^{3}H & ^{7}Be Calculation for T1039 Ammonia Target

Maddie Wolter; Fermilab ESH&Q Radiation Protection

Knowns/Constants/Given Info

Ammonia (NH_3)	Molecular Weight	M	17.031	[g/mol]	
	Density	ρ	0.92	[g/cm^3]	<- known from 11/9/2015 email from Andi Klein to Don Cossairt
	Mass	m	14	[g]	<- known from 11/9/2015 email from Andi Klein to Don Cossairt
Beam Info (High Energy)	Run Time	t	7	[days]	<- known from 11/10/2015 email from Andi Klein to Don Cossairt
	Fluence	Φ	5.00E+12	[protons/spill]	<- known from 11/10/2015 email from Andi Klein to Don Cossairt
		Φ(t)	5.04E+16	[protons]	<- known from 11/10/2015 email from Andi Klein to Don Cossairt

Length of the target, l, is 6% of the interaction lentgh, λ_{int}. <- known from 11/10/2015 email from Andi Klein to Don Cossarit

T1039 will need roughly 60 target loads, at most, over 2 years. <- known from 11/9/2015 email from Andi Klein to Don Cossairt

Total mass	$m_{2\ year\ total}$	840	[g]

Length of the target, l, is 8 cm.	l	8	[cm]	<- known from 3/4/2016 email from Don Crabb to Maddie Wolter

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Find Length of Target

Length of the target, l, is 8 cm.
This is known from 3/4/16 email from Don Crabb

$l = 8$ [cm]

Find Surface Area of Target

In order to find Surface Area, A, first need to know Volume, V.

$$V = \frac{m}{\rho} \quad \frac{[g]}{[g/cm^3]}$$

$V = 15.2173913$ $[cm^3]$

Use Volume, V, to find Surface Area, S.

$$S = \frac{V}{l} \quad \frac{[cm^3]}{[cm]}$$

$S = 1.902173913$ $[cm^2]$

Find # Density of Nitrogen Atoms

Find Number Density, N, of target (use Nitrogen atoms) in $[atoms/cm^3]$.
FERMILAB-TM-1834, pg 2

$$N = \frac{\rho N_A}{A}$$

use molecular weight (M) in place of Atomic wieght (A)

Avagadro's Number

$N_A = 6.02E+23$ [atoms/mol]

$$N = \frac{\rho N_A}{M} \quad \frac{[g/cm^3][atoms/mol]}{[g/mol]}$$

$N = 3.25357E+22$ $[atoms/cm^3]$

Find Long-Lived Nuclides From ^{14}N

Using the Chart of Radionuclides, find ^{7}Be and ^{3}H as long-lived products of ^{14}N.

Find half-lives, $t_{1/2}$, using chart, convert to seconds.

$t_{1/2\text{-}Be}$	=	53.2	[days]			
$t_{1/2\text{-}Be}$	=	4596480	[s]	=	4.60E+06	[s]
$t_{1/2\text{-}H}$	=	12.32	[years]			
$t_{1/2\text{-}H}$	=	388523520	[s]	=	3.89E+08	[s]

Find Cross-Section at High Energy

Need to find cross-section, σ, for ^{7}Be and ^{3}H.
FERMILAB-TM-1834, pg 191, Fig. 7.9, "N^{14}+p"

σ_{Be}	=	10	[mb]
σ_{H}	=	30	[mb]

Convert to cm^2.

σ_{Be}	=	1E-26	[cm^2]
σ_{H}	=	3E-26	[cm^2]

Find Irradiation Time

Run duration is 7 days, convert to sec.

t_{irr}	=	604800	[s]	=	6.05E+05	[s]

Find Number Density for Each Radionuclide

Find the number density, n [$1/cm^3$], at time, t [s], for each radionuclide.
FERMILAB-TM-1834, pg 177, Eq. 7.5

$$n(t) = \frac{N\sigma\phi}{\lambda}(1-e^{-\lambda t})$$

Where: N = number density of target atoms [$1/cm^3$]
σ = cross section [cm^2]
ϕ = flux density [$1/cm^2s$]
λ = decay constant [1/s]
t = irradiation time, t_{irr}, [s]

Need to find flux, ϕ, using known total fluence, Φ(t).

$$\phi = \frac{\Phi(t)}{St_{irr}}$$

$$\phi = 4.38E+10 \quad [1/cm^2s]$$

Need to find decay constants, λ.

$$\lambda = \frac{1}{\tau}$$

Find mean-life, τ, relation to half-life, $t_{1/2}$.

$$\tau = \frac{t_{1/2}}{\ln(2)}$$

Plug back in to find decay constant, λ, in terms of half-life, $t1_{/2}$.

$$\lambda = \frac{\ln(2)}{t_{1/2}}$$

Solve for each ^7Be and ^3H.

$$\lambda_{Be} = \frac{\ln(2)}{t_{1/2\text{-}Be}}$$

$$\lambda_{Be} = 1.51E-07 \quad [1/s]$$

$$\lambda_{H} = \frac{\ln(2)}{t_{1/2\text{-}H}}$$

$$\lambda_{H} = 1.78E-09 \quad [1/s]$$

Plug everything in to find number density, n(t), for ^{7}Be.

$$n_{Be}(t_{irr}) = \frac{N\sigma_{Be}\phi}{\lambda_{Be}}(1-e^{-\lambda\_Be*t\_irr})$$

$n_{Be}(t_{irr})$ = 8.24E+12 [1/cm^3]

Plug everything in to find number density, n(t), for ^{3}H.

$$n_{H}(t_{irr}) = \frac{N\sigma_{H}\phi}{\lambda_{H}}(1-e^{-\lambda\_H*t\_irr})$$

$n_{H}(t_{irr})$ = 2.58E+13 [1/cm^3]

Find Activity

Find activity, a, for ^{7}Be in terms of irradiation time, t_{irr}.
FERMILAB TM-1834, pg 177, Eq. 7.7

$a_{Be}(t_{irr}) = N\sigma_{Be}\phi(1-e^{-\lambda\_Be*t\_irr})=\lambda_{Be}n_{Be}(t_{irr})$ [Bq/cm^3]

$a_{Be}(t_{irr})$ = 1.24E+06 [Bq/cm^3]

Convert Becquerel (Bq)to Curie (Ci)

1 [Ci] = 3.70E+10 [Bq]

$a_{Be}(t_{irr})$ = 3.36E-05 [Ci/cm^3]

Find activity, a, for ^{3}H in terms of irradiation time, t_{irr}.
FERMILAB TM-1834, pg 177, Eq. 7.7

$a_{H}(t_{irr}) = N\sigma_{H}\phi(1-e^{-\lambda\_H*t\_irr})=\lambda_{H}n_{H}(t_{irr})$ [Bq/cm^3]

$a_{H}(t_{irr})$ = 4.61E+04 [Bq/cm^3]

Convert Becquerel (Bq)to Curie (Ci)

1 [Ci] = 3.70E+10 [Bq]

$a_{H}(t_{irr})$ = 1.25E-06 [Ci/cm^3]

Find Volume Activation

Multiply activity, a, by the target volume for ^7Be and ^3H.

$a_{Be}(t_{irr})\_V$	=	$a_{Be}(t_{irr})V$	[Ci]
$a_{Be}(t_{irr})\_V$	=	5.11E-04	[Ci]

Convert to μCi

$a_{Be}(t_{irr})\_V$	=	5.11E+02	[μCi]
$a_{Be}(t_{irr})\_V$	**=**	**511**	**[μCi]**

$a_H(t_{irr})\_V$	=	$a_H(t_{irr})V$	[Ci]
$a_H(t_{irr})\_V$	=	1.90E-05	[Ci]

Convert to μCi

$a_H(t_{irr})\_V$	=	1.90E+01	[μCi]
$a_H(t_{irr})\_V$	**=**	**19**	**[μCi]**