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Los Alamos x-ray characterization facilities for plasma diagnostics

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Abstract

A summary is given of characteristics of x-ray sources used by Los Alamos National Laboratory to calibrate various x-ray diagnostic packages and components. Included are D.C. sources in electron impact and fluorescence modes, a pulsed laser source for soft x rays with 100 ps time resolution, Febetron pulsed electron impact sources, and both EUV and x-ray synchrotron beamlines.

Introduction

Many of the experiments at Los Alamos emphasize measurements of high temperature and high density plasmas. These include major programs in magnetic confinement fusion (MFE), inertial confinement fusion (ICF), and the underground test program (UGT). In all cases, x-ray emission is an important part of the system energy balance and careful measurement of emitted x-ray signatures is important to the detailed understanding of the plasma. However, before these measurements can be interpreted, it is necessary to carefully characterize the instruments with which they are made; and we maintain a wide range of x-ray sources with which to perform the necessary characterizations. In this paper we will review these x-ray characterization facilities.

There are three fundamental parameters which an instrument may sample: energy or wavelength, time, and space. No single instrument completely characterizes all three parameters. Rather, most instruments will emphasize one parameter at the expense of the others; however, it must be possible to calibrate all three properties of any instrument to the necessary level of precision across a broad range of magnitudes. The energy range of interest extends from 10 eV to more than 100 keV while temporal resolution may be from below 50 ps to D.C. Spatial response expresses itself either as spatial resolution which may be as fine as a few microns or as divergence which may be of order a microradian.

Just as no single instrument can simultaneously fully characterize the full x-ray emission of a pulsed plasma, no single x-ray source will allow us to fully characterize all the properties of a measurement instrument. Therefore, we maintain a variety of facilities which allow us to adequately sample the requisite parameter space. Some of these facilities are located at Los Alamos and represent our complement of laboratory sources while others are located at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory.

Both the laboratory and NSLS sources will be described in this paper. The major characteristics of each source will be outlined and some typical experiments will be described. Some of these sources have been described in detail previously,[1,2,3] and this will mainly serve as an overview of these systems.

Laboratory sources

The laboratory sources we maintain at Los Alamos are classed as two major types: D.C. generators and pulsed x-ray sources. The D.C. generators are used, primarily, to measure the spectral and spatial response of detector systems, while the pulsed sources are optimized to measure their temporal behavior.

D.C. generators

Perhaps the most common type of x-ray generator is the D.C. electron impact x-ray generator. This type of system has a long history dating back to the early days of vacuum electron tubes. Though these tubes are limited to a few tens of kilowatts of dissipated electron energy and only a few percent of this appears as x rays, they are still the backbone of most laboratory x-ray programs because of their versatility and ease of use.

Direct anode mode. The cross-section of a typical "Henke-Type" x-ray source is shown in Figure 1. A filament is heated by a small D. C. power supply until it thermionically emits electrons. These electrons are accelerated towards the anode by a large potential supplied by the main high voltage power supply and strike the surface with sufficient energy to excite characteristic x-ray emission from the anode material. In the "Henke" tube the filament is hidden behind the anode to limit the tungsten deposition from the filament on the anode surface. This is particularly important for low energy x-rays, below a kilovolt of energy, since the x-ray generation process is essentially a surface phenomena at these energies and will be strongly affected by any surface contaminants. A more recent innovation used by Robert Liefeld of New Mexico State University replaces the tungsten filament with Thorium Oxide coated Iridium ribbons placed in front of the anode in the same manner as the earliest x-ray tubes. These filaments achieve high emissivity at lower temperature and thus avoid the surface deposition problems seen with tungsten filaments.

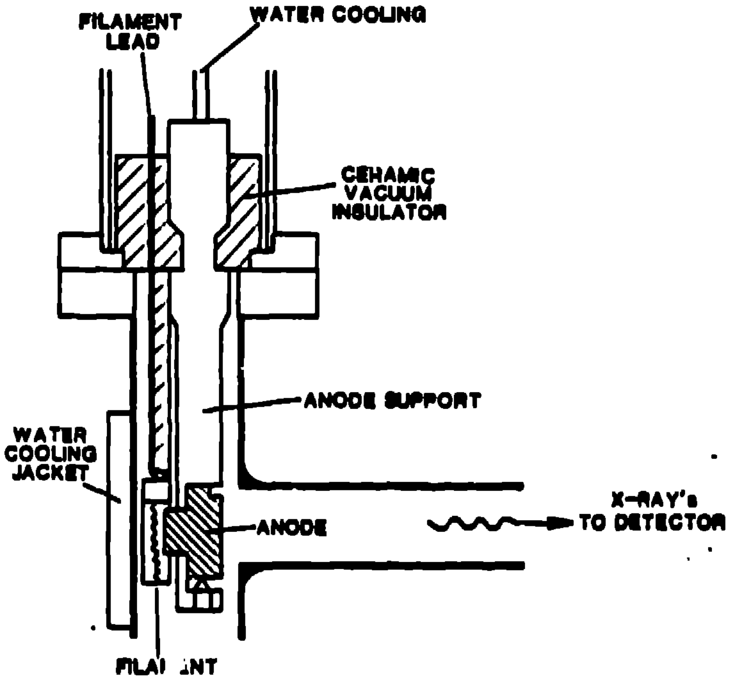

Figure 1. Cross section of typical "Henke-Type" electron impact D.C. x-ray generator.

We have six of these classical generators with primary electron energies from a few kilovolts on our custom-built low-energy x-ray sources to 300 kilovolts on a large commercial Norelco generator. All the systems dissipate between one and five kilowatts of electrical power. A summary of the properties of these tubes is given in the top of Table I. In general, the low energy x-ray sources are Los Alamos built units which are optimized for use at low photon energies with high purity in the photon beam. The higher energy photon sources are typically commercial units which have been heavily modified for laboratory use. For example, the G.E. x-ray source is a commercial diffractometer which has been modified to perform a variety of laboratory measurements including radiography, elemental analysis, and crystal diffraction profile measurements.

In order to achieve the purities listed in Table 1, it is necessary to heavily filter the x-ray beam with a material whose absorption edge is just above the characteristic energy of the anode and to limit the electron energy to about twice the characteristic x-ray energy. The purity and flux numbers listed are associated with this type of operation.

We are presently engaged in a project to upgrade the direct anode x-ray sources. The new version will incorporate a means of changing the anode without venting the vacuum system. The anode filtration will also be changeable remotely. This will greatly enhance the utility of the direct anode x-ray mode of operation.

In Table 1 the fluxes listed are for a detector located 10 inches from the source anode or fluorescence source.

Table 1. Summary of x-ray characterization facilities

Energy Range (KeV)	Source type	Pulse length	Flux at detector @ 10" (ph/cm^2-s)	Purity (% line)
.1 - 1.5	Direct anode	D.C.	> 10^8	> 90%
1.5	"Henke tube"	D.C.	> 10^8	> 90%
1.5 - 10.5	"Henke tube"	D.C.	> 10^7	> 95%
4.5	Commercial ETC point focus x-ray source	D.C.	> 10^6	> 85%
10 - 70	Modified commercial picker unit filter/fluorescer	D.C.	> 10^8	> 90%
30 - 300	Commercial Norelco unit direct of filter/fluorescer	D.C.	> 10^9	> 80%
600	Commercial febetron	3 ns	Bremsstrahlung	broad spectrum
2500	Commercial febetron	20 ns	Bremsstrahlung	broad spectrum

Filter/fluorescer mode. An important adaptation of the direct anode x-ray source is the filter/fluorescer mode of operation. A schematic of this mode of operation is shown in Figure 2. The x-rays from a direct anode x-ray source are filtered for purity and impinge on a fluorescer whose characteristic x-rays one wishes to excite. The characteristic energy of the x-ray tube emission is higher than that of the fluorescer material to be excited. The fluorescent emission is then filtered to reduce scattered radiation.

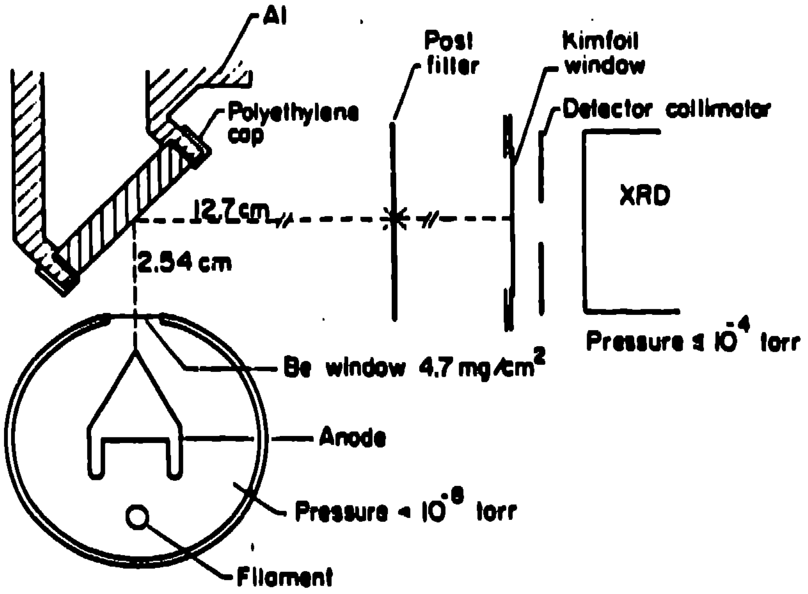

Figure 2. Cross section of an x-ray source in filter/fluorescer mode. The characteristic x-ray tube energy is above the fluorescent emission line and the fluorescent beam is filtered for optimum purity.

The final beam is at least one to two decades less intense than the primary radiation from an x-ray tube; but, the final beam can be very pure (> 90%), even at photon energies of tens of kilovolts. Furthermore, it is very easy to change the photon energy of this type of system by merely changing the electron beam voltage and the filter and fluorescer materials and many systems have been built which automate this process. A picture of a typical filter/fluorescer x-ray source is shown in Figure 3. When used with a solid-state detector as shown in this picture or a flow proportional counter to perform absolute dosimetry, these systems become the standard low energy x-ray calibration sources.

Figure 3. A low-energy "Henke" tube used in the filter/fluorescer mode. The attached solid-state detector is used for beam purity evaluation and absolute dosimetry (usually referenced to a proportional counter or ion chamber).

Pulsed x-ray sources

Many short-lived plasma phenomena have characteristic time constants of a nanosecond or less. An example is the ICF program where laser pulses of one to a few nanoseconds are common. It is necessary to completely time resolve these pulses, so system bandwidths of 3 to 5 gigahertz are essential. In order to characterize the x-ray response of such systems, an x-ray pulse of 100 ps duration or less is essential. For longer lived plasmas, a slower response time is adequate.

Laser source. We have chosen to meet the need for a 100 ps x-ray source with x-ray emission from a plasma created by a short pulse laser interacting with a slab target. The radiative cooling times for x-ray emission from a high intensity laser plasma are typically 70 to 100 ps. The high intensity emission of such a plasma is typically from 100 eV to 1 keV which matches well many of our needs.

The system we are using was assembled recently.[9] A block diagram of the laser chain is shown in Figure 4. A commercial unit consisting of an actively mode-locked and actively Q-switched oscillator and preamplifier model AML 2000 built by J-K Lasers is fed into an amplifier chain of Nd glass rod amplifiers, which were spare SHIVA laser amplifiers from Lawrence Livermore National Laboratory. The oscillator features pulse amplitude stability of better than 10% with 7 mJ of output.

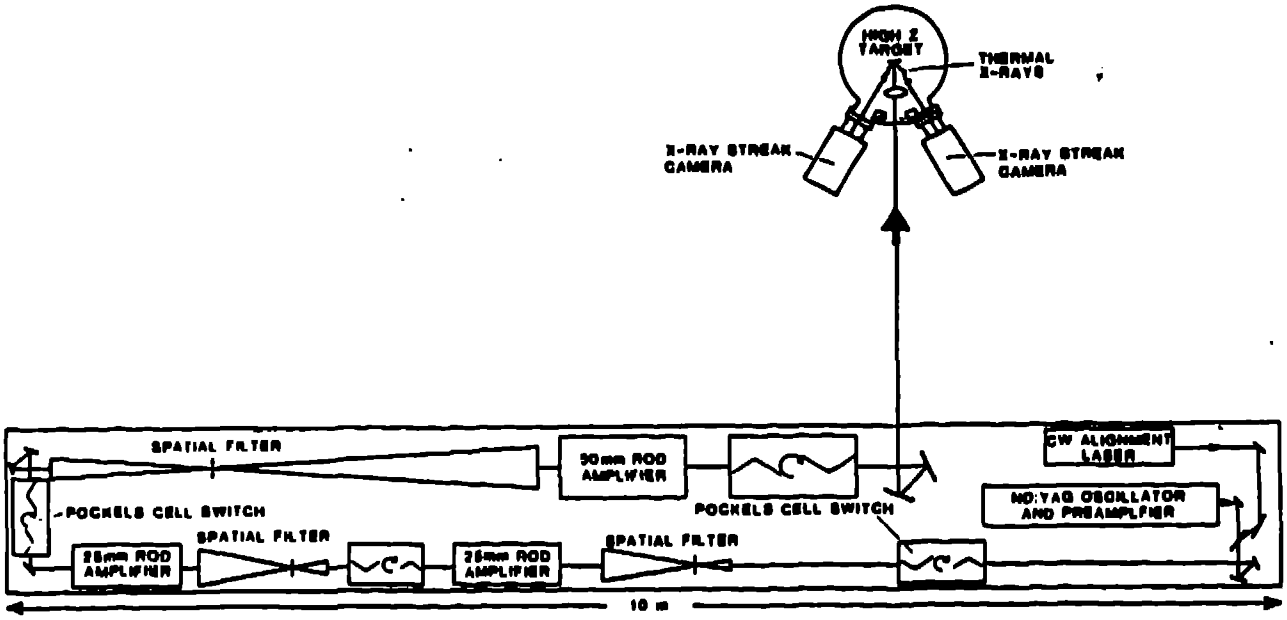

Figure 4. A block diagram of the Forge laser.

The Nd:YAG oscillator can also be used as a stand alone system and can be harmonically converted to 532 nm, 355 nm, or 266 nm. In the frequency doubled modes the system can deliver 4 mJ of energy.

The laser plus amplifiers produce 15 J of 1.06 μm light in a 1 ns pulse and can be focused to a 50 μm spot to achieve laser intensities of greater than 10^{15} w/cm^2. The laser pulse width can be adjusted down to 100 ps with a proportional reduction in total available energy. These laser parameters allow one to achieve up to 20% conversion into x-rays with a characteristic temperature of greater than 100 eV on a slab target. A picture of the system is shown in Figure 5. The system also includes a series of spatial filters to ensure good beam quality. The output beam is then focused inside an evacuated target chamber. The chamber includes remote focus and beam monitoring capability.

Figure 5. A picture of the complete Forge pulsed x-ray source facility. It consists of a commercial J-K Lasers oscillator/preamplifier coupled to a three-stage rod amplifier chain.

These parameters are adequate to characterize many typical fast x-ray detectors. The original system was assembled to characterize fast x-ray sensitive streak cameras; however, it has also proven useful in measuring the time response under x-ray irradiation of photoconductive switches and studies are planned of the time response of fast plastic scintillators and x-ray diodes.

At present we are performing a series of dynamic modulation transfer function (MTF) measurements of most commercially available x-ray streak cameras. This includes MTF measurements of both the spatial and temporal axis. The spatial axis is sampled by placing a resolution mask over the photocathode and backlighting the grid with x rays while the camera is in streak mode. An example of results of this measurement are shown in Figure 6.

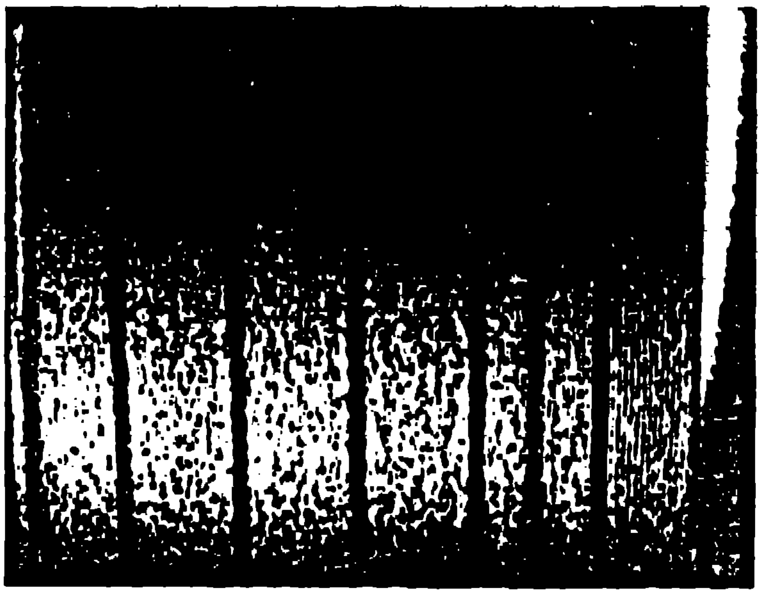

Figure 6. Dynamic resolution data from a Hadland X-Chron 540 streak camera excited by x rays from the Forge laser.

The results are not complete and will be reported at a future meeting. However, preliminary results show that the best available x-ray streak cameras have approximately 10 line pairs per millimeter resolution at 50% modulation.

Electrical pulsed sources. For lower bandwidth systems it is possible to use electrically driven pulsed x-ray sources. We have two such systems whose properties are shown at the bottom of Table 1. They are based upon commercial electron machines which are run in radiation mode.

The power supply is a standard Marx bank which is discharged through a pulse forming line and across an anode-cathode gap. The resulting high energy electrons strike a high-Z material and generate bremsstrahlung radiation. The radiation has the temporal history of the electron beam which can be as short as a few nanoseconds. The energy spectrum, however, is very broad with a typical bremsstrahlung shape with an end-point energy of the full electron energy.

These sources are best suited for time response calibration and we have primarily used them to estimate the time response of high energy x-ray detectors for the laser fusion program and gamma-ray detectors for the underground test program.

Synchrotron facilities

Synchrotron radiation is produced whenever a charged particle is accelerated. For electrons with energy above a few hundred MeV circulating in a magnetic field of order 1 tesla the emission spectrum is predominantly in the ultraviolet and x-ray regime. Indeed this emission has limited the highest energies available from circular electron accelerators. More recently, this effect has been used as a copious source of x-ray emission for a variety of investigations in surface science, materials science, and atomic physics. Indeed several electron storage rings such as the NSLS at the Brookhaven National Laboratory have been built with the dedicated purpose of producing synchrotron radiation.

The properties of synchrotron radiation are particularly well suited for use as a characterization source. First, the radiation from the machine is produced with all energies up to a maximum set by the machine electron energy and the magnetic field in the machine. Therefore, by use of a tunable monochromator, any desired photon energy can be selected. Second, the beam is collimated to an angle of $1/\gamma$ in the vertical direction where

γ is the ratio of the electron kinetic energy to its rest energy. This means that high intensity is available even at large distances and after reflection from beam handling optics. The choice of monochromator and electron energy can therefore be used to optimize synchrotron radiation in various regions of the spectrum. Indeed the NSLS uses two electron storage rings, the first with an energy of 700 MeV and the second with an electron energy of 2 GeV to optimize emission in the subkilovolt and ten kilovolt x-ray regions, respectively. We are building beamlines on both rings to meet the needs of the Los Alamos program in science and technology.

We are building a state-of-the-art facility consisting of four synchrotron radiation beamlines at the NSLS. We propose to cover the energy range from 10 eV to 25 keV with high resolution, high throughput, good higher order and stray light suppression, and to provide flexible experimental stations that are easy to use. Detailed specifications for these lines are shown below.

The first beamline has been installed on the VUV ring at the NSLS. This line, designated U3C, covers the photon energy range from approximately 20 eV to 1200 eV with a resolving power, E/ΔE, of approximately 1000. This is a very versatile line designed for general purpose and spectroscopy experiments. Commissioning of this line is now taking place and our experimental program will begin in July 1986.

A second line, designated U3A, is being designed to be implemented on the VUV ring. This line will augment U3C and extend our capabilities in energy range, 6 eV to 1000 eV with resolving power of approximately 5000. Installation of this line is planned for July 1987.

We are also implementing two hard x-ray beamlines on the x-ray ring at the NSLS. We are building a 5-25 keV line, designated X4C, incorporating a four crystal fixed-exit beam monochromator with a resolving power of 10^4. This line will have an end station apparatus for EXAFS, x-ray diffraction and scattering, and radiometry, contained in a radiation safety hutch. Installation of this line is planned for early 1987 and operation beginning in September 1987.

The second x-ray line, X4A, is a ultra high vacuum line, UHV, covering 1-5 keV with a double crystal fixed-exit beam monochromator with a resolving power of 10^4. This line will be equipped with a UHV experimental chamber equipped for EXAFS, PES, and radiometry. Installation of this line is planned for May 1987 and operation by October 1987.

Beamline U3C

Beamline U3C is a general purpose/spectroscopy beamline. It is designed to collect 10 mr of radiation and use a grazing incidence monochromator (ERG). The line covers the energy range from about 20 eV to 1200 eV with a resolving power of 1000, low stray light, and good harmonic rejection. UHV sample chambers will be available for atomic/molecular physics experiments, solid state and surface science measurements, and detector characterization and calibration.

Table 2. U3C spectroscopy line

Monochromator	Extended Range Grasshopper (ERG) with Mirror Filters
Energy Range	20 eV to 1250 eV
Resolving Power (E/ΔE)	> 670 for E < 1250 eV > 1000 for E < 800 eV
Flux at Exit Slit (Estimate) (ph/sec-0.1% bw-100 ma)	> 10^{10} Over Entire Range
Order Sorting	Excellent Using Mirror Filter
Horizontal Angle Collected	10 mRad
Horizontal Divergence at Exit Slit	10 mRad
Vertical Divergence at Exit Slit	10 mRad

A schematic of this beamline is shown in Figure 7a, while a photograph of the completed line as viewed from the experimental chamber end of the line is shown in Figure 7b.

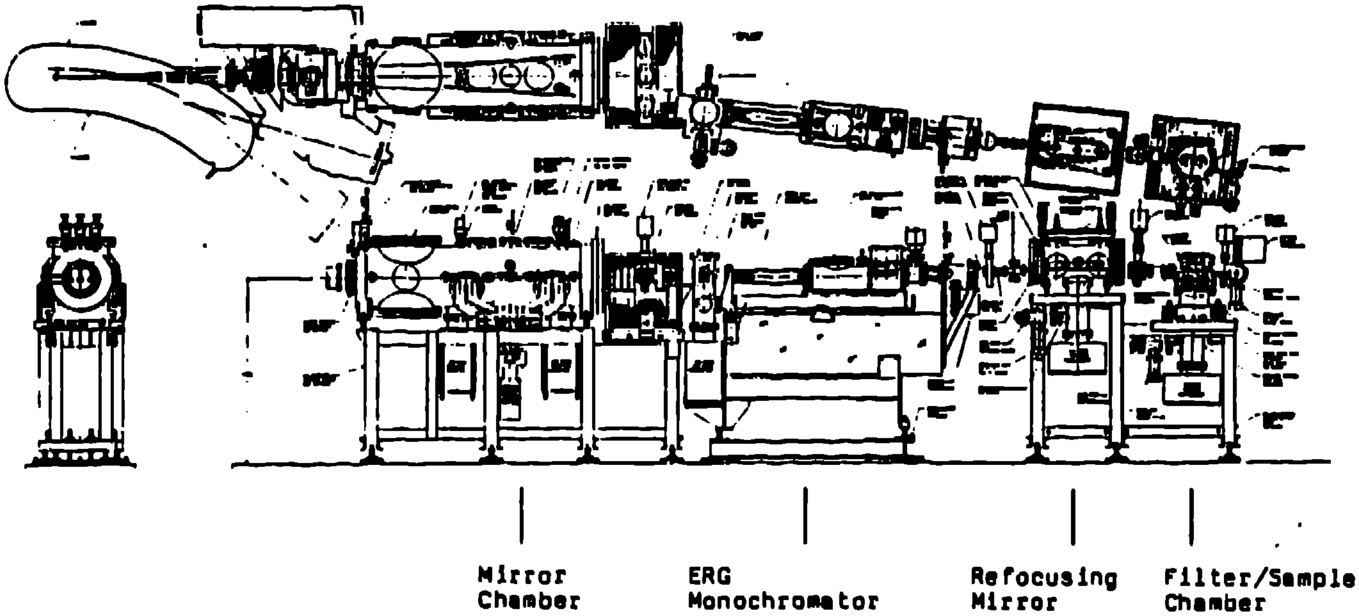

Figure 7a. Schematic of monochromator system on beamline U3C at NSLS.

Figure 7b. Photograph of completed hardware on beamline U3C at NSLS.

Beamline U3A

Beamline U3A will be a high resolution, high throughput beamline. It will cover the energy range from 9 eV to 1000 eV with a resolution of 10^3 to 10^4 over the entire range and a flux of ~ 10^{12}. This beamline would be a general purpose line well suited to x-ray detector and spectrometer development and calibration as well as to spectroscopic measurements on solid and gaseous samples.

Table 3. U3A radiometry/spectroscopy line

Monochromator	Torroidal Grating (6, 10 Meter Combination)
Energy Range	9 eV to 1000 eV
Resolving Power (E/ΔE)	> 10^3 - 10^4
Flux at Exit Slit (ph/sec-0.1% bw-100 ma)	> 10^{12}
Order Sorting	Good
Horizontal Angle Collection	10 mRad

Beamline X4A

The proposed 1-5 keV x-ray beamline consists of a vacuum access line incorporating a UHV double crystal, fixed-exit-beam monochromator with a resolving power of 10^3 to 10^4. The line will be developed so that harmonic and stray light are reduced to less than 1% of the first order light.

Following the monochromator will be an end station apparatus consisting of a UHV sample chamber and/or ionization chamber, EXAFS system, and detector systems for radiometry. Some experiments may need to be done at relatively high pressure. This in turn will require special pressure monitoring equipment and may require a differential pumping system.

Table 4. X4A x-ray line

Monochromator	Double Crystal Fixed Exit Beam
Energy Range	1.0 to 5 keV
Resolving Power (E/ΔE):	10^3 - 10^4
Flux at Exit Slit (Estimate) (ph/sec-1.0% bw-100 ma)	10^{12}
Order Sorting	
With Detuned Crystals	Good
With Mirror Filter	Excellent

Beamline X4C

The proposed 5 - 25 keV beamline consists of a vacuum access line incorporating a four crystal, fixed-exit-beam monochromator with a resolving power of 10^4. The line will have harmonic and stray light reduced to less than 1% of the first order light.

Following the monochromator will be an end station apparatus contained in a hutch consisting of a beryllium window, EXAFS system, x-ray diffraction system featuring a 4-circle goniometer, and detector systems for radiometry. Some experiments may require windowless ionization chambers. This in turn will require a special pumping system.

Table 5. X4C x-ray line

Monochromator	Four Crystal Fixed Exit Beam
Energy Range	5 to 25 keV
Resolving Power (E/ΔE):	$\sim 10^4$
Flux at Exit Slit (Estimate) (ph/sec-1.0% bw-100 ma)	10^{12}
Order Sorting With Four Crystals	Excellent

Conclusion

The mixture of laboratory and synchrotron based x-ray facilities gives Los Alamos a state-of-the-art complement of x-ray sources to meet the needs of our programmatic and science efforts.

References

1. P. B. Lyons and D. W. Lier, IEEE Trans. Nucl. Sci., NS-22, 88 (1975).
2. P. B. Lyons, R. H. Day, D. W. Lier, and T. L. Elsberry, in Proceedings or ERDA X- and Gamma-Ray Symposium, CONF-760539 79, 1976.
3. G. L. Stradling, T. R. Hurry, E. R. Denbow, M. M. Selph, and F. P. Ameduri, "The Forge: a short pulse x-ray diagnostic development facility," SPIE 569, 196, High Speed Photography, Videography, and Photonics III (1985).