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UCRL--86306

DE82 001018

UCRL- 86306
PREPRINT

CONF-811028--2

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This paper was prepared for presentation at the 23rd Annual Meeting of the American Physical Society, Division of Plasma Physics, New York City, October 12-16, 1981.

29 September 1981

Lawrence Livermore Laboratory

Measurement of 2-5 keV X-ray Emission from Laser-Target Interactions by Using Fluor-MCP and CsI-XRD Detectors*

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ABSTRACT

For inertial confinement fusion plasma diagnostics, x-ray diode (XRD) detectors using conventional cathodes are not sensitive enough to measure x-rays above ∿1.5 keV. However, for laser driver fusion targets, x-rays in the range of 2-5 keV are important because of their mobility in the target. We have successfully used fluor-microchannel plate (MCP) detectors to obtain absolute x-ray measurements in the 2-5 keV range. Recent data obtained from experiments on the Shiva laser system are presented. In addition, designs for a variety of channels in the range using fluor-MCP and CsI-XRD's above 1.5 keV will be discussed.

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

For the past four years, we have routinely measured soft x-ray emissions from laser target interactions by using the filtered XRD systems.[1] From the measured soft x-ray spectra, we have been able to provide a data base for LASNEX[2] calculations, to further our understanding in thermal electron conduction and transport phenomena,[3] and to obtain conversion efficiency.[4] On the other hand, the hard x-ray spectra have been monitored by FFLEX,[5,6] a diagnostics system, which utilizes the filter-fluorescer technique.

Due to x-ray fluence levels and sensitivities of XRD detectors using conventional cathodes (e.g. Aℓ, Cr, and Ni), conventional XRD systems are not sensitive enough above ∿1.5 keV. On the other hand, due to the rapidly decreasing fluorescence yield with decreasing atomic number, FFLEX is difficult to use below ∿6 keV.

The x-rays in the 2-5 keV range are nevertheless important.[7] Recent wavelength scaling laser-target experiments[8,9] show that the hard x-ray fluence decreases dramatically and the soft (sub-keV) x-ray fluence increases with decreasing laser wavelength. This means that x-rays in the range of 2-5 keV would most probably also increase. This result indicates that for future experiments using frequency doubled or tripled light, x-rays in the range of 2-5 keV would become more important. This fact justifies the measurement of x-rays in the 2-5 keV range.

Because of the rapidly falling x-ray spectrum at energies above ∿1.5 keV, more sensitive detectors are required. Two such candidates are the CsI-cathode XRD and the fluor-microchannel plate. Figure 1 compares the calibrated x-ray detector sensitivities of a thin fluor-microchannel plate,[*] a 0.3 μm thick CsI-cathode and a conventional Aℓ-cathode. In the 2-5 keV region, a CsI-XRD is almost two orders of magnitude more sensitive than a solid Aℓ-XRD (other metallic cathodes such as Ni and Cr all have sensitivities of the same order as that of Aℓ), while a thin fluor coupled to a microchannel plate is three orders of magnitude more sensitive than an Aℓ-XRD. This means that both the fluor-MCP and the CsI-XRD are potentially capable of measuring x-rays in the 2-5 keV range from laser target interactions.

Cesium-iodide is a hygroscopic material and unless hermetically sealed, its sensitivity changes with time; the long term stability of CsI-cathode sensitivity, however, needs further investigation.

Examples of the design of different x-ray detector channels at intermediate energies (1.5 to 5 keV) are listed in Table I. Using various x-ray diodes with different filters, we can obtain different channel coverages and channel widths. The objective of the present design is to obtain a total signal level above the oscilloscope detection threshold (> 20 mV at Shiva), but at the same time maximize the fraction of signal below the filter K-edge.

As an example, we show the details of design for a relatively broad channel centered at around 3.5 keV. Figure 2 shows the transmission of a 14.15 μm thick titanium foil; the theoretical transmission curve agrees very

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[*] The MCP detector consists of a 36 μm thick NE111 plastic scintillator, a 3 mm thick corning 754 glass blue light filter, an 8 mm thick Pb-glass x-ray filter sandwiched together and coupled to a one-stage ITT 4126 MCP photomultiplier with an S-1 photocathode. The fluor-MCP assembly is housed in an arrangement that effectively reduces stray light to less than 10^{-6} by differentially pumping around the filter using an effective light baffle.

well with calibration data. Folding this transmission curve with the calibrated fluor-MCP sensitivity (shown in Fig. 1), we obtain the channel response, this is shown in Figure 3. Note that the half-width is ∿ 2 keV, which covers the energy range from above 2 keV to 5 keV. Figure 4 shows the channel response folded with a trial spectrum (estimated from earlier x-ray data of Au-disk shots). Integrating the fold with respect to x-ray energy, we obtain the channel center energy defined as the 50%-point of the running integral as shown in Figure 5. In the present case, for the (i) energy 1/2-value, (ii) the fraction of total signal below the filter K-edge, and (iii) the total detector charge, we obtain from Figure 5 the values (i) 3.3 keV, (ii) 99.3% and (iii) 8.4 x 10^7 pC which corresponds to 6.38 V-ns for this channel.

The above channel was installed on the Shiva 9-channel filtered XRD H-system and used to measure x-ray emission from laser-target interactions. Figures 6 and 7 show the results obtained from a 3.8 kJ/4.7 ns FWHM Au-disk shot. The target, 1.5 mm in diameter and 25 μm thick, was irradiated with 1.06 μm light at an intensity of 1 x 10^{14} W/cm^2; the focal spot was 1 mm in diameter. The disk was tilted so that its normal made an angle of 30° with respect to the irradiation axis. The H-system viewed the target at an angle of 66° with respect to the disk normal. In both Figures 6 and 7, the theoretically computed spectra[10] are normalized to the measured spectrum at 800 eV.

In Figure 6, the spectral data are compared to a theoretical spectrum calculated by using non-LTE ionization physics and inhibited electron thermal conductivity. Below 1.5 keV, the experimental data match the numerical simulation quite well, but at 3.5 keV, the experimental value is a factor of 2.5 higher than the theoretically computed value.

In Figure 7, the spectral data are compared to a theoretical spectrum calculated by using non-LTE ionization physics but classical conductivity; this improves the fit to data at 3.5 keV, but worsens the fit at energies below 1.5 keV. The measured value at 3.5 keV is larger than computed values in either case. The reason for this discrepancy is not presently clear.

Based on the success of the 3.5 keV channel, other channels at ∿ 1.5 keV and ∿ 2 keV, (refer to Table 1) will be incorporated into the filtered-XRD system in order to cover the region just below and at the energy where gold M-lines occur, allowing for better comparisons of theoretical calculations with more complete spectral data.

COMPARISON OF DETECTOR SENSITIVITIES USING NE111-MCP, CsI-CATHODE AND AL-CATHODE XRD.

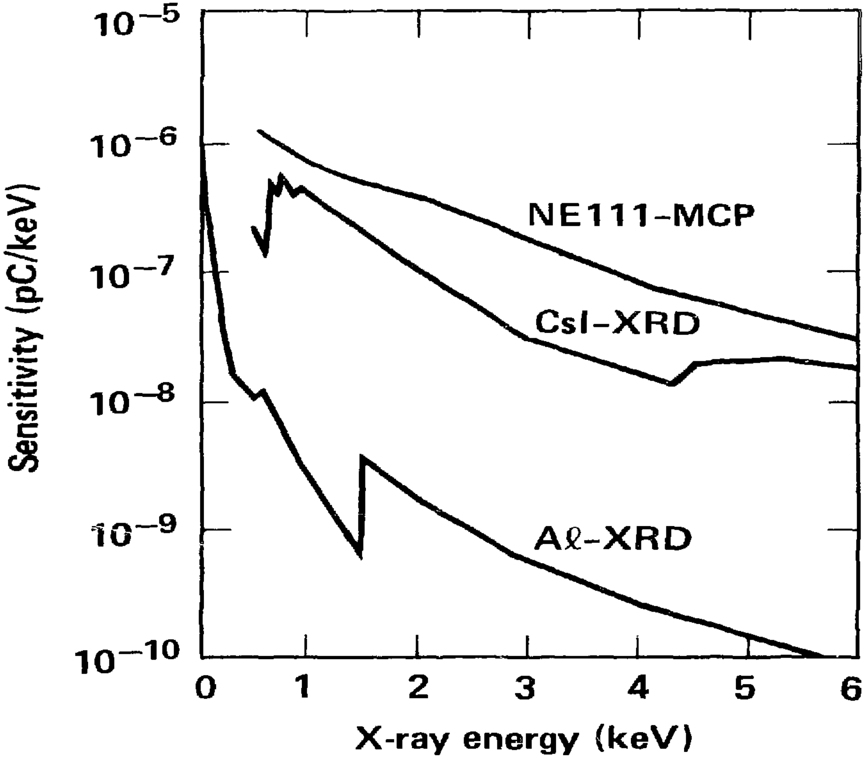

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Figure 1

DESIGN OF X-RAY DETECTOR CHANNELS AT INTERMEDIATE ENERGIES (1.5 TO 5 keV)

	Filter				Channel characteristics (folded with trial spectrum)		
Detector	Material	K-edge (keV)	Thickness (μm)	Channel center (keV)	Channel width (keV)	Fraction of signal below filter K-edge	Total signal charge (V-ns)
CsI-XRD	Al	1.56	25	1.43	0.2	88 %	0.73
CsI-XRD	Zr	2.2	5	1.93	0.49	87 %	0.52
MCP (36 μm NEIII)	Zr	2.2	4	1.97	0.50	90 %	12.4
MCP (36 μm NEIII)	Ti	4.96	14	3.3	1.73	99.3%	6.38
MCP (36 μm NEIII)	Ti	4.96	50	4.28	1.37	99.9%	0.27

Table 1

TRANSMISSION OF A 14.15 μm THICK TITANIUM FOIL (SOLID POINTS ARE CALIBRATION DATA)

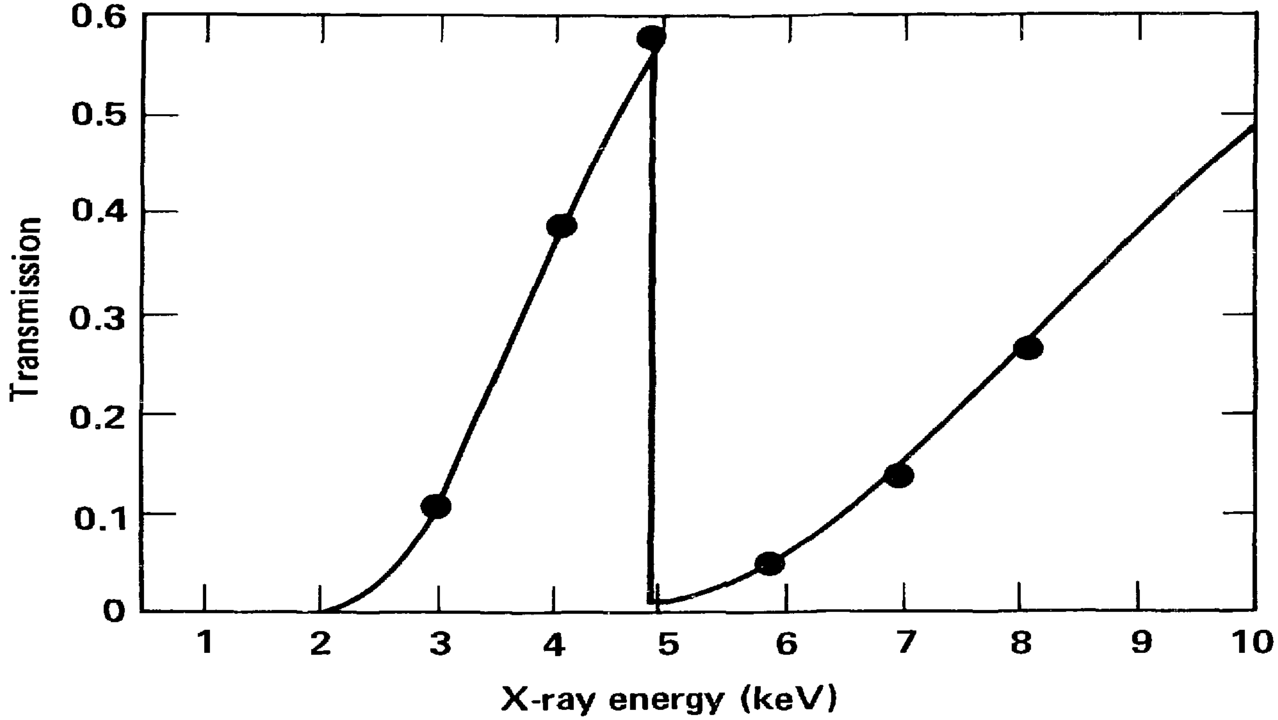

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Figure 2

CHANNEL RESPONSE OBTAINED BY FOLDING 14.15 μm-THICK TITANIUM FILTER WITH CALIBRATED FLUOR-MCP SENSITIVITY

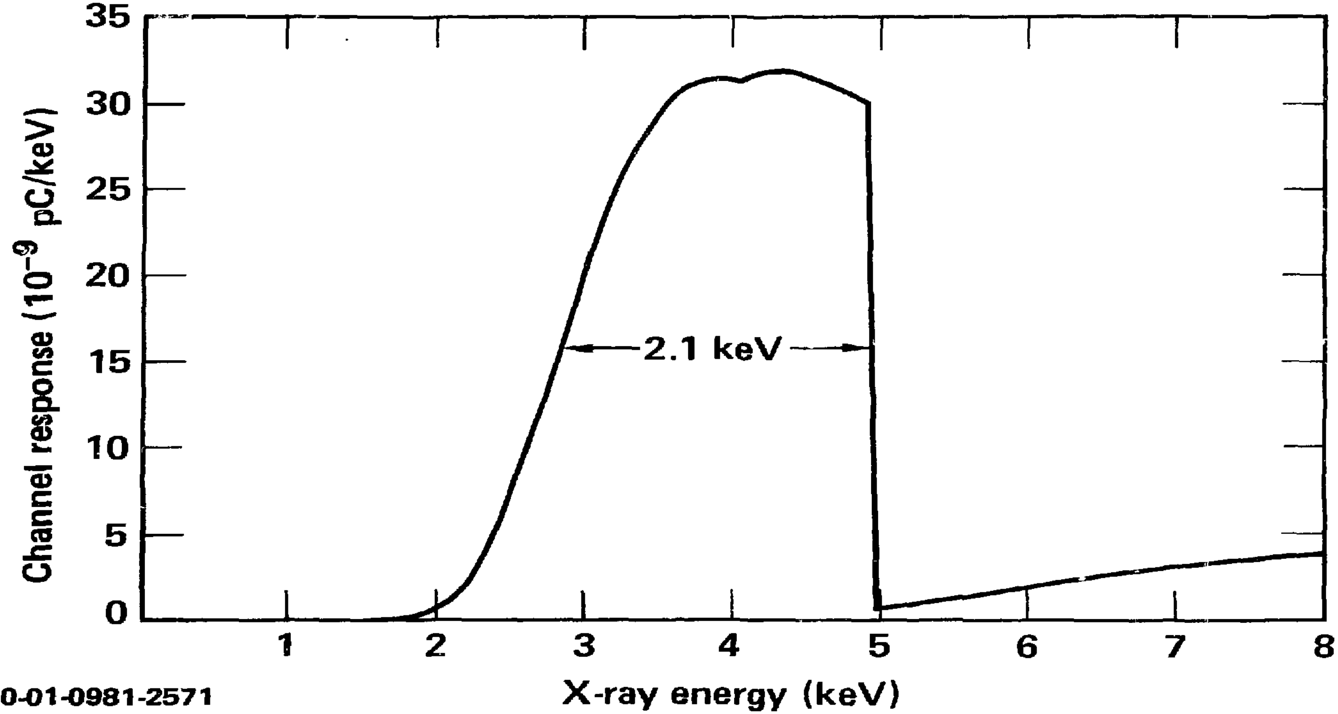

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Figure 3

CHANNEL RESPONSE FOLDED WITH TRIAL SHIVA AU-DISK SPECTRUM

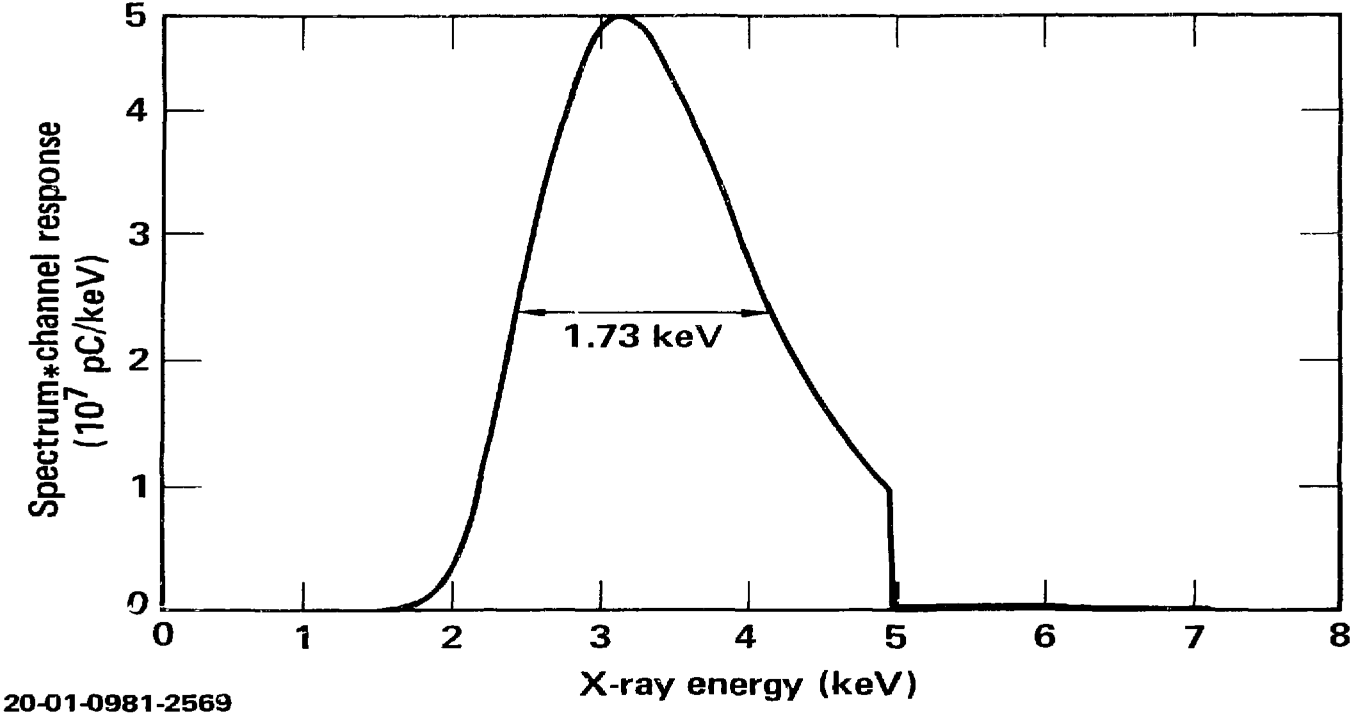

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Figure 4

RUNNING INTEGRAL OF CHANNEL SIGNAL GIVES CHANNEL CENTER, FRACTION OF TOTAL SIGNAL BELOW FILTER K-EDGE AND TOTAL SIGNAL LEVEL
(8.4×10^7 pC = 6.38 V-ns)

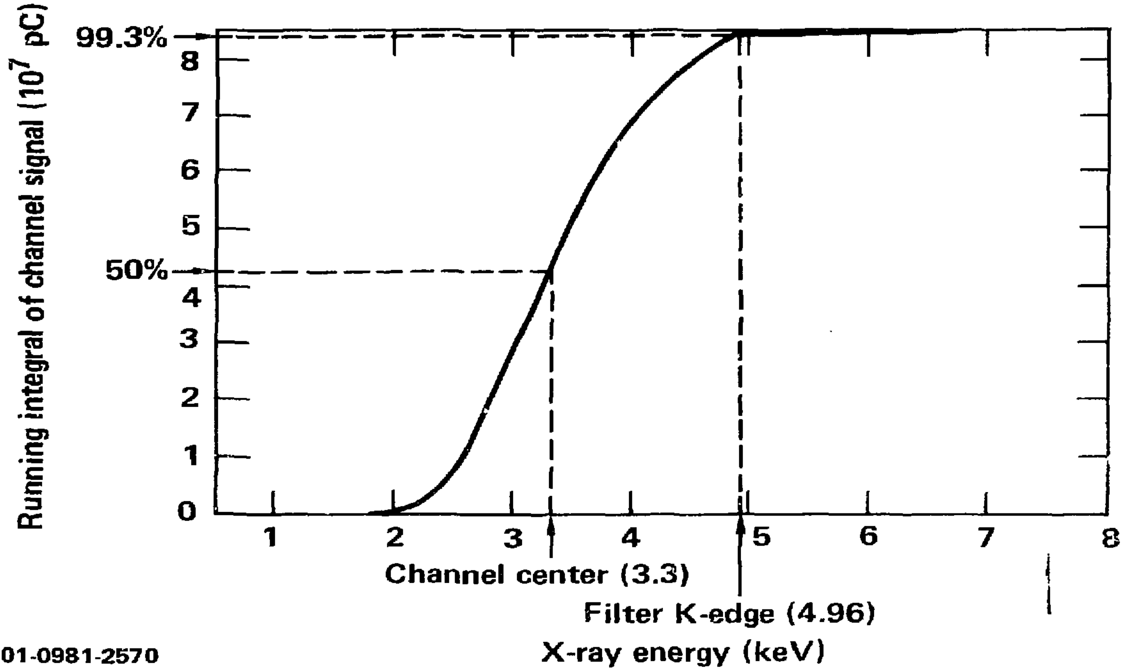

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Figure 5

LOW ENERGY X-RAY SPECTRUM OF GOLD-DISK (1.5 mm DIA., 25 μm THICK). LASER CONDITION: 1.06 μm, 3.8 kJ/4.7 ns FWHM, 1 × 10^{14} W/cm^2, 1 mm SPOT. THEORETICAL SPECTRUM CALCULATED FROM NON-LTE CASE WITH TRANSPORT INHIBITION. SPECTRUM NORMALIZED AT PEAK AT 800 eV.

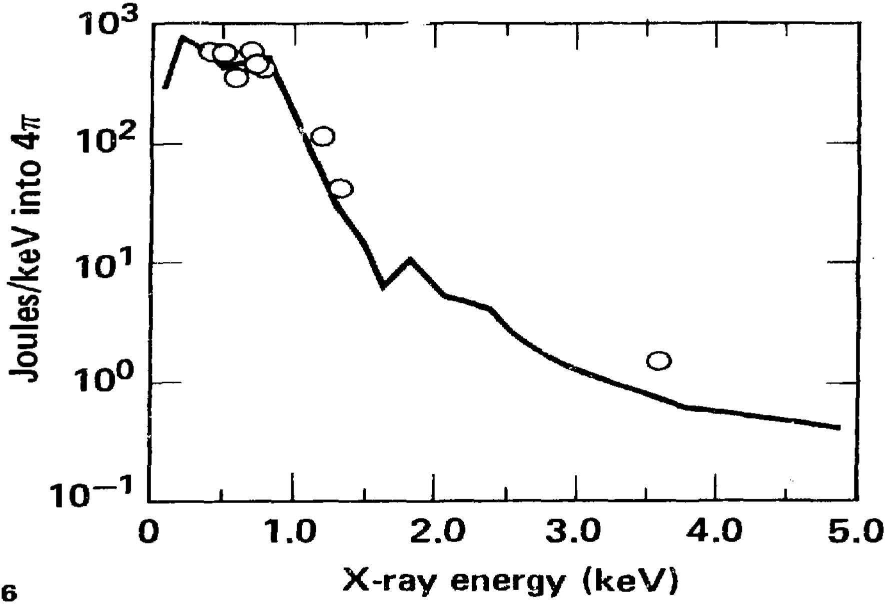

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Figure 6

LOW ENERGY X-RAY SPECTRUM OF GOLD-DISK (1.5 mm DIA., 25 μm THICK). LASER CONDITION: 1.06 μm, 3.8 kJ/4.7 ns FWHM, 1 × 10^{14} W/cm^2, 1 mm SPOT. THEORETICAL SPECTRUM CALCULATED FROM NON-LTE CASE USING CLASSICAL CONDUCTIVITY. SPECTRUM NORMALIZED AT PEAK AT 800 eV.

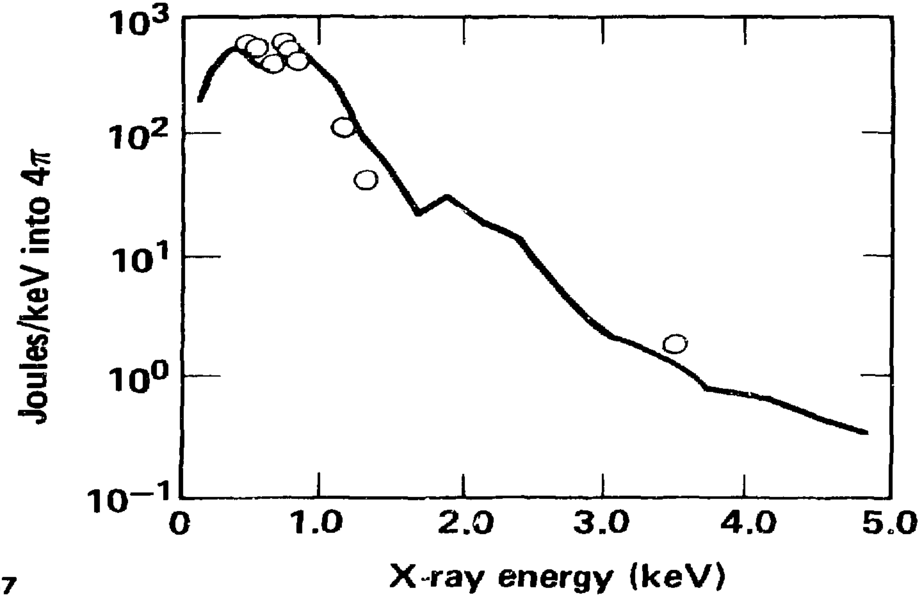

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Figure 7

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