No. Layers
181	84049	97.8	101.5	98.2	96.0	93.0	20
167	84050	89.2	97.1	93.6	91.5	88.0	24
130	84051	67.6	68.0	65.5	62.2	59.0	40

* $\Gamma = 0.3814$; outermost layer is Mo with 10 Å carbon passivation

The key issues to be resolved by LLNL prior to committing to XRL end-mirror deployment were as follows:

1. experimental demonstration of the samples' fitness-for-use, at x-ray photon energies in the neighborhood of the XRL monochromes;
2. calculational extrapolation of the observed LSM dispersion performance into the immediate vicinity of the lasing monochromes; and
3. simulation of the radiation loading to which the LSMs would be subjected in use, for evaluation of their survivability in the XRL environment.

The first issue was resolved by means of a collaboration established between LLNL and the University of California Space Sciences Laboratory (SSL) in Berkeley, with technical leadership provided by Dr. Lyn Pleasance of LLNL and Dr. Jerry Epstein of SSL. The Berkeley facility operates an EUV vacuum diffractometer which was used in this project to measure "rocking curve" profiles (reflection efficiency as a function of dispersion angle, at fixed photon energy) of samples 84040-2 and -3 at $h\nu = 73.0$ eV.

The specific contribution of ARACOR personnel in the project was the resolution of the second issue presented above. As tasked by Dr. Pleasance, ARACOR LSM performance simulation computer codes were used to predict first the experimentally-observed rocking curves at 73 eV and then the spectral passband curves (reflection efficiency as a function of wavelength, at normal incidence) at the XRL energy $h\nu = 68.5$ eV. The nature and results of these calculations are described below.

Resolution of the third critical issue, dealing with LSM survivability in the XRL environment, was addressed by Pleasance using atomic physics codes available at LLNL.

4.2 LSM Dispersion Simulation Technique

The basis for the ARACOR LSM dispersion simulation computer codes is the calculational method developed by J. Underwood (in AIP Conference Proceedings No. 75). This technique involves the recursive solution of the Fresnel boundary equations at successive interfaces of the LSM, for arbitrary x-ray beam/optic geometry and given material constants. Two codes, MLAYERS 1 and MLAYERS 2, were transferred to ARACOR computers by Underwood, while he served as our consultant. The first code calculates rocking curves at fixed photon energy, while the second code calculates spectral passband curves at fixed angle of incidence.

The principal material constant information required as input by the two simulation codes are the components of the complex index of refraction N_r of the LSM constituent elements. These components are δ and β , such that $N_r = 1 - \delta - i\beta$. As the samples considered in this effort were composed of molybdenum and silicon, it was necessary to determine the relevant values of δ and β for these elements in the 170-180 Å wavelength region.

Henke tabulates (also in AIP Proceedings No. 75) the real (f_1) and imaginary (f_2) atomic scattering factors of all elements in the soft x-ray region. These data allow calculation of the complex dielectric constant $k = N_r^2$ as:

$$K = 1 - \alpha - i\gamma$$

where

$$\alpha = 5.404 \times 10^{-6} \cdot \lambda^2 \cdot \rho / A \cdot f_1$$
$$\text{and } \gamma = 5.404 \times 10^{-6} \cdot \lambda^2 \cdot \rho / A \cdot f_2$$

Here, λ is the x-ray wavelength in angstroms

ρ is the elemental density

and A is the elemental atomic weight

It is usually assumed that, in the soft x-ray region, α and γ are so much less than unity that

$$\delta \approx \alpha/2 \text{ and } \beta \approx \gamma/2.$$

In the XUV region considered in this work, the condition $\alpha, \gamma \ll 1$ was in fact not satisfied. Therefore, given values of f_1 and f_2 , the parameters δ and β were calculated exactly as:

$$\beta = [((\alpha-1) + \sqrt{(1-\alpha)^2 + \gamma^2}) / 2]^{1/2}$$

and $\delta = 1 - \gamma/2\beta$, derived from the relation

$$K = (1 - \alpha - i\gamma) = (1 - \delta - i\beta)^2 = N_r^2$$

The atomic scattering factor values taken from Henke's tabulations were:

for molybdenum ($Z=42$): $f_1 = 16 \pm 1$

$$f_2 = 4.5 \pm 0.5$$

for silicon ($Z=14$): $f_1 = 2 \pm 2$

$$f_2 = 0.51 \pm 0.02$$

throughout the 170 - 180 Å region.

4.3 Simulation Results

The x-ray dispersion computer codes were used to generate two types of data for LSM samples 84049-2 ($d=98.2$ Å) and 84049-3 ($d=96.0$ Å). The first type of data shows the predicted reflectivity as a function of Bragg angle for $\lambda=171.4$ Å, the aluminum L-line test wavelength used in the Space Sciences Laboratory (SSL) evaluations. Figures 4.1 and 4.2 show the predicted rocking curves for unpolarized radiation incident on these two samples and were intended for direct comparison with SSL results. The second type of data was the predicted reflectivity as a function of wavelength at a fixed Bragg angle. The predicted spectral passband curves for normal incidence, shown in Figures 4.3 and 4.4, represent the LSM performance in their intended roles as x-ray laser cavity end mirrors.

Figure 4. 1 Rocking curve of sample 84049-2 at test wavelength $\lambda = 171.4 \text{ \AA}$.

Figure 4. 2 Rocking curve of sample 8409-3 at test wavelength $\lambda = 171.4 \text{ \AA}$.

Figure 4. 3 Spectral passband of sample 84049-2 at normal incidence.

Figure 4. 4 Spectral passband of sample 84049-3 at normal incidence.

These results were found to be relatively insensitive to variations of the complex atomic scattering factor within their range of confidence. The calculations were repeated with $f_1 = 16 \pm 1$, $f_2 = 4.5 \pm 0.5$ for moly and $f_1 = 2 \pm 2$, $f_2 = 0.51 \pm 0.02$ for silicon. Table 4.2 demonstrates how the rocking curve centroid angle (θ_0), peak reflectivity (P_0), and reflectivity at $\theta = 90^\circ$ ($P_{\min}$) changed as f_1 was systematically varied. Table 4.3 shows how the normal incidence, spectral response curve centroid wave length (λ_0), peak reflectivity (P_0), band width ($\Delta\lambda$ - FWHM), and x-ray laser wave length reflectivity (P_{XRL}) varied at 181 Å responded to f_1 variations. Tables 4.4 and 4.5 show how these parameters varied as f_2 was systematically varied. In summary, only modest changes in the reflection properties of the LSM samples resulted from varying f_1 and f_2 over their ranges of confidence.

TABLE 4.2. SENSITIVITY OF ROCKING CURVE RESULTS TO VARIATIONS
IN f_1 AT THE TEST WAVELENGTH, $\lambda = 171.4 \text{ \AA}$

SAMPLE	input *		results		
	$f_1 - \text{Mo}$	$f_1 - \text{Si}$	Θ_0	P_0	** $P_{\min}$
84049-2 ($d=98.2 \text{ \AA}$)	16	0	67.5°	.34	.092
	16	2	69.0°	.33	.098
	16	4	70.5°	.31	.105
	15	2	68.0°	.31	.078
	16	2	69.0°	.33	.098
	17	2	69.5°	.34	.123
	17	2	70.5°	.34	.123
84049-3 ($d=96.0 \text{ \AA}$)	16	0	70.5°	.36	.155
	16	2	72.0°	.349	.172
	16	4	73.5°	.33	.19
	15	2	71.0°	.33	.134
	16	2	72.0°	.349	.172
	17	2	73.0°	.36	.21
	17	2	74.0°	.36	.21

*For all calculations, $f_2 = 4.5$ for Mo, $f_2 = 0.51$ for Si

** $P_{\min}$ is the minimum reflectivity observed on the high-angle side of the curve, at $\Theta = 90^\circ$

TABLE 4.3. SENSITIVITY OF SPECTRAL PASSBAND RESULTS TO VARIATIONS IN f_1 AT NORMAL INCIDENCE, $\theta = 90^\circ$

SAMPLE	input *		results			
	$f_1 - \text{Mo}$	$f_1 - \text{Si}$	λ_0 (Å)	P_0	$\Delta\lambda, \text{FWHM}$ (Å)	** P_{xrl}
84049-2 ($d=98.2 \text{ Å}$)	16	0	189	.44	20	.34
	16	2	186	.40	20	.36
	16	4	184	.38	19.5	.36
	15	2	187	.40	17	.32
	16	2	186	.40	20	.36
	17	2	186	.42	19.5	.38
84049-3 ($d=96.0 \text{ Å}$)	16	0	184	.44	20	.42
	16	2	182	.41	19	.41
	16	4	180	.38	21	.37
	15	2	183	.40	16.5	.39
	16	2	182	.41	19	.41
	17	2	181	.42	21.5	.42

*For all calculations, $f_2 = 4.5$ for Mo, $f_2 = 0.51$ for Si

** P_{xrl} is the reflectivity observed at the proposed x-ray laser wavelength, $\lambda = 181 \text{ Å}$

TABLE 4.4. SENSITIVITY OF ROCKING CURVE RESULTS TO VARIATIONS
IN F_2 AT THE TEST WAVELENGTH $\lambda = 171.4 \text{ \AA}$

SAMPLE	input *			results	
	$f_2 - \text{Mo}$	$f_2 - \text{Si}$	Θ_0	P_0	** $P_{\min}$
84049-2 ($d=98.2 \text{ \AA}$)	4.5	0.49	68.9°	0.33	0.098
	4.5	0.51	69°	0.33	0.098
	4.5	0.53	68.9°	0.32	0.098
	4.0	0.51	69.2°	0.35	0.10
	4.5	0.51	69°	0.33	0.098
	5.0	0.51	68.6°	0.30	0.095
84049-3 ($d=96.0 \text{ \AA}$)	4.5	0.49	72°	0.35	0.17
	4.5	0.51	72°	0.35	0.17
	4.5	0.53	72°	0.35	0.17
	4.0	0.51	72.3°	0.38	0.18
	4.5	0.51	72°	0.35	0.17
	5.0	0.51	71.8°	0.33	0.16

*For all calculations, $f_1 = 16$ for Mo, $f_1 = 2$ for Si

** $P_{\min}$ is the minimum reflectivity observed on the high-angle side of the curve, at $\Theta = 90^\circ$

TABLE 4.5. SENSITIVITY OF SPECTRAL PASSBAND RESULTS TO
VARIATIONS IN F_2 AT NORMAL INCIDENCE, $\lambda = 90^\circ$

SAMPLE	input *		results			
	$f_2 - \text{Mo}$	$f_2 - \text{Si}$	σ ($\text{\AA}$)	P_0	$\Delta\lambda, \text{FWHM}$ ($\text{\AA}$)	** P_{Xr1}
84049-2 ($d=98.2 \text{ \AA}$)	4.5	0.49	186	0.44	23.6	0.386
	4.5	0.51	186	0.40	20	0.36
	4.5	0.53	186.5	0.386	24.2	0.33
	4.0	0.51	186.3	0.41	24	0.36
	4.5	0.51	186	0.40	20	0.36
	5.0	0.51	186.2	0.41	24	0.35
84049-3 ($d=96.0 \text{ \AA}$)	4.5	0.49	182.1	0.41	23.6	0.41
	4.5	0.51	182	0.41	19	0.41
	4.5	0.53	182	0.41	17.4	0.40
	4.0	0.51	181.8	0.44	23.2	0.436
	4.5	0.51	182	0.41	19	0.41
	5.0	0.51	182.3	0.386	17.4	0.381

*For all calculations, $f_1 = 16$ for Mo, $f_1 = 2$ for Si

** P_{Xr1} is the reflectivity observed at the proposed x-ray laser
wavelength, $\lambda = 181 \text{ \AA}$

5.0 X-RAY LASER EXPERIMENTAL SUPPORT

5.1 Problem Statement

This section describes the effort performed by ARACOR in support of the Laser Fusion Program's x-ray laser (XRL) experiments. The work discussed herein was performed in the period May to October 1984 according to tasks VII and X of the statement-of-work associated with LLNL purchase order number 4681605. In general, these tasks define the effort required for the reduction of XRL data acquired by the Henway and Micro-Channel Plate Intensified Grazing Incident (MCPIGS) spectrometers. In particular, the Henway spectrometer measures the spectrum of the pumping mechanism while MCPIGS records the spectrum associated with the actual lasing lines.

The reduction of the Henway spectrometer data involved two software codes entitled LINE_SPEC and SPEC_PLOT developed by LLNL. These codes are part of the Fusion Experiments Analysis Facility (FEAF) whose main CPU support is provided by a DEC VAX 11/780 machine. The MCPIGS data was reduced using the OCTOPUS resident software XPORT, NUFORMAT, JOIN10, OGOMON, PLOT3D, UNOP, UNOP3D, and PLOTIT, with the latter three routines being part of the SOCKITTOME code. All of this work was done on a CDC 7600 CPU.

5.2 Data Reduction Procedures

5.2.1 Henway Data Reduction. The major effort associated with the reduction of the Henway Crystal Spectrograph (HWCS) data was accomplished using the FEAF software program LINE_SPEC. A second FEAF code entitled SPEC_PLOT was used to normalize the fluence as a function of photon energy output of LINE_SPEC over a number of XRL shots. By doing this a relative assessment of XRL line strength could be made.

Before any computer-aided reduction of the HWCS data could take place the exposed film had to be marked so that the background and data regions could be properly identified. Once this was done the film was turned over to the

Technical Photography Lab where it was digitized by the photo-densitometer system (PDS). This step ended with the creation of two VMS-11 compatible mag tape films. Each file contained film density values as a function of film position with a distinction between the background data and shot data.

The two files created in the PDS step carried the following file naming convention

MMDNNHWA.PDS

and

MMDNNHWB.PDS

where

MM = month of shot (1-12)

DD = day of shot (1-31)

NN = shot number associated with day DD (1-99)

HW = Henway descriptor

X = Henway NOVETTE number (1 or 2)

A = Henway shot data

B = Henway background data.

Each file was transferred to the VAX system disk from the mag tape for subsequent data reduction.

The execution of LINE_SPEC required a RAMTEK color graphics monitor. The actual processing steps and user prompts of LINE_SPEC are outlined in Table 5.1 with typical responses shown. A detailed description of LINE_SPEC can be found in the LLNL memo DMAG-81-0058, dated 20 April 81, entitled "Processing of Digitized Spectrometer Film Data on FEAF VAX."

A print file labeled FOR099.DAT;VV, where VV is the most recent version number, was created and written to the system disk at the completion of LINE SPEC. This file consisted of four spectral plots. These were 1) film density vs. film position, 2) fluence vs. photon energy in a semi-log format,

Table 5.1 LINE_SPEC Processing Sequence and User Input for the
Reduction of Henway Crystal Spectrograph Data.

<u>Step</u>	<u>Program Prompt/Action</u>	<u>Example of User Response</u>
1.	Film Density Correction?	0.0
2.	Background File Name?	2304HW2B.PDS
3.	Total Data File Name?	2304HW2A.PDS
4.	Disk Output File Name?	2304HW2A.DAT
5.	RAMTEK Unit Number?	2
6.	Program displays plot of film density vs. film position for background data, total data and total minus background data	
7.	Enter Film Position Region for Spectral Unfold.	
	a. Enter Lower Position in cm	0.5
	b. Enter Upper Position in cm	2.5
8.	Program Draws Box around Selected Region of Interest	
9.	Ready for Next Plot?	Yes
10.	Program Displays Plot with User Specified Abscissa	
11.	Program Informs User to Select a Particular Spectral Line to Normalize the Spectral Plot	
	a. Select Position on Curve (cm)	0.459
	Program draws a red vertical line at that position	
	b. Are you satisfied with cursor position?	Yes
	c. Enter energy (keV) corresponding to position	1.439

Table 5.1 LINE_SPEC Processing Sequence and User Input for the
Reduction of Henway Crystal Spectrograph Data. (Cont'd)

<u>Step</u>	<u>Program Prompt/Action</u>	<u>Example of User Response</u>
12.	Enter Spectrograph Type	PP-NVT
13.	Enter Crystal Type	LKAP
14.	Enter Filter Material	BE
15.	Enter Filter Thickness in G/CM*2	0.00157
16.	Rutherford Film Correction?	No
17.	Enter Film Type	S8-5
18.	Program Notifies User Parameter Extraction Complete	
19.	Ready for Next Plot?	Yes
20.	Program Displays Max and Min Values of Fluence	
21.	Hard Copy of Results?	

3) fluence vs. photon energy in a linear format, and 4) the integral of the fluence over the photon energy. Examples of these for shot number 0801205HW2A.DAT are shown in Figures 5.1-5.4, respectively. Additionally, a file labeled MDDNNHXA.DAT following the file naming convention described above was created and stored on the system disk. This file contained the fluence, in units of keV/keV-sphere, as a function of photon energy in keV.

The following processing steps were performed to create normalized fluence plots of data obtained from a number of NOVETTE shots. Upon entering the FEAF code LINE_SPEC the user was prompted for the .DAT file name and the minimum and maximum values of the fluence and photon energy to be plotted. The code checks the input values against the data contained in the .DAT file to ensure they match one another. If they do not match (i.e., a given fluence value exceeds the maximum fluence value for the maximum photon energy), then the user is notified and the program proceeds to create a plot file based on the abscissa range that was entered. The user is then asked to input the terminal type (i.e., RAMTEK color or RETROGRAPHICS VT-100 monochrome monitor) before the plot is displayed.

Once this step is completed the data are displayed at the user's terminal. Hardcopy outputs are available by typing the command

```
PRINT FOR099.DAT;VV
```

where VV is the most recent version number. The VAX responds with a randomly generated print number. This number must be keyed into the nearest VERSATEC printer to obtain the hardcopy output. An example of the fluence vs. photon energy hardcopy copy SPEC_PLOT output is shown in Figure 5.5.

5.2.2 MCPIGS Data Reduction. The data reduction effort associated with the Micro-Channel Plate Intensified Grazing Incident Spectrometer (MCPIGS) involved a number of software routines residing on the OCTUPUS system. The main pieces of code used to reduce the MCPIGS data were XPORT, JOIN10, SOCKITTOME, and OGOMON. A number of subroutines within the SOCKITTOME program were also

Figure 5. 1 LINE SPEC hardcopy output of Henway film density as a function of film position for Novette shot number 080105HW2A.

Figure 5. 2 LINE_SPEC hardcopy output of Henway semi-log plot of fluence as a function of photon energy for Novette shot number 080105HWZA.

Figure 5. 3 LINE SPEC hardcopy of output of Henway linear plot of fluence as a function of photon energy for Novette shot number 080105HW2A.

Figure 5. 4 LINE_SPEC hardcopy output of Henway plot of the integrated fluence as a function of photon energy for Novette shot number 080105HW2A.

Figure 5. 5 SPEC PLOT hardcopy output of Henway fluence as a function of photon energy for Novette shot number 080105HWZA.

used. Included in these were the PLOT3D, UNOP3D, PLOTIT and UNOP routines. The result of all of these processes was to convert the PDS film data to a fluence as a function of wavelength format.

Several steps were required to get the data to its final format of fluence vs. wavelength. Initially, all PDS data are stored in two files for each MCPIGS instrument due to file size restrictions. These files are subsequently combined into a single MCPIGS data file. The sequence of events are detailed in Table 5.2. For all NOVETTE XRL shots two MCPIGS instruments were on-line for any given shot. These were designated MCPIGSI and MCPIGSII, respectively. For a given XRL shot each MCPIGS instrument recorded three time-windowed pieces of information. The time frames were determined by turning off the MCPs at different times during the event with fast Austin switches developed by LLNL. These time frames were designated as early, middle and late time data. All data were referenced to a common fiducial.

The file naming convention followed that of the one described earlier for the HWCs. However, due to the large number of steps required for the MCPIGS data reduction each of the last two characters in each file name differed from step-to-step. In general, the file name followed the convention.

MMDDNNXXST

where MMDDNN are as before, XX is either I or II for MCPIGSI or MCPIGSII data, S is the data processing step identifier described in Table 5.2, and T is either 1, 2 or 3 to distinguish between early, middle, or late time MCPIGS data.

As a result of the processing steps listed in Table 5.2 five sets of hardcopy data were generated. These are summarized in Table 5.3. Examples of the hardcopy output are shown in Figures 5.6-5.16.

**Table 5.2 Data Reduction Steps for MCPIGS (Note: MMDDNN File
descriptor left off file names included in this table)**

<u>Step</u>	<u>Program</u>	<u>Description</u>	<u>Result of Step</u>
1.	XPORT	Get MCPIGS working file (i.e., user software) and data files	Working Files: OGOMON, WAVELEN STID. Data Files: I & II, II & IIA
2.	NUFORMAT	Convert data from PDS format to SOCKITTOME format	Data Files: IS & IAS, IIS & IIAS
3.	JOIN10	Join the data files together to form a single file	Data Files: IJ, IJJ
4.	SOCKITTOME (PLDT3D)	Plot & take back-ground data lineouts from J-file	Horizontal line- outs of back- ground defined by YMIN command. Typical values: YMIN 6 7 & YMIN 13 14
5.	SOCKITTOME (UNOP3D)	Take a row average over background line-outs and create back-ground files	Data Files: IB1 & IB2, IIB1 & IIB2

Table 5.2 Data Reduction Steps for MCPiGS (Cont'd)

<u>Step</u>	<u>Program</u>	<u>Description</u>	<u>Result of Step</u>
5.	SOCKITTOME (PLOTIT)	Plot background to determine average value of background	Record average background c_b , for both files. If these two numbers differ go back to step 4. Typical background values were in the range .24 - .33
7.	SOCKITTOME (UNOP3D)	Normalize background in J-file to .35	Add constant ($z - c_b$) or subtract constant ($c_b - z$) from z data in J-file.
8.	Repeat Steps 5 & 6	Using background corrected J-file confirm average background is .35	Data Files: IB3, IIB3. Hardcopy of J-file.
9.	UTILITY	Copy background corrected J-file to new file ST10	J-files remain & ST10 file is created.

Table 5.2 Data Reduction Steps for MCPiGS (Cont'd)

<u>Step</u>	<u>Program</u>	<u>Description</u>	<u>Result of Step</u>
10.	OGOMON OGO(15)ST1	Convert density data to exposure data	STIE file is created.
11.	UTILITY	Switch file name STIE to E-file	Data Files: IE, IIE
12.	SOCKITTOME (UNOP3D)	Convert exposure file to units of mergs/cm ² using experimental constants	Subtract 1 from E-file and multiply E-file by 0.2093. Hardcopy of E-file.
13.	SOCKITTOME (PLOT3D)	Plot and take early, middle and late time lineouts from E-file.	Typical values: Early:YMIN 3 4.5 Mid: YMIN 10 11.5 Late:YMIN 16 17.5
14.	SOCKITTOME (UNOP3D)	a. Take a row average over early, middle and late time lineouts from E-file and create fluence file. b. Take a row average over early, middle and late time lineouts from J-file and create density files.	Data files: IR1, IR2, IR3, IIR1, IIR2, IIR3. Data files: ID1, ID2, ID3, IID1, IID2, IID3.

Table 5.2 Data Reduction Steps for MCPIGS.(Cont'd)

<u>Step</u>	<u>Program</u>	<u>Description</u>	<u>Result of Step</u>
15.	SOCKITTOME (PLOTIT)	Plot all D-and R-files and print hardcopy	Hardcopies of all D- and R-files
16.	SOCKITTOME (PLOIT)	Plot all R-files to find fiducials.	Record x-position of fiducial peak amplitude. Typical values: Early: 24-25 mm Middle: 24-25 mm Late: 34-35 mm
17.	SOCKITTOME (UNOP)	Time reference all time lineouts by subtracting off fiducial position	Fiducial corrected R-files
18.	UNOP (WAVELENJ) J=1,2,3	Convert x-position to wavelength and create wavelength files	Data files: IW1, IW2, IW3, IIW1, IIW2, IIW3
19.	SOCKITTOME (PLOTIT)	Plot all W-files and print hardcopy. Verify XRL lines @ $\lambda=156.468 \text{ \AA}$ and $\lambda=174.118 \text{ \AA}$.	Hardcopy of all all W-files.
20.	XPORT	Write all files to MCPIGS directory	Final storage of files: J, E, B1, B2, B3, D1, D2, D3, R1, R2, R3, W1, W2, W3.

Table 5.3 Summary of Hardcopy Output from
MCPIGS Data Reduction

<u>File Designator</u>	<u>File Description</u>	<u>Plot Units</u>
1. J	PDS data with background normalized to 0.35.	y(mm) vs x(mm)
2. E	Exposure file from OGOMON and corrected for experimental constants (i.e. exposure to mergs/cm ²)	y(mm) vs x(mm)
3. D1, D2, D3	Film density files created from early, middle and late time line-outs strips of J file	density vs x(mm)
4. R1, R2, R3	Reduced data files created from early, middle and late time line-outs strips of E file	F(mergs/cm ²) vs x(mm)
5. W1, W2, W3	Wavelength data files created from R1, R2 and R3 files using WAVELEN1, WAVELEN2 and WAVELEN3 subroutine and referenced to 156 Å, 156 Å and 169 Å fiducials on R1, R2 and R3 respectively.	F(mergs/cm ²) vs $\lambda(\text{\AA})$

Figure 5. 6 MCPIGS II hardcopy output of J-file for Novette shot number 083007.

SHOT 083007 MCPIGS II EARLY J-DATA
FILES ..083007I1D1

Figure 5. 8 MCPIGS II hardcopy output of D1 file for Novette shot number 083007.

SHOT 083007 MCPIGS II MIDDLE TIME J-DATA
FILES ..08300711D2

Figure 5. 9 MCPIGS II hardcopy output of D2 file for Novette shot number 083007.

Figure 5.10 MCPIGS II hardcopy output of D3 file for Novette shot number 083007.

SHOT 083007 MCPIGS II EARLY TIME
FILES ..08300711R1

Figure 5.11 MCPIGS II hardcopy output of R1 file for Novette shot number 083007.

SHOT 083007 MCP1GS II MIDDLE TIME
FILES ..08300711R2

Figure 5.12 MCP1GS II hardcopy output of R2 file for Novette shot number 083007.

SHOT 083007 MCPIGS II LATE TIME
FILES ..08300711R3

Figure 5.13 MCPIGS II hardcopy output of R3 file for Novette shot number 083007.

SHOT NUMBER 083007 MCPIGS II EARLY TIME WAVELENGTH DATA
FILES ..08300711W1

Figure 5.14 MCPIGS II hardcopy output of W1 file for Novette shot number 083007.

SHOT NUMBER 083007 MCP1GS 11 MIDDLE TIME WAVELENGTH DATA
FILES ..08300711W2

Figure 5.15 MCP1GS II hardcopy output of W2 file for Novette shot number 083007.

SHOT NUMBER 083007 MCPICS II LATE TIME WAVELENGTH DATA
FILES ..08300711W3

Figure 5.16 MCPICS II hardcopy output of W3 file for Novette shot number 083007.

5.3 Reduced Data Sets

5.3.1 Henway Data Set. A complete list of the Henway data reduced by ARACOR is shown in Table 5.4. The data are grouped according to the instrument number (i.e. Henway 1 or Henway 2) and the month in which the XRL shot occurred (i.e. June, July or August).

5.3.2 MCPIGS Data Set. A complete list of the MCPIGS data reduced by ARACOR is shown in Tables 5.5 to 5.11. The data are grouped according to the instrument number (i.e. MCPIGS I or MCPIGS II) and the month in which the XRL shot occurred, (i.e. June, July or August). Tables 5.5 to 5.9 include the early, middle and late time lineout information used to create the D-and R-files while Tables 5.10 and 5.11 note the fiducial position of the early, middle, and late time data used to create the W-files.

5.3.3. XRL Shot Log. The complete XRL shot series, as defined by LLNL, is shown in Table 5.12. This list includes information concerning the shot number, target type and shot description. This information was obtained from the LLNL CTM for this task.

Table 5.4 ARACOR Reduced NOVETTE XRL Henway Data

Henway I Data Set

SHOT NUMBER

052205HW1
052304HW1
052405HW1
052507HW1

060103HW1
060403HW1
060603HW1
060610HW1
060706HW1
060708HW1
060805HW1

Henway II Data Set

SHOT NUMBER

052205HW2
052304HW2
052405HW2
052507HW2

060103HW2
060403HW2
060608HW2
060610HW2
060706HW2
060708HW2
060805HW2

073002HW2
073109HW2

080105HW2
080111HW2

P0515412HW2
P0515417HW2

Table 5.5 MCPiGS I July XRL Data

SHOT #	TIME LINEOUTS (mm)		
	EARLY	MIDDLE	LATE
070105	16 - 17.5	3 - 4.5	9 - 10.5
070109	16 - 17.5	3 - 4.5	9 - 10.5
070203	15 - 16	3 - 4.5	9 - 10.5
070206	16 - 17.5	3 - 4.5	9 - 10.5
070208	15 - 16	3 - 4.5	9 - 10.5
070304	15.5 - 17	3 - 4.5	9 - 10.5
071909	14.5 - 16	2 - 3.5	7 - 8.5
072003	15 - 16.5	2.5- 4	9.5- 11
072010	15.5 - 17	3 - 4.5	9 - 10.5
072307	15 - 16.5	3.5- 5	9.5- 11

Table 5.6 MCPiGS I August XRL Data

SHOT #	TIME LINEOUTS (mm)		
	EARLY	MIDDLE	LATE
080309	15 - 16.5	3 - 4.5	10 - 11.5
080312	16.5 - 18	4 - 5.5	10 - 11.5
080403	14.5 - 16	2 - 3.5	8 - 9.5
080405	16 - 17.5	2 - 3.5	9.5 - 11
080606	16 - 17.5	4 - 5.5	10 - 11.5
080610	16 - 17.5	3.5 - 5	10 - 11.5
080613	16.5 - 18	3.5 - 5	9.5 - 11
080706	16 - 17.5	3 - 4.5	9.5 - 11
080805	16 - 17.5	4 - 5.5	10 - 11.5
080906	15 - 16.5	3 - 4.5	9.5 - 11
081603	16 - 17.5	3 - 4.5	10 - 11.5
082203	16 - 17.5	3.5 - 5	9 - 10.5
082308	16 - 17.5	4 - 5.5	10 - 11.5
082804	16 - 17.5	3 - 4.5	10 - 11.5
082904	15 - 16.5	4 - 5.5	10 - 11.5
082907	16.5 - 18	4 - 5.5	9.5 - 11
083012	15.5 - 17	3 - 4.5	10.5 - 12
083104	16 - 17.5	3 - 4.5	10 - 11.5

Table 5.7 MCPiGS II June XRL Data

<u>SHOT #</u>	TIME LINEOUTS (mm)		
	<u>EARLY</u>	<u>MIDDLE</u>	<u>LATE</u>
062703	16 - 17.5	3 - 4.5	9 - 10.5
062809	16 - 17.5	3.5 - 5	9 - 10.5
063005	16 - 17	3 - 4.5	9 - 10.5

Table 5.8 MCPIGS II July XRL Data

TIME LINEOUTS (mm)			
<u>SHOT #</u>	<u>EARLY</u>	<u>MIDDLE</u>	<u>LATE</u>
070304	16 - 17.5	3 - 4.5	9 - 10.5
070307	16 - 17.5	3 - 4.5	9 - 10.5
070310	16 - 17.5	3 - 4.5	9 - 10.5
071007	16 - 17.5	3 - 4.5	10.5 - 12
071009	16 - 17.5	3 - 4.5	10.5 - 12
071012	16 - 17.5	3 - 4.5	10.5 - 12
071102	16 - 17.5	3 - 4.5	10.5 - 12
071109	16 - 17.5	2 - 3.5	8.5 - 10
071112	16 - 17.5	3 - 4.5	10.5 - 12
071205	16 - 17.5	3 - 4.5	10.5 - 12
071603	16 - 17.5	3.5 - 5	10.5 - 12
071608	16 - 17.5	3.5 - 5	10 - 11.5
072302	16.5 - 18	3 - 4.5	10 - 11.5
072307	16 - 17.5	4 - 5.5	10 - 11.5
072416	16 - 17.5	3 - 4.5	10 - 11.5
072509	15.5 - 17	3 - 4.5	9 - 10.5
072512	17 - 18.5	3 - 4.5	10 - 11.5
072603	16.5 - 18	3 - 4.5	10.5 - 12
072614	16 - 17.5	3 - 4.5	10.5 - 12
072702	15.5 - 17	3 - 4.5	8.5 - 10
072705	15.5 - 17	3 - 4.5	9 - 10.5
072708	15.5 - 17	3 - 4.5	9 - 10.5
072804	15.5 - 17	3 - 4.5	9 - 10.5
072905	17 - 18	3 - 4.5	9 - 10.5
073002	17 - 18	4 - 5.5	9 - 10.5
072907	16.5 - 17.5	3.5 - 5	10 - 11.5
073109	14.5 - 15.5	2 - 3.5	9 - 10.5
073104	15.5 - 16.5	2 - 3.5	9 - 10.5

Table 5.9 MCPiGS II August XRL Data

SHOT #	TIME LINEOUTS (mm)		
	EARLY	MIDDLE	LATE
080103	16 - 17	3 - 4.5	10 - 11.5
080111	15.5 - 16.5	2 - 3.5	9 - 10.5
080207	15.5 - 16.5	2 - 3.5	9 - 10.5
080706	16 - 17.5	4 - 5.5	9.5 - 11
080805	16 - 17.5	3 - 4.5	9.5 - 11
081009	16 - 17.5	3.5 - 5	10 - 11.5
081403	16 - 17.5	3 - 4.5	9 - 10.5
081406	16 - 17.5	3.5 - 5	10 - 11.5
081503	15 - 16.5	2.5 - 4	8 - 9.5
081506	15 - 16.5	4 - 5.5	9.5 - 11
081603	15.5 - 17	4 - 5.5	9.5 - 11
081607	16 - 17.5	3 - 4.5	9 - 10.5
081610	16.5 - 18	3 - 4.5	10.5 - 12
081704	16 - 17.5	3.5 - 5	10 - 11.5
081709	16.5 - 18	3.5 - 5	10.5 - 12
082002	16.5 - 18	3 - 4.5	10.5 - 12
082005	16 - 17.5	4 - 5.5	10 - 11.5
082008	15 - 16.5	3.5 - 5	9 - 10.5
082103	16.5 - 18	4 - 5.5	11 - 12.5
082203	15 - 16.5	4 - 5.5	10 - 11.5
082205*			
082208	17 - 18.5	3.5 - 5	11.5 - 13
082305	15.5 - 17	2.5 - 4	9.5 - 11
082308	16.5 - 18	4 - 5.5	11 - 12.5
082804	16 - 17.5	2.5 - 4	9.5 - 11
082807	16 - 17.5	2.5 - 4	16 - 17.5

*bad film

Table 5.9 MCPIGS II August XRL Data (Cont'd.)

SHOT #	TIME LINEOUTS (mm)		
	EARLY	MIDDLE	LATE
082907	15 - 16.5	3 - 4.5	10 - 11.5
082910	16 - 17.5	3 - 4.5	10 - 11.5
083003	17 - 18.5	4 - 5.5	10 - 11.5
083007	15 - 16.5	2 - 3.5	9.5 - 11
083009	16 - 17.5	4 - 5.5	11 - 12.5
083104	17 - 18.5	4.5 - 6	10 - 11.5
083106	16 - 17.5	3 - 4.5	10.5 - 12
083108	16 - 17.5	3.5 - 5	10 - 11.5

Table 5.10 MCPIGS II July XRL Wavelength Reduced Data

FIDUCIAL X-POSITION (mm)			
<u>SHOT #</u>	<u>EARLY (R1)</u>	<u>MIDDLE (R2)</u>	<u>LATE (R3)</u>
070304	24.56	24.83	34.85
071007	24.96	25.14	35.30
071009	24.95	25.14	35.20
071012	25.00	24.88	34.90
071102	25.06	24.94	34.92
071109	23.10	22.86	33.12
071112	24.57	24.83	34.84
071205	24.65	24.84	34.85
071314	_____	DONE PREVIOUSLY	_____
071603	24.58	24.86	34.88
071608	24.63	24.88	34.91
071705	_____	DONE PREVIOUSLY	_____
071707	_____	DONE PREVIOUSLY	_____
071804	_____	DONE PREVIOUSLY	_____
071807	_____	DONE PREVIOUSLY	_____
071909	_____	DONE PREVIOUSLY	_____
072003	24.17	24.43	... DONE
072010	_____	DONE PREVIOUSLY	_____
072302	24.93	24.77	34.79
072304	_____	DONE PREVIOUSLY	_____
072307	24.63	24.92	34.94
072405	_____	DONE PREVIOUSLY	_____
072409	_____	DONE PREVIOUSLY	_____
072416	24.60	24.88	34.64
072512	24.88	24.72	34.84
072603	24.57	24.97	34.98

Table 5.11 MCPIGS II August XRL WaveLength Reduced Data

FIDUCIAL X-POSITION (mm)

<u>SHOT #</u>	<u>EARLY (R1)</u>	<u>MIDDLE (R2)</u>	<u>LATE (R3)</u>
080209	24.72	24.98	35.00
080212	24.29	24.50	35.54
080306	_____	DONE PREVIOUSLY	_____
080309	_____	DONE PREVIOUSLY	_____
080403	_____	DONE PREVIOUSLY	_____
080606	_____	DONE PREVIOUSLY	_____
080610	_____	DONE PREVIOUSLY	_____
080613	_____	DONE PREVIOUSLY	_____
080703	_____	DONE PREVIOUSLY	_____
080706	24.76	25.04	35.02
080805	24.36	24.72	34.76
080807	24.66	24.90	34.94
080903	24.68	24.96	34.98
080906	24.20	24.70	34.04
080909	24.24	24.52	34.51
081003	24.62	24.88	34.30
081006	24.57	24.82	34.84
081009	24.60	24.85	34.87
081403	25.03	24.85	34.87
081406	24.65	24.94	34.95
081503	24.90	24.76	34.78
081506	24.64	24.90	34.92
081603	24.56	24.80	34.97
081607	24.92	24.78	34.83
081610	24.98	24.78	34.86
081704	24.64	24.88	34.25
081709	24.65	24.91	34.93
082002	24.94	24.73	34.77
082205	24.59	24.92	34.93

Table 5.11 MCPiGS II August XRL Wavelength Reduced Data (Cont'd)

FIDUCIAL X-POSITION (mm)			
<u>SHOT #</u>	<u>EARLY (R1)</u>	<u>MIDDLE (R2)</u>	<u>LATE (R3)</u>
082208	24.94	24.69	34.79
082308	24.58	24.90	34.93
082807	24.96	24.80	34.79
082907	24.52	24.82	34.82
083007	20.36	21.00	33.94
083009	26.44	27.56	34.12
083104	24.70	24.12	34.34

Table 5.12 XRL SHOT SUMMARY

SHOT	TARGET_I	SHOT_DESC
94051613	NI PLATE	CHARACTERIZATION OF THE BEAM SPOT
94051708	FE PLATE	CHARACTERIZATION OF THE BEAM SPOT
94051802	FE PLATE	SETUP TARGET AND SPOT SIZE
94051804	SE FOIL	SETUP TARGET
94052203	FE PLATE	SETUP TARGET FOR SPOT SIZE
94052205	SE FOIL	SETUP TARGET FOR DIAGNOSTICS DEBUG
94052304	SE FOIL	SETUP TARGET FOR DIAGNOSTICS DEBUG
94052307	SE-DE	SETUP TARGET FOR DIAGNOSTICS DEBUG
94052403	SE FOIL	SETUP TARGET DIAGNOSTICS DEBUG
94052409	FORMVAR	SETUP TARGET FOR DIAGNOSTICS DEBUG
94052503	SE-FORMV	SETUP TARGET FOR DIAGNOSTICS DEBUG
94052507	SE-FORMV	SETUP TARGET FOR DIAGNOSTICS DEBUG
94053006	AL FOIL	RETEST OF THE BEST FOCUS SET/CALIBRATION
94053110	AL FOIL	TEST XCSS, FOCUS SET POINTS AND TCSS
SHOT	TARGET_I	SHOT_DESC
94060103	XRL	1500 ASE - 2 BEAM
94060403	XRL	1500A SE - 2 BEAM
94060608	XRL	750A SE - 2 BEAM
94060610	XRL	1500A SE - 2 BEAM
94060706	XRL	3000 A SE - 2 BEAM
94060708	XRL	1500A SE - 1 BEAM
94060805	XRL	750A SE - 1 BEAM
94061102	AL SLAB	MCPIGS ALIGNMENT AND TEST
94061104	AL SLAB	MCPIGS AND TCSS TEST
94061205	AL SLAB	MCPIGS AND TCSS-EN TEST
94061304	NI SLAB	SETUP SHOT
94061306	AL SLAB	NEW PHOTOCATHODE IN TCSS/MCPIGS TESTED
94061311	XRL	3000A THICK FORMVAR TARGET
94061405	XRL	1500A SE - 1 BEAM
SHOT	TARGET_I	SHOT_DESC
94061407	XRL	1500A SE - 2 BEAM
94061503	XRL	750A SE - 2 BEAM
94061506	XRL	750A SE - 2 BEAM
94061803	XRL	750A SE - 2 BEAM
94061805	XRL	REPEAT OF THE "ROGUE SHOT" 94060708
94061902	AL SLAB	BEAM SPOT DETERMINATION
94061906	XRL	750A SE - 2 BEAM
94062003	XRL	1500A SE - 2 BEAM
94062107	XRL	750A SE - FULL LENGTH
94062204	XRL	750A SE - FORMVAR
94062208	XRL	750A SE - FORMVAR - HALF LENGTH
94062502	XRL	SE LADDER - FULL LENGTH
94062504	XRL	SE LADDER - FULL LENGTH
94062506	XRL	SE LADDER - FULL LENGTH
SHOT	TARGET_I	SHOT_DESC
94062603	XRL	SE LADDER - FULL LENGTH
94062605	XRL	750A SE - FORMVAR - HALF LENGTH
94062611	XRL	SE LADDER - HALF LENGTH
94062703	XRL	SE LADDER - FULL LENGTH
94062705	XRL	FORMVAR FOIL - FULL LENGTH
94062803	XRL	750A SE - FORMVAR

Table 5.12 XRL SHOT SUMMARY (Cont'd).

94062807	XRL	3000A SE - FORMVAR - FULL LENGTH
94062809	XRL	SE LADDER - HALF LENGTH
94062903	XRL	SE LADDER - FULL LENGTH
94062906	XRL	FORMVAR FOIL - FULL LENGTH
94062910	XRL	FORMVAR FOIL - HALF LENGTH
94063003	XRL	SE LADDER - FULL LENGTH
94063005	XRL	MC FOIL, 1100A - FULL LENGTH
94070105	XRL	MC FOIL, 2200A - FULL LENGTH

SHOT	TARGET_I	SHOT_DESC
94070109	XRL	MC FOIL, 2200A - FULL LENGTH
94070203	XRL	MC FOIL, 1100A - FULL LENGTH
94070206	XRL	MC FOIL, 2200A - FULL LENGTH
94070208	XRL	MC FOIL, 1100A - FULL LENGTH
94070304	XRL	SE FOIL - FULL LENGTH
94070307	XRL	CE FOIL - FULL LENGTH
94070310	XRL	CE FOIL - FULL LENGTH
94070904	XRL	CE FOIL - FULL LENGTH
94070906	XRL	CE FOIL - FULL LENGTH
94071007	XRL	SE FOIL - FULL LENGTH, SINGLE BEAM
94071009	XRL	SE FOIL - 1/4 LENGTH
94071012	XRL	SE FOIL - FULL LENGTH
94071102	XRL	SE FOIL-FULL LENGTH, MCPICS TIME ADVANCED
94071109	XRL	SE LADDER - 1/4 LENGTH

SHOT	TARGET_I	SHOT_DESC
94071112	XRL	SE FOIL - FULL LENGTH, SINGLE BEAM
94071205	XRL	SE FOIL, DOUBLE LENGTH
94071314	XRL	SE FOIL - FULL LENGTH, 450 PSEC
94071603	XRL	SE FOIL - 1500A - FULL LENGTH - 450 PSEC
94071608	XRL	SE FOIL-FULL LENGTH, 450 PSEC, SINGLE BEAM
94071705	XRL	SE FOIL - FULL LENGTH, 450 PSEC
94071707	XRL	SE FOIL - FULL LENGTH, 450 PSEC
94071804	XRL	SE FOIL - 1/2 LENGTH, 450 PSEC
94071807	XRL	SE FOIL, F. LENGTH, 450 PSEC, NO PH ON TGSS
94071909	XRL	SE FOIL, F. LENG., 450 PSEC, NO PH/TGSS, S.B.
94072003	XRL	SE FOIL, FULL LENGTH, 450 PSEC, NO PH/TGSS
94072010	XRL	SE FOIL-1 F. LENG., 450 PSEC, NO PH TGSS
94072302	XRL	SE ON FORMVAR HOOP, +30 ROTATION, 450 PSEC
94072304	XRL	SE FOIL - 1/4 LENGTH, 450 PSEC

SHOT	TARGET_I	SHOT_DESC
94072307	XRL	SE HOOP ROTATED, +10 DEGREES ROT, 450 PSEC
94072405	XRL	750A SE FOIL, F. LENG., OFFSET B., 450 PSEC
94072409	XRL	750A SE FOIL, 1/2 LENG., S. BEAM, 450 PSEC
94072416	XRL	75M GAP SE LADDER TARGET, 450 PSEC
94072505	XRL	750A SE FOIL, BAR MASKING PH, 450 PSEC
94072509	XRL	CUBR FOIL, 450 PSEC PULSE, 1 LENGTH
94072511	XRL	SE ON FORMVAR, HOOP, -5 DEG. ROT., SI SLIT
94072603	XRL	750A SE FOIL, 700 PSEC, FILM ON TGSS
94072614	XRL	CUBR FOIL, 770 PSEC, FILM ON TGSS
94072702	XRL	MC FOIL - 1100A, NO PINHOLES
94072705	XRL	MC FOIL - 2200A - NO PINHOLES
94072708	XRL	MC FOIL, 1100A, NO PINHOLES, 1/2 LENGTH
94072804	XRL	MC FOIL, 2200A, NO PINHOLES, 200 PSEC
94072905	XRL	MC FOIL, 2200A, NO PH, 200 PSEC, 1/2 LENG.

SHOT	TARGET_I	SHOT_DESC
------	----------	-----------

Table 5.12 XRL SHOT SUMMARY (Cont'd).

94072907	XRL	CF 1.3 FOIL, 3000A, NO PH, 200 PSEC
94073002	XRL	#128, MN-F, GAS=40 TORR CF4 <i>1400 Horn</i>
94073104	XRL	#130, MN-F, GAS=40 TORR CF4 " "
94073106	XRL	#145, MN-F, GAS=40 TORR CF4 " "
94073109	XRL	#129, MN-F, GAS=60 TORR CF4 <i>no focus</i>
94080103	XRL	#154, MN-F, GAS=40 TORR CF4 " "
94080105	XRL	#140, MN-F, GAS=30 TORR SF6 " "
94080111	XRL	#123, MN-F, GAS=30 TORR SF6 " "
94080207	XRL	#164, CR-F, GAS=45 TORR CF4 " "
94080209	XRL	SE FORMVAR, 1.0L, 2B
94080212	XRL	SE FORMVAR, 0.5L, 2B
94080306	XRL	SE FORMVAR, 0.25L, 2B
94080309	XRL	SE FORMVAR, 1.0L, 1B
94080312	XRL	SE FORMVAR, 1.0L, 2B TGSS BARBEE

SHOT	TARGET_I	SHOT_DESC
94080403	XRL	SE FORMVAR, 0.5L, 1B
94080405	XRL	SE FORMVAR, 2.0L, 1B TGSS BARBEE
94080606	XRL	SE FORMVAR, 1.0L, 2B
94080610	XRL	SE FORMVAR, 1.0L, 20 MCPGS BARBEE
94080613	XRL	SE FORMVAR, 2.0L, MCPGS BARBEE
94080703	XRL	SE FORMVAR, 2.0L
94080706	XRL	SE FORMVAR, 1.0L, 2B, HIGH IL
94080803	XRL	SE FORMVAR, 1.0L, 2B, LOW IL
94080807	XRL	SE FORMVAR, 0.5L, 2B
94080903	XRL	SE FORMVAR, 1.0L, 1B
94080906	XRL	SE FORMVAR, 2.0L, OSCILLATOR?
94080909	XRL	SE FORMVAR, 0.75L, 2B
94081003	XRL	SE FORMVAR, 1.5L, 2B
94081006	XRL	SE FORMVAR, 0.75L, 2B

SHOT	TARGET_I	SHOT_DESC
94081009	XRL	SE FORMVAR, 0.25L, 2B
94081403	XRL	SE FORMVAR, 1.5L, 2B
94081406	XRL	SE FORMVAR, 1.0L, 2B, 400 MICRONS FOCUS
94081503	XRL	SE FORMVAR, 1.0L, 2B
94081506	XRL	SE FORMVAR, 1.0L, 2B, NO DEAD SPOT
94081603	XRL	SE FORMVAR, 1.0L, 2B, 100 MICRONS FOCUS
94081607	XRL	SE FORMVAR, 0.5L, 1B, 200 MICRONS FOCUS
94081610	XRL	SE FORMVAR, 0.75L, 1B, 200 MICRONS FOCUS
94081704	XRL	SE FORMVAR, 2.2L, 2B, 200 MICRONS FOCUS
94081707	XRL	MCPGS CALIBRATION, 200 MICRONS DISK
94081709	XRL	SE FORMVAR, 1.0L, 1B, SE SIDE 1ST
94082002	XRL	SE FORMVAR, 0.5L, 1B, SE SIDE 1ST
94082005	XRL	YTTRIUM - FORMVAR, 1.0L, 2B
94082008	XRL	YTTRIUM - FORMVAR, 1.0L, 2B, 750 PSEC

SHOT	TARGET_I	SHOT_DESC
94082103	XRL	YTTRIUM - FORMVAR, 1.0L, 2B, 750 PSEC
94082106	XRL	YTTRIUM - FORMVAR, 1.0L, 2B, 450 PSEC
94082203	XRL	GE FORMVAR, 1.0L, 2B, 450 PSEC
94082205	XRL	SE FORMVAR, 1.0L, VT WIRE OCC NP SIDE
94082208	XRL	SE FORMVAR, 2.0L, SE SIDES FIRST
94082305	XRL	YTTRIUM - FORMVAR, 1.0L, 100 MICRONS FOCUS
94082308	XRL	SE FORMVAR, 250 A FORMVAR, 1.0L, 2B
94082804	AU	AU DISK, MCPGS CALIBRATIONS
94082807	XRL	SE FORMVAR, 2.0L, 8 MRAD. MISALIGNED

Table 5.12 XRL SHOT SUMMARY (Concluded)

94082904 XRL	SE FORMVAR, 2.0L, TCSS BARDEE
94082907 XRL	SE FORMVAR, 2.0L, MCPICS BARDEE
94082910 XRL	YTTRIUM - FORMVAR, 1.0L, 2B
94083003 XRL	YTTRIUM - FORMVAR, 1.0L, 2B
94083007 XRL	SE FORMVAR, 2.0L

SHOT	TARGET_1	SHOT_DESC
94083009 XRL		SE FORMVAR, 16 MRAD, MISALIGNED
94083012 XRL		SE FORMVAR, 2.0L, TCSS BARDEE
94083104 XRL		SE FORMVAR, 1.0L, N = 2 TO 2
94083106 XRL		NN-F, TARGET #192, SF6 = 25 TOR • 1 μ m Boron
94083108 XRL		NN-F, TARGET #208, SF6 = 25 TOR • 1 μ m Boron

159 records selected.

6.0 NOVA Rho-R Diagnostics: Neutron Time of Flight Instrumentation

6.1 Problem Statement

The work described herein was performed in conjunction with the LLNL design effort to develop diagnostic capabilities to measure the fuel ρr of NOVA targets. In particular, ARACOR had the responsibility for a technical performance vs. cost evaluation of currently available instrumentation that would support a neutron time-of-flight (NTOF) experiment designed to satisfy the NOVA target fuel ρr measurement temporal resolution requirements of < 2 ns. The effort performed by ARACOR was completed during the period of 4 September 84 to 1 February and satisfied Tasks XII-XIV of LLNL purchase order number 4681605.

The NOVA NTOF system will deploy a large number (1,000-50,000) of neutron detectors. The actual size of the detector array determines the timing requirements of the individual detector cells. For arrays smaller than 2,000 the detector will be comprised of fast scintillators coupled to micro-channel plate (MCP) photomultipliers. The MCPs will have segmented anodes and exhibit single event response times in the 1-2 ns range. The need for very fast response times are predicated on the probability, albeit an extremely low one, that a given detector will be exposed to more than one neutron event of a particular energy during the duration of the experiment (approximately 20 ns). Specifically, all detectors will see the 14 MeV DT neutrons and will probably be exposed to lower energy neutrons scattered from the fuel. The fast resolving times are necessary since the detector package must be close to the target (about 1-2 meters) to minimize the number of neutrons scattering from the chamber wall and other objects.

As the number of detectors increase (i.e. $> 10,000$) the fast response time requirement decreases. The interference of secondary (i.e. $E_k < 14$ MeV) wall-scattered neutron is minimal since the increased number of detectors provide ample coverage for all neutron energies. The response time of these detectors need to be in the 5-10 ns range and can either be of the MCP or Si solid-state type.

The goal was to design a data acquisition system (DAS) that satisfied the high temporal resolution of the smaller detector array in a cost effective fashion. The LeCroy Research Systems (LRS) model 1879 time-to-digital converter (TDC) was chosen as the baseline instrumentation module because of its low cost per channel (<\$45.00). Additionally, the LRS 1879 TDC exhibits a time resolution of 1 ns and can be operated in a multi-hit mode. This multi-hit capability allows multiple timing events to be recorded by a single channel.

In addition to the LRS 1879 TDC, other instrumentation options were explored. These included coincidence techniques and different passive and active delayed triggering and gating schemes. The details of these are discussed below.

6.2 NTOF Instrumentation Options

A number of instrumentation options supporting the NTOF measurements are presented below. Two active instrumentation approaches were considered. Initially, commercially available off-the-shelf IEEE 488 (GPIB), IEEE 583 (CAMAC), and FASTBUS instrumentation modules were evaluated. As a result of this ARACOR was asked to evaluate a second approach that incorporated the use off-the-shelf instrumentation modules along with component level electronics that complement the FASTBUS approach to lower the complete instrumentation package cost. Within the first approach both direct timing and coincident particle counting measurement techniques are discussed while the second approach considered only the direct timing technique.

The IEEE 488 (GPIB) option was presented to the Contract Technical Monitor (CTM) and was not pursued due to cost considerations and technical feasibility. As a result of this decision the IEEE 583 (CAMAC) and FASTBUS approaches were chosen as the candidate instrumentation bus.

6.2.1 Direct Timing Measurements Using the Off-The-Shelf (OTS) Approach.

The direct timing approach using leading and trailing edge time-of-arrival measurement technique is discussed in detail in Appendix C entitled "Active Instrumentation Options for NOVA Neutron Time-of-Flight Experiment."

6.2.2 Coincidence Counting Measurements Using OTS Approach.

The coincidence counting measurement technique is discussed in detail in Appendix C entitled "Active Instrumentation Options for NOVA Neutron Time-of-Flight Experiments."

6.2.3 Direct Timing Techniques Combining OTS and Component Approach.

Instrumentation options for the direct timing measurements using OTS electronic components coupled to the FASTBUS TDC are discussed below. Only the single-hit detector (i.e. 20,000 detectors) mode of operation is considered. The multi-hit option was eliminated under the direction of the LLNL CTM due to constraints imposed upon that technique by the detectors. As before, issues such as double pulse resolution (OPR), "time walk," and the cost per channel are addressed.

The direct timing measurement in the single-hit mode uses the same LRS 1879 FASTBUS TDC described in Appendix C. In this option, however, the TDC receives its pulse information from an electronic package that functionally provides three areas of pulse conditioning. These are amplitude discrimination, signal delays and signal combining. The effect of this package is two-fold. First, this approach allows the user to take advantage of the full scale time window (1 μ s) provided by an individual TDC channel by assigning more than one detector output to a TDC channel. Secondly, by appropriately delaying the TDC start and stop signals, the signals due to the primary 14 MeV neutrons can be deleted. Although these advantages decrease the instrumentation hardware cost they introduce significant non-recurring engineering (NRE) costs since the electronic package requires design and customization.

A schematic of this technique is shown in Figure 6.1. The key components are the LRS MVL407 Quad (4 channel) Ultrafast Comparator, the Engineered Components Company (ECC) ECLDM 10K ECL series of solid state delay modules and the

Figure 6. 1 Schematic representation of FASTBUS TDC using component level electronics for neutron TOF instrumentation.

Fairchild F100101 Triple 5-Input OR/NOR Gate. These components may be packaged in a modular electronic chassis whose inputs are defined by the detector analog signals and whose output provide the LRS 1879 TDC with the requisite ECL-compatible logic signals. Finally, the TDC is configured to record both leading and trailing edge data.

The data flow begins with the TDC start command supplied by an early time photon detector providing the experiment with its time reference. Each detector output is directly coupled to the AD 9685D Ultra-Fast Comparator. The comparator reference voltage reflects the voltage level at which the comparator will fire. Once the input pulse exceeds this threshold an ECL-level pulse is outputted by the comparator whose pulse duration is equal to the time over threshold.

The next major component in the data flow is the solid state delay. The delay assigned to each detector channel is comprised of any one of the following three components. First, the startup time associated with each TDC module must be considered. This number is conservatively set at 10 ns for the sake of this paper. Next, the experimental event window is considered. Since it is anticipated that the detector output pulse duration will be comparable to that of the event window (from 20% to 30%) sufficient delay must be included so one can ensure the entire pulse is recorded before the next event occurs (Recall that many detector outputs are recorded by a single TDC channel.). Pulses occurring too close in time will be recorded as a single event since all ECL-level durations are determined by the time over a fixed threshold. This time is set at 40 ns. Finally, the double pulse resolution (DPR) of the TDC is taken into account. Measurements made by W. Innes, SLAC, indicate that for pulses of approximately 10 ns duration the leading edge DPR of the LRS 1879 TDC is 20 ns. Thus, after the TDC startup time is considered the relative detector to detector signal delay is 60 ns.

The delay section of the chassis can consist of up to fifteen detector inputs. This arrangement would allow the full $1\text{ }\mu\text{s}$ window of the TDC channel to be used ($15 \times 60\text{ ns} = 900\text{ ns} < 1\text{ }\mu\text{s}$). A total of 1,333 fifteen channel delay sections would be required to accommodate 20,000 detector channels.

Uncertainties in the delays are dependent on power supply fluctuations and temperature differences. Literature supplied by the vendor states that these relationships are $\pm 0.5\%$ fluctuations in the supply voltage and 300 ppm (i.e., 0.0003) for every degree centigrade change in temperature. It is proposed that the details of power supply regulation and cooling be addressed during the next phase of this contract.

The final major component associated with this technique is the OR/NOR gate. The candidate component can accommodate up to 15 inputs. This grouping allows a single delay section to map onto a single OR/NOR gate. The outputs consists of three individual OR gate outputs. The best way to interconnect these outputs (i.e., wire-ORing) will be decided during the prototype PCB design phase. The ECL output will be true only when an ECL-true level is present on any one of the 15 inputs. Since all inputs will be delayed with respect to one another, a time greater than the experimental event window will always be, at most, one ECL true level at any one input.

The data flow is completed with the output of the OR/NOR gate couple directly to the TDC channel input. Again, since the delays greatly exceed the DPR of the TDC, all pulses present to the OR gate will be recorded. The TDC will record both leading and trailing edge information. This information will allow a "walk" correction to be made in the software.

An estimate of the cost of the major components of this scheme are shown in Table 6.1. This approach, albeit costly from a system point of view, offers a low cost per channel of \$36.30 as compared to the previously discussed options. This figure is both sensitive to quantity and labor costs at the time the work will actually take place. Thus, the NRE and production costs included in Table 6.1 should be considered as a preliminary estimate and are subject to change pending the final design that will include the actual components required.

Table 6.1 Cost Breakdown of Single Hit Direct Timing Option
Using OTS and Component-Level Electronics

<u>Interface Hardware</u>	<u>Cost per Item (K\$)</u>	<u>Quantity Required</u>	<u>Quantity Cost (K\$)</u>
1) LRS 1821/DEC UNIBUS Interface Card	1.00	1	1.00
2) LRS 1821 Segment Manager/Interface	7.20	1	7.20
<u>Instrumentation Crates</u>			
1) KSC F050-A02 FASTBUS Crate	2.60	1	2.60
<u>Instrumentation Modules</u>			
1) LRS 1879 FASTBUS TDC	4.28	14	59.85
<u>Electronic Components</u>			
1) LRS MV1407 Quad Ultrafast Comparator	.0126	5000	63.00
2) ECC ECLDM Series of Delay Module	.015	20000	300.00
3) FCIC F100101 Triple 5-Input OR/NOR Gate	.003	1334	4.00
<u>Non-Recurring Engineering (NRE)</u>			
1) Electronic Engineer for design and testing of preproduction prototype 15-channel chassis	--	1/2 FTE + Parts	65.00

**Table 6.1 Cost Breakdown of Single Hit Direct Timing Option
Using OTS and Component-Level Electronics. (Cont'd)**

<u>Production Costs for 1334 15-Channel PCBs</u>	<u>Cost per Item (K\$)</u>	<u>Quantity Required</u>	<u>Quantity Cost (K\$)</u>
1) PCB Layout	--	--	2.00
2) PCB Fab	--	--	14.00
3) PCB Component Stuffing	--	--	7.00
4) Test including test fixture	--	--	100.00
5) Misc. hardware including cables and connectors	--	--	100.00
			<hr/>
Total System Cost (Est.)			725.65 K\$
Cost per channel (Est.)			\$ 36.30

VENDORS

FICI = Fairchild Camera and Instrument Corporation
 ECC = Engineering Components Company
 KSC = Kinetic Systems Corporation
 LRS = LeCroy Research Systems

NOTE: Quantity discounts not included for solid state delays and other miscellaneous hardware.

6.3 Recommended Instrumentation Approach

The direct timing technique that combines the OTS electronic components with the LRS 1879 FASTBUS TDC is recommended based on both the technical feasibility and the cost per channel. The discriminator and TDC option were eliminated due to cost in the single hit mode and detector constraints in the multihit mode. The coincidence counting option is eliminated due to cost.

The advantages of the recommended approach are the following. First, the modularity concept of the approach allows the system to be configured for any number of detectors in groups of 15. This not only ensures LLNL with a system that is upward compatible with future DAS and computer hardware but also ensures system maintainability through the ease of module replacement. Also, this approach affords the user the option "time windowing" for specific events. That is, by appropriately delaying the TDC start pulse the 14 MeV neutrons can be eliminated thereby allowing a further reduction in the size of the detector array. Additionally, specification of ECL level signals eliminates both the need for logic translators required to interface the analog signal to the ECL compatible TDC and helps to reduce the problem of "time walk" associated with analog signals and fixed threshold measurements through the transmission of ECL signals. Finally, this approach will support many detector options including those of the MCP, diffused p-n and surface barrier types.

It is recommended that the next phase of this project included the following. First, the combination of the scintillator, detector, and supporting electronic circuitry (such as the preamp) be specified and candidate hardware procured for a field evaluation. Second, the design phase of the comparator, solid state delay and OR/NOR gate should begin. This effort includes the final specification of these components by manufactures and part number and the PCB layout so that a preproduction prototype board consisting of a single 15 channel section results. This, in turn, could be evaluated with either real or simulated neutron events. Finally, a portion of the CPU and FASTBUS hardware should be procured so that the LRS 1879 TDC can be evaluated for both hardware and software response.

APPENDIX A

I. Investigation of Soft X-Ray Line and Edge Structure for Foil and Cathode Calibrations.

In the process of investigating foil transmissions and cathode calibrations it became necessary to take a detailed look at the line structure of the Ionac and LEX sources and the absorption structure of the foils and cathodes used on the DANTE spectrometers.

In order to facilitate the detailed decisions required to select and evaluate calibration lines, we have compiled this data below for ready reference.

II. Data

DANTE spectrometers are designed to provide a diagnostic capability for x-rays between 0.15 kev and about 2 kev. The x-ray calibration and standards facility uses two machines to cover this range (see Table 1).

TABLE 1

Machine	Excitation	Fluorescer	Line	Energy (keV)
LEX	electron	Vanadium	K _α	4.952
		Scandium	K _α	4.09
		Silver	L _α	2.98
		Zirconium	L _α	2.04
		Aluminum	K _α	1.49
IONAC	proton	Copper	L _α	0.928
		Nickel	L _α	0.851
		Cobalt	L _α	0.776
		Iron	L _α	0.705
		Chromium	L _α	0.578
		Vanadium	L _α	0.5113
		Titanium	L _α , L _β	0.452, 0.395
		Carbon	K _α	0.277
		Boron	K _α	0.183

Assuming that the characteristic x-ray emission rates from proton and electron excitation are similar, the LEX and Ionac emission line spectra will be jointly presented. Data on the emission line energies and their theoretical intensities was obtained from the Handbook of X-Rays, Edited by E.F. Kaelble, McGraw-Hill Book Co., 1967. These data are shown in Table 2 for K-shell fluorescers and in Table 3 for L-shell fluorescers.

TABLE 2. K-Shell Fluorescers

Line : Approx. Intensity:	a_{12} 150	a_1 100	a_2 50	β_1 15	β_3	β_2 5
Vanadium	4.95	4.954	4.946	5.427		...
Scandium	4.09	4.091	4.087	4.460	...	...
Aluminum	1.487	1.487	1.487	1.558	1.539	...
Carbon	0.277	...	...	...	...	...
Boron	0.183	...	...	...	...	...

TABLE 3. L-Shell Fluorescers

Line : Approx. Intensity:	a_{12} 110	a_1 100	a_2 10	β_1 50	β_2 20	β_3 6	β_4 4	γ_1 10	ℓ 3
Silver	...	2.985	2.979	3.151	3.349	3.234	3.204	3.520	2.634
Zirconium	...	2.043	2.040	2.125	2.220	2.202	2.118	2.303	1.792
Copper	0.928	...	...	0.948	...	1.023	...	...	0.811
Nickel	0.850	...	...	0.867	...	0.942	...	...	0.743
Cobalt	0.775	...	...	0.790	...	0.869	...	...	0.675
Iron	0.704	...	...	0.717	...	0.788	...	...	0.614
Chromium	0.572	...	...	0.582	...	0.638	...	...	0.499
Vanadium	0.510	...	...	0.519	...	0.585	...	...	0.446
Titanium	0.452	...	...	0.458	...	...	...	...	0.395

The elements and edges relevant to the present DANTE calibration are shown in Table 4.

TABLE 4 Foil and Cathode Absorption Edges

Element	Absorption Edges			
	L_I	L_{II}	L_{III}	K
Aluminum	0.087	0.073	0.072	1.559
Magnesium	0.0628	0.0497	0.0494	1.303
Zinc	1.20	1.045	1.022	
Copper	1.10	0.953	0.933	
Nickel	1.015	0.871	0.853	
Cobalt	0.929	0.794	0.779	
Iron	0.849	0.721	0.708	
Chromium	0.679	0.583	0.574	
Vanadium	0.604	0.519	0.512	
Oxygen				0.531
Carbon				0.2838
Boron				0.188

APPENDIX B

ELLIPSOIDAL OPTIC X-RAY CALIBRATION

EXPERIMENTAL PLAN BRIEFING

14 FEBRUARY 1984

CONTENTS

1. INTRODUCTION
2. EXPERIMENTAL OBJECTIVES AND CONSTRAINTS
3. METHOD OF ATTACK
4. APPARATUS AND FACILITIES
5. EXPERIMENTAL PROCEDURES
6. SCHEDULE

ELLIPSOIDAL X-RAY COLLECTION OPTIC FOR THE NOVETTE TRANSMISSION GRATING/STREAK CAMERA, DIAGNOSTIC

- A CLOSED ELLIPSOIDAL GRAZING-INCIDENCE X-RAY OPTIC WILL BE USED TO INCREASE THE SENSITIVITY OF THE TRANSMISSION GRATING/STREAK CAMERA, A PRIME DIAGNOSTIC FOR THE NOVETTE X-RAY LASER EXPERIMENTAL SERIES.
- THE OPTIC IS A FIGURE OF REVOLUTION BASED ON A SECTOR OF AN ELLIPSE OF SEMI-MAJOR AXIS $A = 61.00$ CM AND SEMI-MINOR AXIS $B = 4.345$ CM. THE OPTIC'S FOCAL LENGTH IS $P = \sqrt{A^2 + B^2} = 60.845$ CM.
- TWO IDENTICAL PIECES HAVE BEEN FORMED BY SINGLE-POINT DIAMOND TURNING AND CENTERLESS SUPERPOLISHING.
- THE OPTIC WILL BE LOCATED SLIGHTLY CLOSER TO THE SOURCE THAN TO THE IMAGE PLANE, PRODUCING A MAGNIFICATION IN THE NEIGHBORHOOD OF 1.23.
- THE MEAN ANGLE OF INCIDENCE OF RAYS ON THE OPTIC IS 4.15° , PRODUCING FOR THE NICKEL REFLECTING SURFACE A CRITICAL ENERGY CUT-OFF OF ABOUT 0.65 KEV.

X-RAY OPTIC EXPERIMENTAL OBJECTIVES AND CONSTRAINTS

THE OVER-ALL GOALS OF THE X-RAY CALIBRATIONS ARE TO:

- . DEMONSTRATE THE OPTICS' FITNESS FOR USE
- . QUANTIFY THE SPATIAL DISPERSION CAUSED BY FIGURE ABERRATIONS AND ERRORS AND BY SURFACE ROUGHNESS
- . ALIGN AN IN-OPTIC REFERENCE MIRROR TO THE OPTICS' AS-BUILT (TRUE) OPTICAL AXIS

EXPERIMENTAL OBJECTIVES

1. MEASURE OPTIC POINT SPREAD FUNCTION (PSF) RESPONSE AT BEST FOCUS, OVER A 500 μ M-WIDE TRANSVERSE SOURCE POINT FIELD, FOR CORRELATION TO RAY-TRACING SIMULATIONS BEING PERFORMED BY ARACOR,
2. MEASURE OPTIC PSF RESPONSE FOR AXIAL DISPLACEMENT OF THE OPTIC FORE AND AFT OF BEST FOCUS.
3. MEASURE THE DEVIATION OF THE ACTUAL OPTIC AXIS FROM THAT INFERRED BY BUILT-IN DATUM SURFACES, AND ALIGN THE REFERENCE MIRROR TO THE TRUE AXIS.
4. MEASURE THE AZIMUTHAL CONSISTENCY OF FIGURE AND FINISH QUALITY BY 3-FOLD ROLL ROTATION BETWEEN PSF EXPOSURES.
5. OPTIONALLY (AS TIME PERMITS), DISPERSE OPTIC-REFLECTED RADIATION THROUGH A TRANSMISSION GRATING.

CONSTRAINTS

1. THE ILLUMINATING RADIATION MUST BE THE K-SERIES CHARACTERISTIC LINES OF CARBON AT 0.277 KEV.
2. TO REDUCE THE OVER-ALL TECHNICAL RISK OF THE DIAGNOSTIC, AN OPTIC MANIPULATOR ASSEMBLY BUILT FOR NOVETTE DEPLOYMENT MUST BE USED IN THE CALIBRATION EXPERIMENTS.

EXPERIMENTAL METHOD OF ATTACK

THE X-RAY CALIBRATIONS WILL BE PERFORMED AT THE Y-PROGRAM X-RAY OPTICS LABORATORY, TRAILER 2801.

1. A MULTI-PINHOLE, GOLD-FOIL COLLIMATOR WILL BE THE EFFECTIVE SOURCE FOR THE PSF MEASUREMENTS. THE PINHOLES, OF DIAMETER $10\mu\text{m}$, WILL BE SPACED ON $50\mu\text{m}$ CENTERS OVER A $500\mu\text{m}$ SQUARE FIELD.
2. THE SOURCE COLLIMATOR WILL BE BACK-LIT BY A CARBON ANODE PALMIERI TUBE, IN A GEOMETRY TO FULLY-ILLUMINATE THE OPTIC.
3. A ROTATABLE "STOP" APERTURE, 5MM-DIAMETER, WILL LIMIT THE OPTIC ARC LENGTH EXPOSED, SIMULATING THE GRATING APERTURE.
4. ALIGNABLE REFERENCE MIRRORS WILL BE MOUNTED ON WEBS WITHIN THE OPTIC.
5. PSF DATA WILL BE RECORDED ON FILM TYPES 101-06, SB-5 OR RAR2492. CROSS-HAIR WIRES AT THE FILM STATION WILL CAST A REFERENCE SHADOW.

APPARATUS AND FACILITIES

	<u>RESPONSIBLE SCIENTIST</u>	<u>SUPPORT PERSONNEL</u>
1. X-RAY TUBE		
1.1 TUBE AND GENERATOR	KOPPEL/STEARNS	} COOK
1.2 CARBON ANODE PREPARATION	"	
2. MULTI-PINHOLE COLLIMATOR ASSEMBLY		
2.1 APERTURE PLATES, SEVERAL STYLES	CEGLIO	} STONE
2.2 MOUNTING DISK AND PLUG	KOPPEL/STEARNS	
2.3 LOCATING ARM, FOR X-Y-Z STAGE	"	} COOK
2.4 STRAY-LIGHT SHIELD	"	
3. ELLIPSOIDAL OPTICS		
3.1 PIECE POLISHED BY LLNL	CEGLIO	
3.2 PIECE POLISHED BY OUTSIDE VENDOR	"	
3.3 TRANSMISSION GRATING	"	
3.4 TRANSPORT CASE	MEDECKI	} LORD
4. REFERENCE MIRROR ASSEMBLY		
4.1 MIRRORS, K & E RETICLES	MEDECKI	} HOWE TASSANO
4.2 SUPPORT WEBS	"	
5. NOVETTE MANIPULATOR ASSEMBLY		
5.1 MANIPULATOR SET, NRC CATALOG ITEMS	MEDECKI	} LORD TASSANO
5.2 BRACKETS AND OPTIC CRADLE	"	
6. ALIGNMENT TOOLS		
6.1 ALIGNMENT TELESCOPE	MEDECKI	} TASSANO HOWE
6.2 AXIAL-LOCATING "Z" RODS	KOPPEL/STEARNS	
6.3 FILM-PLANE CROSS-HAIRS	"	

APPARATUS AND FACILITIES (CONTINUED)

	<u>RESPONSIBLE SCIENTIST</u>	<u>SUPPORT PERSONNEL</u>
7. VACUUM CHAMBERING		
7.1 PALMIERI TUBE ASSEMBLY	KOPPEL/STEARNS	
7.2 COLLIMATOR MANIPULATOR CROSS SPOOL	"	
7.3 SOURCE-SIDE GLASS GATE VALVE	"	} COOK HOWE TASSANO LORD
7.4 SOURCE-SIDE FLIGHT TUBE	"	
7.5 OPTIC TANK AND FLOOR PLATE	"	
7.6 FILM-SIDE FLIGHT TUBE	"	
7.7 FILM-SIDE GATE VALVE AND TEE	"	
7.8 FILM BOX	"	
8. VACUUM PUMP SYSTEMS		
8.1 PALMIERI TUBE	KOPPEL	} COOK HOWE
8.2 OPTIC TANK TM AND CRYOPUMP	"	
8.3 FILM BOX MEGASORB	"	
9. PHOTOGRAPHIC FILM DENSITOMETRY		
9.1 PHOTOGRAPHIC FILM	KOPPEL	} STONE
9.2 PROCESSING	"	
9.3 MICRODENSITOMETRY	"	

E/66

EXPERIMENTAL PROCEDURES

1. ASSEMBLE "STRAIGHT-PIPE CAMERA" FOR SOURCE PRE-TESTING, CONNECTING IN-LINE THE PALMIERI SOURCE, THE COLLIMATOR MANIPULATOR CROSS SPOOL, A STRAIGHT SPOOL AND THE FILM BOX.
2. DIRECTLY EXPOSE FILM TO ESTABLISH SCALES OF SOURCE INTENSITY AND EXPOSURE TIMES.
3. EXPOSE PINHOLE PHOTOGRAPHS TO GAUGE UNIFORMITY AND EXTENT OF SOURCE REGION.
4. PRE-ALIGN OPTIC REFERENCE MIRROR IN CENTERING AND TILT ON BENCH, BY SCOPE OBSERVATION OF FIXED POINT REFLECTION AS MIRROR WEB IS ROTATED AGAINST OPTIC DATUM SURFACES.
5. ASSEMBLE PSF MEASUREMENT BEAM-LINE CHAMBERING AND VACUUM TEST; ESTABLISH Z-WISE SOURCE/FILM DISTANCE.
6. EXPOSE FILM AT OPTIC MOUNTING STATION, TO ESTABLISH LATERAL POSITION OF INCIDENT BEAM.
7. ESTABLISH SCOPE ON SOURCE/FILM CROSS-HAIR AXIS.
8. INSTALL OPTIC AND NOVETTE MANIPULATOR ASSEMBLY IN CHAMBER AND POSITION IN Z.
9. MANEUVER OPTIC SO THAT DATUM-ALIGNED REFERENCE MIRROR AUTOCOLLIMATES TO AXIS.

E/66

EXPERIMENTAL PROCEDURES (CONTINUED)

10. ITERATE THROUGH OPTIC Z POSITIONING AND MIRROR AUTOCOLLIMATION.
11. EXPOSE PSF/BEST FOCUS FILM AND EVALUATE NEED FOR OPTIC REALIGNMENT DUE TO GROSS DATUM/TRUE AXIS ERRORS.
12. EXPOSE PSF/BEST FOCUS FILM AT TWO SYMMETRIC AZIMUTHAL POSITIONS BY ROTATION OF OPTIC APERTURE PLATE AND DISCRETE EXPOSURES, AND SELECT "BEST" SECTOR.
13. RE-EXPOSE PSF/BEST FOCUS FILM FOR BEST SECTOR. BY ITERATIVE EXPOSURES, MANEUVER FILM CROSS-HAIR OVER "BEST" IMAGE.
14. REMOVE REFERENCE MIRROR AND SET SCOPE ON AXIS CONNECTING BEST IMAGE AND CORRESPONDING SOURCE PINHOLE
15. INSTALL REFERENCE MIRROR AND AUTOCOLLIMATOR TO NEW SCOPE AXIS.
16. EXPOSE PSF FILM WITH OPTIC FCRE AND AFT OF BEST FOCUS.
17. OPTIONALLY, RETURN OPTIC TO BEST FOCUS, INSTALL TRANSMISSION GRATING BEHIND OPTIC AND RECORD DISPERSED IMAGE.
18. RELEASE OPTIC TO MOVETTE.
19. PERFORM IMAGE MICRODENSITOMETRY AND CORRELATE TO PSF CALCULATIONS.

E/66

SCHEDULE

TASK	2/6-10	2/13-17	2/20-24	2/27-3/2	3/5-9	3/12-16	3/19-23
1. X-RAY SOURCE							
1.1 ASSEMBLE & OPERATE STRAIGHT-PIPE CAMERA		K&S					
2. PINHOLE COLLIMATOR							
2.1 DESIGN & FABR. HOLDER AND ARM		K&S					
2.2 FABR. COLLIMATOR		Ceglio					
3. OPTIC REFERENCE MIRROR							
3.1 DESIGN & FABR. WEB FIXTURES		Medeck					
4. ELLIPSOIDAL OPTIC							
4.1 RECEIVE, DO METROLOGY		Ceglio					
4.2 BENCH-ALIGN REF. MIRROR			Medeck				
5. NOVETTE MOUNT							
5.1 PROCURE STAGES	Medeck						
5.2 FABR. BRACKETS & ASSEMBLE			Medeck				
6. CHAMBERING							
6.1 PREPARE LAYOUT DWG.							
6.2 FABR. SPOOLS, FLOOR, Z-RODS		K&S					
6.3 ASSEMBLE CHAMBERING, VACUUM SYSTEMS			K&S				
6.4 INSTALL COLLIMATOR, OPTIC, NOVETTE MOUNT				K&S, Medeck			
7. EXPERIMENTAL PROCEDURES							
7.1 PERFORM PROCEDURES 9-12							
7.2 PERFORM PROCEDURES 13-16							
7.3 PERFORM PROCEDURES 17-19							
			Assemble Expt	Start Expt			

APPENDIX C

Active Instrumentation Options for NOVA Neutron Time-of-Flight Experiment

M E M O

TO: Steve Lane, LLNL DATE: 11/09/84

FROM: Rick Cirigliano, ARACOR

SUBJECT: Active Instrumentation Options for NOVA Neutron Time-of-Flight Experiment

REF: "Measurement of the Fuel Rho-R of NOVA Targets," S. Lane, LLNL, et al., dated 11 September 84.

1. Introduction

Several options of active instrumentation for the NOVA neutron time-of-flight (TOF) experiment are presented here. The objective of each option is to provide large numbers of instrumentation channels capable of measuring the temporal distribution of the scattered 14 MeV DT neutrons with < 2 ns resolution. Each option will be discussed from a technical performance versus cost per channel point of view.

2. Overview of Candidate Detector System

The detection scheme sensing the neutron distribution may consist of 1,000 to 50,000 cells. The number of cells is a function of the modality of the experiment. The 1,000 cell detector array represents the "multi-hit" mode and the 10,000-50,000 cells correspond to the "single-hit" mode. The detector design in the multi-hit mode allows for the detector recovery and subsequent detection of the lower energetic neutrons that immediately follow the 14 MeV neutron burst. These detectors consist of very fast scintillators (i.e., BaF₂, Pilot U, NE111) coupled to micro-channel plates (MCP) with segmented anodes whose single event response times are in the 1-2 ns range. The single-hit detectors will respond only to a single neutron event for the duration of the experiment (approximately 20 ns). These detectors have much slower response times (0(10 ns)) and can either be of the MCP or Si solid-state type.

Steve Lane
November 9, 1984
Page 2 of 16

In both modes the number of cells in each array is a function of many parameters. These are the total neutron yield, the probability of a lower energy event occurring, the probability of an available cell to detect the lower energy neutron, the intrinsic detector efficiency and the geometrical efficiency associated with the experiment. Examples of typical numbers for these variables are discussed in the referenced LLNL document. In the multi-hit mode, it is unlikely that more than one lower energy neutron will follow the initial neutron burst during the duration of the experiment. In this mode, resolving the 14 MeV and 13 MeV neutrons is desirable; however, the resolution between the 14 MeV and 12 MeV neutrons is essential. This is not a problem in the single-hit mode because of the large number of detector cells.

3. Active Instrumentation Schemes

Three (3) different active instrumentation approaches are considered. The approaches are categorized in the general areas of timing spectroscopy and particle counting. The timing concept measures the time-of-arrival (TOA) of the neutrons while the counting technique records the number of neutrons that occur within an externally supplied coincidence gate. Both techniques are time referenced to a LLNL-supplied event trigger. All techniques incorporate, either exclusively or in combination, the CAMAC, FASTBUS and NIM instrumentation buses. The details of these approaches are discussed below.

3.1 Time-of-Arrival Measurements in the Multi-Hit Mode. The time-of-arrival measurements in the multi-hit mode utilize two (2) standard instrumentation modules. These are LeCroy Research System (LRS) 1879 FASTBUS Time-to-Digital Converter (TDC) and the Phillips Scientific (PS) 708 NIM Occal Discriminator. The TDC contains ninety-six (96) channels and the discriminator contains eight (8) channels with one (1) input and three (3) outputs per channel. The time recorded by the TDC is the time-of-arrival of the trailing

edge with respect to the leading edges of the discriminator output pulse. This approach utilizes the facts that 1) the discriminator can operate in an updating mode and 2) the TDC can function in a multi-hit mode.

A schematic of this technique is shown in Figure 1. An event trigger supplied by a photon detector provides the time reference, or common start, to the TDC. The actual neutron signals, delayed with respect to the event trigger, are directly coupled to the discriminator. The discriminator, in turn, provides the TDC with its timing pulse. (The TDC input pulse width requirement of 10 ns prevents a direct link between the detector and TDC.) The scattered neutron distribution can now be derived from these times. However, the operating mode of the discriminator must be understood in order to correctly interpret the TDC data.

The discriminator is configured to operate in its updating mode. This mode allows a second pulse to retrigger the discriminator when the discriminator output is active due to a previous pulse. For example, assume the discriminator is configured such that its input threshold is set at -500 mV and its output NIM pulse duration is set at 50 ns. Further, assume two (2) neutron events separated in time by 15 ns and ≥ -500 mV in amplitude are presented to the input of the discriminator. The first pulse will trigger the discriminator and generate the 50 ns NIM pulse. The second pulse now retriggers the discriminator 15 ns later in time. The resulting output, due to this double pulse situation, is a NIM pulse whose duration is now 65 ns (i.e., $50 \text{ ns} + 15 \text{ ns} = 65 \text{ ns}$). This mode will operate for any number of multiple pulse schemes providing each subsequent pulse satisfies the double pulse resolution (DPR) criteria as defined by the discriminator. For the case of the PS 708 discriminator, the DPR is rated to be 3.3 ns. Thus, an inherent dead-time corresponding to the DPR specification is present in this scheme.

Figure 1. LRS 1879 FASTBUS TDC with PS708 Discriminator for Multi-Hit Mode.

Steve Lane
November 9, 1984
Page 5 of 16

The data present on the TDC can now be interpreted. Because of the low probability of multiple secondary neutrons being present on a given detector's output, all secondary detector output pulses are assumed to be caused by a single neutron. Thus, the leading edge information as recorded by the TDC will contain the TOA data corresponding to the 14 MeV neutrons. The trailing edge information, depending on where it occurs in time with respect to the originally configured discriminator output width, will contain the secondary neutron data.

The major fallback of this technique is the 3 ns resolution imparted on the measurement by the DPR of the discriminator. This implies that, assuming the timing for all detectors is referenced to the 14 MeV neutron burst, the resulting neutron distribution will include the 10, 8, 6, 5, 4, 3, and 2 MeV neutrons at a source-to-detector distance of 1 meter. This can be improved to include the 12 and 10 through 2 MeV neutrons at a source-to-detector distance of 2 meters. Additional attention must be paid to the "walk" due to jitter and long cable runs that are associated with high resolution timing measurements. The "walk," defined as the variance in the time when a signal satisfies a fixed amplitude threshold requirement, can cause a neutron to be measured as occurring either earlier or later in time than it actually occurred. However, as evident in Table 1, the cost per channel of \$324 makes this option cost effective from a total system point of view. Discussions with LRS are currently ongoing to evaluate the feasibility of allowing the detector output to be directly coupled to the TDC in an attempt to further reduce the total system cost.

3.2 Time of Arrival Measurements in the Single-Hit Mode. The single hit version of the time-of-arrival measurements is very similar to the multi-hit version in concept. However, in practice, two (2) major differences exist. First, a direct link between the detector output and LRS 1879 TDC input is made, thus eliminating the discriminator. Secondly, the detector array consists of

TABLE 1. COST BREAKDOWN OF THE MULTI-HIT TOA OPTION

	<u>Cost Per Item (K\$)</u>	<u>Quantity Required</u>	<u>Quantity Cost (K\$)</u>
<u>Interface Hardware</u>			
1) KSC 2050-Z3A Serial Highway Driver	7.25	1	7.25
2) KSC 3952-Z1B Serial Crate Controller	1.85	12	22.20
3) LRS 2891 CAMAC Port to FASTBUS	.75	1	.75
4) LRS 1821 FASTBUS Segment Manager Interface	7.20	1	7.20
5) LRS 4501A CAMAC to NIM Adapter	.15	125	18.75
<u>Instrumentation Crates</u>			
1) KSC F050-A02 FASTBUS Crate	2.60	1	2.60
2) SEC 8211x211 Optima 850	1.76	12	21.12
<u>Instrumentation Modules</u>			
1) LRS 1879 FASTBUS TDC	4.28	11	47.03
2) PS 708 NIM Octal Discriminator	1.58	125	<u>196.88</u>
Total System Cost			323.78K\$
Cost per Channel			\$323.78

Vendors:

KSC = Kinetic Systems Corp.

LRS = LeCroy Research Systems

PS = Phillips Scientific

SEC = Standard Engineering Corp.

NOTE: Quantity discounts not included.

10,000-50,000 cells with much slower response times. Because of the large number of cells, detector recover during the entire event is not required. Additionally, the slower detector response yields an output pulse that satisfies the input timing requirements of the TDC.

A schematic representation of this instrumentation option is shown in Figure 2. A photon detector again provides the instrumentation with an event trigger. The TDC records the leading and trailing edges of the detector pulse with respect to the event trigger. The issue of DPR is not relevant since no multiple pulsing exists. The resolution of the measurement is defined by that of the TDC. When configured for a 2 ns time bin or 1 us full scale per channel (i.e., 512 time bins total), the TDC will resolve stop pulses down to 1 ns. This resolution is attainable since the LRS 1879 TDC contains a phase latch bit that records the clock phase down to half of the time bin.

A cost breakdown of the total system is shown in Table 2. The total system cost, excluding the CPU and its peripherals, falls into the 513.68K\$ (10,000 detector cells) to 2,475.68K\$ (50,000 detector cells) range. This further breaks down to a cost per channel of \$51.37 to \$49.51. While this option offers an attractive cost per channel and satisfies the timing resolution requirement, the total system cost and the impracticality and cost of cabling such a large number of channels make this option undesirable.

3.3 Coincidence Counting in the Multi-Hit Mode. The technique presented in this section differs from the previously discussed options. The coincidence counting technique actually counts the number of neutron events during a discrete timing window as opposed to inferring this information from a time-of-arrival measurement. An external gate defines the discrete timing window.

Figure 2. LRS 1879 TDC for Single-Hit Mode.

TABLE 2. COST BREAKDOWN OF THE SINGLE-HIT TOA OPTION

	<u>Cost Per Item (K\$)</u>	<u>Quantity Required</u>	<u>Quantity Cost (K\$)</u>
<u>Interface Hardware</u>			
1) LRS 1821 FASTBUS Segment Manager Interface	7.20	6 - 23	43.20 - 135.60
2) LRS 1821/DEC 1821 to UNIBUS Interface Card	1.00	6 - 23	6.00 - 23.00
<u>Instrumentation Crates</u>			
1) KSC FD50-A02 FASTBUS Crate	2.60	6 - 23	15.60 - 59.80
<u>Instrumentation Modules</u>			
1) LRS 1879 FASTBUS TDC	4.28	105-521	<u>440.88 - 2,227.28</u>
Total System Cost			513.68 - 2,475.68K\$
Cost per Channel			\$ 51.37 - 49.51

Vendors:

KSC = Kinetic Systems Corp.
LRS = LeCroy Research System

NOTE: Quantity discounts not included.

Steve Lane
November 9, 1984
Page 10 of 16

This option requires three (3) standard instrumentation module implementation. These are the LRS 4448 Coincidence Register, the LRS 2311 Edge Triggered Latch (ETL) and the LRS 4608 Octal Discriminator. Each module contains forty-eight (48), sixteen (16) and eight (8) channels, respectively. The discriminator provides the coincidence register with its timing gate while the edge triggered latch supplies the neutron information to the coincidence register. All events are time referenced to an event trigger provided by a photon detector.

A schematic of this option is shown in Figure 3. The measurement is divided into ten (10) time bins of 4 ns duration. Each time bin defines a particular neutron energy and is time staggered with respect to adjacent bins by appropriately delaying the gate to each coincidence register. The requisite delay times for the down shifted neutron distribution are defined by the time-of-flight figures shown in Table 3 as a function of the source-to-detector distance.

Each detector output must be split into ten (10) individual signals. Since approximately 2 volt signals are expected to be generated by a single neutron, this ten-way power split represents signals of approximately 632 millivolts which can be easily sensed by the ETL.

The timing chain is initiated by an early time signal generated by a photon detector. This signal is split into ten (10) signals each representing the main trigger for each individual time bin. Each signal is further split into seven (7) signals that provide the individual discriminator channels with its trigger pulse. Assuming a 10V photon pulse as the primary event, every discriminator input will sense a 1.20V trigger signal. Each discriminator channel will output three (3) 4 ns-wide NIM level pulses that are directly coupled to the gate input of the coincidence register. A total of twenty (20) coincidence registers per time bin will be gated by each discriminator module.

Note :

1. All delays (dely) TBD.
2. 4 ns wide coincidence gate defines minimum
3. Δt addition to coincidence gate defines next time bin
4. Edge Triggered Latch (ETL) may be optimal
5. Ten (10) time bins provides 5-14 MeV coverage

TABLE 3. NEUTRON TIME-OF-FLIGHTS AS A FUNCTION SOURCE-TO-DETECTOR DISTANCE

The time-of-flight, t_n , for a neutron of energy, E_n , traveling a distance, L , is calculated using the following equation:

$$t_n = L \left[\frac{3.336}{1 - \left(\frac{939.573}{E_n + 939.573} \right)^2} \right]^{1/2} \cong \frac{72.298 L}{\sqrt{E_n}} \quad [\text{ns}]$$

E_n [MeV]	L [m]:	1 m	2 m	3 m
	t_n [ns]:			
14		19.32	38.64	57.97
13		20.05	40.10	60.16
12		20.87	41.74	62.61
11		21.80	43.60	65.40
10		22.86	45.73	68.59
9		24.10	48.20	72.30
8		25.56	51.12	76.68
7		27.33	54.65	81.98
6		29.52	59.03	88.55
5		32.33	64.67	97.00
4		36.15	72.30	108.45

Steve Lane
November 9, 1984
Page 13 of 16

The delayed neutron event signal is then directly coupled to the input of the ETL. Upon sensing each neutron signal, the ETL will output a logic level signal that satisfies both the threshold and coincidence width requirements of the coincidence register. These are specified as a minimum of 400 mV and 2.5 ns, respectively. As long as the leading edge of the ETL output falls within the gate provided by the discriminator, a logic "1" will be stored by the coincidence register. Each coincidence module stores its forty-eight channels of data as a 48-bit word. This word is read out over the CAMAC Dataway using the appropriate CAMAC command. The DPR of the coincidence register (6 ns typically) precludes neutrons of different energies being recorded in any individual time bin since the coincidence gate is set at 4 ns.

A cost breakdown of the total system is shown in Table 4. The total system cost, excluding the CPU and its peripherals, is approximately 1,385.30K\$ or 1.39K\$ per channel. This option represents the best technical option since it is a direct counting measurement and eliminates the problem of signal "walk" due to jitter and long cable runs associated with high resolution timing measurements. However, the cost as it stands makes this option undesirable. Discussions with LRS are currently ongoing regarding a modification to the coincidence register that would allow the direct coupling of the detector to the coincidence register. If this can be worked out, it is anticipated that the cost per channel would be compatible with that of the multi-hit TDC option.

4. Computer and Instrumentation Bus Interface Scheme

The hardware required for the CPU-to-instrumentation bus (IB) and (IB-to-IB) interfacing schemes are discussed here. A total of five (5) interface possibilities will be discussed, of which two (2) fall into the CPU-to-IB category and the remaining three (3) define the IB-to-IB type. In the case of the former, a Digital Equipment Corporation (DEC) PDP-11 CPU is assumed.

TABLE 4. COST BREAKDOWN OF COINCIDENCE COUNTING MULTI-HIT OPTION

	<u>Cost Per Item (K\$)</u>	<u>Quantity Required</u>	<u>Quantity Cost (K\$)</u>
<u>Interface Hardware</u>			
1) KSC 2050-Z3A Serial Highway Driver	7.20	1	7.20
2) KSC 3952-Z1A Serial Crate Controller	1.85	40	74.00
3) LRS 4501A CAMAC to NIM Adapter	.15	10	1.50
<u>Instrumentation Crates</u>			
1) SEC 8211 x 211 Optima 850 CAMAC Crate	1.76	40	70.40
<u>Instrumentation Modules</u>			
1) LRS 46088 Octal Discriminator	1.97	10	19.70
2) LRS 3211 Edge Triggered Latch	1.50	600	900.00
3) LRS 44A8 Coincidence Register	1.57	200	<u>314.00</u>
Total System Cost			1,386.80K\$
Cost per Channel			1.39K\$

Vendors:

KSC = Kinetic Systems Corp.

LRS = LeCroy Research Systems

NOTE: Quantity discounts not included.

Steve Lane
November 9, 1984
Page 15 of 16

The two (2) possibilities of CPU-to-IB interfaces relevant to this experiment are those dealing with the PDP-to-CAMAC and PDP-to-FASTBUS situations. The hardware required to interface the PDP bus to that of CAMAC is the Kinetic Systems Corporation (KSC) option Z3A of the Model 2050 Serial Highway Driver (SHD). This is a dual wide connector that resides in the PDP backplane. The PDP-to-FASTBUS interface is made using the LRS 1821 Segment Manager Interface (SMI) module and the LRS 1821/DEC UNIBUS Interface Card (UIC). The SMI is a two-wide FASTBUS module while the UIC is a hex size board that resides in the PDP-11 backplane. The physical connection between these boards is made with a standard UNIBUS cable. The UIC can also be purchased from DEC under the model number DR11-W.

The three (3) types of IB-to-IB interfaces defines the CAMAC-to-CAMAC, CAMAC-to-FASTBUS and CAMAC-to-NIM interconnects. The CAMAC-to-CAMAC interface is accomplished with the KSC 2050 SHD. This is a rack mountable unit that allows up to sixty-two (62) CAMAC crates to be interfaced in a serial fashion. Both the SHD-to-CAMAC crate and crate-to-crate connections are made with standard D-port connectors. A two-slot-wide KSC 3952 Serial Crate Controller (SCC) for each crate is required.

The CAMAC-to-FASTBUS interface requires two (2) modules to complete. These are the SMI and the LRS 2891 CAMAC Port-to-FASTBUS single wide module. These two (2) modules are connected to one another with the LRS DC4/34 Data Cable.

Finally, the CAMAC-to-NIM interface is made using LRS 4501A NIM to CAMAC Adapter. This unit connects to both the NIM module and CAMAC bus and provides the $\pm 12V$ regulation required by the NIM module.

A summary of all the above hardware options is shown in Table 5. Individual costs were included in Tables 1, 2, and 4, respectively.

**TABLE 5. SUMMARY OF HARDWARE REQUIRED FOR CPU
AND INSTRUMENTATION INTERFACES**

<u>INTERFACE</u>	<u>REQUIRED HARDWARE</u>
1. PDP-to-CAMAC	KSC 2050-Z3A Serial Highway Driver (SHD)
2. PDP-to-FASTBUS	LRS 1821 Segment Manager Interface (SMI)
3. CAMAC-to-CAMAC	KSC 2050-Z3A SHD KSC 3952-Z18 Serial Crate Controller (SCC)
4. CAMAC-to-FASTBUS	LRS 1821 SMI LRS 2891 CAMAC Port to FASTBUS
5. CAMAC-to-NIM	LRS 4501A NIM to CAMAC Adapter