

Isotope Production in the FRIB Beam Dump: 238U case



- How to get isotope yields in the beam dump with the Uranium beam?
- Production settings: why a Li-target was used?
- Radiation residues calculator: T_{1/2} boundaries against the "stiffness" problem
- Link to the "Isotope Production in the FRIB Beam Dump: projectile fragmentation case" presentation



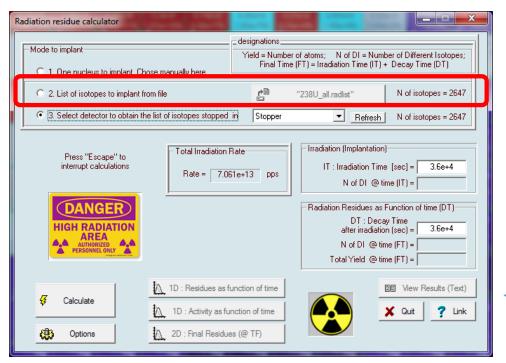
Isotope yields in the beam dump with the Uranium beam: Files

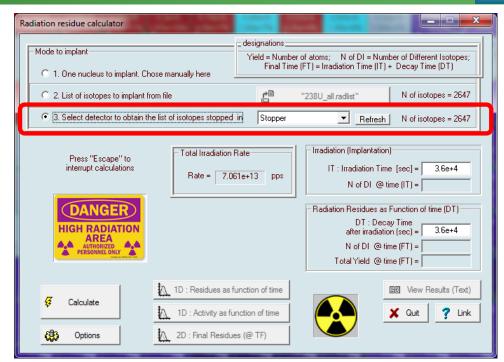


Options:

1. You can use the LISE** file
http://lise.nscl.msu.edu/work/BeamDump/AF 238U Li.lpp

and then Mode #3 (Select detector) in the Radiation
residue calculator





Or You can use the Radiation list file obtained with AF_238U_Li.lpp http://lise.nscl.msu.edu/work/BeamDump/238U_all.radlist
and then Mode #2 (List of isotopes to implant from file) in the

and then Mode #2 (List of isotopes to implant from file) in the Radiation residue calculator





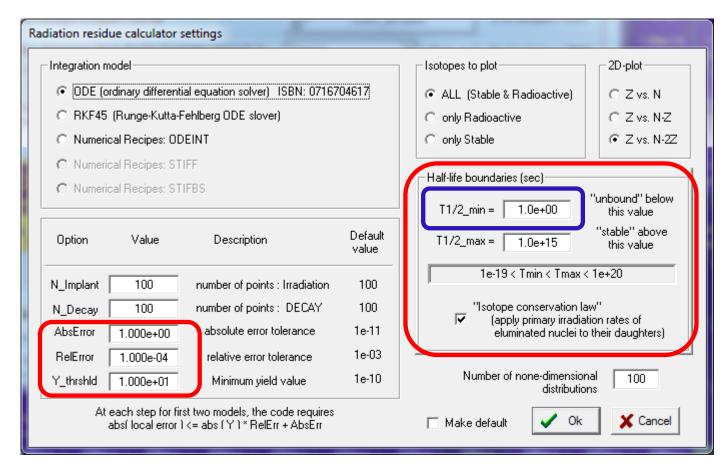


Please download the latest LISE⁺⁺ version <u>9.10.371</u> from 10/28/16 to overcome the stiffness problem in the Radiation Residue Calculator.

See the "Radiation residues calculator: T1/2 boundaries against the "stiffness" problem" page in this presentation

Use the next options for the Radiation Residue calculator:

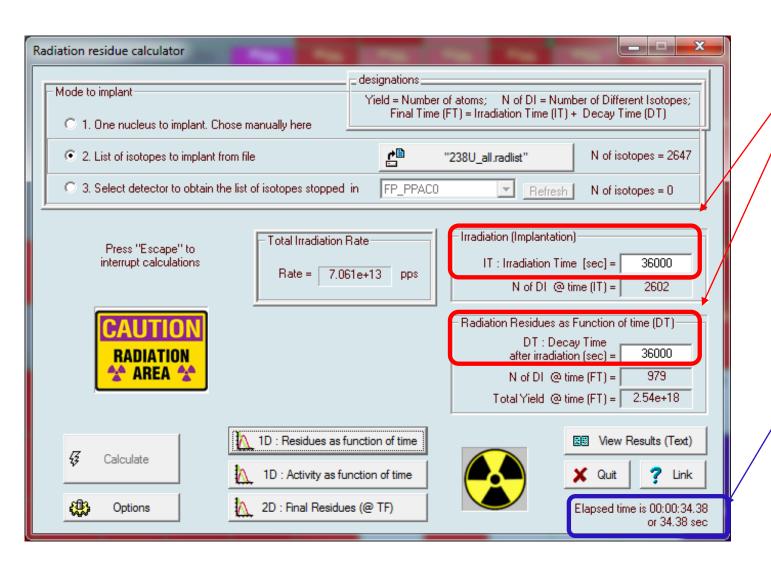
- 1. Total irradiation is 7.1e13 pps, and we are interested in isotopes with residual yield $> 10^5$, so it is possible to increase the global threshold up to 10 for fast calculations avoiding low-yield production
- The decay time is expected more than one hour (that it is obtained from chemistry), so please set the T_{1/2} min boundary (important!) equal to 1 sec assuming short-lived products be unbound for fast calculations.





Calculations with the Radiation residues calculator





After settings of the Radiation Residue calculator options, please, enter the "Irradiation" and "Decay" times (10 h & 10 h in this example).

Press "Calculate"

Pay attention for "stiffness" flag appearance, and change settings.

In the shown here example there was not stiffness problem.

Elapsed time is 34 seconds

Rate x IrradiationTime should be equal to Total Yield @ Final time .

If not, so there are some leaks may be due to low error tolerance in the ODE solver, stiffness problem, or violation of "Isotope conservation law"

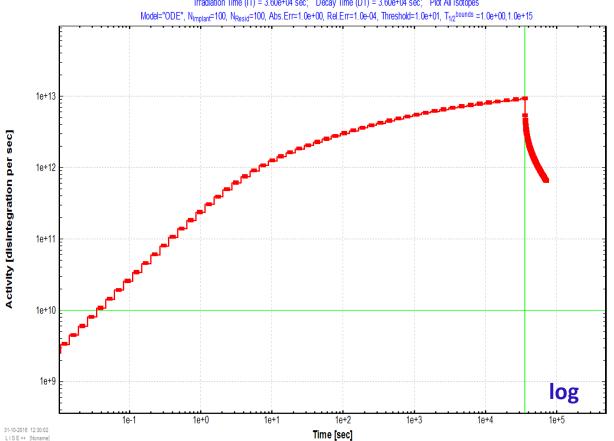
In this example no any leak: 7.063e13 * 3.6e4 = 2.54e18



Calculation results: Activity

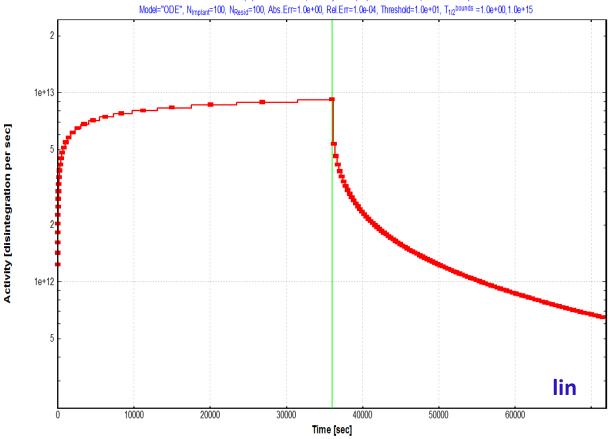






Activity







Calculation results: 2D final plots



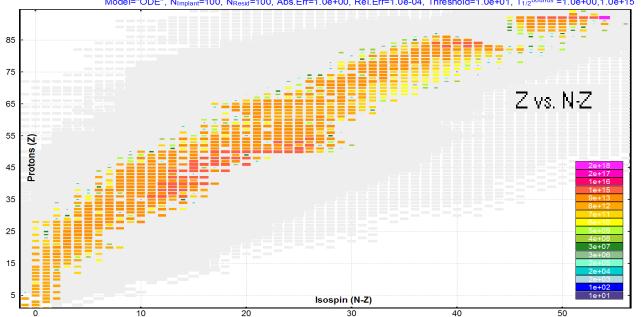
Radioactive decay residues

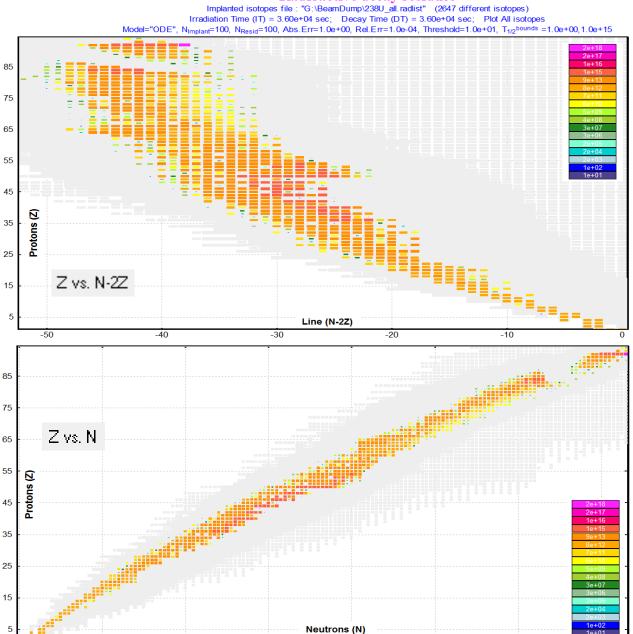
2D-plot C Z vs. N C Z vs. N-Z Z vs. N-2Z

Radioactive decay residues

Implanted isotopes file: "G:\BeamDump\238U_all.radlist" (2647 different isotopes)
Irradiation Time (IT) = 3.60e+04 sec; Decay Time (DT) = 3.60e+04 sec; Plot All isotopes

Model="ODE", N_{Implant}=100, N_{Resid}=100, Abs.Err=1.0e+00, Rel.Err=1.0e-04, Threshold=1.0e+01, T_{1/2}bounds =1.0e+00,1.0e+15







2D final plot: ZOOM



Radioactive decay residues

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Radioactive decay residues

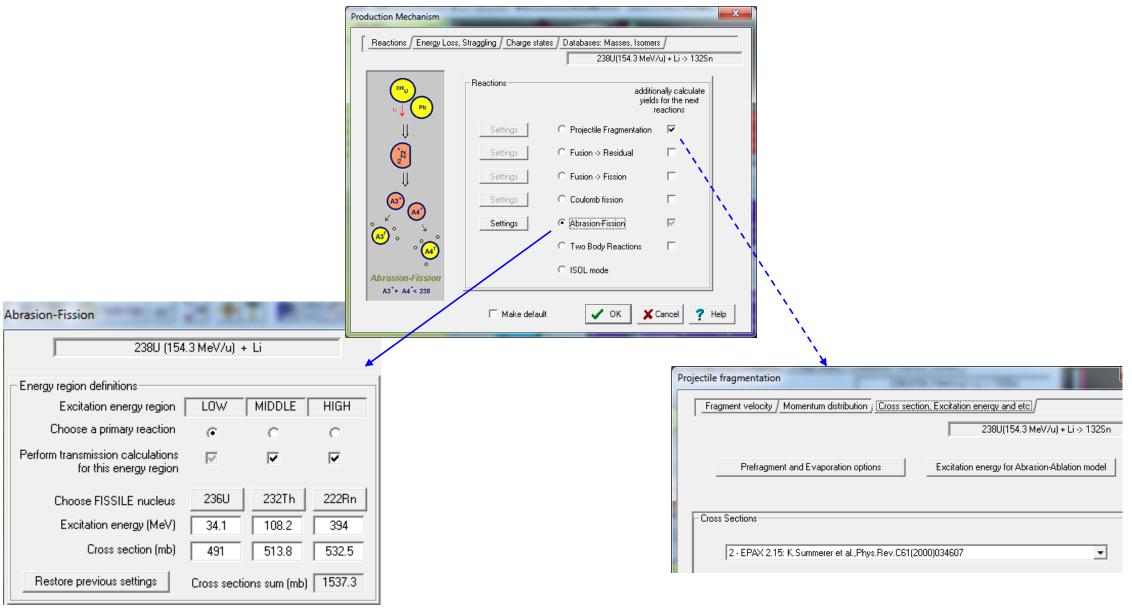
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58	5.1e+14	2.0e+14	5.1e+14	5.1e+14	2.7e+14	6.5e+14	6.4e+14	3.6e+14	3.7e+14						5.1e+14	2.0e+14	.5.1e+14	5.1e+14	2.7e+14	6.5e+14	6.4e+14	3.6e+14	3.7e+14				
	¹³³ La 5.9e+13	¹³⁴ La 5.1e+11	¹³⁵ La 2.3e+14		¹³⁷ La 4.2e+14	¹³⁸ La	¹³⁹ La 8.9e+14	¹⁴⁰ La	¹⁴¹ La 5.3e+13	¹⁴² La 1.2e+12					¹³³ La 5.9e+13	¹³⁴ La 5.1e+11	¹³⁵ La 2.3e+14		¹³⁷ La	¹³⁸ La	¹³⁹ La 8.9e+14	¹⁴⁰ La	¹⁴¹ La 5.3e+13	¹⁴² La 1.2e+12			
56	¹³⁰ Ba 5.2e+14	¹³¹ Ba 5.4e+14	¹³² Ba 5.4e+14	¹³³ Ba 5.9e+14	¹³⁴ Ba 3.2e+14	¹³⁵ Ba 2.1e+14	¹³⁶ Ba 3.1e+14	¹³⁷ Ba 2.4e+14	¹³⁸ Ba 9.0e+14	¹³⁹ Ba 9.9e+11	¹⁴⁰ Ba 6.3e+14	¹⁴¹ Ba 2.1e+03			¹³⁰ Ba 5.2e+14	¹³¹ Ba 5.4e+14	¹³² Ba 5.4e+14	¹³³ Ba 5.9e+14	¹³⁴ Ba 3.2e+14	¹³⁵ Ba 2.1e+14	136 Ba 3.1e+14	¹³⁷ Ba 2.4e+14	¹³⁸ Ba 9.0e+14	139 Ba 9.9e+11	¹⁴⁰ Ba 6.3e+14	¹⁴¹ Ba 2.1e+03	
	¹²⁷ Cs 9.8e+13	¹²⁸ Cs 3.2e+11	¹²⁹ Cs 4.9e+14	¹³⁰ Cs 8.4e+06	¹³¹ Cs 1.8e+14	¹³² Cs 1.0e+14	¹³³ Cs 2.2e+14	¹³⁴ Cs 2.2e+14	¹³⁵ Cs 9.8e+14	¹³⁶ Cs 4.0e+14	¹³⁷ Cs 8.9e+14	1 ³⁸ C s 2.0e+08			¹²⁷ Cs 9.8e+13	¹²⁸ Cs 3.2e+11	¹²⁹ Cs 4.9e+14	¹³⁰ Cs 8.4e+06	¹³¹ Cs 1.8e+14	¹³² Cs 1.0e+14	¹³³ Cs 2.2e+14	¹³⁴ Cs 2.2e+14	¹³⁵ Cs 9.8e+14	¹³⁶ Cs 4.0e+14	¹³⁷ Cs 8.9e+14	1 ³⁸ C s 2.0e+08	
54	¹²⁴ Xe 4.6e+14	¹²⁵ Xe 3.0e+14	¹²⁶ Xe 6.8e+14	¹²⁷ Xe 6.1e+14	¹²⁸ Xe 6.4e+14	¹²⁹ Xe 3.0e+14	¹³⁰ Xe 5.8e+14	¹³¹ Xe 2.8e+14	¹³² Xe 1.1e+15	¹³³ Xe 9.1e+14	¹³⁴ Xe 1.5e+15	¹³⁵ Xe 3.7e+14	¹³⁶ Xe 7.8e+14		¹²⁴ Xe 4.6e+14	¹²⁵ Xe 3.0e+14	¹²⁶ Xe 6.8e+14	¹²⁷ Xe 6.1e+14	¹²⁸ Xe 6.4e+14	¹²⁹ Xe 3.0e+14	¹³⁰ Xe 5.8e+14	¹³¹ Xe 2.8e+14	¹³² Xe 1.1e+15	¹³³ Xe 9.1e+14	134 Xe 1.5e+15	¹³⁵ Xe 3.7e+14	¹³⁶ Xe 7.8e+14
	¹²¹ 5.6e+12	122 5.2e+11	¹²³	¹²⁴	¹²⁵	126 	¹²⁷ 	128 5.7e+05	129 1 7e+15	130 	131 1 7e+15	¹³² 3.8e+13	¹³³ 8.8e+14		121 5.6e+12	122 5,2e+11	123 	124 	125 	126 	¹²⁷ 4 8e+14	128 5.7e+05	129 	130 	131 1 7e+15	132 3.8e+13	133 8.8e+14
52	¹¹⁸ Te 3.1e+14	¹¹⁹ Te 2.1e+14	¹²⁰ Te 5.6e+14	¹²¹ Te 6.4e+14	¹²² Te 7.0e+14	¹²³ Te 5.7e+14	¹²⁴ Te 2.8e+14	¹²⁵ Te	¹²⁶ Te 3.2e+14	¹²⁷ Te	¹²⁸ Te	¹²⁹ Te 3.3e+13	¹³⁰ Te		¹¹⁸ Te 3.1e+14	¹¹⁹ Te 2.1e+14	¹²⁰ Te 5.6e+14	¹²¹ Te 6.4e+14	¹²² Te 7.0e+14	¹²³ Te 5.7e+14	¹²⁴ Te 2.8e+14	¹²⁵ Te	¹²⁶ Te 3.2e+14	¹²⁷ Te	¹²⁸ Te	¹²⁹ Te 3.3e+13	¹³⁰ Te
	115 Sb 6.0e+07	¹¹⁶ Sb 5.0e+11	¹¹⁷ Sb 2.0e+13	¹¹⁸ Sb 1.3e+11	¹¹⁹ Sb 4.6e+14	¹²⁰ Sb 5.0e+01	¹²¹ Sb 1.1e+15	¹²² Sb	¹²³ Sb 3.0e+14	¹²⁴ Sb 3.0e+14	¹²⁵ Sb 6.9e+14	¹²⁶ Sb 6.0e+14	¹²⁷ Sb 1.2e+15		115 Sb 6.0e+07	¹¹⁶ Sb 5.0e+11	¹¹⁷ Sb 2.0e+13	¹¹⁸ Sb 1.3e+11	¹¹⁹ Sb 4.6e+14	¹²⁰ Sb 5.0e+01	¹²¹ Sb 1.1e+15	¹²² Sb 1.8e+14	¹²³ Sb 3.0e+14	¹²⁴ Sb 3.0e+14	¹²⁵ Sb 6.9e+14	¹²⁶ Sb 6.0e+14	¹²⁷ Sb 1.2e+15
s (Z)	¹¹² Sn 3.9e+14	¹¹³ Sn 3.4e+14	¹¹⁴ Sn 8.4e+14	¹¹⁵ Sn 6.0e+14	¹¹⁶ Sn 1.1e+15	¹¹⁷ Sn 3.7e+15	¹¹⁸ Sn 3.6e+15	¹¹⁹ Sn 2.9e+15	¹²⁰ Sn 3.2e+15	¹²¹ Sn 1.6e+15	¹²² Sn 2.3e+15	¹²³ Sn 2.0e+15	¹²⁴ Sn 1.8e+15	•	¹¹² Sn 3.9e+14	¹¹³ Sn 3.4e+14	¹¹⁴ Sn 8.4e+14	¹¹⁵ Sn 6.0e+14	¹¹⁶ Sn 1.1e+15	¹¹⁷ Sn 3.7e+15	¹¹⁸ Sn 3.6e+15	¹¹⁹ Sn 2.9e+15	¹²⁰ Sn 3.2e+15	¹²¹ Sn 1.6e+15	¹²² Sn 2.3e+15	¹²³ Sn 2.0e+15	¹²⁴ Sn 1.8e+15
rotons	¹⁰⁹ In 2.2e+13	¹¹⁰ In 5.4e+13	¹¹¹ In 3.6e+14		¹¹³ In 3.6e+14		¹¹⁵ In 8.8e+14		¹¹⁷ In 2.3e+13	¹¹⁸ In 1.3e+08					¹⁰⁹ In 2.2e+13	¹¹⁰ In 5.4e+13	¹¹¹ In 3.6e+14	beta- beta+	¹¹³ In 3.6e+14	beta- beta+	¹¹⁵ In 8.8e+14	beta- beta+	¹¹⁷ ln 2.3e+13	¹¹⁸ In 1.3e+08			
Pro	¹⁰⁶ Cd 1.9e+14	¹⁰⁷ Cd 5.5e+13	¹⁰⁸ Cd 7.0e+14	¹⁰⁹ Cd 4.4e+14	¹¹⁰ Cd 9.5e+14	¹¹¹ Cd 5.8e+14	¹¹² Cd 1.7e+15	¹¹³ Cd 2.8e+15	¹¹⁴ Cd 3.3e+15	¹¹⁵ Cd 2.5e+15	¹¹⁶ Cd 2.9e+15	¹¹⁷ Cd 5.6e+13	¹¹⁸ Cd 8.1e+10		¹⁰⁶ Cd 1.9e+14	¹⁰⁷ Cd 5.5e+13	¹⁰⁸ Cd 7.0e+14	¹⁰⁹ Cd 4.4e+14	¹¹⁰ Cd 9.5e+14	¹¹¹ Cd 5.8e+14	¹¹² Cd 1.7e+15	¹¹³ Cd 2.8e+15	114 Cd 3.3e+15	¹¹⁵ Cd 2.5e+15	¹¹⁶ Cd 2.9e+15	¹¹⁷ Cd 5.6e+13	¹¹⁸ Cd 8.1e+10
	¹⁰³ Ag 3.9e+10	¹⁰⁴ Ag 1.6e+11	¹⁰⁵ Ag 3.0e+14	¹⁰⁶ Ag 3.4e+05	¹⁰⁷ Ag 5.2e+14		¹⁰⁹ Ag 1.9e+15		¹¹¹ Ag 3.0e+15	¹¹² Ag 3.0e+14	¹¹³ Ag 4.6e+14		¹¹⁵ Ag 1.2e+05		¹⁰³ Ag 3.9e+10	¹⁰⁴ Ag 1.6e+11	¹⁰⁵ Ag 3.0e+14	¹⁰⁶ Ag 3.4e+05	¹⁰⁷ Ag 5.2e+14	beta- beta+	¹⁰⁹ Ag 1.9e+15	beta- beta+	¹¹¹ Ag 3.0e+15	¹¹² Ag 3.0e+14	¹¹³ Ag 4.6e+14		¹¹⁵ Ag 1.2e+05
46	¹⁰⁰ Pd 8.4e+13	¹⁰¹ Pd 4.8e+13	¹⁰² Pd 2.6e+14	¹⁰³ Pd 3.2e+14	¹⁰⁴ Pd 8.9e+14	¹⁰⁵ Pd 7.7e+14	¹⁰⁶ Pd 1.0e+15	¹⁰⁷ Pd 3.0e+15	¹⁰⁸ Pd 3.1e+15	¹⁰⁹ Pd 1.3e+15	¹¹⁰ Pd 3.0e+15	¹ 11 Pd 3.0e+06	¹¹² Pd 1.8e+15		¹⁰⁰ Pd 8.4e+13	¹⁰¹ Pd 4.8e+13	¹⁰² Pd 2.6e+14	¹⁰³ Pd 3.2e+14	¹⁰⁴ Pd 8.9e+14	¹⁰⁵ Pd 7.7e+14	¹⁰⁶ Pd 1.0e+15	¹⁰⁷ Pd 3.0e+15	¹⁰⁸ Pd 3.1e+15	¹⁰⁹ Pd 1.3e+15	¹¹⁰ Pd 3.0e+15	¹ 11 Pd 3.0e+06	¹¹² Pd 1.8e+15
	⁹⁷ Rh 5.4e+06	⁹⁸ Rh 3.4e+01	⁹⁹ Rh 1.9e+14	¹⁰⁰ Rh 1.2e+14	¹⁰¹ Rh 3.8e+14	¹⁰² Rh 2.9e+14	¹⁰³ Rh 4.8e+14	-	105 Db 2.0e+15	106 D L 2. 1e+09	107 Db 7.8e+05			+	97 Dh 5.4e+06	98 ph 3.4e+01	99 Ph	100 Ph	¹⁰¹ Rh 3.8e+14	¹⁰² Rh	¹⁰³ Rh 4.8e+14	beta- beta+	¹⁰⁵ Rh 2.0e+15	¹⁰⁶ Rh 2.1e+09	¹⁰⁷ Rh 7.8e+05		
44	⁹⁴ Ru 1.2e+09	⁹⁵ Ru 2.5e+11	⁹⁶ Ru 1.4e+14	⁹⁷ Ru 1.9e+14	⁹⁸ Ru 3.5e+14	⁹⁹ Ru 2.7e+14	¹⁰⁰ Ru 9.0e+14	¹⁰¹ Ru 2.6e+15	¹⁰² Ru 2.6e+15	¹⁰³ Ru 2.3e+15	¹⁰⁴ Ru 2.3e+15	¹⁰⁵ Ru 2.4e+14	¹⁰⁶ Ru 2.2e+15		⁹⁴ Ru 1.2e+09	⁹⁵ Ru 2.5e+11	⁹⁶ Ru 1.4e+14	⁹⁷ Ru 1.9e+14	⁹⁸ Ru 3.5e+14	⁹⁹ Ru 2.7e+14	¹⁰⁰ Ru 9.0e+14	¹⁰¹ Ru 2.6e+15	¹⁰² Ru 2.6e+15	¹⁰³ Ru 2.3e+15	¹⁰⁴ Ru 2.3e+15	¹⁰⁵ Ru 2.4e+14	¹⁰⁶ Ru 2.2e+15
			⁹³ Tc 2.6e+12	⁹⁴ Tc 2.1e+13	⁹⁵ Tc 1.5e+14	⁹⁶ Tc 1.8e+14	⁹⁷ Tc 3.4e+14	⁹⁸ Tc 3.3e+14	⁹⁹ Tc 8.1e+14		¹⁰ 1 Tc 5.6e+02						⁹³ Tc 2.6e+12	⁹⁴ Tc 2.1e+13	⁹⁵ Tc 1.5e+14	⁹⁶ Tc 1.8e+14	⁹⁷ Tc 3.4e+14	⁹⁸ Tc 3.3e+14	⁹⁹ Tc 8.1e+14		¹⁰ 1 √c 5.6e+02		
42			⁹⁰ Mo 8.3e+12		⁹² Mo 1.9e+14	⁹³ Mo 2.6e+14	⁹⁴ Mo 3.9e+14	⁹⁵ Mo 3.9e+14	⁹⁶ Mo 6.4e+14	⁹⁷ Mo 1.7e+15	⁹⁸ Mo 2.7e+15	⁹⁹ Mo 1.9e+15	¹⁰⁰ Mo 2.2e+15				⁹⁰ Mo 8.3e+12		⁹² Mo 1.9e+14	⁹³ Mo 2.6e+14	⁹⁴ Mo 3.9e+14	⁹⁵ Mo 3.9e+14	⁹⁶ Mo 6.4e+14	⁹⁷ Mo 1.7e+15	⁹⁸ Mo 2.7e+15	⁹⁹ Mo 1.9e+15	¹⁰⁰ Mo 2.2e+15
· '	-38		-36		-34		-32		-30		-28		-26		-38		-36		-34		-32		-30		-28		-26
							Line (N-2	Z)													Line (N-2	Z)					



Uranium beam @ beam dump: Production mechanism







Production settings



Beam dump materials

Ti90 Al6 V4 window: thickness* = 1 mm

Water: thickness** = 2.09 mm

* Its equivalent is pure Ti material a thickness of 1.011 mm

** In the case of the Uranium beam

- LISE** does not calculate isotope Abrasion-Fission production in compounds
- And.... There are two compound targets
- It is necessary to find an equivalent target



Equivalent target



There are two conditions for equivalent target :

(Production mechanism condition)
 Number of fission reactions should be the same in the original (Ti90 Al6 V4 window + Water) case and its equivalent

 (Energy loss condition) The Uranium primary beam passes the equivalent target and stops in a downstream material.

material	Atoms	Abrasion- Fission CS		Thick	NA	"Quasy" Yield		
	in 1 mg/cm2	mb		g/cm2	atoms	CS*NA		
Н	5.97E+20	1101.3		0.023	1.39E+22	1.53E+25		
0	3.76E+19	1652.2		0.185	6.97E+21	1.15E+25		
H2O	1.00E+20	1284.9	target2	0.209	2.09E+22	2.69E+25		
Ti	1.26E+19	1869.7	target1	0.457	5.76E+21	1.08E+25		
Li	8.60E+19	1538.2		0.253	2.18E+22	3.35E+25		
			target1+tar	get2	2.67E+22	3.76E+25		
			_		Thickness from NA	Thickness from Yield		Thickness
					g/cm2	g/cm2	delta %	average
				Н	4.47E-02	5.72E-02	22%	5.09E-02
				О	7.09E-01	6.06E-01	15%	6.57E-01
				H2O	2.67E-01	2.93E-01	9%	2.80E-01
				Ti	2.12E+00	1.60E+00	25%	1.86E+00
			_					
			_	Li	3.10E-01	2.84E-01	<u>8%</u>	2.97E-01
			 					1

Smallest delta is observed in the case of Li-material. The best equivalent material

Final equivalent target thickness



Radiation residues calculator:



$T_{1/2}$ boundaries against the "stiffness" problem

http://lise.nscl.msu.edu/work/BeamDump/RadResCalc v2a.pdf

		@ Final	Time		
T1/2 min boundary	Decay time, s	Number of isotopes	Total yield	Activity	Elapsed calulation time
1E-08	0	13	1E+09	3.0E+11	6.07
1E-05	0	10	1E+09	5.0E+09	1.73
1E-02	0	9	1E+09	1.5E+07	0.57
				@ 1 &10 sec	
1E-08	100	11	1E+09	1.5E+07	9.09
1E-02	100	11	1E+09	1.5E+07	0.81



Link to



the "Isotope Production in the FRIB Beam Dump: projectile fragmentation case" presentation

http://lise.nscl.msu.edu/work/BeamDump/BeamDump v1.pdf

- Energy of beam is taken after the production target Production target thickness is equal to 30% of range of projectile with energy from the FRIB beam list Reactions
- Initial beam intensity (400 kW) is corrected for reaction lost in the primary production target
- Ti90Al6V4 (1 mm) "beam dump window" is assumed be a target in LISE⁺⁺ file

 Equivalent material (<u>Ti</u> 1.011 mm) for energy loss and atoms number (important for CS) is used in LISE⁺⁺
- Water (beam dump material) is assumed be a stripper in LISE⁺⁺ file

"stripper" thickness is equal to difference of projectile ranges in water with energies after the <u>Ti</u>-target and 35 MeV/u correspondingly.

