If you are using a printed copy of this procedure, and not the on-screen version, then you MUST make sure the dates at the bottom of the printed copy and the on-screen version match.
The on-screen version of the Collider-Accelerator Department Procedure is the Official Version.
Hard copies of all signed, official, C-A Operating Procedures are available by contacting the ESSHQ Procedures Coordinator, Bldg. 911A

9.1.15.a BLIP Target and Canning Record

Hand Processed Changes

HPC No.	Date	Page Nos.	Initials

Approved: _____***Signature with Date on File***_____
Collider-Accelerator Department Chairman Date

D. Beavis, S. Smith

Note 1: Uncontrolled copy printed from electronic master that is valid at time of printing. Always check that you have the latest revision of this document before use.

Note2: Leave no blanks. Indicate 'Not Applicable (N/A)', where appropriate.

Title and Preparer
Irradiation of RbCl targets at BLIP with rastered beam at 140 µA to produce Sr-82 MIRP-CAD

Instructions	
Description	**Page No.**
1. Overview [short summary of purpose of experiment; name of principle investigator and researcher involved]	4
2. Target Material and Properties – [Provide physical properties of each component/material to be irradiated]	5
3. Target Canning Process – [provide images or drawings and reference the OPM procedures for closing and opening of target can]	6
4. Beam Characteristics [define required beam on target and total current required]	7
5. Proposed Experiment [Provide general description of a) how target will be supplied BLIP, b) target array in box 1 and box 2; c) thermal analysis of target material and target can d) transport of irradiated target to TPL; target opening and processing at TPL and e) disposal of waste. List persons responsible for conducting each task. If others are required to assist in the research irradiation, define level of skill of staff and contact time.]	7
a. Procedure for Irradiation of Target Material BLIP [Summarize steps for experiment including specialist and contact hours required for task]	7
b. Target Array [Define proposed target array for box 1 and box 2 including SRIM calculated entry and exit energy for each layer. Provide physical dimension of degraders, target can, materials and water gaps]	11
c. Thermal Analysis of Target Materials and Target Can [Provide full description of data provide to specialist for calculations and any assumption made on material for calculations]	12

	d. Transport and Processing at TPL [Provide full description of task involved and responsible persons and contact hours required]	7
	e. Disposal of waste. [describe waste to be generated and how it will be disposed of]	7
6.	**Activation Analysis of Target Material and Can** [Provide full list of radionuclide produced and quantities, references used for calculations, as well as decay profiles if the dose rates exceed limit for removal from BLIP hot-cell. Ensure Health Physics has reviewed data and confirms decay requirement if they are dose related. Attach analyses if any.]	8
	a. Radioactivity of each nuclide at end of bombardment (EOB), at 7 dats post EOB.	8
7.	**Expected Dose Rate (e.g., R/h at 1 m)** [provide expected dose rate using *Microshield or equivalent* calculations for the combined and separate target and can irradiated. Provide expected dose rate at EOB at BLIP and expected dose rate when delivered to TPL]	9
8.	**1Additional Safety Requirements** [address hazardous issues related to volatiles and or corrosive materials used and any additional equipment required for this experiment; hazardous materials information must be submitted to the C-AD ESSHQ Division Head for concurrence]	9
9.	**Special Operating Instructions and List of References or Supporting Documents**	10
10.	**Appendix** [provide additional support information as required]	11-last

1. Overview

This safety submission is triggered by implementation of the rastered beam at BLIP as well as by LINAC upgrade which resulted in proton current increase from 115 μA to 140 μA.

These upgrades will mainly effect 1) RbCl target thermal load and 2) the quantities of the nuclides, produced due to the increased current and hence dose rates to BLIP operator at the end of bombardment, to technical personal during target transfer and processing at TPL.

Changes:	2015	2016
RbCl density	2.380	2.200
1 st RbCl thickness	0.670	0.720
2nd RbCl thickness	0.524	0.565
Current, uA	115	140
Beam	focused	rastered

2. Target Material and Properties

Target Name:	*To be determined*	**Target & Canning No.** *Assign unique no.* (year-00x)	

Target Material Properties				
Purity or Grade	≥99.8 %, Analytical grade			
Chemical Formula	RbCl			
Physical Characteristics at 70 ºF or 21 ºC	**solid**			
Physical Form	**Foil**	**n/a**	**Powder**	**n/a**
	Diameter (inches/mm)	**2.375**	**Pressed (Torr)**	**Pressed pallet at 100 Torr**
Elements (%)	Ba ≤ 3ppm; Cu ≤ 10 ppm; Fe, Zn, Cs≤ 50 ppm; Ca, Sr≤ 5ppm			
Melting Point	**718**	**ºC**	**n/a**	**ºF**
Boiling Point	**1390**	**ºC**	**n/a**	**ºF**
Thermal Conductivity	2.28 **W.m^{-1}.K^{-1}** at r.t	**Temperature dependence**	***(if available)*** 0.4 at 716^{0}C, 0.51 at 857^{0}C	
Density	**2.80 at r.t , 2.2 during irradiation**		**g/cm^3**	
Specific Heat	52.4		J K^{-1} mol^{-1}	

Target Material Reactions / Properties						
Does the Target material react with any of the following?	**Aluminium**	**no**	**Air**	**no**	**CO_2**	**no**
	H_2O	**soluble**	**Lead**	**no**	**Zinc**	**no**
	Inconel 600	**no**	**S/Steel**	**no**	**Copper**	**no**

Canning Material Properties				
Chemical Formula	**Inconel alloy (Ni+Co-72.0%, Cr-14%, Fe-6-10%) window, SS ring**			
Can Wall Thickness (inches/mm)	**0.012 / 0.3048**			
Can Dimensions (inches/mm)	**Can Diameter**	**2.750/69.85**	**Can Width:**	1st RbCl – 0.720 in 2nd RbCl – 0.565 in
Melting Point	**1354-1413**	**ºC**	**n/a**	**ºF**
Thermal Conductivity	**14.9 W.m^{-1}.K^{-1}**	**Temperature dependence**	**27.5 at 800^{0}C**	
Density	**8.43**	**g/cm^3**		
Specific Heat	**444**		**J/kg.K**	

3. Target Canning Process
Follow CA-D OPM 19.7.1 Preparation of accelerator / Cyclotron targets

4. Beam Characteristics		
Beam shape:	Rastered	
Raster parameters:	Gaussian beam spot 12mm FWHM, rotation frequency 5kHz , 4 sweeps 15mm radius per one sweep 5.5mm radius	
Power density:	110 watt/mm2	
Average Current Desired	**150**	**µA**
Total Integrated Current Desired	**75600**	**µA - hrs**
Maximum Proton Energy on Target Material	**95.5-98.5**	**MeV**

5. Experiment Description

5.a Procedure for irradiation of target material in BLIP:

Follow C-AD-OPM 19.17.20 for target installation. Continuous irradiation for no more than 21 days

5.b Target array in Box 1 and Box 2:

Box 1: SS degrader, RbCl target 1(thick), RbCl target 2(thin) Cu stop, Al spacer separated by 0.200 inch water gaps

Box 2: no proton beam: copper degrader 0.220", various Al degraders only as water spacers

See **Appendix 1** for the results of energy propagation calculations

5.c Thermal analysis of target material and target can (attach analyses if any):

Provided by Chris Cullen. See Appendix 2 for more information

5.d Transport of irradiated target to TPL, target opening and processing:

Transfer irradiated targets 1 week after End of Bombardment to TPL following C-AD OPM 19.17.30. Follow C-AD OPM 19.12.1 for target processing

5.e Disposal of waste:

Follow CA-D OPMs 19.30.3 – 19.30.5 for waste disposal

6. Activation Analysis of Target Material and Can*

Main isotopes produced in 3 week (140 μA) irradiation of RbCl targets, their nuclear data,** and activities***

Isotope	Half-life	Eγ, keV (I, %)	Activity, Ci	
			End of Bombardment	7 days past EOB
Sr-82 (Rb-82)	25.34 d	776.52 (15.0)	16.80	13.84
Sr-83	1.35 d	381.53 (14.0) 762.65 (26.7)	69.13	1.90
Sr-85	64.85 d	514.0 (96)	5.04	4.68
Rb-79	0.0159 d	688.1 (23.1) 182.7 (19.2)	28.59	decayed
Rb-81	0.1905 d	190.46 (24.8) 446.15(23.5)	68.93	nil
Rb-82 (metastable)	0.270 d	554.35 (62.4) 776.52 (84.39) 619.11 (37.98)	60.71	nil
Rb-83	86.2 d	520.4 (45) 529.59 (29.3) 552.55 (16.0)	10.99	11.40
Rb-84	32.82 d	881.6 (68.9)	44.38	38.27
Rb-86	18.642 d	1077.0 (8.64)	18.80	14.50
Kr-79	1.46 d	261.29 (12.7)	21.49	0.79
Br-77	2.38 d	238.98 (23.1) 520.69 (22.4)	8.03	1.00

*Contribution to the dose rate from Inconel windows activation is negligible

**Most prominent gamma rays are shown

***Calculated from cross-section data reported by E.Z. Buthelezi et al, Applied Radiation and Isotopes, Vol.64, p.915 (2006), 10.1016/j.apradiso.2006.03.009

Decay Requirements

At least one week cool off time is required after end of bombardment before target transfer to TPL. The cool off time is determined by production schedule and is **NOT** safety driven.

7. Expected Dose Rate

Expected dose rates were calculated for the worst case scenario: 21 days production campaign at 140 µA. See Appendix 3 for Microshield reports

Dose rate to the operator at BLIP, targets are 1 foot away from the hot cell wall:

- **at the EOB**: 24.94 mR/h,
- **at the time of transfer to TPL, 7 days after EOB**: 0.94 mR/h

Historical dose rates for the Transport Pig for 21 day irradiation campaign at 115 µA, reference RWP# BLIP-15-007, Radiological Survey Form FS-SOP-1000 from 07/17/2015

- highest contact on pig body: 60 mR/h
- highest 30 cm from pig body: 2.5 mR/h

Expected dose rates for the Transport Pig, correction factor 140/115=1.22

- highest contact on pig body: 73.2 mR/h
- highest 30 cm from pig body: 3.05 mR/h

8. Additional Safety Requirements

none

9. Special Operating Instructions
none

Supporting Documentation	
References	

Appendix 1.

Energy propagation through RbCl target array, verified by Phil Pile (see next page ragrding energy propagation through RbCl)

	2016	Energy: 116.38 MeV	rastered beam					
					thickness			
water displacement by can	layer number	Layer	Material	density	inches	mm	Ei	Eout
	1	Be window	Berillium	1.85	0.012	0.305	116.38	116.08
	2	AlBeMet window	AlBeMet	2.10	0.012	0.305	116.08	115.74
	3	Beamline window	stainless steel	7.99	0.031	0.787	115.74	112.87
	4	water gap	water	1.00	0.106	2.692	112.87	111.06
	5	BOX front window	stainless steel	7.99	0.020	0.508	111.06	109.14
	6	water gap	water	1.00	0.200	5.080	109.14	105.59
SS degrader: slab	7	stainless steel slab	stainless steel	7.99	0.058	1.473	105.59	99.74
	8	water gap	water	1.00	0.200	5.080	99.74	95.95
1st RbCl	9	can window	inconel	8.43	0.012	0.305	95.95	94.57
0.720	10	RbCl salt	RbCl	2.20	0.696	17.678	94.57	73.15
	11	can window	inconel	8.43	0.012	0.305	73.15	71.47
	12	water gap	water	1.00	0.200	5.080	71.47	66.52
2nd RbCl	13	can window	inconel	8.43	0.012	0.305	66.52	64.71
0.565	14	RbCl salt	RbCl	2.20	0.541	13.741	64.71	41.28
	15	can window	inconel	8.43	0.012	0.305	41.28	38.67
	16	water gap	water	1.00	0.200	5.080	38.67	30.18
Cu stop	17	Cu stop	Cu	8.96	0.300	7.620	30.18	stop
	18	water gap	water	1.00	0.200	5.080	0.00	0.00
Al stop	19	Al stop (Ga dummy)	Al	2.70	0.220	5.588	0.00	0.00
	20	water gap	water	1.00	0.200	5.080	0.00	0.00
			total					
			targets +water gaps		3.063			

The BLIP Target Stack RbCl - 2015	**ppile calculation 10/23/15 using lookup range tables**							
DM array, 11/20/15 with gallium in low E slot				**vary water gap(mm)**	**2.692**			
RbCl Density (g/cm^3) equals	**equals**	**2.200**	**g/cm^3 (change in lookup table)**		**KE (MeV out)**	**PP**	**DM 10/20/2015**	
Material in Beam	**density(g/cm^3)**	**thickness (mm)**	**KE (MeV in)**	**Range(mm)**	**116.4**	**Delta E (MeV)**	**Delta E (MeV)**	**Diff (PP-DM)**
Beryllium	1.85	0.305	116.380	66.650	116.1	0.32	0.30	0.02
AlBeMet	2.10	0.305	116.060	59.550	115.7	0.35	0.34	0.01
Stainless Steel	7.99	0.787	115.710	18.140	112.8	2.93	2.87	0.06
Water	1.00	2.692	112.780	94.580	111.0	1.83	1.81	0.02
Stainless Steel	7.99	0.508	110.950	16.870	109.0	1.92	1.92	0.00
Water	1.00	5.080	109.030	89.080	105.5	3.55	3.55	0.00
Stainless Steel degrader	7.99	1.473	105.480	15.450	99.6	5.90	5.85	0.05
Water	1.00	5.080	99.580	75.820	95.8	3.81		
Inconel	8.43	0.305	95.770	12.350	94.4	1.38	1.38	0.00
RbCl	0.00	**17.678**	**94.390**	48.844	72.900	21.49	21.42	0.07
Inconel	8.43	0.305	72.900	7.669	71.2	1.67	1.68	-0.01
Water	1.00	5.080	71.230	41.640	66.3	4.98	4.95	0.03
Inconel	8.43	0.305	66.250	6.486	64.5	1.80	1.81	-0.01
RbCl	0.00	**13.741**	**64.450**	25.098	40.950	23.50	23.43	0.07
Inconel	8.43	0.305	40.950	2.789	38.3	2.62	2.61	0.01
Water	1.00	5.080	38.330	13.620	29.6	8.73	8.49	0.24

Appendix 2

Thermal studies

Date: December 7, 2015

To: Dana Beavis

From: Chris Cullen

Subject: LINAC beam energy coverage on a RbCl target

Discussion:

This paper documents the particle per unit area coverage for a 140 µA, 200 mev linac beam as applied to a RbCl target. Two cases are documented. The first case is for the Gaussian beam applied in a single, stationary location. This irradiation occurred in July of 2015. No target anomalies were observed. The second case details the particle per area coverage for the proposed raster. The total pulse energy, duration and frequency are identical for both cases.

Case 1. Single, stationary location:

For all pulses the Gaussian beam spot FWHM = 20.2 mm (.795"). The peak intensity is 10,000.

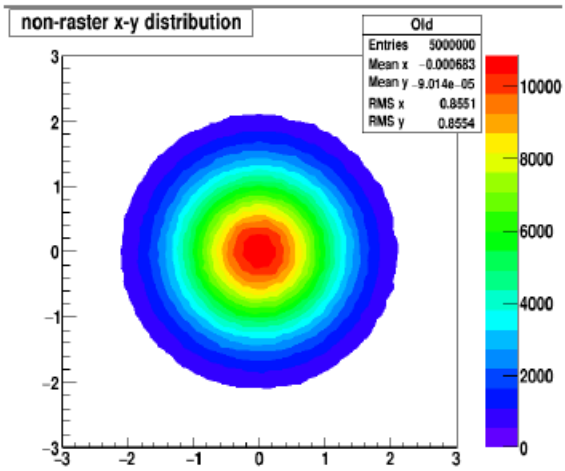


Figure 1. Gaussian Beam FWHM = 20.2 mm

Case 2. Raster locations:

The Gaussian beam spot FWHM = 12.0 mm (.472"). 4 consecutive pulses are swept along a 15 mm radius. Every fifth pulse is swept along a 5.5 mm radius. The peak intensity is 4000.

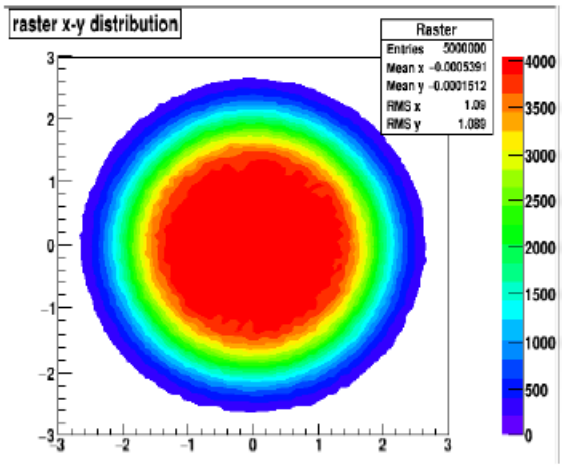


Figure 2. Gaussian Beam, FWHM = 12.0 mm, 15.0 mm Sweep Radius 4X & 5.5 mm Sweep Radius 1X

Conclusion:

The energy per unit area coverage for the 140 µA, 200 mev linac beam is lower for the raster beam than for the Gaussian beam. Therefore the peak temperature of the RbCl target will be lower for the raster beam. Also, since each raster sweep path covers a greater area than the Gaussian beam there is no combination of pulse radii that are more intense than the Gaussian irradiation of July, 2015.

Appendix 3

Microshield reports

Dose rate to the operator at BLIP at EOB

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
RbCl.ms7	November 4, 2015	4:25:29 PM	00:00:00

Project Info	
Case Title	Dose RbCl EOB
Description	Dose RbCl at BLIP
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	3.264 cm (1.3 in)
Radius	3.493 cm (1.4 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	76.2 cm (2 ft 6.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	7.632 in³	RbCl	2.7
Shield 1	12.0 in	Air	0.00122
Shield 2	6.0 in	Lead	11.34
Air Gap		Air	0.00122

Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: ICRP-38

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Br-77	8.0300e+000	2.9711e+011	6.4203e+004	2.3755e+009

Kr-79	2.1490e+001	7.9513e+011	1.7182e+005	6.3574e+009
Rb-79	2.8590e+001	1.0578e+012	2.2859e+005	8.4578e+009
Rb-81	6.8930e+001	2.5504e+012	5.5112e+005	2.0392e+010
Rb-82	1.6800e+001	6.2160e+011	1.3432e+005	4.9699e+009
Rb-82m	6.0710e+001	2.2463e+012	4.8540e+005	1.7960e+010
Rb-83	1.0990e+001	4.0663e+011	8.7869e+004	3.2512e+009
Rb-84	4.4380e+001	1.6421e+012	3.5484e+005	1.3129e+010
Rb-86	1.8800e+001	6.9560e+011	1.5031e+005	5.5616e+009
Sr-82	1.6800e+001	6.2160e+011	1.3432e+005	4.9699e+009
Sr-83	6.9130e+001	2.5578e+012	5.5272e+005	2.0451e+010
Sr-85	5.0400e+000	1.8648e+011	4.0297e+004	1.4910e+009

Buildup: The material reference is Shield 2
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	7.122e+12	0.000e+00	1.333e-20	0.000e+00	1.143e-21
0.02	1.683e+10	0.000e+00	4.199e-23	0.000e+00	1.454e-24
0.04	4.193e+10	0.000e+00	2.212e-22	0.000e+00	9.784e-25
0.05	3.314e+09	0.000e+00	2.254e-23	0.000e+00	6.004e-26
0.08	4.221e+09	2.654e-158	5.393e-23	4.199e-161	8.534e-26
0.1	2.467e+10	0.000e+00	1.250e-05	0.000e+00	1.913e-08
0.15	4.624e+11	2.215e-139	2.698e-19	3.647e-142	4.442e-22
0.2	2.039e+12	4.535e-65	7.835e-20	8.004e-68	1.383e-22
0.3	1.966e+11	2.518e-23	1.378e-20	4.776e-26	2.613e-23
0.4	1.601e+12	3.044e-10	7.376e-10	5.931e-13	1.437e-12
0.5	8.770e+12	1.898e-04	5.504e-04	3.725e-07	1.080e-06
0.6	3.377e+12	3.011e-02	9.484e-02	5.877e-05	1.851e-04
0.8	4.533e+12	1.710e+01	6.216e+01	3.252e-02	1.182e-01

1.0	1.278e+12	1.035e+02	4.053e+02	1.907e-01	7.470e-01
1.5	1.088e+12	2.806e+03	1.156e+04	4.720e+00	1.945e+01
2.0	7.631e+10	7.150e+02	2.986e+03	1.106e+00	4.617e+00
3.0	5.831e+07	1.504e+00	6.164e+00	2.040e-03	8.362e-03
Totals	**3.064e+13**	**3.643e+03**	**1.502e+04**	**6.051e+00**	**2.494e+01**

Dose rate to the operator at BLIP at time of target transfer to TPL, 7 days after EOB

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked
	Medvedev	

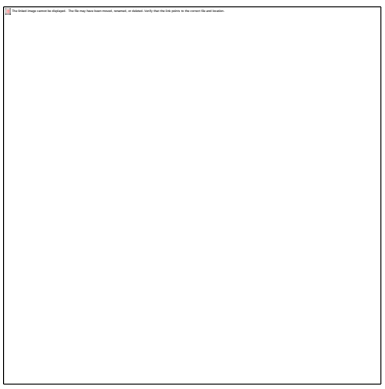
Filename	Run Date	Run Time	Duration
RbCl.ms7	November 4, 2015	4:26:42 PM	00:00:00

Project Info	
Case Title	Dose RbCl BLIP
Description	Dose RbCl at BLIP 7 days past EOB
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	3.264 cm (1.3 in)
Radius	3.493 cm (1.4 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	76.2 cm (2 ft 6.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	7.632 in³	RbCl	2.7
Shield 1	12.0 in	Air	0.00122
Shield 2	6.0 in	Lead	11.34
Air Gap		Air	0.00122



Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: ICRP-38

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Br-77	1.0038e+000	3.7139e+010	8.0254e+003	2.9694e+008
Kr-79	7.8570e-001	2.9071e+010	6.2820e+003	2.3243e+008
Kr-81	1.7150e-007	6.3453e+003	1.3712e-003	5.0734e+001

Kr-83m	8.6914e+000	3.2158e+011	6.9492e+004	2.5712e+009
Rb-79	8.9214e-132	3.3009e-121	7.1330e-128	2.6392e-123
Rb-81	6.2555e-010	2.3145e+001	5.0015e-006	1.8506e-001
Rb-82	1.3837e+001	5.1196e+011	1.1063e+005	4.0933e+009
Rb-82m	4.2298e-007	1.5650e+004	3.3819e-003	1.2513e+002
Rb-83	1.1398e+001	4.2172e+011	9.1131e+004	3.3719e+009
Rb-84	3.8272e+001	1.4161e+012	3.0600e+005	1.1322e+010
Rb-86	1.4495e+001	5.3633e+011	1.1590e+005	4.2882e+009
Sr-82	1.3836e+001	5.1194e+011	1.1063e+005	4.0932e+009
Sr-83	1.9001e+000	7.0303e+010	1.5192e+004	5.6210e+008
Sr-85	4.6766e+000	1.7303e+011	3.7391e+004	1.3835e+009

Buildup: The material reference is Shield 2
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.015	1.453e+12	0.000e+00	2.719e-21	0.000e+00	2.333e-22
0.02	5.250e-123	0.000e+00	1.310e-155	0.000e+00	4.539e-157
0.03	1.637e+08	0.000e+00	6.298e-25	0.000e+00	6.241e-27
0.04	1.168e+09	0.000e+00	6.160e-24	0.000e+00	2.724e-26
0.05	1.034e-123	0.000e+00	7.033e-156	0.000e+00	1.873e-158
0.08	5.276e+08	3.317e-159	6.741e-24	5.249e-162	1.067e-26
0.1	3.581e+08	0.000e+00	1.815e-07	0.000e+00	2.776e-10
0.15	9.153e+08	4.384e-142	5.339e-22	7.219e-145	8.792e-25
0.2	1.131e+10	2.515e-67	4.346e-22	4.439e-70	7.670e-25
0.3	8.347e+09	1.069e-24	5.849e-22	2.027e-27	1.109e-24
0.4	2.429e+10	4.616e-12	1.119e-11	8.995e-15	2.180e-14
0.5	2.260e+12	4.890e-05	1.418e-04	9.599e-08	2.784e-07
0.6	7.593e+10	6.770e-04	2.132e-03	1.321e-06	4.162e-06

0.8	1.104e+12	4.164e+00	1.514e+01	7.920e-03	2.879e-02
1.0	5.867e+10	4.749e+00	1.860e+01	8.753e-03	3.429e-02
1.5	5.717e+09	1.474e+01	6.073e+01	2.480e-02	1.022e-01
2.0	1.270e+10	1.190e+02	4.968e+02	1.840e-01	7.683e-01
3.0	4.802e+07	1.238e+00	5.077e+00	1.680e-03	6.887e-03
Totals	**5.017e+12**	**1.439e+02**	**5.964e+02**	**2.271e-01**	**9.404e-01**