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Review of Radiation Protection Implications of the Cooling Ring Electron Gun

J. D. Cossairt

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Operating Parameters

Voltage: 110 kV

Current: 28 A (the collector is operated at high potential to reduce power dissipation; electrons are collected at about 5 kV energy).

Power Supply: Sufficient to continuously supply up to 100 mA at full voltage to grounded structures. If greater than 100 mA is lost, the supply trips (assured by a method not clarified) during 2 to 20 μsec; at least 30 seconds are then required to restore 100 kV. It is planned to install an integrator whose purpose would be to keep from tripping on transients up to some instantaneous value of current (negotiated with the Safety Section) and yet keep the average current lost less than 100 mA.

X-Ray Production and Shielding

The drift tube, a potential weak spot, has a 20 inch outside diameter with walls of 2-1/2" aluminum and 0.5 inch steel. The hole for the beam pipe is a separate problem

and is discussed below. The principal reference for the dose rate calculation is the Radiological Health Handbook.[1] First consider half value layers (HVL) at 110 keV photon energy:

Material	HVL (mm) (for unfiltered beam)
Al	17.0
Fe	3.0
Cu	2.2
Pb	0.25

Out the side of the drift tube, then we have:

$$\frac{2.5 \times 25.4}{17} = 3.73 \text{ HVL's of Al}$$

and

$$\frac{0.5 \times 25.4}{3.0} = 4.23 \text{ HVL's of Fe}$$

resulting in an attenuation of $0.5^{7.96} = 4 \times 10^{-3}$.

For the source term, Ref. 1 gives an exposure at 90° to the beam axis (e^{-} on a thick target produces an approximately isotropic x-ray spectrum) of:

$$0.6 \frac{R}{mA\text{-}min}$$

at one meter on a tungsten target. The yield is proportional to Z, the atomic number of the target,[2] hence this number becomes 0.2 $\frac{R}{mA\text{-}min}$ at one meter for an Fe target. At the surface nearest the loss point (100 keV electrons have a very short range). The dose rate is then:

$$0.2 \frac{R}{mA\text{-}min} \times \frac{60 \text{ min}}{hr} \times 100 \text{ mA} \times \left(\frac{100 \text{ cm}}{14.2 \text{ cm}}\right)^2 \times 4 \times 10^{-3} = 238 \frac{R}{hr}$$

At the opposite surface the dose rate is then:

$$238 \frac{R}{hr} \times \left(\frac{14.2}{36.6}\right)^2 = 36 \frac{R}{hr}$$

The outside wall of the cooling ring enclosure is 21.5 feet from the tube (the interior of the cooling ring is an exclusion area during operations). The dose rate at the wall would be:

$$238 \frac{R}{hr} \times \left(\frac{14.2}{655}\right)^2 = 112 \text{ mrem/hr}$$

The fence is 15 feet further away so that the dose rate at the fence (beyond which exists an uncontrolled outdoor area is:

$$238 \frac{R}{hr} \times \left(\frac{14.2}{1112.6}\right)^2 = 40 \text{ mrem/hr}$$

If aluminum is the target instead of iron, the doses drop by a factor of 2. The ends are shielded by over 20 HVL's and so are much safer except for the beam pipe which will now be considered. The upstream end does not present the hazard of the electrons escaping into the beam pipe (a reversed or shorted toroid would catch the beam on a structure no worse than those above). The accident mode considered is one in which the 60° and 30° toroids at the collector end were somehow disconnected or shorted allowing electrons to continue along the beam line. The drift region is 5 m long and confined to the vacuum pipe approximately 7.7 cm in diameter so that θ_{max}, the maximum angular deviation from the axis is $\mathrm{Tan}^{-1}\left(\frac{7.7}{500}\right) = 15$ mrad which is sufficient to stop in the beam pipe at locations not well shielded. However, this does not constitute a scrape but instead would trip the supply because the whole beam would be lost and the supply tripped out as above.

Another serious accident condition which is less predictable is that of the electron beam scraping near an end of the drift tube. This would send a x-ray beam along the beam pipe. However, this beam would be collimated by components of the toroids to a restricted volume and some of this beam would hit magnets and other beam line components which would provide some measure of "shadowing". The amount

of this shadowing is very difficult to estimate because of the geometrical complexity but it is obvious that shielding is needed to protect outdoor areas from a direct "line of sight" to such a loss point. Obviously, studies need to be done to verify the above calculations.

References

1. Radiological Health Handbook, U.S. Department of H.E.W., January 1970 Edition.

2. The Physics of Radiology, H. E. Johns and J. Robert Cunningham, Charles C. Tomas Publishing Company, Springfield, Illinois, 1969, p. 53.