C-A OPERATIONS PROCEDURES MANUAL

# 9.1.15.a BLIP Target and Canning Record

## Hand Processed Changes

| HPC No. | Date | Page Nos. | Initials |
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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 irradiation of Copper (0.005'), Titanium (0.005") and Scandium (0.010") foils welded in a copper can (Sc foil target)<br>Dmitri 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] | 5-6 |
| **3.** | **Target Canning Process –** [provide images or drawings and reference the OPM procedures for closing and opening of target can] | 7 |
| **4.** | **Beam Characteristics** [define required beam on target and total current required] | 8 |
| **5.** | **Proposed Experiment**<br>[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.] | 8-9 |
| | **a. Procedure for Irradiation of Target Material BLIP** [Summarize steps for experiment including specialist and contact hours required for task] | 8 |
| | **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] | 8 |

## 1. Overview

The purpose of this experiment is to assess effective beam current and energy in the low energy slot at BLIP. It involves irradiation of Cu, Ti and Sc foils beam-welded in a capsule made of Copper ("Sc foil target" henceforth). This experiment is performed in support of a future irradiation of a thicker Sc (scandium) metal target.

Two Sc scandium metal targets is scheduled to be irradiated in FY2015, one is for 1 week and the other one for a month in a low energy slot at BLIP. The purpose of this irradiations is to produce 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 irradiation with larger targets, the short irradiation with Sc foil target will be carried out. Based on the radionuclide ratio at EOB in the foils, beam current and energy can be evaluated to project the yields in thicker targets more accurately.

This canning record submission is for the Sc foil target irradiation only. The canning record for larger Sc targets 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** |

**Foil 1 of 3: Target Material Properties: copper foil**

| | | | | |
|---|---|---|---|---|
| **Purity or Grade** | 99.99% | | | |
| **Chemical Formula** | Cu | | | |
| **Physical Characteristics at 70 °F or 21 °C** | **Metal** | | | |
| **Physical Form** | **Foil** | **yes** | **Powder** | **n/a** |
| | **Diameter (inches/mm)** | **2.5** | **Thickness, mm** | **0.005 (0.127)** |
| **Elements (%)** | **Cu, 99.99%** | | | |
| **Melting Point** | **1084** | **°C** | **1984** | **°F** |
| **Boiling Point** | **2562** | **°C** | **4346** | **°F** |
| **Thermal Conductivity** | **401 $W.m^{-1}.K^{-1}$** | **Temperature dependence** | ***(if available)*** ***n/a*** | |
| **Density** | **8.96** | | **$g/cm^3$** | |
| **Specific Heat** | **24.44** | | **J/mol.K** | |

**Target Material Reactions / Properties**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Does the Target material react with any of the following?** | **Aluminium** | **no** | **Air** | **no** | **$CO_2$** | **no** |
| | **$H_2O$** | **no** | **Lead** | **no** | **Zinc** | **no** |
| | **Inconel 600** | **no** | **S/Steel** | **no** | **Copper** | **no** |

**Foil 2 of 3. Target Material Properties: Titanium foil**

| | | | | |
|---|---|---|---|---|
| **Purity or Grade** | 99% | | | |
| **Chemical Formula** | Ti | | | |
| **Physical Characteristics at 70 °F or 21 °C** | **Metal** | | | |
| **Physical Form** | **Foil** | **yes** | **Powder** | **n/a** |
| | **Diameter (inches/mm)** | **2.5** | **Thickness, mm** | **0.005 (0.127)** |
| **Elements (%)** | **Ti, 99.99%** | | | |
| **Melting Point** | **1668** | **°C** | **3034** | **°F** |
| **Boiling Point** | **3287** | **°C** | **5949** | **°F** |

| | | | |
|---|---|---|---|
| **Thermal Conductivity** | **21.9 $W.m^{-1}.K^{-1}$** | **Temperature dependence** | ***(if available)*** ***n/a*** |
| **Density** | **4.51** | | **$g/cm^3$** |
| **Specific Heat** | **25.06** | | **J/mol.K** |

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

| **Foil 3 of 3. Target Material Properties: Scandium foil** | | | | |
|---|---|---|---|---|
| **Purity or Grade** | 99.99% | | | |
| **Chemical Formula** | Sc | | | |
| **Physical Characteristics at 70 °F or 21 °C** | **Metal** | | | |
| **Physical Form** | **Foil** | **yes** | **Powder** | **n/a** |
| | **Diameter (inches/mm)** | **1.97 (50)** | **Thickness, mm** | **0.010 (0.254)** |
| **Elements (%)** | **Sc, 99.9%** | | | |
| **Melting Point** | **1541** | **°C** | **2806** | **°F** |
| **Boiling Point** | **2836** | **°C** | **5136** | **°F** |
| **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?** | **Aluminium** | **no** | **Air** | **no** | **$CO_2$** | **no** |
| | **$H_2O$** | **no** | **Lead** | **no** | **Zinc** | **no** |
| | **Inconel 600** | **no** | **S/Steel** | **no** | **Copper** | **no** |

| **Canning Material Properties** | | | | |
|---|---|---|---|---|
| **Chemical Formula** | **Cu** | | | |
| **Can Wall Thickness (inches/mm)** | | | | |
| **Can Dimensions (inches/mm)** | **Can Diameter 2.75 (69.85)** | | **Can Width 0.220 (5.59)** | |
| **Melting Point** | **1668** | **°C** | **3034** | **°F** |
| **Thermal Conductivity** | **400 $W.m^{-1}.K^{-1}$** | **Temperature dependence** | *(if available)* *n/a* | |

| | | |
|---|---|---|
| **Density** | **8.96** | **g/cm$^3$** |
| **Specific Heat** | **24.44** | **J/mol.K** |

## 3. Target Canning Process

The target will be beam-welded by EB industries, following CAD OPM 19.17.1
The foils will be placed in the following order in the lower part of the target:
1) Sc-foil
2) Titanium foil on top of Sc foil
3) Cu foil on top of Titanium foil

| 4. Beam Characteristics | | |
|---|---|---|
| **Maximum Instantaneous Current Desired** | **40** | **µA** |
| **Average Current Desired** | **Available at BLIP at the time of irradiation (90-115)** | **µA** |
| **Total Integrated Current Desired** | **100** | **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 1 hour from 9:00 am to 10:00 am 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 appendix 1. Briefly, the target array is the same as OPM 19.17.20 a, except the Al beam stop is replaced by the Sc foil target

**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 Copper holder temperature = 245°C (234°C on water contact surface)
- Copper melting temperature = 1085 °C
- SAFE on melting. The water contact temperature is above boiling, but much less than other targets that have been irradiated (351°C on the $SrCl_2$ target).
- Maximum Copper foil temperature = 296 °C
- Copper melting temperature = 1085 °C
- SAFE
- Maximum Titanium temperature = 373 °C
- Titanium melting temperature = 1668 °C
- SAFE
- Maximum Scandium temperature = 368 °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

The foils will be allowed to decay and removed from hot cell for assay. *Samples removal is governed by RWP which limits dose rate to less than a 100 mr/h at contact with the sample or 5 mr/h at 1 foot. The intention is not to remove the foils from the hot cell until dose rate at contact is <20 mr/h or so. The foils will go inside the contamination area in semihot 4 hood in a secondary container*.

*In the hood the foils will be dissolved in stoichiometric excess of acids as outlined below and assayed using gamma spectroscopy:*

*Copper foil – concentrated $HNO_3$*

*Sc-foil – 2N HCl*

*Ti foil – 6N HCl at 100 $^0C$*

**5.e Disposal of waste:**

Liquid waste will be 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 produced in the foils and target can after **1 h** of irradiation:

| Nuclide | Cu-61 | Cu-64 | Zn-62 | Zn-65 | Sc-43 | Sc-44g |
|---|---|---|---|---|---|---|
| T1/2, h | 3.333 | 12.701 | 9.186 | 5854.32 | 3.891 | 3.97 |
| A, mCi | 100.1 | 188.8 | 155.0 | 44.8 | 35.0 | 1285.1 |

| Nuclide | Sc-44m | Sc-46 | Sc-47 | V-48 | Ti-45 | Ti-44 |
|---|---|---|---|---|---|---|
| T1/2, h | 58.61 | 2011.0 | 80.38 | 383.4 | 3.08 | 525600 |
| A, mCi | 50.0 | 0.04 | 1.4 | 1.2 | 242.7 | 9.98E-04 |

### Decay Requirements

None at BLIP.

## 7. Expected Dose Rate

**Expected dose rate to the operator from Sc foil target at EOB at BLIP is 0.1 mR/h. The Microshield® report is attached.**

## 8. Additional Safety Requirements

none

## 9. Special Operating Instructions

none

| Supporting Documentation | |
|---|---|
| **References** | |
| | |
| | |

## Appendix 1.

## Target array and energy propagation

| | | Energy: 117.1 MeV | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | thickness | | | |
| water displacement by can | layer number | Layer | Material | density | inches | mm | Ei | Eout |
| | 1 | Be window | Berillium | 1.85 | 0.012 | 0.305 | 117.10 | 116.80 |
| | 2 | AlBeMet window | AlBeMet | 2.10 | 0.012 | 0.305 | 116.80 | 116.46 |
| | 3 | Beamline window | stainless steel | 7.99 | 0.031 | 0.787 | 116.46 | 113.61 |
| | 4 | water gap | water | 1.00 | 0.106 | 2.692 | 113.61 | 111.80 |
| | 5 | cooling channel | water | 1.00 | 0.200 | 5.080 | 109.91 | 106.38 |
| SS degrader: vacuum box 0.654 | 6 | vacuum box | stainles steel | 7.99 | 0.029 | 0.737 | 106.38 | 103.61 |
| | 7 | | vacuum | 0.00 | 0.596 | 15.138 | | |
| | 8 | | stainless steel | 7.99 | 0.029 | 0.737 | 103.61 | 100.57 |
| | 9 | cooling channel | water | 1.00 | 0.200 | 5.080 | 100.57 | 96.80 |
| 1st RbCl 0.670 | 10 | can window | inconel | 8.43 | 0.012 | 0.305 | 96.80 | 95.48 |
| | 11 | RbCl salt | RbCl | 2.38 | 0.646 | 16.410 | 95.48 | 74.14 |
| | 12 | can window | inconel | 8.43 | 0.012 | 0.305 | 74.14 | 72.54 |
| | 13 | cooling channel | water | 1.00 | 0.200 | 5.080 | 72.54 | 67.65 |
| 2nd RbCl 0.524 | 14 | can window | inconel | 8.43 | 0.012 | 0.305 | 67.65 | 65.93 |
| | 15 | RbCl salt | RbCl | 2.38 | 0.500 | 12.700 | 65.93 | 42.97 |
| | 16 | can window | inconel | 8.43 | 0.012 | 0.305 | 42.97 | 40.53 |
| | 17 | cooling channel | water | 1.00 | 0.200 | 5.080 | 40.53 | 32.58 |
| Sc foil target | 18 | Copper window | Cu | 8.96 | 0.020 | 0.508 | 32.58 | 26.93 |
| | 19 | Copper foil | Cu | 8.96 | 0.005 | 0.127 | 26.93 | 25.39 |
| | 20 | Titanium foil | Ti | 4.50 | 0.005 | 0.127 | 25.39 | 24.55 |
| | 21 | Scandium foil | Sc | 2.99 | 0.010 | 0.254 | 24.55 | 23.36 |
| | 22 | Copper window | Cu | 8.96 | 0.180 | 4.572 | 23.36 | stop |
| | 23 | cooling channel | water | 1.00 | 0.200 | 5.080 | 0.00 | 0.00 |

**Appendix 2**

**Thermal heat load calculations for the Sc foil target**

## Sc, Ti & Cu Target & Copper Holder Thermal Analysis

Chris Cullen

December 18, 2014

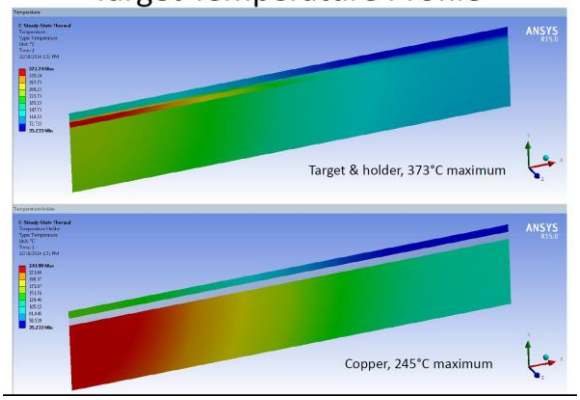
## Conditions

- Steady state average current = 115 µA
- Pulse width = .000425 sec
- Pulse Frequency = 6.667 Hz
- 4 targets, (5) .20" water gaps

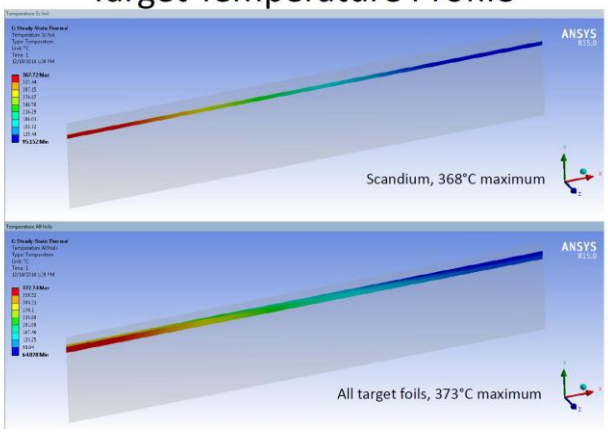
## Finite Element Model

- 2D Axi-symmetric model
- Target, .220" thick assembled
  - (1) x .020" thick Copper face, upstream
  - (1) x .005" thick Copper foil
  - (1) x .005" thick Titanium foil
  - (1) x .010" thick Scandium foil
  - (1) x .180" thick Copper face, downstream
- Steady-state analysis
- Thermal contact conductance between each layer=2,000 $W/m^2*°C$
- Steady state water cooling on exterior=8,388 $W/m^2*°C$
- Gaussian Internal heat generation for all bodies

## Target Temperature Profile




## Target Temperature Profile




## Summary & Conclusion

- Maximum Copper holder temperature = 245°C (234°C on water contact surface)
- Copper melting temperature = 1085 °C
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- Maximum Copper foil temperature = 296 °C
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- SAFE
- Maximum Scandium temperature = 368 °C
- Scandium melting temperature = 1541 °C
- SAFE

**Appendix 3**

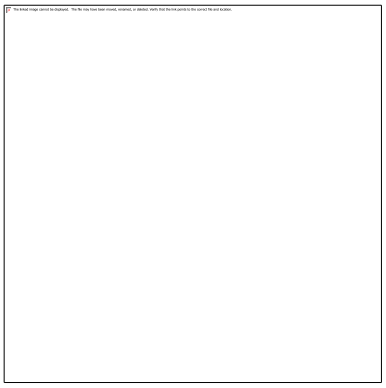
**Microshield® report: dose rate at BLIP at EOB, 1 hour at 100 µA**

| MicroShield 7.02<br>BNL (7.02-0000) | | |
|---|---|---|
| **Date** | **By** | **Checked** |
| | | |

| Filename | Run Date | Run Time | Duration |
|---|---|---|---|
| Sc foil target.ms7 | January 29, 2015 | 9:46:29 AM | 00:00:00 |

| Project Info | |
|---|---|
| Case Title | Sc foil target |
| Description | Dose rate at BLIP |
| Geometry | 8 - Cylinder Volume - End Shields |

| Source Dimensions | |
|---|---|
| Height | 0.559 cm (0.2 in) |
| Radius | 6.985 cm (2.8 in) |



| Dose Points | | | |
|---|---|---|---|
| **A** | **X** | **Y** | **Z** |
| #1 | 0.0 cm (0.0 in) | 45.72 cm (1 ft 6.0 in) | 0.0 cm (0.0 in) |

| Shields | | | |
|---|---|---|---|
| **Shield N** | **Dimension** | **Material** | **Density** |
| Source | 5.227 in³ | Copper | 8.96 |
| Shield 1 | 6.0 in | Air | 0.00122 |
| Shield 2 | 6.0 in | Lead | 11.72 |
| Air Gap | | Air | 0.00122 |

| Source Input: Grouping Method - Standard Indices<br>Number of Groups: 25<br>Lower Energy Cutoff: 0.015<br>Photons < 0.015: Included<br>Library: ICRP-38 | | | | |
|---|---|---|---|---|
| **Nuclide** | **Ci** | **Bq** | **µCi/cm³** | **Bq/cm³** |
| Cu-61 | 1.0012e-001 | 3.7044e+009 | 1.1689e+003 | 4.3250e+007 |
| Cu-64 | 1.8881e-001 | 6.9860e+009 | 2.2044e+003 | 8.1562e+007 |

| | | | | |
|---|---|---|---|---|
| Sc-43 | 3.5010e-002 | 1.2954e+009 | 4.0875e+002 | 1.5124e+007 |
| Sc-44 | 1.2850e+000 | 4.7545e+010 | 1.5003e+004 | 5.5509e+008 |
| Sc-44m | 4.9980e-002 | 1.8493e+009 | 5.8352e+002 | 2.1590e+007 |
| Sc-46 | 4.0000e-005 | 1.4800e+006 | 4.6700e-001 | 1.7279e+004 |
| Sc-47 | 1.3600e-003 | 5.0320e+007 | 1.5878e+001 | 5.8749e+005 |
| Ti-44 | 9.9800e-007 | 3.6926e+004 | 1.1652e-002 | 4.3112e+002 |
| Ti-45 | 2.4275e-001 | 8.9818e+009 | 2.8341e+003 | 1.0486e+008 |
| V-48 | 1.2300e-003 | 4.5510e+007 | 1.4360e+001 | 5.3133e+005 |
| Zn-62 | 1.5502e-001 | 5.7357e+009 | 1.8099e+003 | 6.6965e+007 |
| Zn-65 | 4.4770e-002 | 1.6565e+009 | 5.2269e+002 | 1.9340e+007 |

| **Buildup: The material reference is Shield 2<br>Integration Parameters** | |
|---|---|
| Radial | 20 |
| Circumferential | 10 |
| Y Direction (axial) | 10 |

**Results**

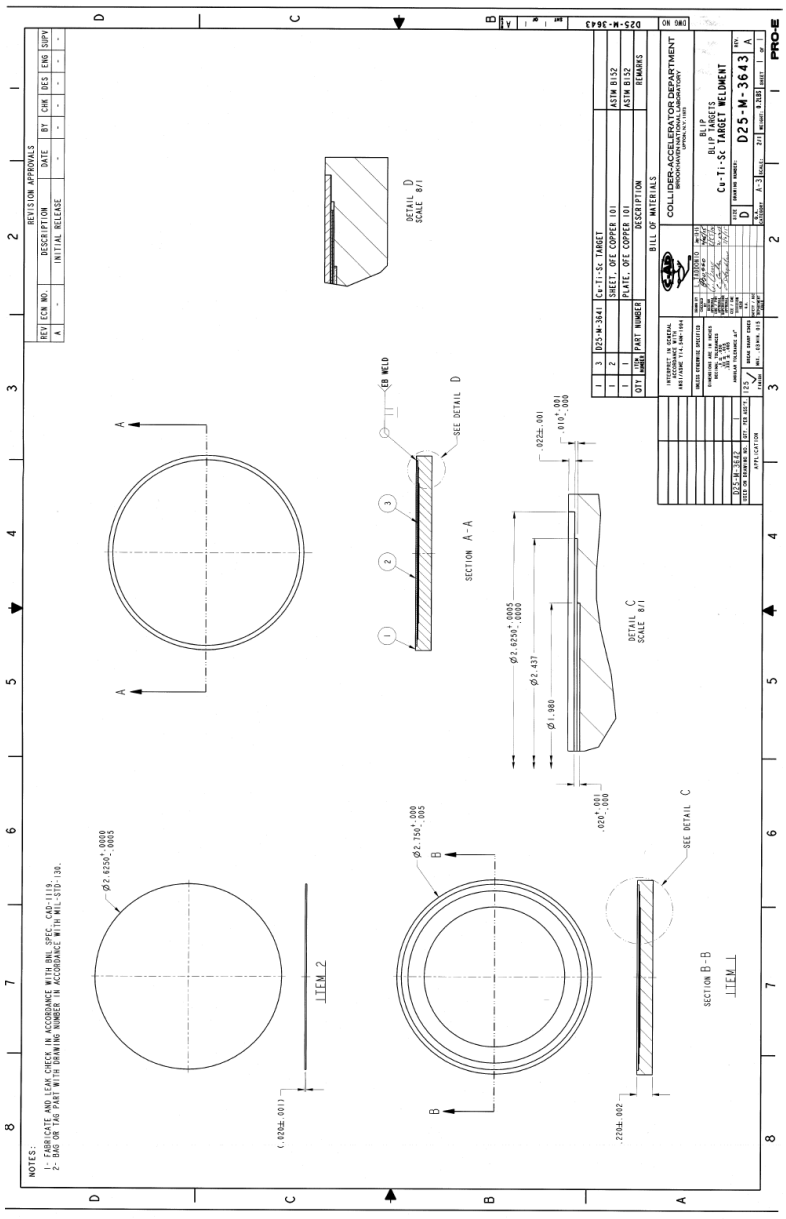
| Energy (MeV) | Activity (Photons/sec) | Fluence Rate MeV/cm²/sec No Buildup | Fluence Rate MeV/cm²/sec With Buildup | Exposure Rate mR/hr No Buildup | Exposure Rate mR/hr With Buildup |
|---|---|---|---|---|---|
| 0.015 | 5.577e+09 | 0.000e+00 | 2.824e-23 | 0.000e+00 | 2.422e-24 |
| 0.04 | 1.445e+09 | 0.000e+00 | 2.062e-23 | 0.000e+00 | 9.120e-26 |
| 0.06 | 1.897e+08 | 0.000e+00 | 4.389e-24 | 0.000e+00 | 8.717e-27 |
| 0.08 | 3.497e+04 | 1.561e-168 | 1.209e-27 | 2.469e-171 | 1.913e-30 |
| 0.15 | 3.422e+07 | 2.883e-148 | 5.401e-23 | 4.748e-151 | 8.895e-26 |
| 0.2 | 2.512e+08 | 4.042e-71 | 2.613e-23 | 7.134e-74 | 4.611e-26 |
| 0.3 | 2.194e+09 | 7.393e-26 | 4.160e-22 | 1.402e-28 | 7.892e-25 |
| 0.4 | 1.176e+09 | 1.645e-13 | 4.017e-13 | 3.204e-16 | 7.827e-16 |
| 0.5 | 1.169e+11 | 2.837e-06 | 8.319e-06 | 5.569e-09 | 1.633e-08 |
| 0.6 | 1.914e+09 | 2.368e-05 | 7.549e-05 | 4.622e-08 | 1.474e-07 |
| 0.8 | 4.029e+07 | 2.591e-04 | 9.565e-04 | 4.929e-07 | 1.819e-06 |
| 1.0 | 4.868e+10 | 7.412e+00 | 2.955e+01 | 1.366e-02 | 5.447e-02 |
| 1.5 | 5.337e+08 | 2.861e+00 | 1.206e+01 | 4.814e-03 | 2.029e-02 |
| 2.0 | 4.257e+06 | 8.535e-02 | 3.653e-01 | 1.320e-04 | 5.649e-04 |

| | | | | | |
|---|---|---|---|---|---|
| 3.0 | 5.373e+07 | 3.005e+00 | 1.267e+01 | 4.077e-03 | 1.718e-02 |
| **Totals** | **1.790e+11** | **1.336e+01** | **5.464e+01** | **2.269e-02** | **9.251e-02** |

**Appendix 4**

**Blueprints**

**Sc foil target**



**Basket assembly**