Distribution
MS 12A
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J. Bisognano
J. Boyce
D. Dotson
A. Hutton
R. May
G. Neil
C. Rode
R. Rossmanith
S. Schwahn
C. Sinclair
R. Sundelin
K. Welch
MS12H
J. Domingo
R. Whitney
MS 15A
K. Mahoney
MS 16C
B. Hartline
MS 28G
O. Matherny
MS 28H
C. Ficklen
T. Hassler
MS 58B
R. Campisi
MS 85A
J. Kewisch
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Radiological Control Group Note #93-13

Requirements for 100 keV Injector

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Synopsis

Shielding and other personnel protection requirements are needed for the operation of a 100 keV photoelectron accelerator. The electron beam causes a potential bremsstrahlung radiation hazard. The final determination is made that 0.21 cm of lead is required to shield the beam dump. The same thickness of lead around the beamline should also protect nearby personnel from radiation in the event of a catastrophic failure that would cause the beam to be lost into the beamline. As a further necessary precaution, radiation interlocks shall be used to terminate the beam in the event that there are inadequately shielded areas in the apparatus. Radiological Control Group personnel shall be present to test the interlock and to make measurements during initial operation.

CEBAF
The Continuous Electron Beam Accelerator Facility

Radiological Control Group
Note #93-13

Requirements for 100 keV Injector

The experimental setup consists of primary target of GaAs crystal deposited on stainless steel. The target is biased from a 100 kV power supply. Directly across from the target is an argon ion tunable laser (4579-5145 Å) capable of 10 W cw operation. The laser beam has a photoelectric effect on the GaAs, releasing electrons that are immediately accelerated to 100 keV. The electrons travel down the beam line, are bent at a 90° angle toward the "dumplet", a small water-cooled copper target sleeved with stainless steel. An approximate drawing of the experimental setup is included at the end of this report. The electron beam causes a potential bremsstrahlung radiation hazard, which is the subject of this note.

Calculation of dose rate at 1 meter from Photo-Electron Source

First Method - Electron Analysis (Cember,319)

In order to find the number of electrons hitting the target per unit time, we use:

$$current(A) = \frac{charge(C)}{time(s)} = \frac{N(e^-) \times 1.6E\text{-}19\, C/e^-}{time(s)} \quad (1)$$

Rearranging the equation for a maximum current of 2 mA, the number of electrons per second hitting the target is:

$$\Phi_{e^-} = \frac{0.002A}{1.6E\text{-}19\, C/e^-} = 1.25E16\, e^-/s$$

The fraction of electrons resulting in bremsstrahlung is approximated by:

$$f \approx (3.5E\text{-}4)ZE = (3.5E\text{-}4)(29)(0.1) = 1.03E\text{-}3 \quad (2)$$

where Z is the atomic number of copper and E is the energy of the electron in MeV.

The energy fluence of the electron beam is calculated by:

$$\dot{E}_\beta = (1.25E16 e^-/s)(0.1 MeV/e^-) = 1.25E15\ MeV/s \quad (3)$$

The unshielded dose equivalent rate in air at one meter from the source may be calculated by:

$$\dot{D}_{Air} = \frac{(f)(E\ MeV/s)(1.6E\text{-}13 J/MeV)(\mu_e m^{-1})(3600 sec/hr)}{(1.293 kg/m^3)(4\pi)(1m)^2 (1\frac{J/kg}{Gy})(1E\text{-}3 Gy/mSv)(10 mSv/rem)} \quad (4)$$

where μ_e is the energy absorption coefficient of air for the bremsstrahlung energy. Therefore:

$$\dot{D}_{Air}=\frac{(1.02E\text{-}3)(1.25E15)(1.6E\text{-}13)(2.7E\text{-}3)(3600)}{(1.293)(4\pi)(1)^2(1)(1E\text{-}3)(10)}=12\ rem/hr$$

Second Method - Rule-of-Thumb (IAEA,53)

An alternate method of calculating dose rates is based on a rule-of-thumb approximation for a high-Z target. It is:

$$\dot{D}[(rad/hr)(kW\ m^{-2})^{-1}]\approx 2000\,E_0^2 \tag{5}$$

The dump is designed to accept up to 200 W of power from the incident electron beam; the electron beam is biased from a 100,000 volt (0.1 MV) power supply. Therefore, the unshielded dose rate at 1 meter may be calculated as:

$$\dot{D}_{1m}\approx(2000)(0.1)^2(0.2kW)(1m)^{-2}$$
$$=4\ rad/hr$$

This figure, as a rule of thumb, confirms the utility of the first method.

Dump Shielding Requirements

With an assumption of **12 rad/hr** as the more conservative estimate, the amount of shielding required to reduce the dose rate to the uncontrolled area level of 50 μrem/hr may be determined by:

$$\dot{H}_0=\dot{H}e^{-\mu_l t}\rightarrow t=\frac{-\ln(\dot{H}_0/\dot{H})}{\mu_l} \tag{6}$$

Therefore, for lead shielding with a linear attenuation coefficient of **59.7 cm^{-1}** for 0.1 MeV photons,

$$t=\frac{-\ln\left(\frac{50E\text{-}6\ rem/hr}{12\ rem/hr}\right)}{59.7\ cm^{-1}}=0.21\ cm$$

The thickness calculated is conservative, as it accounts for no self-attenuation in the target and maximum power. If a thinner lead shield is desired, the self-shielding of the target may be calculated. In any case, empirical measurements are required during initial operation.

Beamline Shielding Requirements

Another area of concern is the possibility for missteering of the beam. In the worst-case scenario, the beam hits the beam line at a 90° angle. The thickness of the stainless steel beam line is 0.060" (0.152 cm). Since the range of 0.1 MeV electrons in steel is 0.0013 cm, the resultant bremsstrahlung must travel through 0.151 cm of steel. From equation (6), we know that 66% of the bremsstrahlung produced (0.1 MeV) is emitted to the outside of the beam pipe.

Using the same formulas (1)-(4), the unshielded bremsstrahlung dose rate at 1 meter from the beam pipe is **7.2 rem/hr.** The thickness of lead shielding needed to bring the dose rate down to 50 μrem/hr is 0.20 cm.

Conclusion

The final determination is made that 0.21 cm of lead is required to shield the beam dump. The same thickness of lead around the beamline should also protect nearby personnel from radiation in the event of a catastrophic failure that would cause the beam to be terminated into the beamline.

As a further necessary precaution, radiation interlocks shall be used to terminate the beam in the event that there are inadequately shielded areas in the apparatus. The recommended equipment are two Eberline SMART-100 base units with pancake Geiger probes. These units have normally-closed interlocks that will provide the logic to shut down beam in the event of high radiation levels. Other equipment that serves the same purpose may be satisfactory.

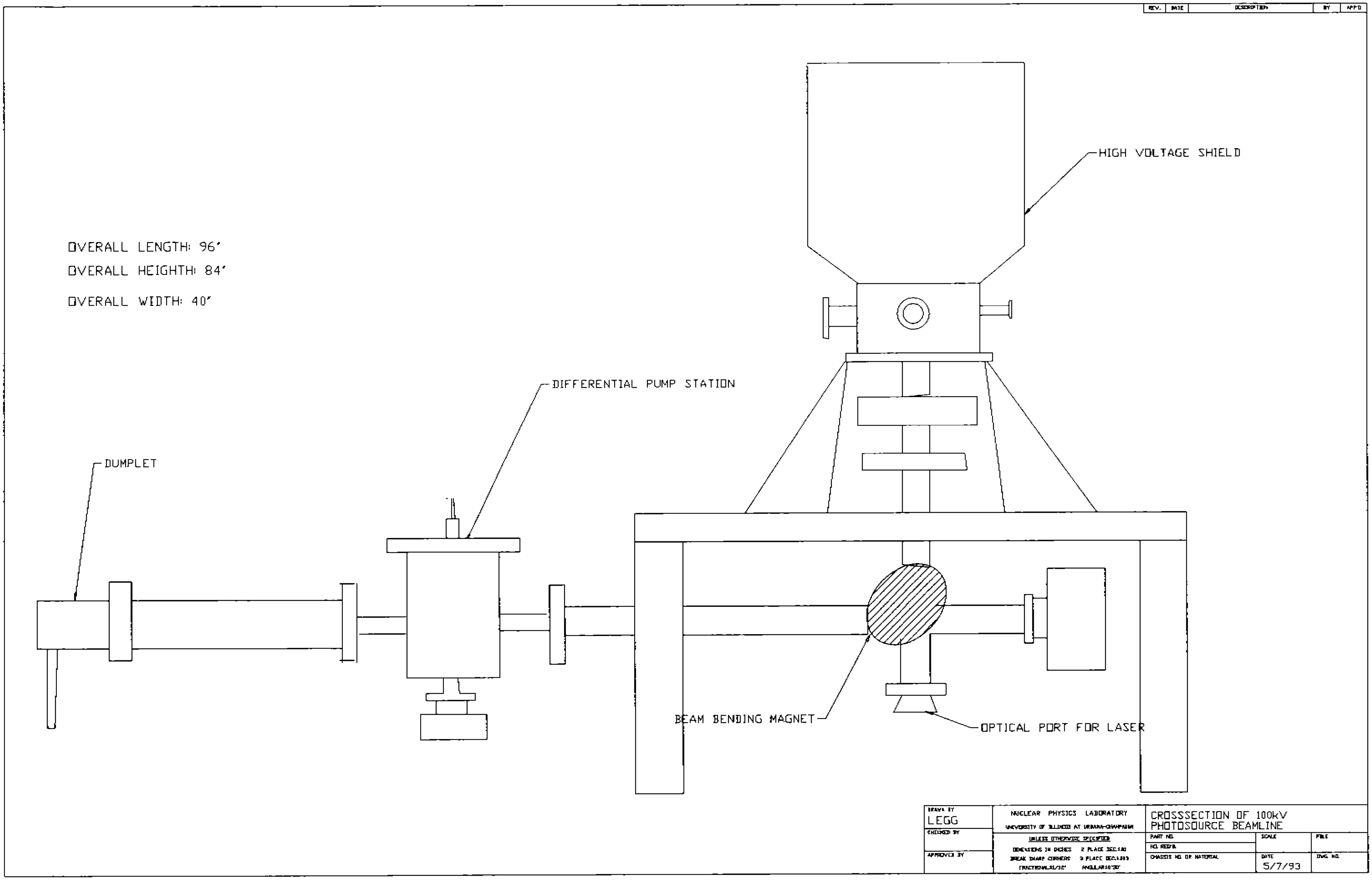
Radiological Control Group personnel shall be present to test the interlock and to make measurements during initial operation.

ES&H (Patty Hunt) should be contacted for appropriate protective coatings to be put on the lead shielding before handling.

References

Cember,H., Introduction to Health Physics. Pergamon Press, New York, 1987.

International Atomic Energy Agency, Radiological Safety Aspects of the Operations of Electron Linear Accelerators. Technical Reports Series No. 188 (IAEA 188), Vienna, 1979.


HIGH VOLTAGE SHIELD
OVERALL LENGTH: 96"
OVERALL HEIGHTH: 84"
OVERALL WIDTH: 40"
DIFFERENTIAL PUMP STATION
DUMPLET
BEAM BENDING MAGNET
OPTICAL PORT FOR LASER
DRAWN BY
LEGG
CHECKED BY
APPROVED BY
NUCLEAR PHYSICS LABORATORY
CROSSSECTION OF 100kV
PHOTOSOURCE BEAMLINE
PART NO.
SCALE
FILE
CHASSIS NO. OR MATERIAL
DATE
5/7/93
DWG. NO.