FRIB Estimated Rates

v 3.0

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This document describes the assumptions used to generate version 3.0 of the estimated FRIB fast, stopped, and reaccelerated beam rates.

Primary beams: PAC3

The list of FRIB Primary Beams and intensities currently available are at:
https://frib.msu.edu/users/beams
The online rates assume that 15 kW will be available for many beams during the PAC3 period of validity. The table of primary beams used is provided in Table 1.

Table 1: List of primary beams, energies, and intensities assumed in the rare isotope estimations.

Beam	Z	A	I ECR [μA]	Maximum Energy [MeV/u]	BDS current [pnA]
^{16}O	8	16	75.00	150	6250
^{18}O	8	18	66.67	150	5556
^{22}Ne	10	22	64.82	170	4011
^{28}Si	14	28	43.23	290	1847
^{28}Si	14	28	48.15	155	2304
^{36}Ar	18	36	46.82	200	2083
^{36}Ar	18	36	31.21	300	1389
^{40}Ar	18	40	28.95	262	1431
^{40}Ar	18	40	37.92	200	1875
^{48}Ca	20	48	36.89	242	1291
^{48}Ca	20	48	39.88	200	1396
^{58}Ni	28	58	43.08	270	848
^{64}Ni	28	64	38.87	245	765
^{64}Zn	30	64	47.98	254	922
^{70}Zn	30	70	46.48	240	893
^{70}Zn	30	70	55.77	200	1071
^{70}Ge	32	70	29.95	249	688
^{82}Se	34	82	24.53	227	806
^{78}Kr	36	78	27.98	254	757
^{86}Kr	36	86	28.03	230	758
^{92}Mo	42	92	4.95	252	108

^{124}Xe	54	124	39.41	228	531
^{198}Pt	78	198	4.93	192	68
^{208}Pb	82	208	39.18	190	380
^{209}Bi	83	209	38.99	190	378
^{238}U	92	238	28.66	177	356
^{238}U	92	238	15.12	191	55

Transmission and yield calculations

Transmission efficiency calculations were performed with LISE^{++} v. 17.6.0 using the "Distribution" analytical method [1]. Calculation settings are given in Table 2. An approximation of the optimum production target thickness was chosen to speed the calculations.

Table 2. *Fragment separators characteristics, physical models, and assumptions been used LISE^{++} in transmission calculations:*

Objects/characteristic	Parameter	Value / Model
Target	Material	C
	Thickness	**40**% of range of projectile in target
Angular acceptance after target	Horizontal (full)	80 mrad
	Vertical (full)	80 mrad
	Solid angle	5 msr
Momentum acceptance	dp/p (full)	6 %
Momentum distribution:	Convolution model	[1] – Es (s0=160, coef=1,shift-1)
Charge states :	Yes (target,wedge)	[3] – Global
Energy loss model :		[1] – Atima 1.4
Primary reactions in target:		NP=32; EPAX 3.1 [2]
Secondary reactions in target:	Yes	NP=64; EPAX 3.1 [2]

The optimal charge state combination through the various stages of separation was chosen, and then spectrometer has been tuned for maximum production of each isotope. The production cross sections for projectile fragmentation have been calculated using the EPAX 3.1 parameterization [2] for each beam from the list.

Fission

Production cross sections following projectile fission of ^{238}U have been calculated with the use of the LISE^{++} 3EER model [3]. BigRIPS tabulated user cross sections were used to assist in fission yield estimations. The characteristics of excitation energy regions used in calculations are given in Table 3.

Table 3.

Region	A Z	CS, mb	E*, MeV
Low	^{236}U	576	34
Middle	^{230}Ac	492	144
High	^{220}At	557	394

For each excitation energy region, yield calculations were done and used to optimize the fragment separator. Depending on which region provided the highest yield for a given fragment, the resulting maximum yield was used for the fission fragment rate displayed.

Stopped Beams

Beam rates for experiments in the stopped beam areas and for delivery to ReAccelerator (ReA) have been estimated based on observed performance of the Advanced Cryogenic Gas Stopper (ACGS). The estimates assume optimal conditions and are only intended to provide a rough indication of experiment feasibility. Actual rates will likely be less. The rate estimates take into account the transport efficiency for fast beams from the ARIS separator to the gas stoppers and the stopping efficiency, calculated with LISE++ assuming optimum fast beam momentum compression settings. Also included is a parametrization of the extraction efficiency from the gas stopper as a function of the ion mass and the incoming fast beam rate. Stopping efficiency range from a maximum of 95% for heavy ions to 10% for low atomic numbers. Extraction efficiency vary from 20% for mass numbers A > 6 to near unity for A > 70. Decay losses are considered using measured extraction times that vary from 15 ms for light ions to 60 ms for heavy ions. The possible effect of radio-molecule formation that can lead to lower delivered beam rates is not taken into account. Atomic numbers lower than four were excluded from rate estimates.

Reaccelerated beams

Beam intensities in the reaccelerated beam areas have been estimated using the stopped beam intensities multiplied by efficiencies for the Beam-Cooler-Buncher (BCB), the Electron Beam Ion Trap (EBIT) charge breeder, and the ReA-linac. The efficiencies are based on data from experiment runs and beam tests. The BCB efficiency ranges from 15% for ions with A<12 to 60% for heavier ions up to A=133. EBIT breeding efficiencies into a single charge states vary from 30% for atomic numbers Z<5 to 10% for Z>50. Decay losses in the EBIT are considered assuming an average breeding time of 100 ms. The ReA-linac and beamline transport efficiencies are assumed to be 60%.

References:

[1] O.B. Tarasov and D. Bazin, NIM B 266 (2008) 4657-466

[2] K. Sümmerer, Phys. Rev. C 86 (2012) 014601.

[3] O.B. Tarasov, Tech.Rep. MSUCL1300, NSCL, Michigan State University 2005.