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.

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

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.

Note 2: Leave no blanks. Indicate 'Not Applicable (N/A)', where appropriate.

Title and Preparer
[High Current Zinc Irradiation for the Production of 67Cu] Target Submission Number: TS-tgt-16-08_____ [by Dmitri Medvedev and Timothy Phelps]

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.]	7
a. Procedure for Irradiation of Target Material at 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 calculated entry and exit energy for each layer. Provide physical dimension of degraders, target can, materials and water gaps. Provide total water gap for the array]	11

	c. Thermal Analysis of Target Materials and Target Can [provide full description of data to specialist for calculations and any assumption made on material for calculations]	7
	d. Transport and Processing at TPL [provide description of task involved if different from C-AD OPM 19.17.30 BLIP Target Transfer Procedure]	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 list of radionuclide produced and their quantities, references used for calculations at the time points of: end of bombardment (EOB) 1 hour after EOB and at the time of transport to TPL]	8-9
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, 1 h after EOB and expected dose rate at the time of transfer to TPL. Provide decay profiles if the dose rates exceeds limits set up in applicable RWP for removal from BLIP hot-cell. Attach analyses if any]	8-9
8.	**Additional Safety Requirements:** [provide list of isotopes for monitoring in Blip target cooling water in case of target leak/failure visual inspection schedule impact on BLIP air emissions if water gap exceeds historical values hazardous issues related to volatiles and or corrosive materials used hazardous materials information must be submitted to the C-AD ESRC]	9
9.	**Special Operating Instructions and List of References or Supporting Documents**	9
10.	**Appendix 1:** Target Array and Energy Propagation Calculations **Appendix 2:** Target Array Loading Table (LT) [provide additional supporting information as required]	10-12

1. Overview

High Current Zinc Irradiation for the Production of 67Cu

Background: The irradiation described in this safety submission is part of planned research program entitled “Production and Separation of 186Re, 189Re and 72Se/72As for Research and Radiopharmaceutical Applications.”

The work described here is to specifically address the production of high specific activity 67Cu. Copper-67 is a β- emitter with nuclear properties that make it ideal as a therapeutic radionuclide.

This safety submission outlines the issues related to the production of 67Cu from either an electroplated zinc metal target encapsulated in Aluminum bolted target. The basis for the production is the 68Zn(p,2p)67Cu nuclear reaction. The experiment will involve the irradiation of the electroplated zinc target either overnight (~18 hours) or over the weekend (66 hours) with an average current of 165 µA. Once irradiated, the target will be transported to Target Processing Lab (TPL), opened and the irradiated Zn disk for dissolution and processing in a hot cell.

There will be 2 targets in the target array. The first target will be positioned thin window upstream, the second will be positioned thin window downstream. Referred as "flipped" henceforth. The reverse or "flipped" position ensures the desired energy on the target and that beam does not stop and water

2. Target Material and Properties

Target Name:	TBD	**Target Submission No.** *Assign unique no.* (year-00x)	TS-tgt-16-08

Target Material Properties				
Purity or Grade	99.9			
Chemical Formula	Zn			
Physical Characteristics at 21 ºC	solid			
Physical Form (foil, disk, pressed pellet…)	Electroplated disk			
Target dimensions (inches/mm)	**Diameter**	1.1 (27.9)	**Thickness**	0.020 (25.4)
Elements (%)	Zn-68 (99.26%)			
Melting Point	419.53			**ºC**
Boiling Point	907			**ºC**
Decomposition temperature	Does not decompose			**ºC**
Thermal Conductivity	120 **$W.m^{-1}.K^{-1}$**	**Temperature dependence**	*(if available)*n/a	
Density	7.0-7.14		**g/cm^3**	

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

Canning Material Properties				
Chemical Formula	Aluminum			
Can Window Thickness (inches/mm)	0.02 inch / 0.508 mm			
Can Dimensions (inches/mm)	**Diameter:** 2.75		**Thickness:**0.5	
Melting Point	660.32			**ºC**
Thermal Conductivity	205 **$W.m^{-1}.K^{-1}$**	**Temperature dependence**	*(if available)*n/a	
Density	2.7	**g/cm^3**		

3. Target Canning Process

The zinc metal disc will be sealed in the screw bolted aluminum can within a glove box under helium gas. The sealed aluminum can (containing the zinc) will be leak tested for helium prior to placing it within the target assembly box in front of the 82Sr target array replacing the vacuum box in front of the first RbCl target.

General considerations:

The aluminum target consists of two parts referred to as upper half (D25-M-3188), normally positioned upstream and lower half (D25-M-3292) positioned downstream that are secured together with eight Allen screws located at the periphery of the target (D25-M-3186)
The water-tight seal is ensured by a silver-coated inconel c-ring (refer to D25-M-3186)
In the center of the lower half there is a well which is designed to hold the foils/disks for irradiation
The material from the back of the lower half of the target is removed to facilitate better target cooling
Packaging and sealing of the target should be carried out in a glove box in Helium atmosphere

Sequence of operations for target closing for irradiation:

Create a target card as per C-A-OPM-ATT 19.3.6.2.a
Label the upper part placing the letter stamps between the screw holes
Machine a well in the center of the lower part to accommodate Zn disk. The depth of the well should not exceed the thickness of the disk to ensure thermal contact
Place the disk inside the well of the lower half with Al monitor (0.005') foil upstream
Position the c-ring in the grove of the lower half
Position the upper half of the target on top of the lower half and align the indexing slits
Insert eight Allen screws into the holes individually and secure them in the threads
Tighten the Allen screws until the slight resistance is felt in the following sequence: 12-6-9-3-11-4-1-7 o'clock
Tighten the Allen screws to torque 90 inch-pounds until the upper and lower halves come in contact in the following sequence: 12-6-9-3-11-4-1-7 o'clock
Provide the sealed target to CAD vacuum group for He-leak check
Ensure sign off for leak check test on the target card
The target is now sealed for irradiation
Deliver target to BLIP staff

4. Beam Characteristics		
Beam pattern (rastered/focused)	focused	
Incident LINAC energy	117	**MeV**
Energy on Target Material	105/50.5	**MeV**
Maximum Instantaneous Current permitted	165	**µA**
Average Current Desired	165	**µA**
Total Integrated Charge Desired	At least 3168 (overnight irradiation)	**µA-hrs**

5. Experiment Description

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

Follow CAD OPM 19.17.20 to install or remove the target. Follow corresponding LT for the target sequence in the beam

5.b Target array in Box 1 and Box 2 (detailed in Appendix 1):

Target array is given in the Appendix 1

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

Performed by: C. Cullen **Date:** **Checked by:** **Date:**

Follow CAD OPM 19.17.30 to transport the target from BLIP in a pig

Follow CAD OPM 19.9.4. to open the target using target cutter

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

Follow CAD OPM 19.17.30 to transport the target from BLIP in a pig. Target will be opened remotely by removing the bolts

The irradiated disc will be processed under approve ESR

5.e Disposal of waste:

Liquid waste will be neutralised and disposed in D tank system. Target body will be disposed as TPL solid waste CAD OPM 19.30.3

6. Activation Analysis of Target Material and Can

Activation data* for target material is given below for 0.8 days (overnight) and 2.8 days (weekend irradiations. Major activation products for 0.020 Zn-68 disk and Al capsule calculated for the target irradiated at 105 MeV entrance energy in Zn-68 disk.

Isotope	Z	Half-life, d	0.8 days at 165 uA		2.8 days at 165 uA	
			A @ EOB, Ci	A @ 24h, Ci	A @ EOB, Ci	A @ 24h, Ci
Cu	67	2.58	0.181	0.138	0.494	0.378
Cu	64	0.53	2.67	0.72	4.0	1.08
Ga	66	0.394	0.981	0.167	1.29	0.22
Ga	67	3.26	0.302	0.244	0.866	0.72
Zn	65	2.44	0.013	0.013	0.046	0.046
Na	22	949	0.009	0.009	0.033	0.033
Na	24	0.625	5.37	1.77	8.7	2.9
Dose rate, mR/h	At BLIP hot cell		18.1	5.8	28.9	9.3

Activation data for target material is given below for 0.8 days (overnight) and 2.8 days (weekend irradiations. Major activation products for 0.020 Zn-68 disk and Al capsule calculated for the target irradiated at 50.2 MeV entrance energy in Zn-68 disk.

Isotope	Z	Half-life, d	0.8 days at 165 uA		2.8 days at 165 uA	
			A @ EOB, Ci	A @ 24h, Ci	A @ EOB, Ci	A @ 24h, Ci
Cu	67	2.58	0.155	0.118	0.424	0.324
Cu	64	0.53	0.806	0.218	1.210	0.33
Ga	66	0.394	3.727	0.64	4.899	0.83
Ga	67	3.26	0.623	0.50	1.786	1.44
Zn	65	2.44	0.030	0.030	0.105	0.105
Na	22	949	0.018	0.018	0.062	0.062
Na	24	0.625	2.95	0.97	4.78	1.58
Dose rate, mR/h	At BLIP hot cell		13.9	3.86	21.2	6.0

*the activities were calculated using activation equation and cross section data available through NNDC http://www.nndc.bnl.gov/

Decay Requirements

none

7. Expected Dose Rate

The dose rates to the operator of the BLIP hot cell were calculated using Microshield 7 and are given in Section 6, page 8. The Microshield repoorts are given in the Appendix 3.

8. Additional Safety Requirements

Nuclides released to Blip Target Cooling Water in the unlikely event of target leak/failure

Nuclide	Half life	Eγ (abundance, %)
Cu-67	2.58 d	184.87 (48.7)
Ga-66	0.394 d	1039 (37.0)

9. Special Operating Instructions

none

Supporting Documentation

References	

Appendix 1

Target Array and Energy Propagation Calculations

TITLE: Irradiation of Zn-68 targets at 117 MeV Linac: 105 and 50 MeV entrance on the targets_____

Target Array Number: TA-16-08_____

Preparer: ___Medvedev/Phelps_____

Layer Number	Layer	Material	Density	Thickness		MeV		Energy deposited
				inch	mm	Ei	Eout	

		Energy: 116.8 MeV					165			
					thickness					
water displacement by can	layer number	Layer	Material	density	inches	mm	Ei	Eout	delta E	power, Wts
	1	Be window	Berillium	1.85	0.012	0.305	116.80	116.50	0.30	49.27
	2	AlBeMet window	AlBeMet	2.10	0.012	0.305	116.50	116.16	0.34	56.09
	3	Beamline window	stainless steel	7.99	0.031	0.787	116.16	113.30	2.86	471.74
	4	water gap	water	1.00	0.106	2.692	113.30	111.49	1.81	298.72
	5	1st box upstream window	stainless steel	7.99	0.020	0.508	111.49	109.60	1.90	312.72
	6	water gap	water	1.00	0.200	5.080	109.60	106.06	3.53	583.21
Zn target can 0.500	7	Zn can window	Al 6061	2.70	0.020	0.508	106.06	105.31	0.75	123.65
	8	Zn disk	Zn	7.13	0.020	0.508	105.31	103.60	1.71	282.31
	9	Aluminum well bottom	Al 6061	2.70	0.167	4.229	103.60	97.13	6.47	1068.01
	10	water outside well	water	1.00	0.298	7.569	97.13	91.31	5.82	960.89
	11	cooling channel	water	1.00	0.100	2.540	91.31	89.29	2.02	332.76
Al degrader	12	Al degrader	Aluminum	2.70	0.354	8.992	89.29	73.22	16.07	2651.72
	13	cooling channel	water	1.00	0.200	5.080	73.22	68.37	4.85	800.40
Zn target can 0.500 flipped	14	water outside well	water	1.00	0.298	7.568	68.37	60.58	7.78	1284.02
	15	Aluminum well bottom	Aluminum	2.70	0.167	4.241	60.58	50.57	10.01	1652.11
	16	Zn disk	Zn	7.13	0.020	0.508	50.57	47.66	2.91	480.80
	17	can window	inconel	8.43	0.020	0.508	47.66	46.28	1.38	228.16
	18	cooling channel	water	1.00	0.200	5.080	46.28	39.10	7.18	1184.62
Al stop 0.754	19	Al beam stop	Aluminum	8.92	0.754	19.152	39.10	stop	39.10	6450.81
	20	cooling channel	water	1.00	0.200	5.080	0.00	0.00		

RSC Approval:		Date Approved:

Appendix 2

Target Loading Table

Title Irradiation of Zn-68 targets at 117 MeV Linac: 105 and 50 MeV entrance on the targets _____

Target Array Number: **TA**-16-08_____

Preparer: ___Medvedev/Phelps_____

Proposed Run Time (e.g. days, hrs.): up to 2.8

Desired Completion Date: July 31

Requested Beam Energy (MeV): 117 | Requested Beam Current (μA): 165

	Item	Type and stamped ID (*if available*)	Layer #'s from "Target Array and Energy Propagation Calculations"	Thickness *inch*	BLIP Operator *(Initial)*	Witness *(Initial)*
Box 1	Water gap	n/a	6	0.200		
	Zn-68 target can		7-10	0.500		
	Water gap	n/a	11	0.200		
	Al degrader		12	0.354		
	Water gap	n/a	13	0.200		
	Zn-68 target can (flipped)		14-17	0.500		
	Water gap	n/a	18	0.200		
	Al beam stop		19	0.754		
	Water gap	n/a	20	0.200		

RSC Approval: | **Date Approved:**

Appendix 3

Microshield reports

105 MeV, 0.8 days

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 105 MeV.ms7	July 20, 2016	2:00:24 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP EOB, 105 MeV target, 0.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³

Cu-64	2.6680e+000	9.8716e+010	9.9624e+006	3.6861e+011
Cu-67	1.8100e-001	6.6970e+009	6.7586e+005	2.5007e+010
Ga-66	9.8100e-001	3.6297e+010	3.6631e+006	1.3553e+011
Ga-67	3.0200e-001	1.1174e+010	1.1277e+006	4.1724e+010
Na-22	9.0000e-003	3.3300e+008	3.3606e+004	1.2434e+009
Na-24	5.3700e+000	1.9869e+011	2.0052e+007	7.4192e+011
Zn-65	1.3200e-002	4.8840e+008	4.9289e+004	1.8237e+009

Buildup: The material reference is Shield 3 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	3.042e+10	0.000e+00	5.134e-23	0.000e+00	4.404e-24
0.1	5.855e+09	0.000e+00	2.676e-06	0.000e+00	4.094e-09
0.2	5.722e+09	1.359e-68	1.983e-22	2.399e-71	3.500e-25
0.3	1.841e+09	3.855e-26	1.163e-22	7.313e-29	2.206e-25
0.4	5.558e+08	2.135e-14	5.222e-14	4.160e-17	1.018e-16
0.5	7.600e+10	3.831e-07	1.130e-06	7.519e-10	2.218e-09
0.6	1.097e+08	2.536e-07	8.167e-07	4.949e-10	1.594e-09
0.8	2.307e+09	2.638e-03	9.932e-03	5.018e-06	1.889e-05
1.0	1.462e+10	4.014e-01	1.647e+00	7.399e-04	3.035e-03
1.5	2.011e+11	2.107e+02	9.277e+02	3.545e-01	1.561e+00
2.0	3.980e+09	1.678e+01	7.526e+01	2.595e-02	1.164e-01
3.0	2.087e+11	2.696e+03	1.189e+04	3.657e+00	1.613e+01
4.0	2.533e+09	4.846e+01	2.077e+02	5.995e-02	2.570e-01
5.0	5.478e+08	1.177e+01	5.362e+01	1.349e-02	6.147e-02
Totals	5.542e+11	2.984e+03	1.315e+04	4.112e+00	1.813e+01

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 105 MeV.ms7	July 20, 2016	2:03:03 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP 24h, 105 MeV target, 0.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Cu-64	7.2004e-001	2.6641e+010	2.6886e+006	9.9480e+010
Cu-67	1.3833e-001	5.1183e+009	5.1654e+005	1.9112e+010
Ga-66	1.6714e-001	6.1842e+009	6.2411e+005	2.3092e+010
Ga-67	2.4417e-001	9.0343e+009	9.1175e+005	3.3735e+010

Na-22	8.9934e-003	3.3276e+008	3.3582e+004	1.2425e+009
Na-24	1.7714e+000	6.5543e+010	6.6146e+006	2.4474e+011
Zn-65	1.3163e-002	4.8702e+008	4.9150e+004	1.8185e+009

Buildup: The material reference is Shield 3 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	1.125e+10	0.000e+00	1.899e-23	0.000e+00	1.629e-24
0.1	4.666e+09	0.000e+00	2.132e-06	0.000e+00	3.262e-09
0.2	4.481e+09	1.065e-68	1.553e-22	1.879e-71	2.741e-25
0.3	1.486e+09	3.112e-26	9.388e-23	5.903e-29	1.781e-25
0.4	4.227e+08	1.624e-14	3.971e-14	3.164e-17	7.738e-17
0.5	1.697e+10	8.552e-08	2.522e-07	1.679e-10	4.951e-10
0.6	2.761e+07	6.381e-08	2.055e-07	1.245e-10	4.011e-10
0.8	4.029e+08	4.608e-04	1.735e-03	8.764e-07	3.300e-06
1.0	2.696e+09	7.401e-02	3.036e-01	1.364e-04	5.597e-04
1.5	6.628e+10	6.944e+01	3.058e+02	1.168e-01	5.144e-01
2.0	6.781e+08	2.859e+00	1.282e+01	4.421e-03	1.983e-02
3.0	6.720e+10	8.681e+02	3.828e+03	1.178e+00	5.193e+00
4.0	4.518e+08	8.646e+00	3.706e+01	1.070e-02	4.584e-02
5.0	9.334e+07	2.004e+00	9.135e+00	2.298e-03	1.047e-02
Totals	1.771e+11	9.511e+02	4.193e+03	1.312e+00	5.785e+00

105 MeV 2.8 days

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 105 MeV_2.8d.ms7	July 20, 2016	2:09:26 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP 24h, 105 MeV target, 2.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Cu-64	1.0817e+000	4.0022e+010	4.0390e+006	1.4944e+011
Cu-67	3.7755e-001	1.3969e+010	1.4098e+006	5.2162e+010
Ga-66	2.1979e-001	8.1321e+009	8.2069e+005	3.0366e+010

Ga-67	7.2362e-001	2.6774e+010	2.7020e+006	9.9975e+010
Na-22	3.2976e-002	1.2201e+009	1.2313e+005	4.5559e+009
Na-24	2.8699e+000	1.0619e+011	1.0716e+007	3.9651e+011
Zn-65	4.5870e-002	1.6972e+009	1.7128e+005	6.3373e+009

Buildup: The material reference is Shield 3 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	2.488e+10	0.000e+00	4.200e-23	0.000e+00	3.602e-24
0.1	1.355e+10	0.000e+00	6.193e-06	0.000e+00	9.474e-09
0.2	1.270e+10	3.016e-68	4.400e-22	5.323e-71	7.766e-25
0.3	4.394e+09	9.203e-26	2.776e-22	1.746e-28	5.266e-25
0.4	1.238e+09	4.758e-14	1.164e-13	9.271e-17	2.267e-16
0.5	2.553e+10	1.287e-07	3.796e-07	2.526e-10	7.450e-10
0.6	5.494e+07	1.270e-07	4.090e-07	2.478e-10	7.982e-10
0.8	5.504e+08	6.295e-04	2.370e-03	1.197e-06	4.508e-06
1.0	4.081e+09	1.121e-01	4.597e-01	2.065e-04	8.473e-04
1.5	1.080e+11	1.131e+02	4.981e+02	1.903e-01	8.380e-01
2.0	8.917e+08	3.759e+00	1.686e+01	5.813e-03	2.607e-02
3.0	1.083e+11	1.400e+03	6.171e+03	1.899e+00	8.373e+00
4.0	6.070e+08	1.161e+01	4.978e+01	1.437e-02	6.158e-02
5.0	1.227e+08	2.636e+00	1.201e+01	3.022e-03	1.377e-02
Totals	3.049e+11	1.531e+03	6.749e+03	2.112e+00	9.313e+00

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 105 MeV_2.8d.ms7	July 20, 2016	2:07:50 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP EOB, 105 MeV target, 2.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Cu-64	4.0080e+000	1.4830e+011	1.4966e+007	5.5374e+011
Cu-67	4.9400e-001	1.8278e+010	1.8446e+006	6.8251e+010
Ga-66	1.2900e+000	4.7730e+010	4.8169e+006	1.7823e+011

Ga-67	8.9500e-001	3.3115e+010	3.3420e+006	1.2365e+011
Na-22	3.3000e-002	1.2210e+009	1.2322e+005	4.5593e+009
Na-24	8.7000e+000	3.2190e+011	3.2486e+007	1.2020e+012
Zn-65	4.6000e-002	1.7020e+009	1.7177e+005	6.3553e+009

Buildup: The material reference is Shield 3 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	5.447e+10	0.000e+00	9.194e-23	0.000e+00	7.886e-24
0.1	1.699e+10	0.000e+00	7.765e-06	0.000e+00	1.188e-08
0.2	1.619e+10	3.847e-68	5.611e-22	6.789e-71	9.904e-25
0.3	5.442e+09	1.140e-25	3.439e-22	2.162e-28	6.523e-25
0.4	1.576e+09	6.056e-14	1.481e-13	1.180e-16	2.886e-16
0.5	1.080e+11	5.443e-07	1.605e-06	1.068e-09	3.151e-09
0.6	1.673e+08	3.867e-07	1.245e-06	7.547e-10	2.431e-09
0.8	3.059e+09	3.498e-03	1.317e-02	6.654e-06	2.505e-05
1.0	1.976e+10	5.426e-01	2.226e+00	1.000e-03	4.103e-03
1.5	3.259e+11	3.415e+02	1.504e+03	5.746e-01	2.530e+00
2.0	5.234e+09	2.206e+01	9.896e+01	3.412e-02	1.530e-01
3.0	3.349e+11	4.327e+03	1.908e+04	5.870e+00	2.589e+01
4.0	3.369e+09	6.447e+01	2.763e+02	7.976e-02	3.419e-01
5.0	7.204e+08	1.547e+01	7.051e+01	1.774e-02	8.083e-02
Totals	8.958e+11	4.771e+03	2.103e+04	6.577e+00	2.899e+01

55 MeV, 0.8 days

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 50.5 MeV 0.8.ms7	July 20, 2016	2:16:07 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP 24 h, 50.5 MeV target, 0.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Cu-64	2.1752e-001	8.0483e+009	8.1224e+005	3.0053e+010
Cu-67	1.1846e-001	4.3831e+009	4.4234e+005	1.6367e+010
Ga-66	6.3500e-001	2.3495e+010	2.3711e+006	8.7731e+010

Ga-67	5.0370e-001	1.8637e+010	1.8809e+006	6.9592e+010
Na-22	1.7987e-002	6.6551e+008	6.7164e+004	2.4851e+009
Na-24	9.7314e-001	3.6006e+010	3.6337e+006	1.3445e+011
Zn-65	2.9915e-002	1.1069e+009	1.1170e+005	4.1330e+009

Buildup: The material reference is Shield 3 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	1.708e+10	0.000e+00	2.882e-23	0.000e+00	2.472e-24
0.1	8.198e+09	0.000e+00	3.747e-06	0.000e+00	5.732e-09
0.2	6.230e+09	1.480e-68	2.159e-22	2.612e-71	3.811e-25
0.3	3.016e+09	6.317e-26	1.906e-22	1.198e-28	3.615e-25
0.4	8.704e+08	3.344e-14	8.178e-14	6.515e-17	1.593e-16
0.5	3.006e+10	1.515e-07	4.470e-07	2.975e-10	8.773e-10
0.6	8.530e+07	1.971e-07	6.349e-07	3.847e-10	1.239e-09
0.8	1.509e+09	1.726e-03	6.497e-03	3.282e-06	1.236e-05
1.0	9.865e+09	2.708e-01	1.111e+00	4.992e-04	2.048e-03
1.5	3.774e+10	3.954e+01	1.741e+02	6.652e-02	2.929e-01
2.0	2.576e+09	1.086e+01	4.871e+01	1.679e-02	7.533e-02
3.0	4.260e+10	5.503e+02	2.426e+03	7.465e-01	3.292e+00
4.0	1.580e+09	3.023e+01	1.296e+02	3.740e-02	1.603e-01
5.0	3.546e+08	7.615e+00	3.471e+01	8.730e-03	3.979e-02
Totals	1.618e+11	6.388e+02	2.815e+03	8.765e-01	3.862e+00

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 50.5 MeV 0.8.ms7	July 20, 2016	2:15:12 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP EOB, 50.5 MeV target, 0.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Cu-64	8.0600e-001	2.9822e+010	3.0096e+006	1.1136e+011
Cu-67	1.5500e-001	5.7350e+009	5.7878e+005	2.1415e+010
Ga-66	3.7270e+000	1.3790e+011	1.3917e+007	5.1492e+011

Ga-67	6.2300e-001	2.3051e+010	2.3263e+006	8.6073e+010
Na-22	1.8000e-002	6.6600e+008	6.7213e+004	2.4869e+009
Na-24	2.9500e+000	1.0915e+011	1.1015e+007	4.0757e+011
Zn-65	3.0000e-002	1.1100e+009	1.1202e+005	4.1448e+009

Buildup: The material reference is Shield 3 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	4.538e+10	0.000e+00	7.660e-23	0.000e+00	6.570e-24
0.1	1.021e+10	0.000e+00	4.667e-06	0.000e+00	7.140e-09
0.2	7.859e+09	1.867e-68	2.724e-22	3.295e-71	4.807e-25
0.3	3.732e+09	7.818e-26	2.358e-22	1.483e-28	4.474e-25
0.4	1.200e+09	4.609e-14	1.127e-13	8.980e-17	2.196e-16
0.5	1.643e+11	8.279e-07	2.442e-06	1.625e-09	4.793e-09
0.6	3.926e+08	9.074e-07	2.922e-06	1.771e-09	5.704e-09
0.8	8.737e+09	9.991e-03	3.762e-02	1.900e-05	7.155e-05
1.0	5.516e+10	1.515e+00	6.213e+00	2.792e-03	1.145e-02
1.5	1.160e+11	1.215e+02	5.351e+02	2.045e-01	9.002e-01
2.0	1.512e+10	6.374e+01	2.859e+02	9.857e-02	4.421e-01
3.0	1.480e+11	1.911e+03	8.429e+03	2.593e+00	1.144e+01
4.0	9.209e+09	1.762e+02	7.552e+02	2.180e-01	9.343e-01
5.0	2.081e+09	4.470e+01	2.037e+02	5.124e-02	2.335e-01
Totals	5.873e+11	2.319e+03	1.021e+04	3.168e+00	1.396e+01

50.5 MeV, 2.8 days

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 50.5 MeV 2.8.ms7	July 20, 2016	2:20:02 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP 24h, 50.5 MeV target, 2.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Cu-64	3.2655e-001	1.2082e+010	1.2194e+006	4.5116e+010
Cu-67	3.2405e-001	1.1990e+010	1.2100e+006	4.4771e+010
Ga-66	8.3468e-001	3.0883e+010	3.1167e+006	1.1532e+011

Ga-67	1.4440e+000	5.3428e+010	5.3920e+006	1.9950e+011
Na-22	6.1955e-002	2.2923e+009	2.3134e+005	8.5596e+009
Na-24	1.5768e+000	5.8342e+010	5.8879e+006	2.1785e+011
Zn-65	1.0470e-001	3.8740e+009	3.9096e+005	1.4466e+010

Buildup: The material reference is Shield 3 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	4.031e+10	0.000e+00	6.803e-23	0.000e+00	5.835e-24
0.1	2.337e+10	0.000e+00	1.068e-05	0.000e+00	1.634e-08
0.2	1.758e+10	4.177e-68	6.093e-22	7.371e-71	1.075e-24
0.3	8.641e+09	1.810e-25	5.460e-22	3.433e-28	1.036e-24
0.4	2.453e+09	9.424e-14	2.305e-13	1.836e-16	4.491e-16
0.5	4.267e+10	2.151e-07	6.344e-07	4.222e-10	1.245e-09
0.6	1.483e+08	3.428e-07	1.104e-06	6.691e-10	2.155e-09
0.8	2.024e+09	2.314e-03	8.713e-03	4.402e-06	1.657e-05
1.0	1.419e+10	3.897e-01	1.599e+00	7.184e-04	2.947e-03
1.5	6.204e+10	6.500e+01	2.862e+02	1.094e-01	4.816e-01
2.0	3.386e+09	1.428e+01	6.403e+01	2.208e-02	9.902e-02
3.0	6.699e+10	8.654e+02	3.816e+03	1.174e+00	5.177e+00
4.0	2.084e+09	3.988e+01	1.709e+02	4.933e-02	2.115e-01
5.0	4.661e+08	1.001e+01	4.562e+01	1.148e-02	5.230e-02
Totals	2.864e+11	9.949e+02	4.384e+03	1.367e+00	6.024e+00

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
BLIP EOB 50.5 MeV 2.8.ms7	July 20, 2016	2:19:09 PM	00:00:00

Project Info	
Case Title	Zn disk at BLIP
Description	Dose rate at BLIP EOB, 50.5 MeV target, 2.8 d
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.051 cm (0.0 in)
Radius	1.295 cm (0.5 in)

Dose Points			
A	X	Y	Z
#1	0.0 cm (0.0 in)	78.74 cm (2 ft 7.0 in)	0.0 cm (0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	.016 in³	Zinc	7.12
Shield 1	12.0 in	Air	0.00122
Shield 2	.5 in	Stainless steel	8
Shield 3	6.0 in	Lead	11.34
Shield 4	.5 in	Stainless steel	8
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: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Cu-64	1.2100e+000	4.4770e+010	4.5182e+006	1.6717e+011
Cu-67	4.2400e-001	1.5688e+010	1.5832e+006	5.8580e+010
Ga-66	4.8990e+000	1.8126e+011	1.8293e+007	6.7684e+011

Ga-67	1.7860e+000	6.6082e+010	6.6690e+006	2.4675e+011
Na-22	6.2000e-002	2.2940e+009	2.3151e+005	8.5659e+009
Na-24	4.7800e+000	1.7686e+011	1.7849e+007	6.6040e+011
Zn-65	1.0500e-001	3.8850e+009	3.9207e+005	1.4507e+010

Buildup: The material reference is Shield 3 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	8.217e+10	0.000e+00	1.387e-22	0.000e+00	1.190e-23
0.1	2.910e+10	0.000e+00	1.330e-05	0.000e+00	2.035e-08
0.2	2.216e+10	5.265e-68	7.681e-22	9.293e-71	1.356e-24
0.3	1.069e+10	2.240e-25	6.757e-22	4.249e-28	1.282e-24
0.4	3.197e+09	1.228e-13	3.004e-13	2.393e-16	5.852e-16
0.5	2.205e+11	1.112e-06	3.278e-06	2.182e-09	6.435e-09
0.6	5.609e+08	1.296e-06	4.175e-06	2.530e-09	8.149e-09
0.8	1.153e+10	1.319e-02	4.966e-02	2.509e-05	9.446e-05
1.0	7.374e+10	2.025e+00	8.306e+00	3.732e-03	1.531e-02
1.5	1.873e+11	1.962e+02	8.640e+02	3.301e-01	1.454e+00
2.0	1.988e+10	8.379e+01	3.758e+02	1.296e-01	5.812e-01
3.0	2.278e+11	2.943e+03	1.298e+04	3.993e+00	1.761e+01
4.0	1.213e+10	2.320e+02	9.945e+02	2.870e-01	1.230e+00
5.0	2.736e+09	5.875e+01	2.678e+02	6.735e-02	3.070e-01
Totals	9.035e+11	3.516e+03	1.549e+04	4.811e+00	2.120e+01