C-A OPERATIONS PROCEDURES MANUAL

9.1.15.a BLIP Target and Canning Record

Hand Processed Changes

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

D. Beavis, S. Smith

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

Title and Preparer
Low energy slot 1 week irradiation of Scandium metal target (d×h=2.38×0.060 inch) beam welded in Aluminum can Dmitri Medvedev

Instructions

1. Overview

This document represents an amended submission for the irradiation experiment of thick Sc target. The corresponding original safety submission (TgT_15_04) can be found here: http://www.c-ad.bnl.gov/esfd/RSC/BLIP/BLIP_canning.htm. The revision of the target design was required due to the failure of the original target. The critique for the above incident can be found here: http://www.c-ad.bnl.gov/ESSHQ/SND/Critiques/Critique%20-%20BLIP%20Scandium%20Target%20Failure%20%20%20%205-27-15.pdf

While the actual cause of the target failure was not determined, the critique suggested that actual temperature of Sc metal was too high.

To reduce Sc temperature the following modification to the target design has been made:

1)The thickness of the target was reduced from 0.125 to 0.060 inches to minimize energy deposition in the Sc disk and windows

2)The canning material was replaced with Aluminum alloy to reduce energy deposition in the windows

3)The downstream window thickness was reduced from 0.083 to 0.020

The purpose of this experiment is to irradiate a full scale Sc (Scandium) target in the low energy slot at BLIP for 7 days. This experiment is performed in support of a future irradiation of the Sc metal target for 30 days. The results of this experiment provide insight into target survivability and anticipated yield of Ti-44 as well as allow comparison of the dose rate estimation calculations.

The overall purpose of these series of experiments is to assess feasibility of production of a long lived nuclide Ti-44 (T1/2=60 years) which is a parent nuclide of a short lived PET emitter Sc-44 (T1/2=3.97 h). Hence, Ti-44 and Sc-44 form a generator pair. Ti-44 will be separated from Sc and used to make a generator for Sc-44.

Before executing a long term 30 days irradiation, a 1 week short irradiation of an identical target will be carried out.

This canning record submission is only for the Sc metal target to be irradiated for 1 week. The canning record for Sc target to be irradiated for 30 days will be submitted separately.

2. Target Material and Properties

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

Target Material Properties: Scandium disk				
Purity or Grade	99.99%			
Chemical Formula	Sc			
Physical Characteristics at 70 ºF or 21 ºC	**Metal**			
Physical Form	**Foil (disk)**	**yes**	**Powder**	**n/a**
	Diameter (inches/mm)	**2.38 (60.45)**	**Thickness, mm**	**0.060 (15.20 mm)**
Elements (%)	**Sc, 99.9%**			
Melting Point	**1541**	**ºC**	**2806**	**ºF**
Boiling Point	**2836**	**ºC**	**5136**	**ºF**
Thermal Conductivity	**15.8 $W.m^{-1}.K^{-1}$**	**Temperature dependence**	***(if available)*** ***n/a***	
Density	**2.99**		**g/cm^3**	
Specific Heat	**25.52**		**J/mol.K**	

Target Material Reactions / Properties						
Does the Target material react with any of the following?	**Aluminum**	**no**	**Air**	**no**	**CO_2**	**no**
	H_2O	**no**	**Lead**	**no**	**Zinc**	**no**
	Inconel 600	**no**	**S/Steel**	**no**	**Copper**	**Yes at 600^0 C**

Canning Material Properties				
Chemical Formula	**Al**			
Can Wall Thickness (inches/mm)				
Can Dimensions (inches/mm)	**Can Diameter 2.75 (69.85)**		**Can Width 0.220 (5.59)**	
Melting Point	**660.3**	**ºC**	**1221**	**ºF**
Thermal Conductivity	**167 $W.m^{-1}.K^{-1}$**	**Temperature dependence**	*(if available)* *n/a*	
Density	**2.7**	**g/cm^3**		
Specific Heat	**24.3**		**J/mol.K**	

3. Target Canning Process

The target will be beam-welded by EB industries, following CAD OPM 19.17.1

4. Beam Characteristics

Maximum Instantaneous Current Desired	**40**	**mA**
Average Current Desired	**Up to 120**	**µA**
Total Integrated Current Desired	**Up to 16800**	**µA - hrs**
Maximum Proton Energy on Target Material	**27 MeV**	**MeV**

5. Experiment Description

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

Irradiate target at BLIP in the low energy slot for 7 days and transport to BLIP after irradiation. Follow CAD OPM 19.17.20 to install or remove the target.

5.b Target array in Box 1

Target array is given in the Appendix 1.

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

Thermal analysis is given in appendix 2. The conclusions are given below:

Summary & Conclusion

- Maximum Aluminum temperature = 192 °C
- Aluminum melting temperature = 660 °C
- SAFE
- Maximum Scandium temperature = 528 °C
- Scandium melting temperature = 1541 °C
- SAFE

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

Target processing:

The irradiated Sc disk will be dissolved in stoichiometric excess of 2N HCl. The target solution will be subjected to ion-exchange columns. Several evaporations will be carried out. The solvent involved in processing is HCl of various concentrations. No organic or solvents potentially generating mixed waste will be used. Evaporated acid fumes will be scavenged using TPL scrubber.

5.e Disposal of waste:

Liquid waste will be neutralized 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

Nuclides and activities (in Ci) produced in 7 days of irradiation at EOB and 24 h after EOB:

Target can

The cross section for activation products of Aluminum below 27 MeV, Na-22 and Na-24 are 0 and 0.03 mbarns. Hence activation of Al can is negligible compared to Sc activation

Sc pack

Nuclide	Z	Activity EOB, Ci	Activity 24 h, Ci
sc	44	5.28E+01	8.63E-01
ti	45	3.86E+00	1.74E-02
sc	43	2.27E+00	3.17E-02
sc	44m	1.26E-01	9.48E-02
k	42	7.72E-02	2.01E-02
sc	46	3.85E-02	3.82E-02
k	43	2.40E-02	1.13E-02
k	44	6.42E-03	1.67E-22
ca	45	6.20E-03	6.18E-03
ar	37	4.44E-03	4.36E-03
cl	38	1.54E-03	1.02E-14
ti	44	8.17E-04	8.17e-04
ar	41	7.92E-04	8.17E-04
cl	39	1.86E-04	8.80E-08

The radionuclide composition of Sc pack was calculated using MCNPX code by Dr. Albert Hanson

Decay Requirements

None at BLIP.
Expected dose rate to the operator from Sc target at EOB at BLIP is 2.11 mR/h. The Microshield® report is attached (see Appendix 3). **In 24 hours the dose rate at BLIP to the operator is0.038 mR/h (see Appendix 3)**
none

9. Special Operating Instructions

none

Supporting Documentation	
References	

Appendix 1

Target array and energy propagation calculations

layer number	Layer	Material	density	inches	mm	Ei	Eout	energy deposited
1	Be window	Berillium	1.85	0.012	0.305	116.38	116.08	**0.30**
2	AlBeMet window	AlBeMet	2.10	0.012	0.305	116.08	115.74	**0.34**
3	Beamline window	stainless steel	7.99	0.031	0.787	115.74	112.87	**2.87**
4	water gap	water	1.00	0.106	2.692	112.87	111.06	**1.82**
5	BOX front window	stainless steel	7.99	0.020	0.508	111.06	109.14	**1.92**
6	cooling channel	water	1.00	0.200	5.080	109.14	105.59	**3.55**
7	slab degrader	stainless steel	7.99	0.058	1.473	105.59	99.74	**5.85**
8	cooling channel	water	1.00	0.200	5.080	99.74	95.95	**3.80**
9	can window	inconel	8.43	0.012	0.305	95.95	94.57	**1.38**
10	RbCl salt	RbCl	2.38	0.646	16.410	94.57	73.05	**21.52**
11	can window	inconel	8.43	0.012	0.305	73.05	71.36	**1.68**
12	cooling channel	water	1.00	0.200	5.080	71.36	66.41	**4.95**
13	can window	inconel	8.43	0.012	0.305	66.41	64.60	**1.81**
14	RbCl salt	RbCl	2.38	0.500	12.700	64.60	41.13	**23.48**
15	can window	inconel	8.43	0.012	0.305	41.13	38.51	**2.62**
16	cooling channel	water	1.00	0.200	5.080	38.51	29.35	**9.16**
17	Aluminum window	Al	2.70	0.020	0.508	29.35	27.31	**2.04**
18	Scandium disk	Sc	2.99	0.060	1.535	27.31	20.09	**7.22**
19	Aluminum window	Al	2.70	0.020	0.508	20.09	17.27	**2.82**
20	cooling channel	water	1.00	0.200	5.080	17.27	stop	
21	Copper spacer	Cu	8.96	0.543	13.780	stop	stop	

Appendix 2

Thermal heat load calculations for the Sc target

Scandium Target & Holder Thermal Analysis

Chris Cullen

May 10, 2015

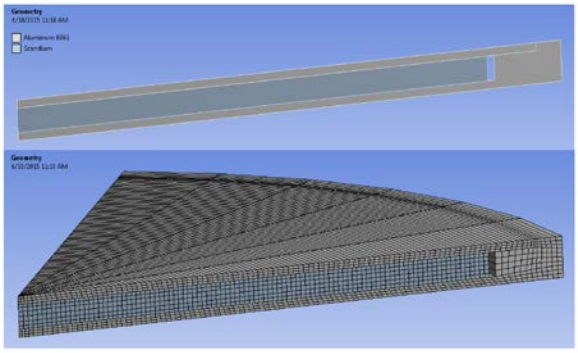
Conditions

- Steady state average current = 115 μA
- Pulse width = .000450 sec
- Pulse Frequency = 6.667 Hz
- 5 targets, (6) .20" water gaps
- 20% cooling water flow bypass assumed

Finite Element Model

- 2D Axi-symmetric model
- Aluminum Target, .100" thick assembled
- (1) x .060" thick Scandium
- (1) .020" thick Aluminum face, upstream
- (1) x .020" thick Aluminum face, downstream
- Steady-state analysis
- Thermal contact conductance between each layer=2,000 W/m^2*°C
- Steady state water cooling on exterior=5900 W/m^2*°
- Gaussian Internal heat generation for all bodies
- 1390 Watts total input

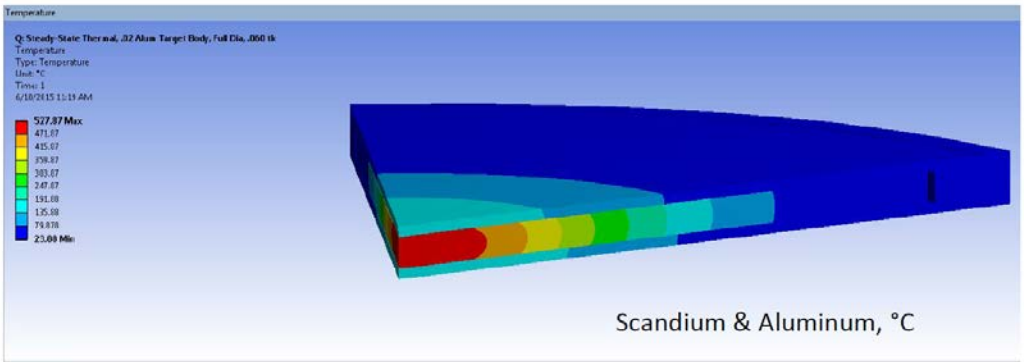
Finite Element Model



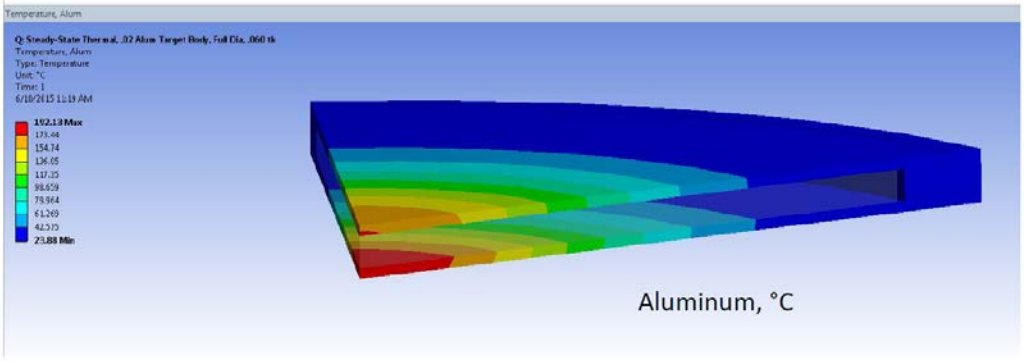
Reference Slides

- Files
  - D:\Jobs - Active\BLIP\Target Analyses\FY 15 Scandium\FY15 target arrays_big Sc_Al_can_v3.xlsx
  - D:\Jobs - Active\BLIP\Target Analyses\FY 15 Scandium\Scandium 2D SS.wbpj

Target Temperature Profile

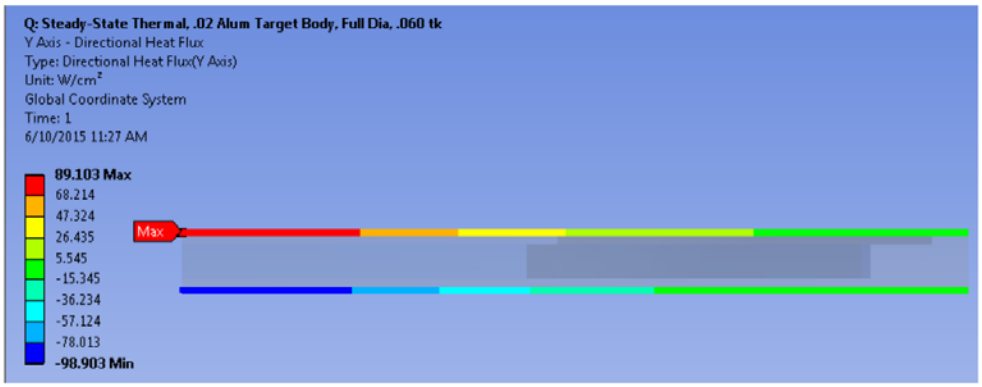


Scandium & Aluminum, °C



Aluminum, °C

Boiling Summary and Conclusion, External Heat Flux



The critical heat flux in free convection water is 132.2 W/cm^2. The maximum heat flux is 89.1 W/cm^2, so critical boiling will not occur. The target is in a forced convection environment, so this criteria is conservative.

Appendix 3

Microshield® report: dose rate at BLIP at EOB, 7 days at 115 µA

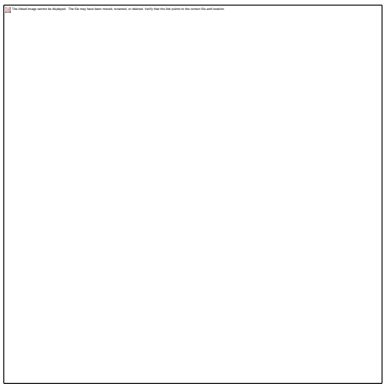
MicroShield 7.02 BNL (7.02-0000)		
Date	**By**	**Checked**

Filename	Run Date	Run Time	Duration
Sc puck target_nuclides_0.060.ms7	June 9, 2015	9:51:50 AM	00:00:00

Project Info	
Case Title	Sc puck BLIP
Description	Dose rate EOB 7 day beam_0.060 target
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	0.152 cm (0.1 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	.267 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**
Cl-38	1.5360e-003	5.6832e+007	3.5115e+002	1.2993e+007
Cl-39	7.9200e-004	2.9304e+007	1.8106e+002	6.6993e+006

K-42	7.7280e-002	2.8594e+009	1.7667e+004	6.5369e+008
K-43	2.4000e-002	8.8800e+008	5.4867e+003	2.0301e+008
K-44	6.4320e-003	2.3798e+008	1.4704e+003	5.4407e+007
Sc-43	2.2752e+000	8.4182e+010	5.2014e+005	1.9245e+010
Sc-44	5.2800e+001	1.9536e+012	1.2071e+007	4.4662e+011
Sc-44m	1.2576e-001	4.6531e+009	2.8751e+004	1.0638e+009
Sc-46	3.8500e-002	1.4245e+009	8.8017e+003	3.2566e+008
Ti-44	8.1600e-004	3.0192e+007	1.8655e+002	6.9023e+006
Ti-45	3.8544e+000	1.4261e+011	8.8117e+005	3.2603e+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	2.648e+07	0.000e+00	2.184e-25	0.000e+00	4.339e-28
0.08	2.859e+07	1.424e-159	3.525e-25	2.254e-162	5.578e-28
0.15	3.019e+04	3.449e-146	1.699e-26	5.680e-149	2.799e-29
0.2	3.884e+07	1.557e-69	1.440e-24	2.748e-72	2.542e-27
0.3	4.052e+09	7.718e-25	2.740e-22	1.464e-27	5.197e-25
0.4	6.401e+10	1.683e-11	4.071e-11	3.280e-14	7.931e-14
0.5	4.064e+12	1.168e-04	3.375e-04	2.292e-07	6.624e-07
0.6	8.186e+08	9.428e-06	2.954e-05	1.840e-08	5.767e-08
0.8	1.658e+09	7.780e-03	2.805e-02	1.480e-05	5.336e-05
1.0	1.953e+12	1.915e+02	7.424e+02	3.531e-01	1.369e+00
1.5	1.856e+10	5.568e+01	2.259e+02	9.367e-02	3.800e-01
2.0	1.382e+08	1.474e+00	6.051e+00	2.279e-03	9.358e-03
3.0	2.251e+09	6.461e+01	2.603e+02	8.766e-02	3.531e-01
4.0	1.049e+07	4.188e-01	1.640e+00	5.181e-04	2.029e-03
5.0	3.022e+06	1.310e-01	5.443e-01	1.502e-04	6.240e-04

Totals	6.109e+12	3.139e+02	1.237e+03	5.374e-01	2.114e+00

Microshield® report: dose rate at BLIP at 24 hours after EOB, 7 days at 115 µA

MicroShield 7.02 BNL (7.02-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Sc puck target_nuclides_0.060.ms7	June 9, 2015	9:52:27 AM	00:00:00

Project Info	
Case Title	Sc puck BLIP
Description	Dose rate EOB 7 day beam_0.060 target
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
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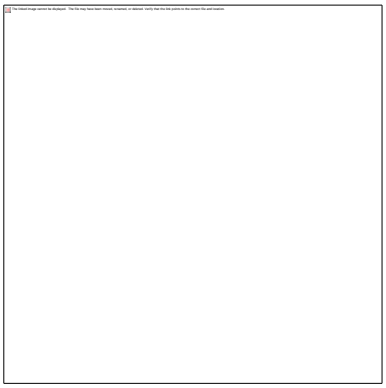

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Air Gap		Air	0.00122

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
Ar-39	3.1124e-010	1.1516e+001	7.1153e-005	2.6327e+000
Cl-38	3.4415e-015	1.2734e-004	7.8678e-010	2.9111e-005
Cl-39	1.2655e-011	4.6824e-001	2.8931e-006	1.0705e-001
K-42	2.0116e-002	7.4429e+008	4.5988e+003	1.7016e+008
K-43	1.1496e-002	4.2534e+008	2.6281e+003	9.7239e+007
K-44	1.6608e-022	6.1449e-012	3.7968e-017	1.4048e-012
Sc-43	3.1640e-002	1.1707e+009	7.2335e+003	2.6764e+008
Sc-44	8.6259e-001	3.1916e+010	1.9720e+005	7.2964e+009
Sc-44m	9.4679e-002	3.5031e+009	2.1645e+004	8.0087e+008
Sc-46	3.8183e-002	1.4128e+009	8.7292e+003	3.2298e+008
Ti-44	8.1597e-004	3.0191e+007	1.8654e+002	6.9021e+006
Ti-45	1.7389e-002	6.4338e+008	3.9753e+003	1.4709e+008

Buildup: The material reference is Shield 2 Integration Parameters	
Radial	20
Circumferential	10
Y Direction (axial)	10

Results					
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0.08	2.859e+07	1.424e-159	3.525e-25	2.254e-162	5.578e-28
0.15	3.019e+04	3.449e-146	1.699e-26	5.679e-149	2.798e-29
0.2	1.860e+07	7.457e-70	6.899e-25	1.316e-72	1.218e-27
0.3	3.036e+09	5.782e-25	2.053e-22	1.097e-27	3.894e-25
0.4	1.298e+09	3.413e-13	8.253e-13	6.650e-16	1.608e-15
0.5	6.320e+10	1.816e-06	5.248e-06	3.565e-09	1.030e-08
0.6	3.894e+08	4.485e-06	1.405e-05	8.754e-09	2.743e-08
0.8	1.415e+09	6.637e-03	2.393e-02	1.262e-05	4.552e-05
1.0	3.345e+10	3.280e+00	1.271e+01	6.046e-03	2.343e-02
1.5	4.255e+08	1.276e+00	5.178e+00	2.148e-03	8.712e-03

2.0	1.304e+06	1.390e-02	5.707e-02	2.150e-05	8.826e-05
3.0	3.607e+07	1.035e+00	4.170e+00	1.404e-03	5.657e-03
4.0	3.183e-08	1.271e-15	4.978e-15	1.573e-18	6.159e-18
5.0	7.804e-14	3.383e-21	1.406e-20	3.879e-24	1.611e-23
Totals	**1.033e+11**	**5.612e+00**	**2.214e+01**	**9.632e-03**	**3.794e-02**