Lawrence Livermore Laboratory

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J. L. Gaines

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THE LAWRENCE LIVERMORE LABORATORY X-RAY CALIBRATION FACILITY

J. L. Gaines
Lawrence Livermore Laboratory, University of California
Livermore, California 94550

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SUMMARY

An X-Ray Calibration and Standards Laboratory has been established at the Lawrence Livermore Laboratory to provide x-ray calibrations of various types of x-ray diagnostic equipment presently being utilized. This Laboratory is the outgrowth of many years of involvement in the development of x-ray generation and calibration equipment. X-ray calibrations in a steady state mode are available from 100 eV to 100 keV. Pulsed response and linearity studies as well as radiation damage studies can also be performed. A crystal fabrication, characterization and calibration facility is an integral part of the Laboratory. A general discussion of various equipment and capabilities within the Laboratory is presented.

INTRODUCTION

Because of the importance of x-ray diagnostics in so many areas of physics research, the Lawrence Livermore Laboratory has assembled one of the most sophisticated, fully equipped x-ray calibration facilities in the country. Indeed, our X-Ray Calibration and Standards Laboratory is one of only a few such facilities in the world that can perform x-ray measurements throughout the 100-eV-to-100-keV energy range. This paper describes this facility--its x-ray generators, its radiation sources, its calibration capabilities (some of which are unique in the scientific community).

The x-ray measurements lab was originally built in support of LLL's nuclear weapons program. Our weapons work relies on a tremendous array of sophisticated x-ray detection and diagnostic devices, all of which must be precisely calibrated to very exact standards. Today, we still support the weapons effort, but we are also heavily involved in calibration work for the Laboratory's laser and magnetic fusion energy programs. X-ray diagnostics is proving to be one of the most effective methods for analyzing fusion plasmas. In addition, we calibrate x-ray detectors and spectrographs for a variety of biomedical, radiation-monitoring, and industrial radiography applications.

We can provide many levels of service to the x-ray community. Our scientific staff has extensive expertise in the general area of diagnostic techniques and carries out basic and applied research to improve existing technology. Current areas of research include:

- Interaction of x-rays with matter.
- X-ray spectroscopy.
- Crystal fabrication and characterization.
- Instrumentation development.
- X-ray source development.

One of the unique features of our x-ray calibration facility is the computer complex supporting it. Nearly all of the data generated by our x-ray calibration equipment are processed using the main LLL computer network, one of the largest, most powerful computer networks in the world. In some cases, data-acquisition equipment is tied directly to this computer complex by way of microcomputers and telecommunication interfaces.

Finally, we should mention that, while we describe our x-ray calibration facilities in terms of their primary uses today, all of them can be modified to perform different tasks and provide different energies.

X-RAY FACILITIES

Henke Tube Spectrometer Facility

This system uses a 1.2-kW Henke-type x-ray source. A Siemens goniometer supplies a θ - 2θ capability in the inside of an evacuated 66-cm-diameter stainless steel experiment chamber incorporating light barriers, filter stations, and a selectable slit array. A thin-window proportional counter is mounted on the 2θ arm of the goniometer. There is also a high-resolution, windowless lithium-drifted, silicon detector attached to the chamber through a 12.7-cm-diameter bellows for low-dispersion angle measurements.

Capabilities: The Henke tube provides subkilovolt x-rays with a source intensity of approximately 10^6 to 10^7 photons per steradian-second. The bremsstrahlung x-ray beam can be used for evaluation, transmission, and reflection studies of filters, film, and thin windows. The Henke tube has interchangeable anodes.

Unique Features:

- A horizontally moveable, high-resolution, windowless, lithium-drifted, silicon detector.
- A remotely controlled, horizontally rotatable, precision stage for double-reflection studies.
- A remotely controlled, eight-station, fluorescence array for obtaining fairly monoenergetic subkilovolt x-rays of limited intensity.

Figure 1. Henke Tube Spectrometer Facility

Henke-Tube Double-Crystal Facility

This facility, which uses a 3.5-kW Henke tube attached to an 84-cm-diameter stainless steel evacuated chamber, has a double goniometer. That is, it has a θ - 2θ stage with another θ - 2θ stage mounted on the 2θ arm of the first stage. By using two reflectors with

these two θ - 2θ stages, you can significantly reduce the bremsstrahlung continuum from the Henke tube. Also, since the efficiency of the reflectors is fairly high, you can produce a fairly intense, monoenergetic, subkilovolt x-ray beam.

Capabilities: Facility enables double-critical-angle reflector studies to be performed using subkilovolt x-rays. It can also be used to evaluate filters, thin windows, and reflectors. The large vacuum chamber will accommodate fairly large experimental setups. Both bremsstrahlung radiation and fairly monoenergetic x-rays are available.

Unique Features:

- A large, evacuated, stainless steel experiment chamber.
- A double-goniometer system.
- Clean vacuum system that allows surface studies to be conducted.

Figure 2. Henke-Tube Double-Crystal Facility

Picker 160 kV Crystal-Calibration Facility

This facility uses a Picker Gemini 160-kV radiographic x-ray unit and a Seifert tungsten-anode x-ray tube head with a 0.025-cm-thick beryllium exit window. The primary x-ray beam from this tube is used to fluoresce one of ten selectable fluorescers. The fluorescent beam can then be filtered with absorption-edge filters to get a readily accessible, fairly monoenergetic, fluorescent x-ray beam.

Capabilities: Facility can be used to calibrate crystals in the 8-to-98-keV energy range using a θ - 2θ system. Energies are readily selectable and are fairly monoenergetic when absorption-edge filters are used. Intensity of the filtered fluorescent beam ranges from 10^6 to 10^7 x-rays/cm²-sec. Spectral purity and absolute flux are determined using either a scintillation detector or a high-resolution germanium detector.

Unique Features:

- Crystal efficiencies determined easily.
- Very stable x-ray generator.
- Mechanical design makes facility easy to operate.
- Readily selectable energies.

Figure 3. Picker 160-kV Crystal Calibration Facility

General Electric/Diano Crystal-Calibration Facility

This facility consists of a General Electric 75-kV XRD-6 radiographic x-ray unit, a θ - 2θ goniometer with a Diano Corporation detector system, and four x-ray-tube heads of different anode materials. The four x-ray-tube heads are coupled in direct-beam mode to four vacuum lines-of-sight that, in turn, are attached to chambers for calibrating and characterizing crystals or complete crystal spectrographs.

Capabilities: Facility can provide an intense (6.5 roentgens/sec) bremsstrahlung beam with characteristic anode lines present. Accessibility of the radiation beam makes it relatively easy to calibrate or characterize individual crystals or complete spectrograph assemblies. A 24-position filter wheel for K-edge absorption allows easy calibration of the film-spectrograph assembly.

Figure 4. General Electric/Diano Crystal-Calibration Facility

Unique Features:

- Mechanical design enables easy calibration of crystals and spectrographs.
- One power supply operates a spectrogoniometer and three other tubes.

Low-Energy X-Ray Facility

This x-ray generator was designed and developed here at Livermore. It is used to produce monoenergetic, high-intensity x-ray beams in the 1.5-to-8-keV energy range. Electrons from an annular-shaped triode electron gun bombard one of nine individual water-cooled targets that can be rotated into the electron beam. With appropriate filtration, each target provides a very intense source of fairly monoenergetic x-rays, whose intensity and spectral purity can be measured very accurately.

Capabilities: Facility has a detector-calibration chamber and a spectrometer chamber with a 8-28 Siemens goniometer. The high intensity ($\sim 10^9$ x-rays/cm²-sec) and high spectral purity ($>95\%$) of the x-ray beam in the detector-calibration chamber makes this one of the best--if not the best--detector-calibration facilities in the world. The goniometer provides a means of calibrating crystals and devices employing crystals.

Unique Features:

- Most intense-spectrally pure, steady-state x-ray source in the 1.5-to-8-keV energy range in the world.
- Different energies quickly available from nine-target array.
- Intense bremsstrahlung x-ray beam also available.

Figure 5. Low-Energy X-Ray Facility

General Electric 75-kV Detector-Calibration Facility

This facility uses a 75 kV, 36-mA generator in conjunction with a tungsten-anode x-ray tube with a 0.025-cm-thick beryllium exit window. The primary x-rays from this tube are used to excite fluorescent x-rays in a selectable metal foil positioned near the beryllium window. The fluorescent x-rays are then filtered, using K₂ absorption-edge filters, to produce a fairly monoenergetic x-ray beam, which can be measured to determine its absolute intensity as well as its spectral purity. Remote manipulators are available to position the detectors to be calibrated.

Figure 6. General Electric 75-kV Detector-Calibration Facility

Capabilities: Facility can provide either a bremsstrahlung beam or a fluorescent x-ray beam. The fluorescent x-rays available are in the 6-to-45-keV energy range. The intensity of the accessible fluorescent x-ray beam range from $\sim 10^6$ to 10^7 x-rays/cm²-sec.

Unique Features:

- Can produce either bremsstrahlung or fluorescent x-ray beams.
- Easy access to x-ray beam.
- Other x-ray-tube heads are available (e.g., Cr or Mo anodes).

Picker 160-kV Detector-Calibration Facility

In this facility, a Picker Gemini model control console and power supply are coupled with a Seifert 150-kV, 12-mA x-ray tube. The tube is housed in a totally shielded box with a remotely controlled, ten-position, fluorescer changer all arranged in such a way that a beam of fluorescent x-rays is generated and directed at 90° to the tube beam line. These fluorescent x-rays are absorption-edge filtered resulting in a nearly monoenergetic beam of readily accessible fluorescent x-rays.

Capabilities: Unit can deliver essentially monoenergetic beams ($< 10\%$ spectral contamination) in the 8-to-97-keV energy region, with the intensity of the accessible beam ranging from 10^5 to 10^7 x-rays/cm²-sec. Absolute photon fluxes are determined by counting methods and precisely known geometries.

Figure 7. Picker 160-kV Detector-Calibration Facility

Unique Features:

- High-intensity, monoenergetic x-rays.
- Numerous energy points (8 to 96 keV).
- Absolute calibrations are possible.
- Excellent beam-intensity stability.
- Easy to operate and set up.

Foil-Calibration Facility

This facility uses radioactive sources in conjunction with high-resolution detectors to measure the x-ray transmission of thin foils. With a computer code, this information is used to compute the x-ray thickness of these foils.

Capabilities: Facility can be used to measure the x-ray thickness of typical filter/fluorescer foils from 3 to 15 keV or from 2 to 120 keV, depending on the radioactive source used.

Unique Features:

- Facility is fully automated.
- Many foils (14 maximum) can be loaded at once.
- X-ray thickness can be measured to within 1% for typical foils.

Figure 8. Foil-Calibration Facility

Febetron 706 Pulsed-Radiation Facility

Int'l Field Emission Corporation Febetron (model 706) is a Marx generator system used to charge a group of capacitors in parallel to a high voltage and then discharge them in series to provide a short, high-voltage pulse, which is then applied to a field-emission cathode tube to produce a short pulse of energetic electrons. The resulting pulsed electron beam can be used directly or it can be converted to x-rays by having the electrons strike a metal target.

Capabilities: Unit produces a 20-nsec, full-width-at-half-maximum pulse of electrons with a maximum energy of 2 MeV. Dose rate is 3×10^{11} roentgens/sec, and total energy per pulse is approximately 400 J.

Unique Features:

- Short-pulse, high-intensity x-ray or electron source.
- Easily accessible radiation beam.
- Short turnaround time between exposures (about 3 min).
- Relatively low maintenance.

Figure 9. Febetron 706 Pulsed-Radiation Facility

Febetron 706 Pulsed-Radiation Facility

This Field Emission Corporation Febetron (model 706) operates the same as model 706 except that peak voltage is only 600 keV, electron beam diameter is 1 mm, and model 706, the electron beam is converted to x-rays if desired.

Capabilities: Unit produces a 20-nsec, full-width-at-half-maximum pulse of electrons with a maximum energy of about 600 keV. Dose rate is about 10^{11} roentgens/sec, and total energy per pulse is approximately 400 J.

Unique Features:

- Can produce either x-ray or electron beam.
- Beam is fully accessible.
- Beam is fully accessible for electron beam.
- Beam intensity is adjustable.
- Beam is easily accessible.

Figure 10. Febetron 706 Pulsed-Radiation Facility

This high-intensity, sub-MeV x-ray calibration source and k_α-induced inner-shell atomic fluorescence of low-Z elements. The high proton yields and low inner-shell band background associated with this phenomenon are ideally suited to provide an intense, nearly homogeneous, x-ray calibration source for detector-background applications. The proton accelerator is a 100-kV, 300-1000-keV electrostatic Van de Graaff or potential difference hydrogen ion source, (see schematic). Suitable liquid-cooled targets are used to provide characteristic x-rays with energies between 100 and 1500 eV.

Capabilities: Facility incorporates a detector calibration chamber and a detector chamber employing a 400-cc moderator (lead, cadmium, iron, copper, etc.) to allow for availability. Making the detector chamber available to the user requires a detector calibration chamber to be available. Detector calibration chamber is available to the user only with the calibration facility and is required to be in operation. In addition, if the moderator chamber and assembly is placed in the moderator chamber, all of the features of the facility will be available. The facility will be available to the user only if the facility is available to the user.

1. The first group of variables includes the demographic characteristics of the respondents, such as age, gender, and education level. These variables are used to control for potential confounding factors that may influence the relationship between the independent and dependent variables.

- Many proteins are secreted into the periplasmic space and exported into the medium.
- In addition, proteins can be transported into the periplasmic space.
- and some proteins are imported.

Figure 13. Calibration curve for a silicon-semiconductor detector with a 500 micron depletion depth.

Figure 14. Calibration curves for a Pilot B scintillator photodiode detector and a gold cathode photoelectric diode detector.

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