recorded image. This may even forbid precise quantitative analysis of the recorded x-ray images. It is therefore desirable that an x-ray source in the water-window range should have a narrow spectrum for live sample imaging.

At Laser Plasma Division of RRCAT, a narrow band x-ray source in the water window spectral range at 25 Å ± 1 Å (i.e. 24 – 26 Å), has been made. The source was produced by focussing second harmonic of a glass laser (4J, 3ns) to an intensity of ~ 10^{13} W/cm^2 on a 50-50 (atomic fraction) copper-gold mix-Z target, filtered through a 0.4 µm aluminium / 0.9 µm vanadium free-standing x-ray filter. It provides a high transmission over a narrow spectral band starting from $\lambda \sim 24$ Å (corresponding to the L-edges of vanadium) with a peak transmission of ~ 9.4 %. A typical x-ray spectrum from gold-copper mix-Z plasma, transmitted through this filter is shown in Fig.L.16.1. The purpose of using mix-Z target was that these targets are very good soft x-ray converters [J.A.Chakera et al, *Appl. Phys. Letters* 83, 27, 2003]. The x-ray spectrum and the energy flux were measured at two angles viz. 45° and 85° from the target normal using a transmission grating spectrograph and calibrated xuv p-i-n diodes. The angular distribution of the radiation intensity is usually fitted to a form $I_\theta = I_o \cos^n\theta$, where I_o is the intensity in the direction of the target normal, θ is the angle between the direction of observation and the target normal, and 'n' is the scaling exponent whose value lies in the range $0 < n < 1$. In our case, a scaling exponent of 0.23 was obtained. From this value of the scaling exponent, the x-ray conversion of the plasma in the 24 -26 Å spectral range, integrated over full solid angle, turns out to be ~ 4.9 %. An x-ray yield of ~ 3 mJ /sr is observed in the direction of 45° from the target normal in the narrow spectral range of 24 -26 Å. This x-ray flux is sufficient for single shot x-ray imaging of live biological samples with high contrast. [For more details, please see : J. A. Chakera, S. R. Kumbhare, P. A. Naik, and P. D. Gupta, *Applied Phys. B 86, 510, 2007*].

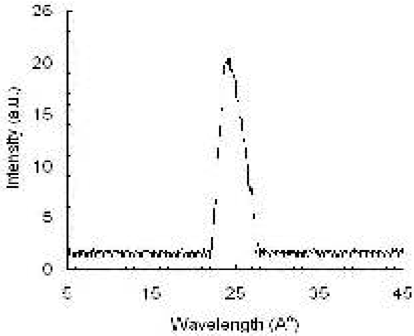

Fig.L.16.1 : A typical x-ray spectrum from gold-copper mix-Z plasma, transmitted through the narrow band filter

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L.17 : Sub-MeV bremsstrahlung x-ray emission from intense laser-plasma interaction

Ultrashort duration terawatt laser pulses when focussed to an intensity > 10^{18} W/cm^2 interact with matter to produce high energy electrons with energies beyond MeV. The high energy electrons produced from solid targets may result in production of intense hard x-rays via bremsstrahlung process and high energetic particles through secondary interactions. Owing to the unique features of these sources, they may be used for applications in both basic sciences and technology. Although these sources are interesting, they also pose potential threat of radiation hazard to the experimentalists routinely working with such laser systems. In the context of both the applications and radiation hazard, it is imperative to have knowledge of the radiation dose and its angular distribution outside the interaction chamber. Moreover, it is desirable to identify and characterize all sources of radiation to take necessary safety measures.

Laser Plasma Division of RRCAT has carried out detailed measurements of the radiation dose produced due to the interaction of Ti:sapphire laser pulses (45 fs, 150 mJ) focussed on a solid planar copper target at a laser intensity of 1.3×10^{18} W/cm^2. The schematic of the experiment is shown in Fig.L.17.1.

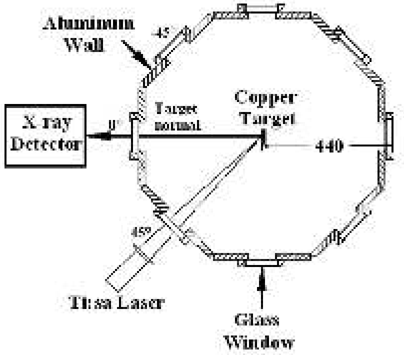

Fig.L.17.1 : Schematic of the experimental setup

In the present experimental conditions, fast electrons with temperature of ~200 keV can be produced along the target normal direction by the process of resonance excitation of plasma wave and wave breaking. Initially, the fast electrons escape the interaction region along the target normal direction leaving behind intense space charge fields which then pull back the remaining outgoing fast electrons in to the target resulting in bremsstrahlung hard x-rays. Hard x-rays with energy ≥ 40 keV can pass through the 10 mm glass windows distributed at 22.5° angular intervals in the laser incident plane. The dose due to this hard x-ray radiation was measured with radiation detector (Victoreen, 450 P) outside the plasma chamber at a distance of about 50 cm from the plasma chamber centre at all glass windows.

The measured angular dose rate distribution showed anisotropy with a peak in the direction of the target normal with a dose of 40μSv/h as shown in Fig.L.17.2. The peak value is more than 200 times the background radiation dose rate ~ 0.2 μSv/h. To find the sources causing the anisotropy, the dependence of the x-ray dose rate as a function of distance along target normal direction ($\theta=0^0$) was measured. The inverse square distance dependence of the dose revealed that there exists a second source of hard x-rays at the glass window along the target normal direction. This further indicates that a significant number of fast electrons are produced along the target normal direction and they get slowed down / stopped in the glass window to produce another source of hard x-rays. The angular distribution of the hard x-rays from individual sources should be somewhat isotropic. However, the combination of two sources gives rise to the experimentally observed anisotropy due to the different detector-second source distance for various angular positions of the detector.

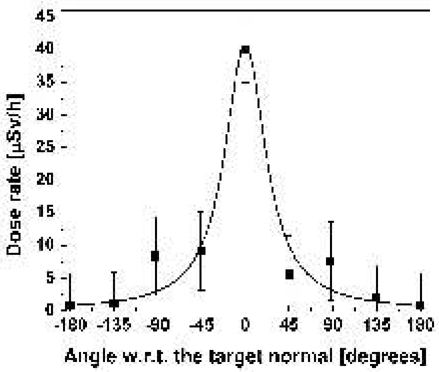

Fig.L.17.2 : Angular distribution of the hard x-ray dose rate outside the interaction chamber.

The present study [B. S. Rao, V. Arora, P. A. Naik, R. A. Khan, and P. D. Gupta, *J. Appl. Phys. 102, 063307(2007)*] reveals that the laser-solid interaction at intensities ~10^{18} W/cm^2 produces significant radiation not only from the interaction region but also from the surrounding materials as well. This radiation provides opportunity to tailor the geometry of the experiment so that the secondary sources may be put to useful radiological applications with more convenience. Considering the significant radiation levels observed in the present experiment, one should take appropriate steps to protect experimentalists from possible radiation hazards.

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L.18 : DSP based motion control system with fully digital PWM AC servo motor drive

An AC servo motor is highly efficient, has fast dynamic response, low maintenance and therefore most suitable for computer numerical control systems (CNC's), motion controllers and robots. The control system and drive developed at the Industrial CO$_2$ Laser Section of RRCAT, provides position, speed, direction and acceleration control of motor with trapezoidal motion profile. Such type of motion is required during laser material processing experiments.

The motor drive is controlled digitally by using digital signal processor (DSP) to provide electronic commutation. The algorithm is implemented for pulse width modulation (PWM) control of the motor for closed loop position control with inner speed control loop. A PC based user interface is developed using Visual Basic language. In order to use this system as an embedded system, a multi-line liquid crystal display (LCD) and a PC keyboard have also been used. The commands are sent to the system through keyboard using a very simple language. Actual speed and actual position can be read during run time. All PI parameters can be changed for smooth response according to application requirement. Fig.L.18.1 shows response of the system to a step command.

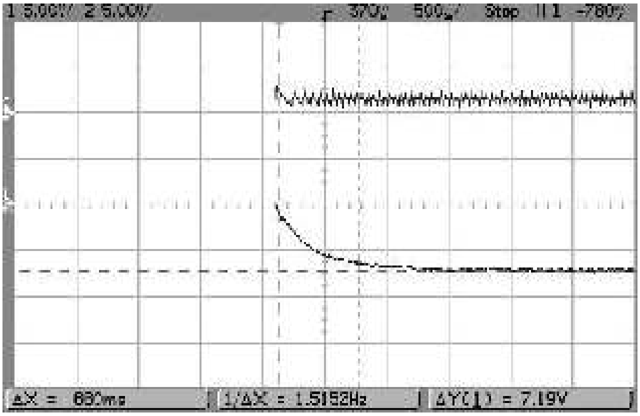

Fig.L.18.1 : Channel 1: 500 rpm/div, Step response of the drive for commanded speed 720 rpm ; Channel 2: 16.67 amp/div, Current in phase a of the motor.

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