

SINGLE PASS COLLIDER MEMO CN-337 Rev.

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OCT 1986

**TITLE: RADIATION IN THE SLC FINAL FOCUS ALCOVES
FROM BEAM LOSSES IN COLLIMATORS AND
DUMPS**

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DATE: 1 October 1986

Introduction. There are various beam line components between the interaction point and the beam dumps which will intercept enough beam to warrant calculating the radiation levels inside the final focus alcoves. Previously, CN-69¹ listed the doses in the arcs from synchrotron radiation. CN-332² covered radiation streaming from these devices to the interaction halls.

The three types of devices which are of concern are:

1. Main dump. This absorbs full beam power (72 kW) after the beam has passed the IP. The dump is behind concrete walls.
2. Tune-up dumps. There are two of these in each line. One or the other will be placed in the beam line 3 hours every day, intercepting full beam current (5×10^{10} electrons per pulse), but at a reduced rep rate of 10 pps (i.e., 4 kW beam power). Beam will strike from either direction (i.e., before reaching the IP or after having passed the IP).
3. Adjustable collimators. These will intercept differing amounts of the beam³ after the beam has passed the IP.

Whether the beam has passed the IP or not is important in choosing a source term for photons. Neutron calculations are done only for giant resonance neutrons (which are isotropic) since they are much more abundant than higher energy neutrons, and will scatter down the tunnel whereas high energy neutrons are more forward peaked, and follow a line-of-sight path. High energy neutrons will, however, strike beam transport components downstream and may add to the overall doses in the alcoves.

Fluences of (and doses from) neutrons and photons in alcoves S-15, S-15T, S-16 and N-15, N-15T and N-16, as well as in N-14 which is close to the north beam dump, are the subject of this note.

The conclusions of these calculations, briefly stated, are that if the beam losses do indeed occur as advertised, many of the electronic components in the alcoves will begin to fail after a very short running period. For N-14, these doses are in addition to synchrotron radiation already present in the alcove. It is obvious from these calculations that the final focus is a hostile environment for sensitive electronics. Some combination of local shielding around the beam intercepting devices and shielding of the alcoves themselves will need to be employed if the electronics are to remain in the tunnels.

Table 1 summarizes the annual doses in the alcoves.

*Work supported by the US Department of Energy under Contract DE-AC03-76SF00515.

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Table 1
Annual Photon Doses and Neutron Fluences.

Alcove	γ (rad/yr)	Neutron ($n - cm^{-2} - yr^{-1}$)
S-15	4.6 +5	6.7 +12
S-15T	4.5 +6	1.2 +14
S-16	1.0 +6	5.0 +13
N-14	1.0 +4	1.7 +11
N-15	1.8 +6	5.8 +13
N-15T	2.8 +5	1.3 +13
N-16	6.8 +4	1.2 +12

(Note: Read 4.6 +5 as 4.6×10^5 .)

Calculations. To augment these calculations, a Cf neutron source was placed inside the arc near the south dump (about 548 feet from the interaction point (IP), and measurements made down the tunnel toward the collider experimental hall (CEH). The Cf source also gives off gamma rays, so measurements were made of both neutrons and photons. The results are given in Figure 1. For neutrons, there is an initial build-up, followed by a rapid fall-off. After about 40 m, the slope changes. This second slope has been fit with a straight line reflecting the removal mean-free-path in air for neutrons of a few meV of 52.5 m, the value previously measured in the SLAC linac tunnel.⁴

The photon measurements also show an initial build-up. The low value at 2 m is probably due to shadowing of the source by the magnet near which the source was placed. After about 10 m, the photons follow the calculated values, at least out to about 70 m or so where the doses became too small to measure. For this note, a build-up factor of 2 is assigned to photons at all locations less than 10 m. No build-up or decay is used for photons after that point.

Table 2 lists beam losses in the beam line components.

Tables 3 and 4 list the radiation levels at the various alcoves in the south and north arcs from those sources close enough to contribute significant doses. The numbers are given in Rad/yr for photons and $n - cm^{-2} - yr^{-1}$ for neutrons. For reference, the tolerance levels for the electronics are given^{5,6} as 10^3 rad/yr from photons and 10^{13} $n - cm^{-2} - yr^{-1}$ from neutrons. At those levels, electronics would last perhaps 5 to 10 years before failure. Items starred are above tolerance.

Discussion. The numbers summarized in Table 1 are well above the tolerance level for electronic devices, such that they might begin failing within hours if no remedial action is taken. The photon levels are too high in all alcoves, while the neutron levels are too high in S-15T, S-16 and N-15. A combination of high and low Z materials would be required to bring the levels to within tolerance. As a general rule of thumb, 12 inches of concrete will bring the neutron doses down by a factor of ten⁷. Alternately 4 inches of polyethylene would do the same thing. Thus, to

bring the neutron levels down to tolerance, about 4 inches of polyethylene would be needed for S-15T, S-16 and N-15. For photons, a high-Z material is needed. If we assume 4 MeV average energy, then the tenth-value thickness in lead would be about 4.9 cm. To achieve three orders-of-magnitude reduction in the dose would require about 14.6 cm lead (5.7 inches). This could be done with a combination of local shielding around the sources, and some shielding of the electronics themselves in the alcoves.

The types, locations of devices and beam losses are listed next.³

Table 2
Devices and Beam Losses

Device	Distance From IP (m)	e^\pm /pulse South		e^\pm /pulse North	
		Incoming	Outgoing	Incoming	Outgoing
Dump	167.1 (S)	5×10^{10}		-	
Dump	183.6 (N)	-		5×10^{10}	
TD-23	146.4	5×10^{10}		5×10^{10}	
PC-24	148.0	-	-	1.7 +4	-
C0	142.2	4.9 +7	-	4.0 +4	-
PC-19	134.9	-	-	4.5 +2	-
PC-18	124.1	8.2 +6	1.0 +6	6.7 +3	5.5 +9
C1X	114.0	2.6 +8	-	2.5 +8	1.6 +5
C1Y	112.0	3.1 +8	7.1 +8	1.4 +8	4.0 +7
PC-16.5	109.5	-	-	3.6 +2	1.3 +5
PCB-3	100.4	-	-	-	1.4 +7
PC-14	95.7	-	6.6 +7	1.4 +3	2.7 +7
PC-12.5	86.7	-	-	-	9.6 +5
PC-12	81.0	2.1 +7	2.0 +7	2.9 +7	4.0 +8
PC-11.5	77.0	5.8 +2	9.4 +7	2.1 +3	-
PC-10.5	71.9	8.4 +7	1.3 +9	3.7 +7	8.2 +7
PC-10	65.5	5.6 +6	9.8 +8	5.5 +6	9.6 +7
PC-8.5	56.5	-	-	-	1.0 +5
PC-8	50.6	1.1 +7	2.4 +8	3.9 +7	3.8 +8
PC-7.5	46.8	3.0 +7	4.4 +8	-	6.8 +2
ST-4	19.8	5.0 +10	-	5.0 +10	-

(Note: Read 5.0 +10 as 5.0×10^{10} .)

Table 3
Dose and Fluences in the South Arc Alcoves.

Alcove	Source	γ (rad/yr)	Neutron ($n - cm^{-2} - yr^{-1}$)
S-15	Dump	1.2 +3	3.1 +10
	TD-23	2.0 +5*	1.5 +12
	C0	1.7 +5*	4.7 +12
	PC-18	3.4 +2	2.1 +10
	C1X,Y	8.2 +4*	4.7 +11
	PC-14	2.5 +3*	3.5 +9
	PC-12	4.3 +2	7.4 +8
	Total	4.6 +5*	6.7 +12
S-15T	Dump	3.7 +2	3.9 +9
	TD-23	1.9 +4*	3.6 +10
	C0	5.6 +3*	1.9 +10
	PC-18	7.9 +2	2.8 +9
	C1X,Y	4.3 +6*	1.2 +14*
	PC-14	1.6 +4*	2.2 +11
	PC-12	2.1 +3*	1.2 +10
	PC-11.5	6.9 +3*	1.7 +10
	PC-10.5	6.9 +4*	1.4 +11
PC-10	3.7 +4*	5.1 +10	
	Total	4.5 +6*	1.2 +14*
S-16	Dump	7.4 +1	2.2 +8
	TD-23	2.2 +3*	1.1 +8
	C1X,Y	8.3 +3*	1.3 +10
	PC-12	1.1 +3*	4.2 +9
	PC-11.5	2.3 +2	1.3 +10
	PC-10.5	1.2 +4*	2.0 +11
	PC-10	6.6 +3*	6.0 +11
	PC-8	3.8 +4 *	4.1 +12
	PC-7.5	9.4 +5*	4.5 +13*
ST-4	3.4 +4*	9.8 +10	
	Total	1.0 +6*	5.0 +13*

(Note: Read 3.1 +10 as 3.1×10^{10} .)

Table 4
Dose and Fluences in the North Arc Alcoves.

Alcove	Source	γ (rad yr)	Neutron ($n - cm^{-2} - yr^{-1}$)
N-15	Dump	2.2 - 2	1.8 - 9
	TD-23	2.0 +4*	4.1 +10
	PC-18	2.4 +5*	1.9 +13*
	CIX,Y	1.5 +6*	2.9 +13*
	PCB-3	2.8 +3*	3.0 +10
	PC-14	3.8 +3*	2.4 +10
	PC-12	2.4 +4*	5.5 +10
	Total	1.8 +6*	5.8 +13*
N-15T	Dump	1.8 - 2	1.3 - 9
	TD-23	1.4 - 4*	2.0 +10
	PC-18	4.5 - 4*	5.3 +12
	CIX,Y	4.9 +4*	5.4 +12
	PCB-3	5.2 - 4*	1.4 +12
	PC-14	3.8 +4*	5.5 +11
	PC-12	6.7 +4*	2.7 +11
	PC-10.5	6.4 +3*	2.6 +10
	PC-10	5.0 +3*	1.0 +10
	Total	2.8 +5*	1.3 +13
N-16	Dump	4.8 +1	8.2 +7
	TD-23	1.9 +3*	6.0 +8
	PC-18	1.8 +3*	2.3 +10
	CIX,Y	4.3 +3*	2.9 +9
	PC-12	1.8 +3*	1.7 +10
	PC-10.5	2.1 +3*	1.1 +10
	PC-10	7.2 +2	2.2 +10
	PC-8	5.4 +3*	8.1 +11
	ST-4	5.0 +4*	3.3 +11
	Total	6.8 +4*	1.2 +12

(Note: Read 2.2 +2 as 2.2×10^2 .)

In these tables, devices which gave less than 10^2 rad/yr (γ) to a particular alcove were not included in the listing for that alcove.

Appendix - Source terms. Photons - For all devices, a $20X_0$ target is assumed since the devices aren't designed yet. This is important only for the forward direction; i.e., $5 - 10^0$. Making the device thicker would decrease this radiation, but no more than about a factor of ten since the large angle radiation would then dominate. Dose rate as a function of angle is given in Fig 2⁸. The slope beyond 10^0 can be approximated by

$$D = \frac{2.3 \times 10^{-13} E_0}{r^2} e^{-\frac{\theta}{72}} \quad \text{R/electron,}$$

with r in meters, E_0 in GeV, and θ in degrees. Note that the constant assumes a thick target and not edge scraping. If edge scraping were assumed, the doses at large angles (i.e., 90^0) would be greater by about a factor of 2.

The photon dose rates from each of the three devices can be derived using the following simple formulae:

1. Tune-up dumps. These absorb 4 kW beam power for 500 hours per year. The annual dose is

$$D = \frac{2.15 \times 10^4 \times \text{Fig.2}}{(\text{distance in ft.})^2} \quad \text{rad - yr}^{-1}$$

2. Protection collimators. These absorb varying amounts of beam power, with the photon source term depending upon direction. The annual dose is

$$D = \frac{6.19 \times 10^{-5} \times B \times \text{Fig.2} \times \text{Beam loss (e}^\pm/\text{pulse)}}{(\text{distance in ft.})^2} \quad \text{rad - yr}^{-1}$$

where $B = 1$ or 2 depending on whether the distance is greater than 10 m or not.

3. Main dump. The source term in the aisle is $6 \times 10^{10} \gamma$ per pulse. Using 4.4×10^{-10} rad per $\gamma - \text{cm}^{-2}$ and 2.6×10^9 pulses per year, the dose becomes

$$D = \frac{1.17 \times 10^7 \times \text{Fig.2.}}{(\text{distance in ft.})^2} \quad \text{rad - yr}^{-1}$$

Neutrons - For giant resonance neutrons which are isotropic, we use Fig. 1 in conjunction with a source term derived from previous measurements⁹. For the tune-up dumps, this becomes

1.

$$H = \frac{7.7 \times 10^{14} \times \text{Fig.1}}{(\text{distance in ft.})^2} \quad \text{n - cm}^{-2} \text{ - yr}^{-1}$$

2. The annual neutron fluence from the collimators, which intercept varying amounts of beam power, is

$$H = \frac{2.22 \times 10^6 \times \text{Beam loss (e}^\pm/\text{pulse)} \times \text{Fig.1}}{(\text{distance in ft.})^2} \quad \text{n - cm}^{-2} \text{ - yr}^{-1}$$

3. For the dumps, we let the source term, $1 \times 10^9 \text{ n - cm}^{-2} \text{ - pulse}^{-1}$ radiate into 2π steradians and use Fig 1 to get

$$H = \frac{4.45 \times 10^{14} \times \text{Fig.1}}{(\text{distance in ft.})^2} \quad \text{n - cm}^{-2} \text{ - yr}^{-1}.$$

Next we give a breakdown of the distances to alcoves, the production angles for photons, beam loss for a given production, and photon source terms used to generate Tables 3 and 4.

Table 5
Photon Sources in the South Arc Alcoves

Alcove	Source Device	Distance (feet)	θ (Production)	Beam Loss e^{\pm} - pulse $^{-1}$	γ Source Term rad - m 2 - kW $^{-1}$ - hr $^{-1}$
S-15	Dump	100	-	-	-
	TD-23	32.8	12	5.0 +10	5.0 +3
	C0	7	90	4.9 +7	1.35 +3
	PC-18	41.6	9.7	1.0 +6	5.8 +3
	"	"	170	8.2 +6	4.4 +2
	C1X,Y	78	5	7.1 +8	1.1 +4
	"	"	175	5.7 +8	4.2 +2
	PC-14	134	5	6.6 +7	1.1 +4
	PC-12	182	175	2.1 +7	4.2 +2
"	"	5	2.0 +7	1.1 +4	
S-15T	Dump	179	-	-	-
	TD-23	111	5	5 +10	1.1 +4
	C0	77	5	4.9 +7	1.1 +4
	PC-18	38.6	10	8.2 +6	5.8 +3
	"	"	170	1.0 +6	4.4 +2
	C1X,Y	7.1	90	1.3 +9	1.35 +3
	PC-14	35.7	11	6.6 +7	4.9 +3
	PC-12	83	175	2.1 +7	4.2 +2
	"	"	5	2.0 +7	1.1 +4
	PC-11.5	96	175	5.8 +2	4.2 +2
	"	"	5	9.4 +7	1.1 +4
	PC-10.5	113	175	8.4 +7	4.2 +2
	"	"	5	1.3 +9	1.1 +4
	PC-10	134	175	5.6 +6	4.2 +2
"	"	5	9.8 +8	1.1 +4	

(Note: Read 5.0 +10 as 5.0×10^{10} .)

Table 5- Continued
Photon Sources in the South Arc Alcoves

Alcove	Source Device	Distance (feet)	θ (Production)	Beam Loss $e^{\pm} - \text{pulse}^{-1}$	γ Source Term $\text{rad} - \text{m}^2 - \text{kW}^{-1} - \text{hr}^{-1}$
S-16	Dump	399	-	-	-
	TD-23	331	5	5 +10	1.1 +4
	C0	297	5	4.9 +7	1.1 +4
	PC-18	258	5	1.0 +6	1.1 +4
	"	"	175	8.2 +6	4.2 +2
	C1X,Y	221	5	5.7 +8	1.1 +4
	"	"	175	7.1 +8	4.2 +2
	PC-14	165	175	6.6 +7	4.2 +2
	PC-12	117	5	2.1 +7	1.1 +4
	"	"	175	2.0 +7	4.2 +2
	PC-11.5	104	5	5.8 +2	1.1 +4
	"	"	175	9.4 +7	4.2 +2
	PC 10.5	87	5	8.4 +7	1.1 +4
	"	"	175	1.3 +9	4.2 +2
	PC-10	66	6	5.6 +6	1.0 +4
	"	"	174	9.8 +8	4.2 +2
	PC 8	18.4	21	1.1 +7	3.7 +3
"	"	159	2.4 +8	5.2 +2	
PC-7.5	8.1	120	4.4 +8	1.0 +3	
"	"	60	3.0 +7	2.0 +3	
ST-4	84	5	5.5 +10	1.1 +4	

(Note: Read 5.0 +10 as 5.0×10^{10} .)

Table 6
Photon Sources in the North Arc Alcoves

Alcove	Source Device	Distance (feet)	θ (Production)	Beam Loss $e^{\pm} - \text{pulse}^{-1}$	γ Source Term $\text{rad} - \text{m}^2 - \text{kW}^{-1} - \text{hr}^{-1}$
N-15	Dump	230	-	-	-
	TD-23	108	5	5.0 +10	1.1 +4
	PC-18	35.7	11	6.7 +3	5.2 +3
	"	"	169	5.5 +9	4.2 +2
	C1X,Y	7	90	4.3 +8	1.35 +3
	PCB-3	43.4	9	1.4 +7	6.1 +3
	PC-14	58	7	2.7 +7	7.7 +3
	"	"	169	1.4 +3	5.6 +2
	PC-12.5	87.7	5	9.6 +5	1.1 +4
	PC-12	108	175	2.9 +7	4.2 +2
"	"	5	4.0 +8	1.1 +4	
N-15T	Dump	252	-	-	-
	TD-23	130	5	5.0 +10	1.1 +4
	PC-18	57	7	6.7 +3	7.7 +3
	"	"	173	5.5 +9	4.3 +2
	C1X,Y	21	19	4.0 +7	3.0 +3
	"	"	181	3.9 +8	5.0 +2
	PCB-3	7.1	82	1.4 +7	1.5 +3
	PC-14	17.5	24	2.7 +7	3.5 +3
	"	"	156	1.4 +3	5.6 +2
	PC-12.5	46.3	9	9.6 +5	6.3 +3
	PC-12	84	175	2.9 +7	4.2 +2
	"	"	5	4.0 +8	1.1 +4
	PC-10.5	94	175	3.7 +7	4.2 +2
	"	"	5	8.2 +7	1.1 +4
	PC-10	115	175	5.5 +6	4.2 +2
"	"	5	9.6 +7	1.1 +4	

(Note: Read 5.0 +10 as 5.0×10^{10} .)

Table 6- Continued
Photon Sources in the North Arc Alcoves

Alcove	Source Device	Distance (feet)	θ (Production)	Beam Loss $e^{\pm} - \text{pulse}^{-1}$	γ Source Term $\text{rad} - \text{m}^2 - \text{kW}^{-1} - \text{hr}^{-1}$
N-16	DUMP	493	-	-	-
	TD-23	358	5	5.0 +10	1.1 +4
	PC-18	285	5	6.7 +3	1.1 +4
	"	"	175	5.5 +9	4.2 +2
	C1X,Y	248	5	3.9 +8	1.1 +4
	"	"	175	4.0 +7	4.2 +2
	PCB-3	207	175	1.4 +7	4.2 +2
	PC-14	102	175	2.7 +7	4.2 +2
	PC-12.5	162	175	9.6 +5	4.2 +2
	PC-12	144	5	2.9 +7	1.1 +4
	"	"	175	4.0 +8	4.2 +2
	PC-10.5	114	5	3.7 +7	1.1 +4
	"	"	175	8.2 +7	4.2 +2
	PC-10	93	5	5.5 +6	1.1 +4
"	"	175	9.6 +7	4.2 +2	
PC-8	44	171	3.8 +8	4.4 +2	
ST-4	57.5	7	5.0 +10	7.7 +3	
N-14	Dump	59	-	-	-
	TD-23	181	5	5.0 +10	1.1 +4

(Note: Read 5.0 +10 as 5.0×10^{10} .)

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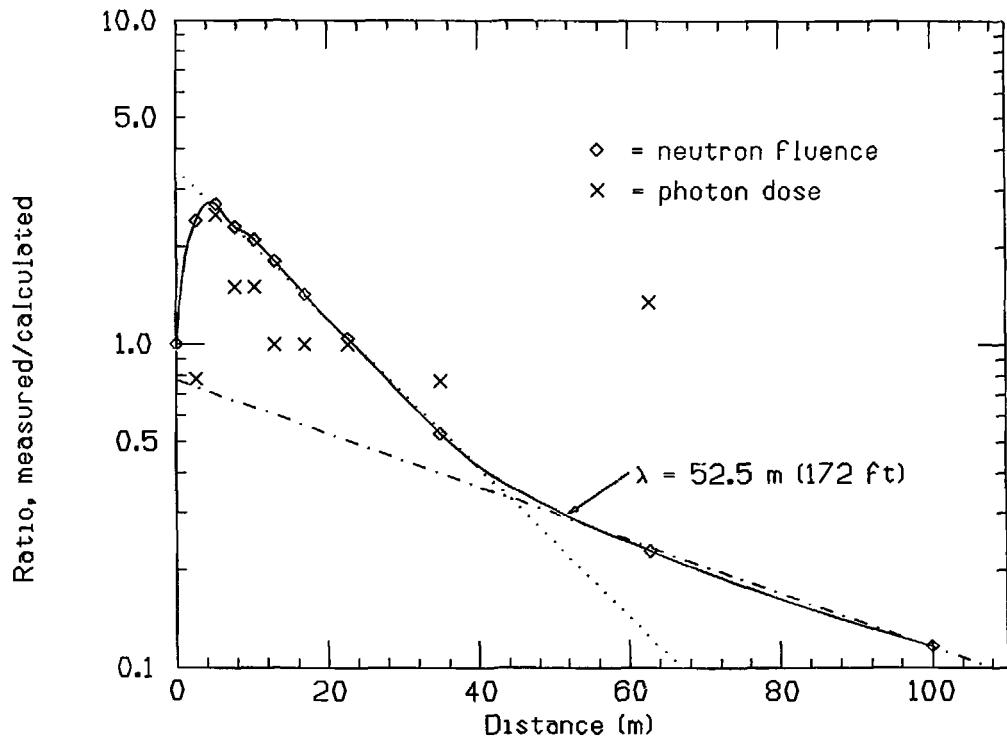


FIG 1

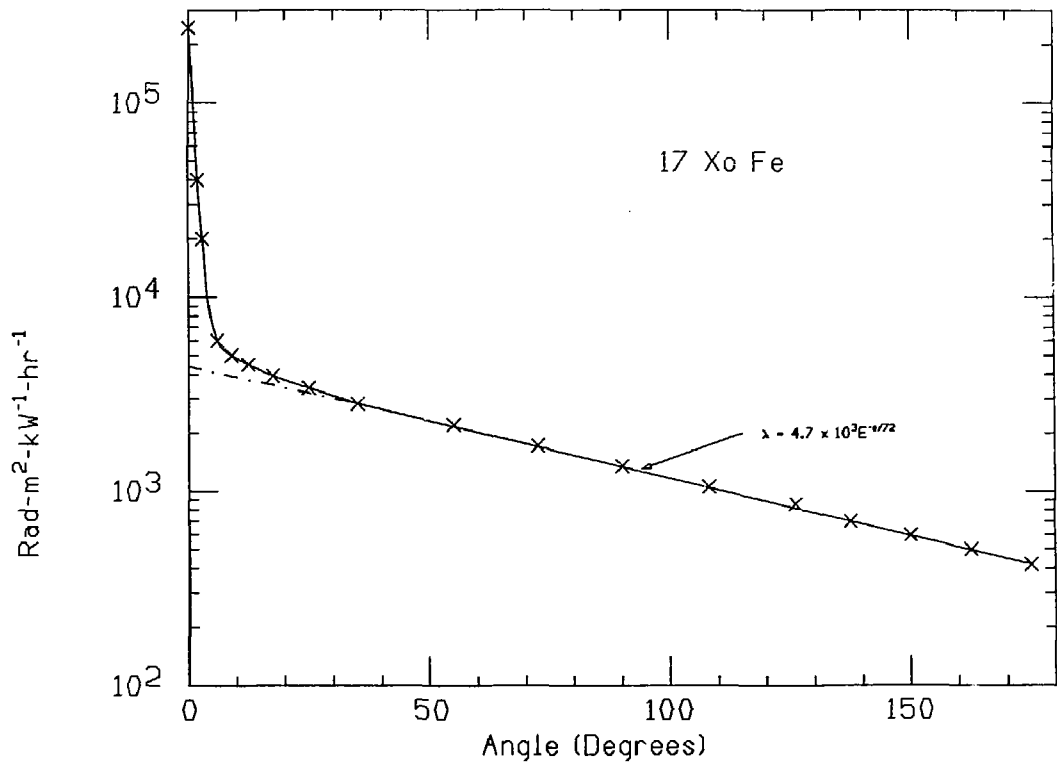


FIG 2