Building XXX
P.O. Box 5000
Upton, NY 11973-5000
Phone 516 344-XXXX
Fax 516 344-XXXX
XXXXXXXX@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

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to: *D. Beavis, I. Ben-Zvi, M. Benmerrouche, P. Bergh, P. Cirnigliaro, A. Etkin, M. Fedurin, C. Folz, C. Gardner, R. Karol, E. Lessard, M. Minty, J. Reich, C. Montag, J. Sandberg, C. Schaefer, C. Theisen, K. Yip, C. Naylor, B. Van Kuik*

from: *I. Pogorelsky*

subject: *ATF-II CO_2 laser*

This Memo provides introduction to potential radiation hazards pertinent to a high-power CO_2 laser system and its operation for users' experiments at ATF-II (bldg. 912).
The principle diagram and layouts of the system are illustrated in the attached presentation and the ATF-II facility layout.
Main parameters of the system are compiled in Table 1.

Table 1: Main parameters of the ATF-II CO_2 laser

Parameter	Value
Laser wavelength	9-10 μm
Peak power	100 TW (25TW)
Pulse energy	10 J (50J)
Pulse duration	100 fs (2 ps)
Repetition rate	0.2 Hz
Gas content	CO_2:N_2:He
Gas pressure	10 atm
Internal x-ray preionizer	100 kV, 3 Roentgen

As is depicted in Slide1 of the attached presentation, the main active laser components of the system include: seed-pulse generator, regenerative preamplifier and a final amplifier. The seed generator is based on a Ti:Sapph lasers and wavelength-conversion crystals. Two laser amplifiers are energized by a volumetric gas discharge. Passive elements of the system include pulse stretcher, pulse compressor (both based on diffraction gratings), and a nonlinear compressor based on nonlinear material response to incoming laser beam. Laser pulse duration is 2 ps after the first compressor at the amplifier output. It reaches 100 fs after the nonlinear compressor. See Table 1 for corresponding power and energy parameters.

Two potential sources for ionizing radiation can be considered in conjunction with this laser. The first source is the internal x-ray tube that serves to ionize a gas discharge volume inside the final amplifier (see Slide 2 of the attached presentation). The 12-mm thick stainless steel skin of the amplifier vessel provides sufficient protection against up to 100 keV x-rays produced inside. In addition to estimates for the stopping depth, this fact is supported by the 15-year experience of operating an identical amplifier module at ATF with a chipmunk sitting next to it. (The purpose of the chipmunk is actually to spot radiation from the ATF

experimental hall across a concrete wall.) The x-ray tube power supply is interlocked against the pressure drop within the amplifier vessel below 4 atm.

The second source of ionizing radiation is a focused laser beam. The output high-power is transported to experiments as a 10-cm diameter beam with peak intensity below 10^{13} W/cm^2. This relatively low intensity does not produce ionizing radiation. Such radiation can be produced only in locations where the laser beam is tight focused.

One relatively mild focus will be produced at the location of the in-vacuum nonlinear compressor positioned in a laser room (see Slide 3 of the attached presentation and a facility layout drawing). The peak laser intensity will reach there 10^{16} W/cm^2, which is sufficient for converting the laser power to hot electrons with max temperature 1 MeV. Note that this situation actually corresponds to a fault condition when a laser is misaligned from a pinhole, which it should normally propagate. At routine conditions, the laser power on the target is greatly reduced. Operation parameters on a nonlinear compressor are shown in Table 2. Byproducts of hot electrons are secondary positive ions, which are typically protons from the target surface contamination, and x-rays from stopping electrons on a target and the metal skin of the vacuum chamber. The sufficiency of the metal wall of the chamber for suppressing this radiation needs to be considered to determine occupancy of the laser room.

Table 2: Operating Parameters for a Nonlinear Compressor

Parameter	Routine	Maximum	Comments*
Laser energy	2 J	10 J	
Laser intensity	10^15 W/cm^2	10^16 W/cm^2	
Laser repetition rate	500/h	20/h	
Primary hot electrons			isotropic
Laser deposition to hot electrons	10%	100%	
Electron temperature	<300 keV	1 MeV	
Secondary gammas			isotropic
Electron energy conversion	<1%	10%	
Temperature	400 keV	1 MeV	
Secondary ions	10 nC	100 nC	isotropic
Electron energy conversion	negligible	10%	
Temperature	negligible	1 MeV	

* Maximum regime in this situation corresponds to laser misalignment resulting in higher energy deposition on a target. This is a fault condition that can be spotted and corrected. That is why the accumulated number of shots per hour is substantially reduced to compare with a routine operation where most of the laser radiation propagates through a hole in the target without producing ionizing radiation.

The second location of the laser focus is for strong-field users' experiments. These experiments are conducted in radiation-interlocked experimental hall behind a concrete wall (4 feet or thicker). At such locations, the laser intensity should reach 10^{18} W/cm^2. Focused on a solid or dense gas target, such radiation is efficiently converted to hot electrons of the 100 MeV max temperature. One example is Ion Acceleration experiment that will be parked in a Laser Experimental Hall (see Slide 3 of the attached presentation and a facility layout drawing). Operation parameters for this experiment are compiled in Table 3. The sufficiency of a concrete blockhouse for suppressing this radiation needs to be considered to determine occupancy of the nearby laser room and safety of pedestrians outside the facility.

Other category of users' experiments requires laser focusing in a low-density gas. Although the laser energy is not converted to hot electrons in this case, extended acceleration of electrons to 3 GeV energies can be expected with the maximum charge 10 nC. A location for this category of experiments could be in the Laser Experimental Hall, or within a 100-MeV electron beamline inside the Experimental Hall 1. This is the third situation that requires attention from RSC.

Table 3: Operating Parameters for Ion Accelerator

Parameter	Routine	Maximum	Comments*
Laser energy	10 J	10 J	
Laser intensity	10^18 W/cm^2	10^18 W/cm^2	
Laser repetition rate	50/h	500/h	
Primary hot electrons			isotropic
Laser energy deposition to hot electrons	100%	100%	
Electron temperature	100 MeV	100 MeV	
Secondary gammas			isotropic
Electron energy conversion	50%	50%	
Temperature	100 MeV	100 MeV	
Secondary ions	1000 nC	1000 nC	30^0 cone
Electron energy conversion	30%	30%	
Temperature	100 MeV	100 MeV	

* The routine and maximum operational regimes are discriminated here by the assumed repetition rate only. There is no difference in physical nature of the radiation exposure for these two cases. The maximum radiation exposure will be proportionally 10 times higher to compare with routine. "Routine" regime can be understood as an administratively imposed limit on the laser repetition rate if the radiation shield is impractically thick otherwise.

Attachments:
PDF presentation
PDF partial layout of ATF-II facility