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MONTE-CARLO CALCULATIONS OF FORWARD
DIRECTED BREMSSTRAHLUNG PRODUCED BY
20 AND 45 MEV ELECTRONS ON TUNGSTEN

D. R. Goosman

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ABSTRACT

The SANDYL Monte-Carlo code has been used to calculate the Bremsstrahlung photon production from beams of parallel electrons incident upon three target geometries. These are 20 MeV electrons onto 1 mm of tungsten + 59 mm of Be, which simulates the operating parameters of the FXR electron accelerator at LLNL Bldg. 801, 45 MeV electrons onto 1 mm of tungsten, and finally 45 MeV electrons onto 1 mm of tungsten and 147 mm of Be. The latter two situations simulate possible future modifications to the FXR accelerator. Graphs of the spectral shape of the Bremsstrahlung photons emitted with angles between 0° and 1° to the electron direction, the angular distribution of photon-MeV, and the dose reduction curves for each of the three geometries are given. The latter dose reduction curves allow one to calculate forward-directed photon fluxes in real-life situations where the electron beam has non-zero angular divergence.

The recent completion of the FXR accelerator at Bldg. 801 allows a large improvement to be had in pulsed radiographs compared to the existing electron linac at Bldg. 851. It is useful to know the expected spectral shape and number of photons produced by the FXR in order to properly design experiments and analyze the statistics involved in radiographs of very thick objects. It is also useful for the design of new radiographic imaging systems for thick objects. It has recently been shown¹ that by choosing a fine-enough electron substep size in the SANDYL code², good agreement with published experimental 20.9 MeV Bremsstrahlung can be had. This comparison involved a target which is different from that used in the FXR, and the three geometries presented in the results below are ones applicable to the existing accelerator or to future modifications of it. The calculations were done for parallel electron beams incident on the 1 mm W target and (in two of the geometries) the electron stopper made of beryllium. Real electron accelerators have electron angular divergence because the smallest spot size is usually accomplished at large electron angles. The effect of the angular divergence is to reduce the forward flux and to broaden the photon angular distribution. The results calculated for parallel electrons are easily converted into expected results for finite electron angular divergence, if one assumes that the incident electron beam is distributed uniformly in solid angle out to a maximum angle. The details of this calculation will be shown below.

EJR

Figure 1 shows the spectrum exiting the beryllium electron stopper for 20 MeV parallel electrons. The electrons lose about 6 MeV in the W and the electron angles in both the W and Be increase with distance penetrated. The SANDYL Monte-Carlo electron-photon coupled transport code was used to calculate the expected resulting Bremsstrahlung spectrum made by this distribution of electron energies and angles. The relevant angular range for the photons is from 0° – 1° for hydrodynamic experiments involving flash radiography of very thick objects, and this is what is plotted in figure 1. It is actually the spectrum entering zone 5 shown in figure 1 for angles between 0° and 1° . Another edit was taken of the photon spectrum entering zone 6 with angles between 0° and 1° . Zone 6 is specially configured to subtend a cone with a 1° HWHM relative to the point of intersection of the incident electron beam with the W. The spectrum entering zone 6 is the same as that entering zone 5, but the magnitude of the zone 6 flux is 3% lower. Not all the photons entering 5 appear to be coming from a point source.

The meaning of the vertical scale for figure 1 requires some explanation. The SANDYL code provided the number of photons per incident electron entering zone 5 with angles less than 1° . I took that result, divided by the width of the photon energy bin in MeV and divided by the number of steradians in the 0° – 1° cone, the latter of which is numerically $\approx 9.57 \cdot 10^{-4}$. The result is what is plotted in figure 1 and other figures showing spectra. The vertical scale is best interpreted as the photons per MeV per electron per steradian, averaged from 0° to 1° . Numerically, between 6 and 7 MeV, there are expected to be 0.21 photons per steradian near 0° per incident electron. It is impractical to edit in angular bins smaller than 1° , because of the long computing time required. As explained in reference 1, one cannot use the default value of IESBS for the W because this represents too coarse an electron substep size to calculate the fine angular information. The value of 96 for this IESBS input makes the substep size 6 times smaller than the default value, and causes the calculation to take about 6 times more CPU time. Figure 1 required 280 minutes on the CDC7600 machine.

The minimum photon and electron energies used in the calculation were 0.75 and 3 MeV, respectively. Photons transported below these cutoff energies were discarded. The calculation for figure 1 is the histogram and the error bars are statistical only. The smooth curve is an eyeball fit to the histogram.

Figure 2 shows the angular distribution of photon energy content for parallel incident electrons. For an infinitely thin W target, this distribution would have an HWHM of 0.9° , as explained in reference 1. Because of electron direction and energy changes in the thick target here, the HWHM has broadened to about 3.5° . Again the smooth curve is a fit to the histogram. The photon-MeV plotted represents the sum of the number of photons in an energy bin times that bin's average energy, summed from the minimum photon energy of 0.75 MeV to infinity.

Figure 3 shows the energy content reduction factor as a function of electron angular divergence, to simulate what happens in real accelerators. As will be shown later, the spectral energy shape varies only slightly with angle, so that this may also be thought of approximately as a dose-reduction factor. The diagram in figure 3 indicates incident 20 MeV electrons that uniformly fill a conical beam shape. The number of incident electrons per unit solid angle can then be expressed as

$$dE/d\Omega = \frac{1}{2\pi (1 - \cos \theta_e^{\max})} \quad \text{for } 0 < \theta_e < \theta_e^{\max}$$

$$= 0 \quad \text{for } \theta_e^{\max} < \theta_e$$

This distribution is normalized to one incident electron. $\theta_e^{\max}$ represents the maximum electron angle contained in the beam relative to the axis. The axis is the direction a 0° photon propagates.

The incident electrons contained between angles θ_e and $\theta_e + d\theta_e$ will contribute a photon energy content flux per steradian at 0° equal to

$$\left[\frac{2\pi \sin \theta_e d\theta_e}{2\pi (1 - \cos \theta_e^{\max})} \right] \left[\frac{dP}{d\Omega} \text{ (evaluated at } \theta_p = \theta_e) \right]$$

where the first term is the number of such electrons contributing and the second factor is the photon energy content per unit solid angle per electron produced at a photon angle θ_p equal to the electron angle θ_e under consideration. $dP/d\Omega$ can be taken directly from figure 2. The total photon energy content per steradian at 0° per electron is the integral of the above expression from $\theta_e = 0$ to $\theta_e^{\max}$; thus

$$\frac{dP}{d\Omega} \text{ (divergent electrons)} = \frac{\int_0^{\theta_e^{\max}} \left[\frac{dP}{d\Omega} (\theta_e) \right] \sin \theta_e d\theta_e}{(1 - \cos \theta_e^{\max})}$$

Figure 3 was obtained by approximating the integral in the above expression by a summation over angular bins 1° wide, and then dividing by the result from figure 2 in the first angular bin for parallel electrons. This gives a good approximation to the dose-reduction factor. For example, if the 20 MeV electron beam has a maximum angle of 6° on either side of the axis, figure 3 indicates that the forward-directed dose (at angles less than 1°) is only about half of what it would be if the incident electrons had been parallel to the axis.

Figure 4 shows the input deck to SANDYL that produced the results plotted in figures 1 - 3. The last line shows material #4 as gold, but material 4 was not used in this calculation.

Figure 5 shows the spectrum for 45 MeV electrons onto 1 mm W. Figure 6 shows this and other larger-angle energy spectra superimposed. The meaning of the $0^\circ-1^\circ$, $2^\circ-3^\circ$ and $8^\circ-9^\circ$ averages are the same as for figure 1, but the lowest curve is the total number of photons emitted between 0 and 180° per MeV per electron. The spectral shapes do not change significantly for angles less than 9° .

Figures 7 and 8 show the angular distribution and dose-reduction curves, respectively. Figures 9 - 11 show the SANDYL input for this geometry, as echoed by the code.

Similar results for 45 MeV electrons onto 1 mm of W + 147 mm of Be as an electron stopper are shown in figures 12 - 18.

For deep penetration radiography, it is useful to know the integrated number of photons emitted over various energy ranges centered around 4 MeV, since they are the ones that survive without having scattered. For very thick objects, only the 4 - 5 MeV flux need be considered, but for most objects within the capability of the FXR accelerator it is the 1.8 - 10 MeV flux that determines the statistics of the radiograph. For this purpose, various integrals for the three geometries considered are shown in Table 1. These are for parallel electrons; for real accelerators the respective dose-reduction curves should be used. The 150 μC shown in this table represents a normal value for the charge hitting the FXR target.

REFERENCES

1. D. R. Goosman, "Comparison of the SANDYL Monte-Carlo Code Calculations of 20.9 MeV Bremsstrahlung with Published Experimental Data", Lawrence Livermore National Laboratory, UCID-19791, April 27, 1983.
2. H. M. Colbert, "SANDYL, A Computer Program for Calculating Combined Photon-Electron Transport in Complex System," Sandia Laboratories report SLL-74-0012, May, 1974.

Figure 2

Figure 3

8.

Figure 4

9.

```

BOX C89 GOOSMAN
20 MEV ON 1 MM W AND 6 CM BE WITH 1 DEG EDIT ZONE IESBS = 96
 7 10 2 7 20 10000 1 3 1 1 4 2
 1 1 1 -18 1 1 1 3
1. 2. 3. 4. 5. 6. 7
7. 8. 9. 10. 11. 12. 13.
13. 14. 15. 16. 17. 18. 19.
26 27 28 29 30 31 32 33 34 35 36 37 38
 2 -2 -10 -1 9 2
 3 -3 -1 -2 9 2
 4 -4 -2 -3 9 2
 5 -5 -3 -4 9 2
 6 -6 -4 -5 9 2
 8 -7 -5 -6 7 1
 8 -7 -5 -6 9 2
-8 -7
-9 2
10 -1
.00001 1. 7
20.
-3.75
      0.4468 10
      5. 10
26.61 -0.1 1. 1.05 1.1 7. 26.6
1 1 3.
2 1 3.
2 1 3.
3 1 -5 3.
1 1 -5 3.
1 1 -6 3.
1 1 -6 3.
1 1 0.001 1. 1
2 1. 19.3 1. 74
3 1. 1.85 1. 4
4 1. 19.32 1. 79
96
24
96

```

Figure 5

BREMSTRAHLUNG SPECTRUM FOR
45 MeV PARALLEL ELECTRONS ON
1 MM TUNGSTEN ACCORDING TO
THE SANDYL CODE VERSION
HANDYL7X

10

45 MeV

PARALLEL
ELECTRONS

1 MM W

10CM DIAM

PHOTONS
EXITING W WITH
ANGLES LESS THAN
 10°

1

PHOTONS EXITING TUNGSTEN
MeV-STERADIAN-ELECTRON
AVERAGED BETWEEN 0° AND 1°

0 - 35 MeV

0.1

30 - 45 MeV

$E_{\text{photon}}(\text{MIN}) = 0.2 \text{ MeV}$
 $E_{e^-}(\text{MIN}) = 3.0 \text{ MeV}$
 IESBS = 96

0 5 10 15 20 25 30 35
 30 35 40 45 PHOTON ENERGY IN MeV

Figure 6

BREMSSTRAHLUNG SPECTRA FOR
VARIOUS ANGULAR BINS FOR 45
MeV PARALLEL ELECTRONS ON
1 MM TUNGSTEN, ACCORDING TO
HANDYL7X

Figure 7

Figure 8

13.

DOSE REDUCTION FACTOR VS. ELECTRON
ANGULAR DIVERGENCE FOR 45-MeV ELECTRONS
ON 1 MM TUNGSTEN

COMPILE DATE: 01/21R 16.48.50
BOX C09 GOOSMAN

SMALL CORE MEMORY USED=0134375
LARGE CORE MEMORY USED=0272460

BOX C09 GOOSMAN

45 MEV V 1 MM W 3. MEV E- CUTOFF 1ESBS = 96
45 MEV ON 1 MM W 3. MEV E- CUTOFF 1ESBS = 96

NUMBER OF ZONES

5 INSIDE

8 TOTAL

SURFACES

1 QUADRICS

6 PLANES

-O X PLANES

-O Y PLANES

SOURCE

50 SAMPLES

4000 HISTORIES PER SAMPLE

SOURCE ZONE SET TO 1

REACTION WEIGHTS RWT1

2.5000E-01 2.5000E-03 2.5000E-05 2.5000E-06 1.0000E+00 1.0000E+00 1.0000E+00

FLUORESCENCE AND AUGER (IONIZATION) NOT FOLLOWED

IN ZONE 1

TYPE 10000= 1

REFERENCE DIRECTION 1ANG= -O

TIME DIST 1T= 1

TYPE 1SPEC= -O

PHOTON EDIT 1TN= 3

SPECTRUM OPTION 1SENT= 1

PHOTON EDIT 1TIMES 1M= 0

JDEBUG= -O

1BTST# 2

1CH= 1

1B= -O

1C= -O

1J= -O

1JH= 1

1N IN= L

1UNIT= -O

1OBD= -O

1NDRY= -O

RANDOM NUMBER SEQUENCE 1

REACTION WEIGHTS -O

DEPOSITION SPECTRUM -O

CHANGE TALLY ENERGIES -O

CHANGE ANGULAR TALLY ENERGIES 1

NUMBER OF MATERIALS 4

Figure 9

14.

UPPER ANGLES FOR EDIT BINS

1.000	2.000	3.000	4.000	5.000
6.000	7.000	8.000	9.000	10.000
11.000	12.000	13.000	14.000	15.000
16.000	17.000	18.000		

$$dA = 2\pi R_y \cdot dy \cdot dx$$

ENERGY GRID INDICES--ITAP

33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	
65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99														

ANGULAR ENERGY GRID INDICES--ILAP

29	30	31	32	33	34	35	36	37	38	39	40	41
----	----	----	----	----	----	----	----	----	----	----	----	----

ZONE BOUNDARY DATA

ZONE	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B
1	2	-2	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B
2	3	-3	-8	-1	7	1												
3	4	-4	-1	-2	7	1												
4	5	-5	-2	-3	7	1												
5	6	-6	-3	-4	7	1												
6	7	-7	-4	-5	7	1												
7	8	-8																
8	9	-9																

FUOGE XN YN ZN GPPP GPXP
 1.000000E+05 0. 0. 0. 0. 1.000000E+00
 SOURCE ENER S8 S9 S10 S11 S12
 4.500000E+01 0. 0. 0. 0. 0.
 MIN ENERGY INITIAL TIME BZ ACC S15 PROB. MULT
 -2.000000E+01 0. 0. 0. 0. 0.

QUADRIC DATA

SURFACE X-ZERO Y-ZERO Z-ZERO C K K SQUARED
 1 0. 0. 0. 0. 5.0000000E+00 2.5000000E+01

PLANE DATA

1	-1.00000000E+01
2	1.00000000E+00
3	1.10000000E+00
4	1.58100000E+01
5	1.80000000E+01
6	1.70000000E+01

MAT NO	ELS NO	NO	NNNN	A	APCT	1	1	1.000E+00	1.000E+00	1.000E+00
MAT NO	ELS NO	NO	NNNN	A	APCT	2	2	7.400E+01	1.839E+02	1.000E+00
MAT NO	ELS NO	NO	NNNN	A	APCT	3	3	4.000E+00	9.020E+00	1.000E+00
MAT NO	ELS NO	NO	NNNN	A	APCT	4	4	8.200E+01	2.072E+02	1.000E+00

ZONE	MATERIAL	IELTR	LTYPE	ECUT	VGFL	WGT	ETA	PCT	COL	VOLUME	MASS
1	-1	1	-0	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.		8.639E+01	8.639E-02
2	-2	1	-0	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.		7.854E+00	1.516E+02
3	-1	1	-6	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.		1.155E+03	1.155E+00
4	-1	1	-6	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.		1.492E+01	1.492E-02
5	-1	1	3	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.		7.854E+01	7.854E-02

TOTAL VOLUME = 1.34303086E+03 CC. TOTAL WEIGHT = 1.52917022E+02 GRAMS

ELECTRON SOURCE
ELECTRON TRANSPORT REQUESTED ETA SET TO 1.0

MATERIAL MASS
1 1.335177E+00
2 1.515818E+02
3 0.
4 0.

MAT/L	ATOM/CM-B	FRACTIONS	ISOTOPES
4			
1	0.00059769	1.000000	1.
2	0.05322155	1.000000	74.
3	0.12356687	1.000000	4.
4	0.03285524	1.000000	82.

Figure 12

17.

Figure 13

Figure 14

DOSE REDUCTION FACTOR VS. ELECTRON
ANGULAR DIVERGENCE FOR 45-MeV ELECTRONS
ON 1 MM TUNGSTEN + 147 MM BERYLLIUM

1.0

0.9 $\frac{\text{PHOTON} \cdot \text{MeV} (0^\circ - 1^\circ), \text{NON-}}{\text{PARALLEL ELECTRONS}}$
0.8 $\frac{\text{PHOTON} \cdot \text{MeV} (0^\circ - 1^\circ), \text{FOR}}{\text{PARALLEL ELECTRONS}}$

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0

0

2

4

6

8

10

12

14

16

θ_e = ELECTRON HALF ANGULAR DIVERGENCE IN DEGREES

BOX C09 GOOSMAN

45 MEV E- ON 1 MM W + 14.7 CM BE 3 MEV E- CUTOFF 1ESBS = 96 HIGH BINS

5 8 1 6 50 4000 1 3 1 4 2

1 1 1 1 -10 1 4 2

1. 2. 3. 4. 5. 6. 3C

7. 8. 9. 10. 11. 12. 3E

13. 14. 15. 16. 17. 180. 3E

8 8 6 29 30 31 32 33 34 35 36 37 38 39 40 41

2 -2 -8 -1 7 1

3 -3 -1 -2 7 1

4 -4 -2 -3 7 1

5 -5 -3 -4 7 1

6 -6 -4 -5 7 1

7 1

8 -1

.80001 1. 7

45. 10

-0.2 5. 17.

1 1 -0.1 1. 1.1 15.81 16. 17. 12

2 1 3. 12

3 1 -6 3. 12

1 1 -6 3. 12

1 1 3 3. 12

1 1. 0.001 1. 1 96

2 1. 19.3 1. 74

3 1. 1.85 1. 4

4 1. 11.3 1. 82 (not used)

COMPILE DATE: 01/21R 16.48.50
BOX 051 HANDYL76 VERSION=X

SMALL CORE MEMORY USED=0134375
LARGE CORE MEMORY USED=0272460

BOX C00 GOSSMAN

45 MEV E- ON 1 MM W * 14.7 CM BE 3 MEV E- CUTOFF 1ESBS = 96 HIGH BINS
45 MEV E- ON 1 MM W * 14.7 CM BE 3 MEV E- CUTOFF 1ESBS = 96 HIGH BINS

NUMBER OF ZONES

5 INSIDE

0 TOTAL

SURFACES

1 QUADRICS

6 PLANES

-0 X PLANES

-0 Y PLANES

SOURCE

50 SAMPLES

4000 HISTORIES PER SAMPLE

SOURCE ZONE SET TO 1

REACTION WEIGHTS RWT1

2.5000E-01 2.5000E-03 2.5000E-05 2.5000E-06 1.0000E+00 1.0000E+00 1.0000E+00

FLOURESCENCE AND AUGER (IONIZATION) NOT FOLLOWED

IN TIME 1

TYPE ICODD= 1

REFERENCE DIRECTION IANG= -0

TINE DIST ITH= 1

TYPE ISPEC= -0

PHOTON EDIT ITH= 3

SPECTRUM OPTION ISENT= 1

PHOTON EDIT TIMES ITH= 0

JDBUG= -0

IBTST= 2

ICH = 1

IBZ = -0

JO = -0

JM = -0

JHPSEC= 1

INGBIT= L

JUNITS=-0

IDBS = -0

IBDRY= -0

RANDOM NUMBER SEQUENCE 1

REACTION WEIGHTS -0

DEFINITION SPECTRUM -0

CHANGE TALLY ENERGIES -0

CHANGE ANGULAR TALLY ENERGIES 1

NUMBER OF MATERIALS 4

Figure 16

21.

UPPER ANGLES FOR EDIT BINS

1.000	2.000	3.000	4.000	5.000
6.000	7.000	8.000	9.000	10.000
11.000	12.000	13.000	14.000	15.000
16.000	17.000	18.000		

ENERGY GRID INDICES--ITAP

33	34	35	36	37	39	41	43	45	47	49	51	53	55	57	59	61	63
65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99
101	103	105	107	109	111	113	115	117	119	121	123	125	127	129			

ANGULAR ENERGY GRID INDICES--ILAP

29	30	31	32	33	34	35	36	37	38	39	40	41
----	----	----	----	----	----	----	----	----	----	----	----	----

ZONE BOUNDARY DATA

ZONE	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B	JP	B
1	2	-2	-8	-1	7	1										
2	3	-3	-1	-2	7	1										
3	4	-4	-2	-3	7	1										
4	5	-5	-3	-4	7	1										
5	6	-6	-4	-5	7	1										
6	-6	-6														
7	-7	1														
8	8	-1														

FUDGE	XN	YN	ZN	GPPP	GPXP
1.00000E-05 0.	0.	0.	0.	0.	1.00000E+00
SOURCE ENER	SB	SG	S10	S11	S12
4.50300E+31 0.	0.	0.	0.	0.	0.
MIN ENERGY	INITIAL TIME	BZ	ACC	S15	PROB. MULT
-2.00000E-31 0.	0.	0.	0.	0.	0.

QUADRIC DATA

SURFACE	X-ZERO	Y-ZERO	Z-ZERO	C	K	K SQUARED
1	0.	0.	0.	0.	5.0300000E+00	2.5600000E+01

PLANE DATA

1	-1.0000000E-01
2	1.0000000E+00
3	1.1000000E+00
4	1.5010000E+01
5	1.6000000E+01
6	1.7000000E+01

Figure 17

MAT NO	ELE NO	Z	A	APCT	1	1	1.000E+00	1.000E+00	1.000E+00
MAT NO	ELE NO	Z	A	APCT	2	2	7.400E+01	1.000E+00	1.000E+00
MAT NO	ELE NO	Z	A	APCT	3	3	4.000E+00	9.020E+00	1.000E+00
MAT NO	ELE NO	Z	A	APCT	4	4	8.200E+01	2.072E+02	1.000E+00

ZONE	MATERIAL	IELTR	LTYPE	ECUT	VOFL	WGT	ETA	PCT CGL	VOLUME	MASS
1	-1	1	-0	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.	8.639E+01	8.639E+02
2	-2	1	-0	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.	7.954E+00	1.515E+02
3	-3	1	-0	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.	1.155E+03	2.137E+07
4	-1	1	-0	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.	1.492E+01	1.492E+02
5	-1	1	0	3.000E+00	-2.000E-01	1.000E+00	1.000E+00	0.	7.954E+01	7.954E+02
TOTAL VOLUME = 1.34303036E+03 CC.									TOTAL WEIGHT = 2.20910499E+03 GRAMS	

ELECTRON SOURCE
ELECTRON TRANSPORT REQUESTED ETA SET TO 1.0

MATERIAL MASS

1	1.798562E-01
2	1.515810E+02
3	2.137449E+03
4	0.

MAT/L ATOM/CM-B FRACTIONS ISOTOPES

1	0.00059769	1.000000	1.
2	0.06322156	1.000000	74.
3	0.12396697	1.000000	4.
4	0.03285524	1.000000	82.

TABLE I
RESULTS INTEGRATED OVER PHOTON ENERGY RANGE

PHOTON ENERGY INTEGRATION LIMITS IN MeV	PHOTONS WITH $0 \leq \theta \leq 1^\circ$ PER 150 μC OF PARALLEL ELECTRONS		
	20 MeV+ 1 MM W+ 59 MM Be	45 MeV+ 1 MM W	45 MeV+ 1 MM W+ 147 MM Be
4 - 5	$3.09 \cdot 10^{11}$	$1.72 \cdot 10^{12}$	$9.76 \cdot 10^{11}$
2.37 - 7.5	$1.60 \cdot 10^{12}$	$8.92 \cdot 10^{12}$	$4.83 \cdot 10^{12}$
1.80 - 10.	$2.40 \cdot 10^{12}$	$1.19 \cdot 10^{13}$	$6.98 \cdot 10^{12}$

FOR FXR PULSE OF 150 μC AND 6° HALF ANGULAR DIVERGENCE
SIMULATING 1983 FXR PARAMETERS, MULTIPLY THE PHOTON
FLUXES IN THE 20 MeV COLUMN ABOVE BY 0.49