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
Full scale irradiation of Scandium target in Inconel cladding Target Submission Number: TS-16-05_____ [D. Medvedev]

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]	3
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]	7
c. Thermal Analysis of Target Materials and Target Can [provide full description of data to specialist for calculations and any	8

assumption made on material for calculations]	
d. Transport and Processing at TPL [provide description of task involved if different from C-AD OPM 19.17.30 BLIP Target Transfer Procedure]	8
e. Disposal of waste [describe waste to be generated and how it will be disposed of]	8
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]	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]	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) **Appendix 3 –** Thermal studies Appendix 4 – Microshield reports [provide additional supporting information as required]	11-22

1. Overview

The purpose of this experiment is to irradiate a full size Sc (Scandium) target in the low energy slot at BLIP. After Sc target failure in FY2015 (TGT_15_04) followed by investigation and critique it was concluded that the failure was mainly due to chemical incompatibility of the target cladding (Cu) and target material (Sc) at high temperatures. A thin Sc target (Tgt_15_08) in aluminium cladding was irradiated for 1 week in 2015 aiming to produce Ti-44 for chemistry development. The results indicated that a thicker target is required to improve yield of Ti-44 and also stop the beam fully.

Based on experience from Los Alamos group which successfully irradiated Sc target at 250 µA at a beam stop position, we changed the Sc cladding target material to Inconel. The target is designed to stop the beam. The current on the target should be increased stepwise, followed by visual inspection after each current increase. See section 5a for more information.

The following safety submission includes thermal analysis for three beam current values through the Sc target:

Conditions

- 1. Steady state average current = 110 µA, 3975 Watts total
- 2. Steady state average current = 135 µA, 4878 Watts total
- 3. Steady state average current = 150 µA, 5420 Watts total
- 4 targets, (5) .20" water gaps
  - Box 2, 14.0 gpm total (case 1)
  - Box 1, 22.5 gpm total (cases 2 & 3)
- Raster 12.5 mm / 5.5 mm (4:1)
- Beam 10.5 FWHM

This analysis will cover irradiation of the Sc target in the following arrays as long as incident energy on Sc target does not exceed 36 +/-1.0 MeV as calculated by SRIM/LET. The reduction of the current due to proton death estimated based on MCNPX calculations (Appendix 3, end)

1) Irradiation of Sc target in low energy slot (beam stop) Box 1 in tandem with RbCl targets at incident energy 117 MeV at 150 uA (layer 10 of C-AD OPM 19.17.20.a, http://www.c-ad.bnl.gov/esshq/snd/opm/Ch19/19-17-20-a.PDF)
2) Irradiation of Sc target in low energy slot in Box 2 behind RbCl targets in Th array at incident energy 200 MeV, current through Sc is 110 µA (layer 31 of CAD OPM 19.17.20.au, http://www.c-ad.bnl.gov/esshq/snd/opm/Ch19/19-17-20-au.PDF)
3) irradiation in low energy slot in Box 2 behind RbCl targets in physics arrays (aka Nick Simos arrays) at incident 160 MeV or 200 MeV (layer 49 CAD OPM 19.17.20.f, http://www.c-ad.bnl.gov/esshq/snd/opm/Ch19/19-17-20-f.PDF)

   The loading tables (LT) will be provided once irradiations scheduled. Only generic loading table is provided in this safety submission reflecting scenario 1)

2. Target Material and Properties

Target Name:	*To be determined*	**Target Submission No.** *Assign unique no.* (year-00x)	TS-16-05

Target Material Properties				
Purity or Grade	99.99% (Sc/TREM) – Scandium metal target			
Chemical Formula	Sc			
Physical Characteristics at 21 ºC	**solid**			
Physical Form (foil, disk, pressed pellet…)	**disk**			
Target dimensions (inches/mm)	**Diameter**	**2.375/60.33**	**Thickness**	**0.196/4.98**
Elements (%)	**Scandium, 99.99%**			
Melting Point	**1541**			**ºC**
Boiling Point	**2836**			**ºC**
Decomposition temperature	**Does not decompose (stable)**			**ºC**
Thermal Conductivity	**15.8 $W.m^{-1}.K^{-1}$**	**Temperature dependence**	*(if available)* n/a	
Density	**2.99**		**g/cm^3**	

Target Material Reactions / Properties						
Does the Target material react with the following or any other material?	**Aluminium**	**no**	**Air**	**tarnishes**	**Copper**	**Yes at 800 C**
	H_2O	**slowly**	**S/Steel**	**no**		
	Inconel 600	**no**	**CO_2**	**no**		

Canning Material Properties				
Chemical Formula	**Inconel**			
Can Window Thickness (inches/mm)	**0.012/0.3048**			
Can Dimensions (inches/mm)	**Diameter: 2.750/69.85**		**Thickness:0.220/5.59**	
Melting Point			**1290-1350**	**ºC**
Thermal Conductivity	**9.8 $W.m^{-1}.K^{-1}$**	**Temperature dependence**	*(if available)* 9.8 at 21^0C, 13.7 at 416^0C	
Density	**8.43**	**g/cm^3**		

3. Target Canning Process

The target will be laser welded at EB industries under Helium atmosphere

4. Beam Characteristics		
Beam pattern (rastered/focused)	**Rastered**	
Incident LINAC energy	**117, 160, 200**	**MeV**
Energy on Target Material	**34.4**	**MeV**
Maximum Instantaneous Current permitted	**150**	**µA**
Average Current Desired	**110-150**	**µA**
Total Integrated Charge Desired	**At least 25200**	**µA-hrs**

5. Experiment Description

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

The target shall be irradiated at in the low energy slot. Follow CAD OPM 19.17.20 to install or remove the target.

Initial irradiation start up sequence:

step	Beam current	Time of irradiation
1	~50 µA	10 min
2	Visual inspection	
3	~100 µA	10 min
4	Visual inspection	
5	~130 µA	10 min
6	Visual inspection	
7	<150 µA	60 min
8	Visual inspection	
9	<150 µA	As scheduled
10	Visual inspection at close of business and in 24 hours from Start of B-nt	
11	<150 µA	As scheduled
12	Visual inspection during target change	

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

Target array is given in the Appendix 1. Briefly, the target array is the same as OPM 19.17.20 a, except the Cu beam stop is replaced by the Sc target.

It is permissible to run this target at the low energy slot in any research array (Th array for example) as

long as the following conditions are met: 1)the Sc target is located behind two RbCl production targets in Box 2 and 2)the incident LINAC current does not exceed 135 µA.

The change in the irradiation conditions (beam current 150 uA when in Box 1 vs 135 uA when in Box 2) is caused by a reduced water flow in the Box 2.

The current limitations will be reviewed once practical experience with this target design is obtained.

Updated Loading Table will be provided

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

Thermal analysis is given in Appendix 3. The conclusions are below:

Conclusions

- 110 uA is safe
- 135 uA is safe
- 150 uA is the maximum condition that this target can be irradiated.
  - This is a peak condition, not an average. Short excursions above 150 uA are not acceptable.

Performed by: Chris Cullen **Date:** 04/21/2016 **Checked by:** S. Belavia **Date:**05/27/2016

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

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

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 of the target can is negligible compared to the activation of the target material. Activation of target material is given for 7 days and 240 days

Isotope	Z	Half life	7 days at 150 uA		240 days at 150 uA	
			A^{EOB}, Ci	A^{24h}, Ci	A^{EOB}, Ci	A^{24h}, Ci
ti	44	60 years	2.22E-03	2.22E-03	7.58E-02	7.58E-02
sc	46	83.79 d	1.05E-01	1.04E-01	1.60E+00	1.59E+00
sc	44	3.97h	1.43E+02	2.3373	1.43E+02	2.45E+00
ti	45	184.8 m	1.05E+01	4.74E-02	1.05E+01	4.74E-02
sc	43	3.891 h	6.18E+00	8.59E-02	6.18E+00	8.59E-02
sc	44m	58.61 h	3.42E-01	2.57E-01	3.97E-01	2.99E-01
k	42	12.321 h	2.10E-01	5.47E-02	2.10E-01	5.47E-02
k	43	22.3 h	6.52E-02	3.12E-02	6.55E-02	3.14E-02

Decay Requirements

none

7. Expected Dose Rate

Exposure rate to BLIP operator, mR/h			
7 days at 150 uA		240 days at 150 uA	
EOB	24 hours	EOB	24 hours
5.59	0.10	5.63	0.15

See Appendix 4 for Microshield reports

8. Additional Safety Requirements

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

Nuclide	Half life	Eγ (abundance, %)
Sc-46	83.79 d	889.3 keV (99.98%);1120.5 keV (99.99%)
Sc-44	3.97 h	1157.02 (99.9%)

9. Special Operating Instructions

Supporting Documentation

References	

Appendix 1

Target Array and Energy Propagation Calculations

TITLE: **Full scale irradiation of Scandium target in Inconel cladding**

Target Array Number: **TS-16-05**_____

Preparer: Medvedev_____

2016	Energy: 116.5 MeV	rastered beam						
				thickness				
layer number	Layer	Material	density	inches	mm	Ei	Eout	E deposited, MeV
1	Be window	Berillium	1.85	0.012	0.305	116.50	116.20	0.30
2	AlBeMet window	AlBeMet	2.10	0.012	0.305	116.20	115.86	0.34
3	Beamline window	stainless steel	7.99	0.031	0.787	115.86	113.00	2.86
4	water gap	water	1.00	0.106	2.692	113.00	111.18	1.81
5	BOX front window	stainless steel	7.99	0.020	0.508	111.18	109.26	1.92
6	water gap	water	1.00	0.200	5.080	109.26	105.72	3.54
7	stainless steel	stainless steel	7.99	0.029	0.737	105.72	102.83	2.89
8	vacuum		0.00	0.596	15.138	102.83	102.83	0.00
9	stainless steel	stainless steel	7.99	0.029	0.737	102.83	99.88	2.95
10	water gap	water	1.00	0.200	5.080	99.88	96.09	3.79
11	can window	inconel	8.43	0.012	0.305	96.09	94.71	1.38
12	RbCl salt	RbCl	2.20	0.646	16.398	94.71	75.01	19.70
13	can window	inconel	8.43	0.012	0.305	75.01	73.36	1.65
14	water gap	water	1.00	0.200	5.080	73.36	68.52	4.84
15	can window	inconel	8.43	0.012	0.305	68.52	66.75	1.77
16	RbCl salt	RbCl	2.20	0.500	12.701	66.75	46.09	20.66
17	can window	inconel	8.43	0.012	0.305	46.09	43.70	2.39
18	water gap	water	1.00	0.200	5.080	43.70	36.13	7.56
19	Can window	Inconel	8.43	0.012	0.305	36.13	34.36	1.77
20	Sc metal	Sc	2.99	0.196	4.979	34.36	6.14	28.22
21	Can window	Inconel	8.43	0.012	0.305	6.14	stop	6.14
22	water gap	water	1.00	0.200	5.080	0.00	0.00	0.00

RSC Approval:	**Date Approved:**

Appendix 2

Target Loading Table

Title Full scale irradiation of Scandium target in Inconel cladding

Target Array Number: **TA 16-05**_____

Preparer: Medvedev

Proposed Run Time (e.g. days, hrs.): minimum 7 or longer as scheduled

Desired Completion Date: July 1

Requested Beam Energy (MeV): 117 MeV

Requested Beam Current (µA): 150 uA

	Item	Type and stamped ID (*if available*)	Layer #'s from "Target Array and Energy Propagation Calculations"	Thickness *inch*	Thickness *mm*	BLIP Operator *(Initial)*	Witness *(Initial)*
Box 1	Water gap	n/a	6	0.200	5.04		
	SS vacuum degrader		7-9	0.654	16.61		
	Water gap	n/a	10	0.200	5.04		
	RbCl1		11-13	0.670	17.02		
	Water gap	n/a	14	0.200	5.04		
	RbCl2		15-17	0.524	13.31		
	Water gap	n/a	19	0.200	5.04		
	Sc target		19-21	0.220	5.59		
	Water gap	n/a	22	0.200	5.04		

RSC Approval:

Date Approved:

Appendix 3

Thermal studies

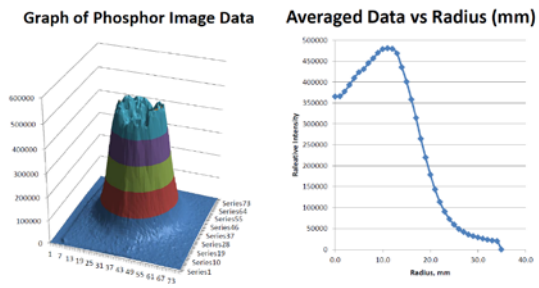
Conditions

- 1. Steady state average current = 135 µA, 4878 Watts total
- 2. Steady state average current = 150 µA, 5420 Watts total
- 116 MeV
- 4 targets, (5) .20" water gaps, 22.5 gpm total
- Raster 12.5 mm / 5.5 mm (4:1)
- Beam 10.5 FWHM

Finite Element Model

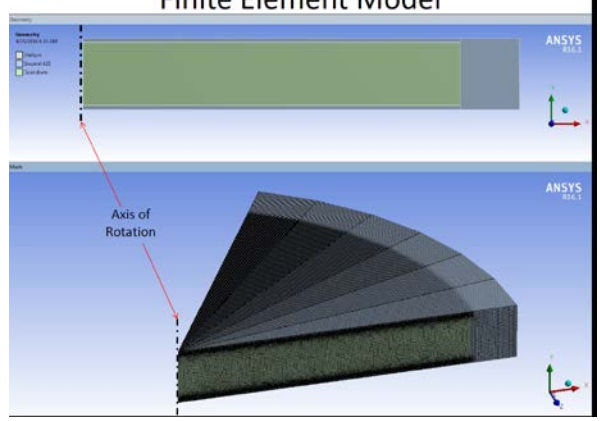
- 2D axi-symmetric model
- (1) x .012" thick Inconel window, upstream
- (1) x .196" thick Scandium
- (1) x .012" thick Inconel window, downstream
- Steady-state analysis
- Steady state water cooling on exterior
- Internal heat generation for all bodies

Steady State Raster Particle Distribution

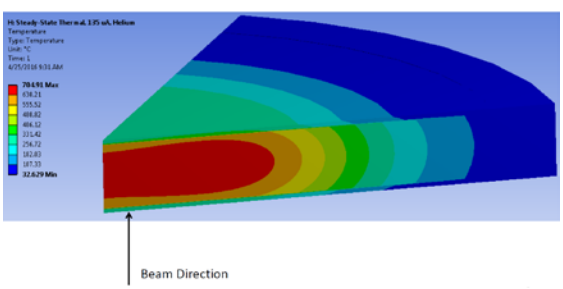


Ref 032516.xls

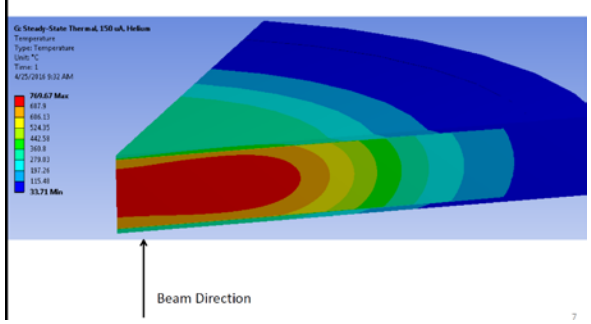
Finite Element Model



Target Temperature Profile, 135 uA



Target Temperature Profile, 150 uA



Summary, 135 µA

- Maximum Scandium temperature = 705°C
- Sc melting temperature = 1541 °C
- Maximum Inconel temperature = 357°C
- Inconel melting temperature = 1290 °C
- Maximum heat flux to water = 195 W/cm^2
- Bernath Correlation critical heat flux = 241 W/cm^2 (217 W/cm^2 with standard 10% safety factor)

Summary, 150 µA

- Maximum Scandium temperature = 770°C
- Sc melting temperature = 1541 °C
- Maximum Inconel temperature = 393°C
- Inconel melting temperature = 1290 °C
- Maximum heat flux to water = 217 W/cm^2
- Bernath Correlation critical heat flux = 241 W/cm^2 (217 W/cm^2 with standard 10% safety factor)

Conclusions

- 135 uA is safe
- 150 uA is the maximum condition that this target can be irradiated.
  - This is a peak condition, not an average. Short excursions above 150 uA are not acceptable.

Reference Slides

- Files
  - D:\Jobs - Active\BLIP\Target Analyses\FY 16\Scandium\12_5 4x 5_51x 11 FWHM 032516 Phosphor.csv
  - D:\Jobs - Active\BLIP\Target Analyses\FY 16\Scandium\Sc Thermal with Raster.wbpj
    - Case G, Steady-State Thermal, 150 uA, Helium
    - Case H, Steady-State Thermal, 135 uA, Helium
  - D:\Jobs - Active\BLIP\Target Analyses\FY 16\Scandium\FY2016 RbCl energy propagation_raster_Cu stop_02_24.xlsx
    - Sheet summary Sc stop

Calculation of the fraction of the protons surviving upon traveling through 200 MeV target array (provided by Al Hanson)

Surface Number	Surface Description		Fraction of original beam
1	Be window	entrance	1.00E+00
2	Be window	exit	1.00E+00
10	Th foil 1	entrance	9.96E-01
11	Th foil 1	exit	9.97E-01
13	Th foil 2	entrance	9.97E-01
14	Th foil 2	exit	9.95E-01
16	Th foil 3	entrance	9.95E-01
17	Th foil 3	exit	9.94E-01
21	Cu - degrader front	entrance	9.75E-01
22	Cu - degrader front	exit	9.36E-01
23	Cu - degrader rear	entrance	9.10E-01
24	Cu - degrader rear	exit	8.71E-01
34	RbCl 1	entrance	8.21E-01
35	RbCl 1	exit	7.78E-01
38	RbCl 2	entrance	7.61E-01
39	RbCl 2	exit	6.91E-01
41	Cu - stop	entrance	4.50E-01
42	Cu - stop	exit	6.50E-05

Appendix 4

Microshield reports

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Sc puck target_nuclides_150_EOB.ms7	May 4, 2016	4:17:36 PM	00:00:00

Project Info	
Case Title	Sc puck BLIP
Description	Dose rate EOB 7 day beam 150
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.498 cm (0.2 in)
Radius	3.023 cm (1.2 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	.872 in³	Scandium	2.99
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: Excluded
Library: ICRP-38

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
K-42	2.1000e-001	7.7700e+009	1.4697e+004	5.4378e+008
K-43	6.5200e-002	2.4124e+009	4.5630e+003	1.6883e+008
Sc-43	6.1800e+000	2.2866e+011	4.3250e+005	1.6003e+010

Sc-44	1.4300e+002	5.2910e+012	1.0008e+007	3.7029e+011
Sc-44m	3.4200e-001	1.2654e+010	2.3935e+004	8.8558e+008
Sc-46	1.0500e-001	3.8850e+009	7.3483e+003	2.7189e+008
Ti-44	2.2200e-003	8.2140e+007	1.5536e+002	5.7485e+006
Ti-45	1.0500e+001	3.8850e+011	7.3483e+005	2.7189e+010

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
0.06	7.204e+07	0.000e+00	5.997e-25	0.000e+00	1.191e-27
0.08	7.779e+07	3.301e-159	9.677e-25	5.224e-162	1.531e-27
0.15	8.214e+04	8.758e-146	4.666e-26	1.442e-148	7.683e-29
0.2	1.055e+08	4.003e-69	3.949e-24	7.065e-72	6.969e-27
0.3	1.098e+10	2.003e-24	7.494e-22	3.800e-27	1.421e-24
0.4	1.739e+11	4.405e-11	1.066e-10	8.584e-14	2.076e-13
0.5	1.101e+13	3.062e-04	8.853e-04	6.011e-07	1.738e-06
0.6	2.209e+09	2.470e-05	7.745e-05	4.820e-08	1.512e-07
0.8	4.490e+09	2.055e-02	7.419e-02	3.909e-05	1.411e-04
1.0	5.289e+12	5.077e+02	1.971e+03	9.359e-01	3.633e+00
1.5	5.014e+10	1.480e+02	6.018e+02	2.490e-01	1.012e+00
2.0	1.441e+08	1.517e+00	6.243e+00	2.346e-03	9.654e-03
3.0	5.979e+09	1.701e+02	6.866e+02	2.307e-01	9.315e-01
Totals	**1.655e+13**	**8.274e+02**	**3.266e+03**	**1.418e+00**	**5.587e+00**

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

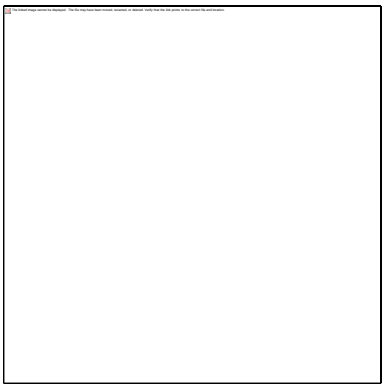
Filename	Run Date	Run Time	Duration
Sc puck target_nuclides_150_EOB.ms7	May 4, 2016	4:27:08 PM	00:00:00

Project Info	
Case Title	Sc puck BLIP
Description	Dose rate 24 h after EOB 7 day beam 150
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.498 cm (0.2 in)
Radius	3.023 cm (1.2 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	.872 in³	Scandium	2.99
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: Excluded
Library: ICRP-38

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
K-42	5.4663e-002	2.0225e+009	3.8256e+003	1.4155e+008
K-43	3.1230e-002	1.1555e+009	2.1856e+003	8.0867e+007
Sc-43	8.5943e-002	3.1799e+009	6.0146e+003	2.2254e+008
Sc-44	2.3373e+000	8.6480e+010	1.6357e+005	6.0522e+009
Sc-44m	2.5748e-001	9.5266e+009	1.8019e+004	6.6671e+008

Sc-46	1.0414e-001	3.8530e+009	7.2878e+003	2.6965e+008
Ti-44	2.2199e-003	8.2137e+007	1.5536e+002	5.7483e+006
Ti-45	4.7370e-002	1.7527e+009	3.3151e+003	1.2266e+008

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
0.06	7.203e+07	0.000e+00	5.997e-25	0.000e+00	1.191e-27
0.08	7.778e+07	3.301e-159	9.677e-25	5.224e-162	1.531e-27
0.15	8.214e+04	8.758e-146	4.666e-26	1.442e-148	7.683e-29
0.2	5.054e+07	1.917e-69	1.891e-24	3.384e-72	3.338e-27
0.3	8.256e+09	1.506e-24	5.633e-22	2.856e-27	1.069e-24
0.4	3.526e+09	8.933e-13	2.161e-12	1.741e-15	4.210e-15
0.5	1.713e+11	4.764e-06	1.377e-05	9.350e-09	2.703e-08
0.6	1.058e+09	1.183e-05	3.709e-05	2.309e-08	7.240e-08
0.8	3.858e+09	1.766e-02	6.374e-02	3.358e-05	1.212e-04
1.0	9.065e+10	8.702e+00	3.378e+01	1.604e-02	6.227e-02
1.5	1.154e+09	3.407e+00	1.385e+01	5.733e-03	2.331e-02
2.0	3.536e+06	3.723e-02	1.532e-01	5.757e-05	2.369e-04
3.0	9.772e+07	2.779e+00	1.122e+01	3.771e-03	1.522e-02
Totals	**2.801e+11**	**1.494e+01**	**5.907e+01**	**2.563e-02**	**1.012e-01**

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Sc puck target_nuclides_150_EOB.ms7	May 4, 2016	4:29:38 PM	00:00:00

Project Info	
Case Title	Sc puck BLIP
Description	Dose rate EOB 240 day beam 150
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.498 cm (0.2 in)
Radius	3.023 cm (1.2 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	.872 in³	Scandium	2.99
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: Excluded
Library: ICRP-38

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
K-42	2.1000e-001	7.7700e+009	1.4697e+004	5.4378e+008
K-43	6.5500e-002	2.4235e+009	4.5840e+003	1.6961e+008
Sc-43	6.1800e+000	2.2866e+011	4.3250e+005	1.6003e+010
Sc-44	1.4300e+002	5.2910e+012	1.0008e+007	3.7029e+011
Sc-44m	3.9700e-001	1.4689e+010	2.7784e+004	1.0280e+009

Sc-46	1.6000e+000	5.9200e+010	1.1197e+005	4.1431e+009
Ti-44	7.5800e-002	2.8046e+009	5.3048e+003	1.9628e+008
Ti-45	1.0500e+001	3.8850e+011	7.3483e+005	2.7189e+010

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
0.06	2.460e+09	0.000e+00	2.048e-23	0.000e+00	4.067e-26
0.08	2.656e+09	1.127e-157	3.304e-23	1.784e-160	5.229e-26
0.15	2.805e+06	2.990e-144	1.593e-24	4.924e-147	2.623e-27
0.2	1.060e+08	4.022e-69	3.967e-24	7.098e-72	7.001e-27
0.3	1.275e+10	2.324e-24	8.696e-22	4.409e-27	1.650e-24
0.4	1.739e+11	4.406e-11	1.066e-10	8.584e-14	2.076e-13
0.5	1.101e+13	3.062e-04	8.853e-04	6.011e-07	1.738e-06
0.6	2.219e+09	2.481e-05	7.780e-05	4.843e-08	1.519e-07
0.8	5.980e+10	2.737e-01	9.879e-01	5.205e-04	1.879e-03
1.0	5.345e+12	5.131e+02	1.992e+03	9.457e-01	3.671e+00
1.5	5.014e+10	1.480e+02	6.018e+02	2.490e-01	1.012e+00
2.0	1.441e+08	1.517e+00	6.243e+00	2.346e-03	9.654e-03
3.0	5.979e+09	1.701e+02	6.866e+02	2.307e-01	9.315e-01
Totals	**1.667e+13**	**8.329e+02**	**3.287e+03**	**1.428e+00**	**5.627e+00**

MicroShield 7.02
BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Sc puck target_nuclides_150_EOB.ms7	May 4, 2016	4:30:39 PM	00:00:00

Project Info	
Case Title	Sc puck BLIP
Description	Dose rate 24 h after EOB 240 day beam 150
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.498 cm (0.2 in)
Radius	3.023 cm (1.2 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	.872 in³	Scandium	2.99
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: Excluded
Library: ICRP-38

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
K-42	5.4663e-002	2.0225e+009	3.8256e+003	1.4155e+008
K-43	3.1374e-002	1.1608e+009	2.1956e+003	8.1239e+007
Sc-43	8.5943e-002	3.1799e+009	6.0146e+003	2.2254e+008
Sc-44	2.4527e+000	9.0751e+010	1.7165e+005	6.3511e+009
Sc-44m	2.9888e-001	1.1059e+010	2.0917e+004	7.7393e+008

Sc-46	1.5868e+000	5.8713e+010	1.1105e+005	4.1089e+009
Ti-44	7.5797e-002	2.8045e+009	5.3046e+003	1.9627e+008
Ti-45	4.7370e-002	1.7527e+009	3.3151e+003	1.2266e+008

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
0.06	2.460e+09	0.000e+00	2.048e-23	0.000e+00	4.067e-26
0.08	2.656e+09	1.127e-157	3.304e-23	1.784e-160	5.229e-26
0.15	2.804e+06	2.990e-144	1.593e-24	4.924e-147	2.623e-27
0.2	5.077e+07	1.926e-69	1.900e-24	3.400e-72	3.353e-27
0.3	9.583e+09	1.748e-24	6.538e-22	3.315e-27	1.240e-24
0.4	3.531e+09	8.947e-13	2.164e-12	1.743e-15	4.217e-15
0.5	1.793e+11	4.988e-06	1.442e-05	9.790e-09	2.830e-08
0.6	1.063e+09	1.188e-05	3.727e-05	2.319e-08	7.274e-08
0.8	5.871e+10	2.687e-01	9.700e-01	5.111e-04	1.845e-03
1.0	1.498e+11	1.438e+01	5.583e+01	2.651e-02	1.029e-01
1.5	1.193e+09	3.522e+00	1.432e+01	5.926e-03	2.409e-02
2.0	3.655e+06	3.848e-02	1.584e-01	5.951e-05	2.449e-04
3.0	1.026e+08	2.917e+00	1.178e+01	3.957e-03	1.598e-02
Totals	**4.085e+11**	**2.113e+01**	**8.306e+01**	**3.697e-02**	**1.451e-01**