Distribution
MS 12A
C. Leemann
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
MS 85C
S. Suhring

Radiation Control Group Note

93-14

A Controlled Area/PSS Gate is required in the in the East Arc during North Linac/High Power Dump operations. This RCG Note provides a means of calculating the radiation levels at the 90° Point and at the 135° Point in the East Arc and the relative merits of Gate placement at each location. The Note indicates that full rated power in the High Power Dump will not result in radiation levels in excess of Controlled Area limits at the 90° Point. Accidental beam loss, however, may result in radiation levels of approximately 10 mrem/h at this location. CARM placement at the Gate would detect and terminate these conditions. Placement of the Gate at or near the old EAst Arc Dump wall location (135° Point) would likely result in radiation levels lower than 0.050 mrem/h, the Controlled Area Limit, despite beam loss any where along the transport line to the North Linac High Power Dump.

Introduction

A source term, utilizing two configurations, was used to calculate (by Jenkin's[1] method) direct radiation exposure and the resulting dose equivalent rate at several locations. Locations A,B, and C on Diagram 1 indicate these locations in the East Arc near the NL HP Dump. The source term was calculated using a 600 MeV, 200 μA beam. The locations represent points at the entry to the East Arc which is not line-of-sight to the NL HP Dump. The NL HP Dump produced little direct radiation exposure to those locations. Table 1 presents these results. The second source term, which represents accidental beam loss into bending dipole BE1A01, produced appreciable direct radiation into the East Arc, Location D. That data is presented in Table 2. This direct exposure was used the calculate the scattered exposure around the East Arc to the approximate location of the 90° point. Table 2 also presents the approximate radiation levels at the 90° point.

Direct Exposure Calculations

The photon source term at the NL HP Dump is inconsequential as the shielding required for neutrons is more than adequate to attenuate the photons. The neutron source term in rem per electron is calculated by :

$$D.E. = 10^{-11} E_0 \left(\frac{\sin\theta}{a+d}\right)^2 \left[\frac{\exp\left(\frac{-d\rho}{\lambda_1 \sin\theta}\right)}{(1-0.72\cos\theta)^2} + 10 \frac{\exp\left(\frac{-d\rho}{\lambda_3 \sin\theta}\right)}{(1-0.75\cos\theta)} + 3.79 Z^{0.73} \exp\left(\frac{-d\rho}{\lambda_2 \sin\theta}\right) \right] \text{, Eq. 1}$$

where:

	$D.E$	= neutron dose equivalent, rem/e
	λ_x	= removal mean free path for (energy group x) neutrons, g/cm^2
	ρ	= shield density, g/cm^3
	a	= target to shield distance, cm
	d	= shield thickness, cm
	θ	= angle from target to measurement point
	E_0	= beam energy, GeV

The results of the calculations indicate only neutrons produced by the photopion mechanism contribute signifigantly to exposure from the NL HP Beam Dump. A weighted neutron production term taking into account approximately 97% of beam power into the the aluminum and 3% into the copper was used. The results are listed in Table 1 as D.E. rate in μrem/h.

Table 1

Location	Distance, m	Thickness, m Concrete	Iron	Earth	Angle, deg.	D.E., μrem/h
A	7.4	2.5	1.7	1.6	135	20
B	7.6	1.3	1.2	3.2	90	280
C	12.2	1.3	1.2	3.2	90	110

The results of similar calculations for (the same beam loss assumptions) into magnet BE1A01 are presented in Table 2. Magnet BE1A01 is assumed to be a thick, unshielded source with composition similar to the dump. Consequently the photon source term cannot be ignored and is calculated by:

$$D.E. = E_0\, C\left(\frac{\sin\theta}{a+d}\right)^2 \left(\frac{1}{E_0}\frac{dN}{d\Omega}\right) B(\ )\, x \exp\left(\frac{-\mu}{\rho}\frac{\rho d}{\sin\theta}\right), \text{ Eq. 2}$$

where:

- $D.E$ = photon dose equivalent, rem/cm^2·sr·e
- E_0 = electron energy, GeV
- C = fluence to dose conversion factor, 2.14E^{-9} rem/photon
- B( ) = buildup factor, energy and material dependent
- a = target to shield distance, cm
- d = shield thickness, cm
- θ = angle from target to measurement point
- μ/ρ = mass attenuation coefficient, compton min. in iron ≈ 0.024 cm^2/g.
- $\frac{1}{E_0}\frac{dN}{d\Omega} = \frac{0.83}{(1-0.98\cos\theta)^{1.2}}$ photon/sr·GeV·e

The neutron and photon D.E.rates at one meter from the dipole BE1A01 are 145 Krad/h and 3.3 Mrad/h at 35° off beam axis. The radiation source is 20 meters from Location D at 35° off beam axis.

There are several ways to estimate the dose due to scattered scattered neutron radiation at a point of interest. One method, by Patterson and Thomas(2), is indicates that the attenuation is a function of the radius of curvature. The formula is:

$$\lambda = 0.7\sqrt{R} \quad \text{Eq. 3}$$

where:

- λ = attenuation length, m
- R = radius of curvature, m

The formula is valid for R from 4 to 40 meters. Use of the formula for our Arcs (radius of curvature ≈ 80m) yields an attenuation length of ≈ 6 m. If one takes the 100 m from the dipole to the 90° point in the east arc as the transmission distance, this represents 100/6 or 16.7 attenuation lengths and a corresponding reduction in D.E. rate of exp-(16.7) or ≈ 5.8E-8. If one applies this reduction to the 145 Krad/h neutron D.E. rate above, the result is ≈ 10 mrem/h. An additional 40 meters, the distance to about the 135° Point in the East Arc, results in a D.E. rate of less than 0.050 mrem/h.

A second formula proposed by Tesch(3), which assumes a straight duct in full view of the source represented by:

$$D.E.(r_1) = 2\,D.E._a\, a^2\, r_1^{-2} \quad \text{Eq. 4}$$

where:

- D.E.(r_1) = Dose Equivalent Rate at depth r into the first leg.
- a = the dist. from the source to the mouth of the first leg

which is followed by one or more 90° bends as follows:

$$D.E.=\frac{\left[\exp\left(-r_i/0.45\right)+0.022A_i^{1.3}\exp\left(-r_i/2.35\right)\right]}{\left[1+0.022A_i^{1.3}\right]}x\,D.E._{i}\quad \text{Eq.5}$$

where:
- r_i = distance into the i^{th} leg of the duct, m
- A_i = the cross-sectional area of the duct, m^2
- $D.E._{i}$ =.dose equivalent rate at entrance to i^{th} leg of the duct

If one breaks the East Arc into two "ducts" and applies Eqs. 4 and 5, a more substantial reduction is calculated. The results, as listed in Table 2, are about a factor of 10 lower than predicted by Eq. 3. The arc, however long , is not well represented by a 90° bend.

Table 2

Source to First leg distance	First leg distance	Second leg distance	D.E. rate end of leg 1 Krad/h	D.E. rate at the arc 90° point (end of leg 2) mrem/h
20 m	40 m	40 m	7.25	0.85

A small component for the thermal neutron contribution can increment the D.E. rate. This can be approximated, after Patterson[(4)], by the formula:

$$\phi_{th}=\frac{1.25Q}{S}$$

where:
- Q= fast neutron flux, by conversion from Eq. 1, ≈ 3 E+13 n/sec
- S= Cross-sectional area of tunnel, 9 E+4 cm^2

Thermal neutrons are not diminished substantially by scattering. Thermal neutron transmission in the tunnel is roughly approximated by two formulas[(6)]:

Transmission through a straight cylindrical duct where:

$$\phi=2J'\left[1-\left(1+\left(\frac{a}{z}\right)^2\right)^{-\frac{1}{2}}\right]\approx J'\frac{a^2}{z^2}\,for\,a<<z,\ \text{Eq. 6}$$

where:
- J' = thermal neutron fluence rate, n/cm²·sec
- a = radius of duct, cm (180 cm. effective for tunnel)
- z = distance along duct, cm

which represents thermal neutron fluence rate at the entry to the East Arc, and transmission through two subsequent 60 m sections of bent cylindrical duct of equal diameters:

$$\phi(z_i)=\frac{\phi_{jk}Ka^2\beta_{jk}}{2z_i^2}\cos ec\theta_i\,\text{Eq. 7}$$

where: $\phi(z_i)$ = thermal neutron fluence rate, n/cm^2·sec, at a distance z along the duct i

$K\beta_{ij}$ = for thermal neutrons, approximates a constant of 1/3

β_{jk} = effective albedo from surface jk for thermal neutrons $\approx$0.55

a, z = as previously defined

θ_i = angle of the i duct (or tunnel) with a bend of approx. 160°

ϕ_{jk} = thermal neutron fluence rate, n/cm^2·sec, from surface jk

The calculated thermal neutron fluence rate at the entrance to the EA tunnel is 3.2 E6 n/cm^2·sec and, 3.2 E8 n/cm^2·sec at the end of the first duct section (distances in Table 2). Transmission down the final leg results in a fluence of ≈ 3 n/cm^2·sec and is converted to D.E. rate by the factor 3.85E-3[5] mrem/hr per n/cm^2·sec. The thermal neutron D.E. at the 90° point is ≈ 10 μrem/hr.

The corresponding D.E. rate from neutrons is approximately between 1 and 10 mrem/h.

Photon transmission in the tunnel is calculated by:

$$D.E. = D.E._0 \times B(E_0, L, R)\ln\left[1 + \left(\pi L^2\right)^{-1}\right], \text{ Eq. 8}$$

where $D.E.$ = photon dose at a distance L in tunnel

$D.E._0$ = photon dose equivalent at entrance to tunnel

$B(E_0, L, R)$ = buildup factor, energy (E_0), and dimensionally (R - lateral tunnel dimension, L- length into tunnel) related, 1.5 chosen as a conservative value.

If D.E.$_0$ is 3.3 Mrad/h, as previously mentioned, the D.E. rate at the Point D (entrance to East Arc) is approximately 3.9 Krad/h. The value for photon albedo in excess of 100 MeV at a 160° bend tends towards 2 E-2[7]. Photon transmission under those conditions through two 160 ° bends of 40 meters each results in a D.E. rate of less than 1 μrem/h.

The total D.E. rate at the 90° position (due to neutron and photon radiation) is estimated to be less than 10 mrem/hr. As mentioned in the cover letter, if the gate placement is made at approximately the 135° point the estimated radiation D.E. rate is less than .050 mrem/h for continuous beam loss into dipole Magnet BE1A01.

Summary:

With the appropriate passive and active dosimeter (TLDs and CARMs) installation at a gate location near the 90° point, accidental beam loss at Magnet BE1A01 is not likely to produce a High Radiation Area beyond the Controlled Area Gate "boundary". This beam loss scenario would be detected and terminated by active dosimeters (CARMs). Potential accidental beam loss beyond Magnet BE1A01 in the East Arc must be mitigated by a positive means of securing (locking and tagging out) the Magnet BE1A01 power supply in the off position. Full rated operation of the NL Attachment 1, page 5.

HP Dump will not result in radiation levels in excess of the limit for a controlled area at the East Arc Gate if the Gate is placed at the 90° point. A gate location near the old location of the East Arc Dump, ≈ °135, making use of the previous safety system hookups would be desirable in that beam loss into Magnet BE1A01 would **not** result in radiation levels in excess of Controlled Area limits.

Notes: (1) "NEUTRON AND PHOTON MEASUREMENTS THROUGH CONCRETE FROM A 15 GEV ELECTRON BEAM ON A TARGET-COMPARISON WITH MODELS AND CALCULATIONS", T.M. Jenkins, Nuclear Instruments and Methods 159 (1979) 265-288.

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CEBAF
The Continuous Electron Beam Accelerator Facility

MEMORANDUM

To: Kelly Mahoney

From: Robert May

Subject: Placement of East Arc Gate

Date: May 5, 1993

Attachment: Basis for Gate Placement in the East Arc (RCG Note 93-14)

Attached is a review of the radiation exposure conditions in the East Arc at the potential locations we discussed for the gate. One good location appears to be at the 90° point in the arc. The result of operation of the High Hower Dump (HPD) should be direct and scattered radiation levels much less than 0.050 mrem/h to areas accessible to unmonitored personnel. Accidental beam loss in the HPD/East Arc dipole can result in scattered radiation levels in the 1 to 10 mrem/h range. As in the past, CARMs interlocked to the PSS should be placed at the gate. We will conduct measurements in conjunction with the first high power run into the NL HPD for scattered radiation (and for other potential radiological hazards i.e. airborne gaseous radionuclides). We will also request time to make similar measurements for low current loss into the HPD/East Arc dipole. The most desirable location would be at the old East Arc wall location (135° Point). This location would allow for inaccuracies in the radiation dose rate calculations. By current calculations, it would result radiation levels less than 0.050 mrem/h for most beam loss scenarios in bending magnets directing beam to the HPD. If you have any questions please let me know.

cc: D. Dotson
A. Hutton
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K. Welch

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cc: D. Dotson
A. Hutton
C. Rode
S. Schwahn
K. Welch

rtm[rtm/Memos/Accel Div Memos]EAGate, May 11, 1993

Attachment 1, page 1.

RCG Note 93-14

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$$D.E. = \frac{\left[\exp\left(-\frac{r_i}{0.45}\right) + 0.022A_i^{1.3}\exp\left(-\frac{r_i}{2.35}\right)\right]}{\left[1 + 0.022A_i^{1.3}\right]} x\, D.E._{,i} \quad \text{Eq.5}$$

where:
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If one breaks the East Arc into two "ducts" and applies Eqs. 4 and 5, a more substantial reduction is calculated. The results, as listed in Table 2, are about a factor of 10 lower than predicted by Eq. 3. The arc, however long , is not well represented by a 90° bend.

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$\bar{\beta}_{jk}$ = effective albedo from surface jk for thermal neutrons ≈0.55
a, z = as previously defined
θ_i = angle of the i duct (or tunnel) with a bend of approx. 160°
ϕ_{jk} = thermal neutron fluence rate, n/cm^2·sec, from surface jk

The calculated thermal neutron fluence rate at the entrance to the EA tunnel is 3.2 E6 n/cm^2·sec and, 3.2 E8 n/cm^2·sec at the end of the first duct section (distances in Table 2). Transmission down the final leg results in a fluence of ≈ 3 n/cm^2·sec and is converted to D.E. rate by the factor 3.85E-3[5] mrem/hr per n/cm^2·sec. The thermal neutron D.E. at the 90° point is ≈ 10 μrem/hr.

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Summary:

With the appropriate passive and active dosimeter (TLDs and CARMs) installation at a gate location near the 90° point, accidental beam loss at Magnet BE1A01 is not likely to produce a High Radiation Area beyond the Controlled Area Gate "boundary". This beam loss scenario would be detected and terminated by active dosimeters (CARMs). Potential accidental beam loss beyond Magnet BE1A01 in the East Arc must be mitigated by a positive means of securing (locking and tagging out) the Magnet BE1A01 power supply in the off position. Full rated operation of the NL

HP Dump will not result in radiation levels in excess of the limit for a controlled area at the East Arc Gate if the Gate is placed at the 90° point. A gate location near the old location of the East Arc Dump, ≈ °135, making use of the previous safety system hookups would be desirable in that beam loss into Magnet BE1A01 would **not** result in radiation levels in excess of Controlled Area limits.

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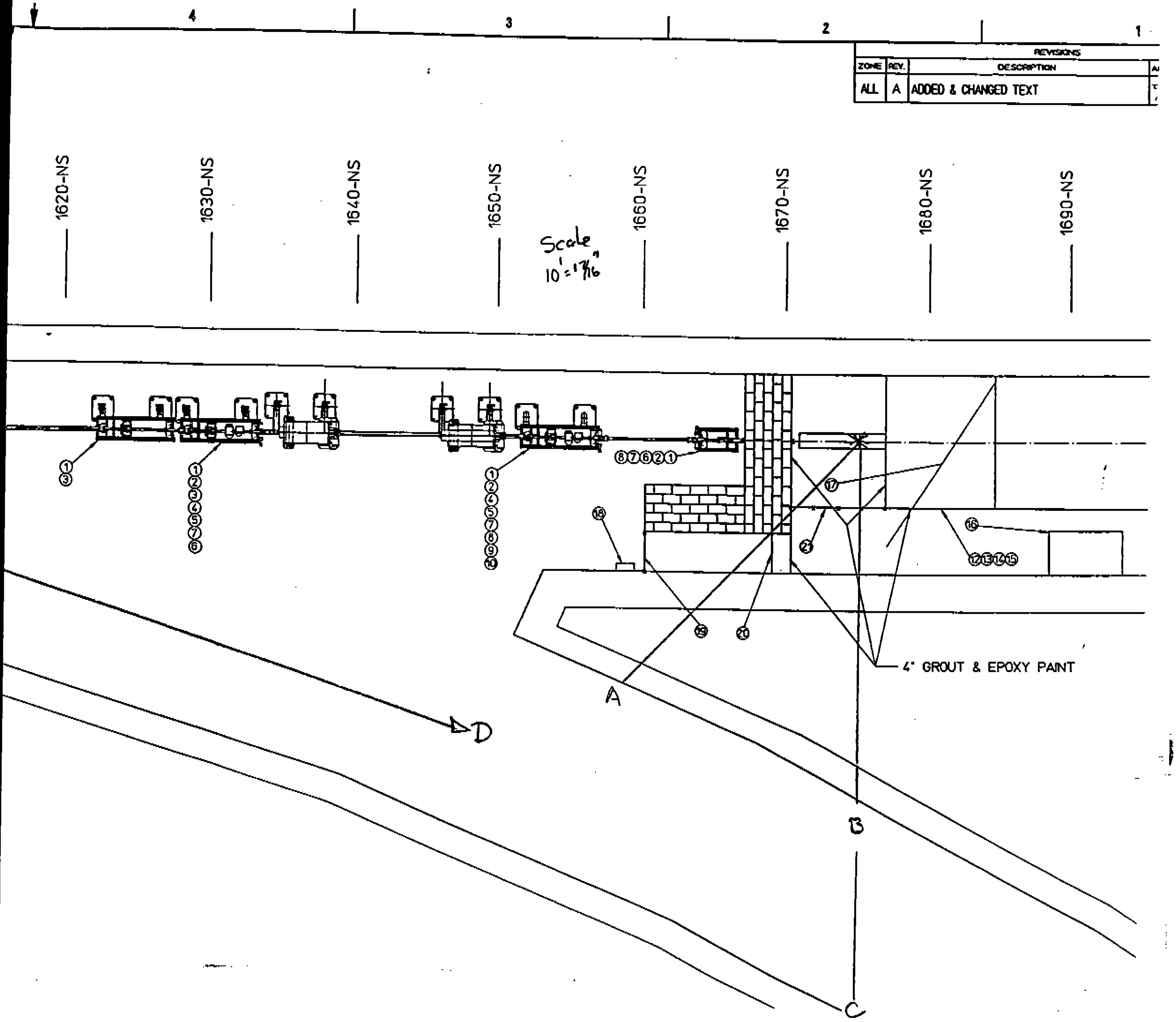
DIAGRAM 1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REVISIONS
ZONE
REV.
DESCRIPTION
ALL
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1630-NS
1640-NS
1650-NS
1660-NS
1670-NS
1680-NS
1690-NS
Scale
10' = 1 7/16"
4" GROUT & EPOXY PAINT
A
B
C
D