70 YEARS OF CREATING TOMORROW

Los Alamos NATIONAL LABORATORY

Parasitic Isotope Production with Cyclotron Beam Generated Neutrons

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UNCLASSIFIED

Accelerator production of isotopes

TABLE 3.2. POPULAR RADIONUCLIDES VERSUS THE PROTON ENERGIES REQUIRED FOR THEIR PRODUCTION

Proton energy (MeV)	Radionuclides easily produced
0–10	F-18, O-15
11–16	C-11, F-18, N-13, O-15, Na-22, V-48
17–30	I-124, I-123, Ga-67, In-111, C-11, F-18, N-13, O-15, Na-22, V-48, Tl-201
30+	I-124, I-123, Ga-67, In-111, C-11, F-18, N-13, O-15, Sr-82, Ge-68, Na-22, V-48

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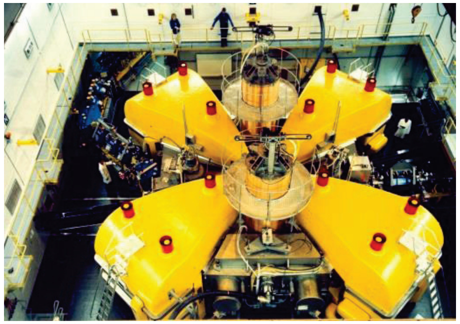
Intermediate energies
~60 MeV and higher

Operating Intermediate Energy Facilities Worldwide

- **LANL, USA – 100 MeV, 250 μA**
- BNL, USA – 200 MeV, 100 μA
- INR, Russia – 160 MeV, 120 μA

- iThemba, South Africa – 66 MeV, 250 μA
- PSI, Switzerland – 72 MeV, 100 μA
- TRIUMF, Canada – 500, 70 MeV, 100 μA
- ARRONAX, France – 70 MeV, 2X 375 μA



From a production volume perspective the IPF at LANL is presently the leading high power facility

Operating Intermediate Energy Facilities Worldwide

Facility	Beam Energy (MeV)	Operating Beam Current (μA)
ARRONAX, France	70	2X 375
LANL, USA	**100**	250
iThemba, South Africa	66	250
INR, Russia	160	120
BNL, USA	200	100
TRIUMF, Canada	500, 70	100
PSI, Switzerland	72	100

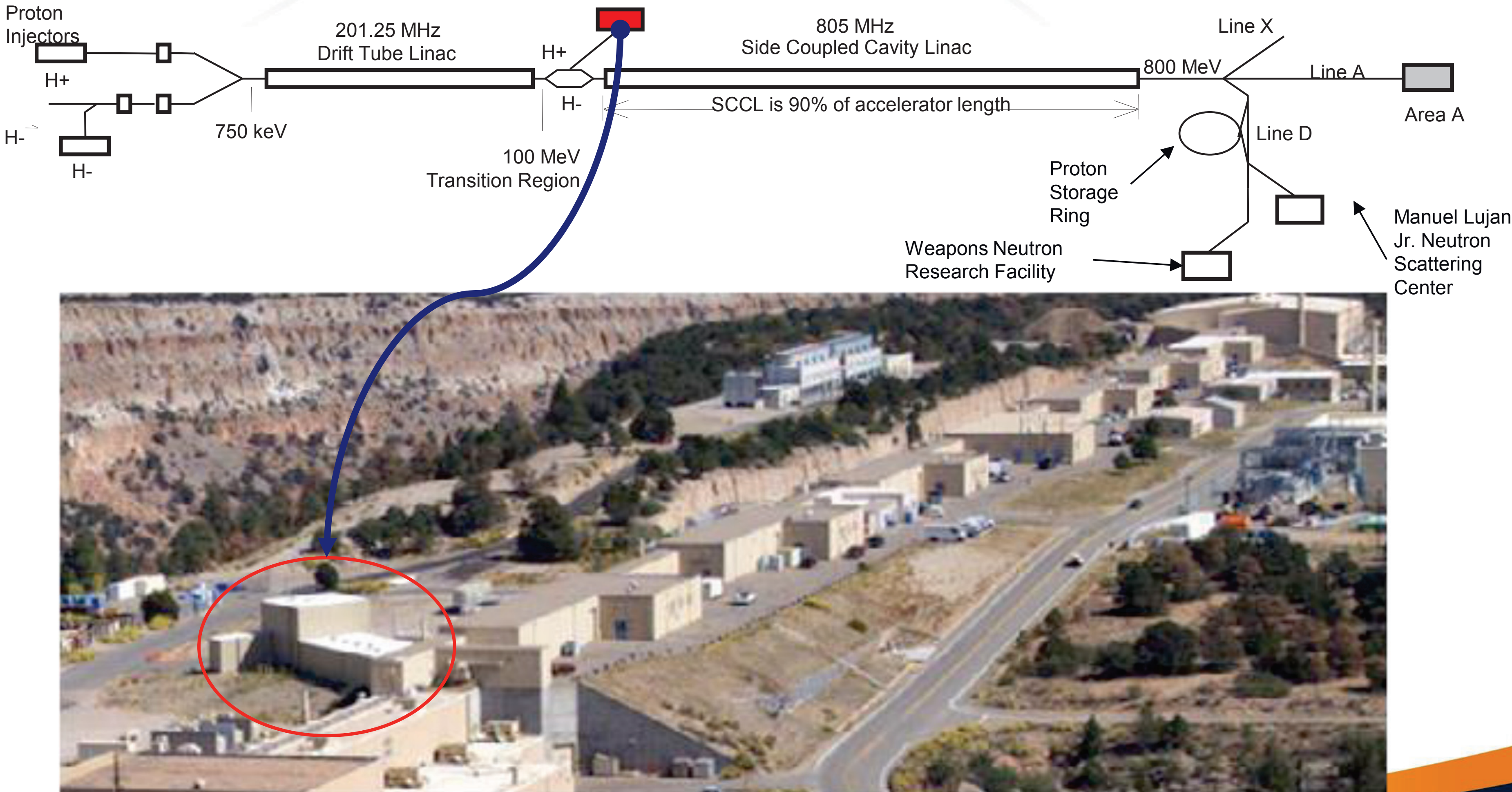
New Facility	Beam Energy (MeV)	Beam Current (μA)
Deajeon, Korea	100	600

The LANL experience – commercial isotopes ^{82}Sr and ^{68}Ge produced on a large scale

Isotope	Half-life	Main Use
^{82}Sr	25.5 d	Parent of ^{82}Rb used in cardiac perfusion studies with PET
^{68}Ge	270 d	Positron emitter used in calibration sources for every PET scanner in clinical use
^{88}Zr	83.4 d	Parent of ^{88}Y used as a tracer surrogate for ^{90}Y in oncological bio-distribution studies
^{22}Na	2.6 a	Test objects for PET studies, tracer for natural Na
^{32}Si	153 a	Tracer for environmental transport studies
^{73}As	80.3 d	Tracer for toxicology studies
^{109}Cd	462.6 d	Source for X-ray fluorescence
^{67}Cu	2.6 d	Treatment of non-Hodgkin's Lymphoma
^{225}Ac	10 d	Alpha emitter used in cancer therapy clinical trials
^{186g}Re	90.6 h	Bone pain palliation, cancer therapy

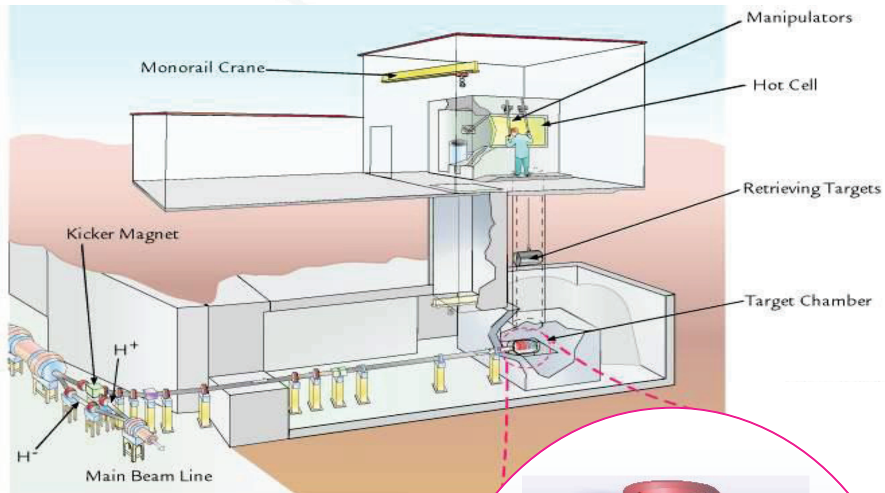
Other facilities has similar experience

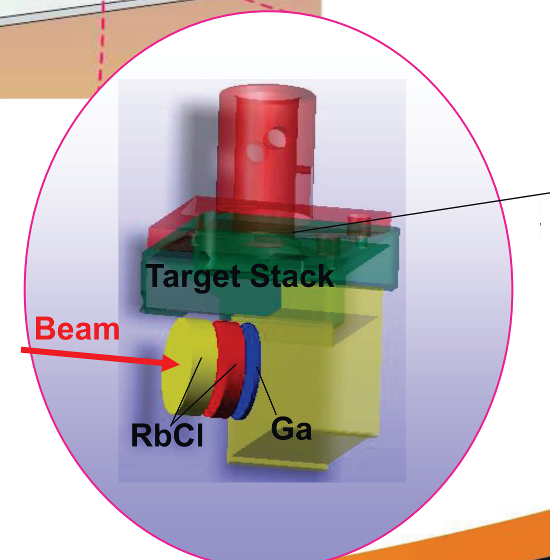
Overview – Isotope Production Facility (IPF) at LANSCE

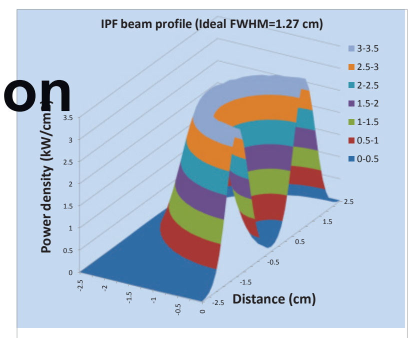


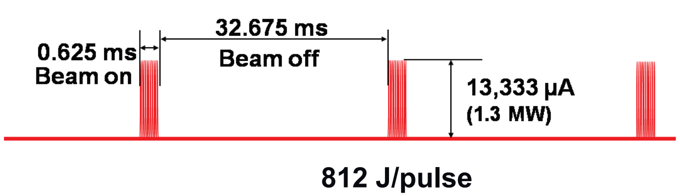
Overview - Large Scale Production

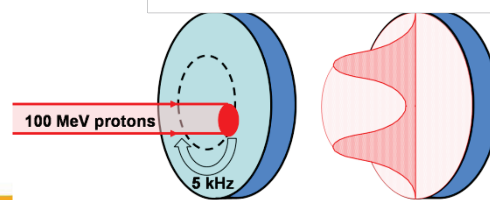
- Production targets are routinely irradiated with 250 μA of 100 MeV protons
- Pulsed beam has a ring-shaped profile
- Three targets in a stack with cooling channels in between
- Production occurs simultaneously in 3 production energy windows



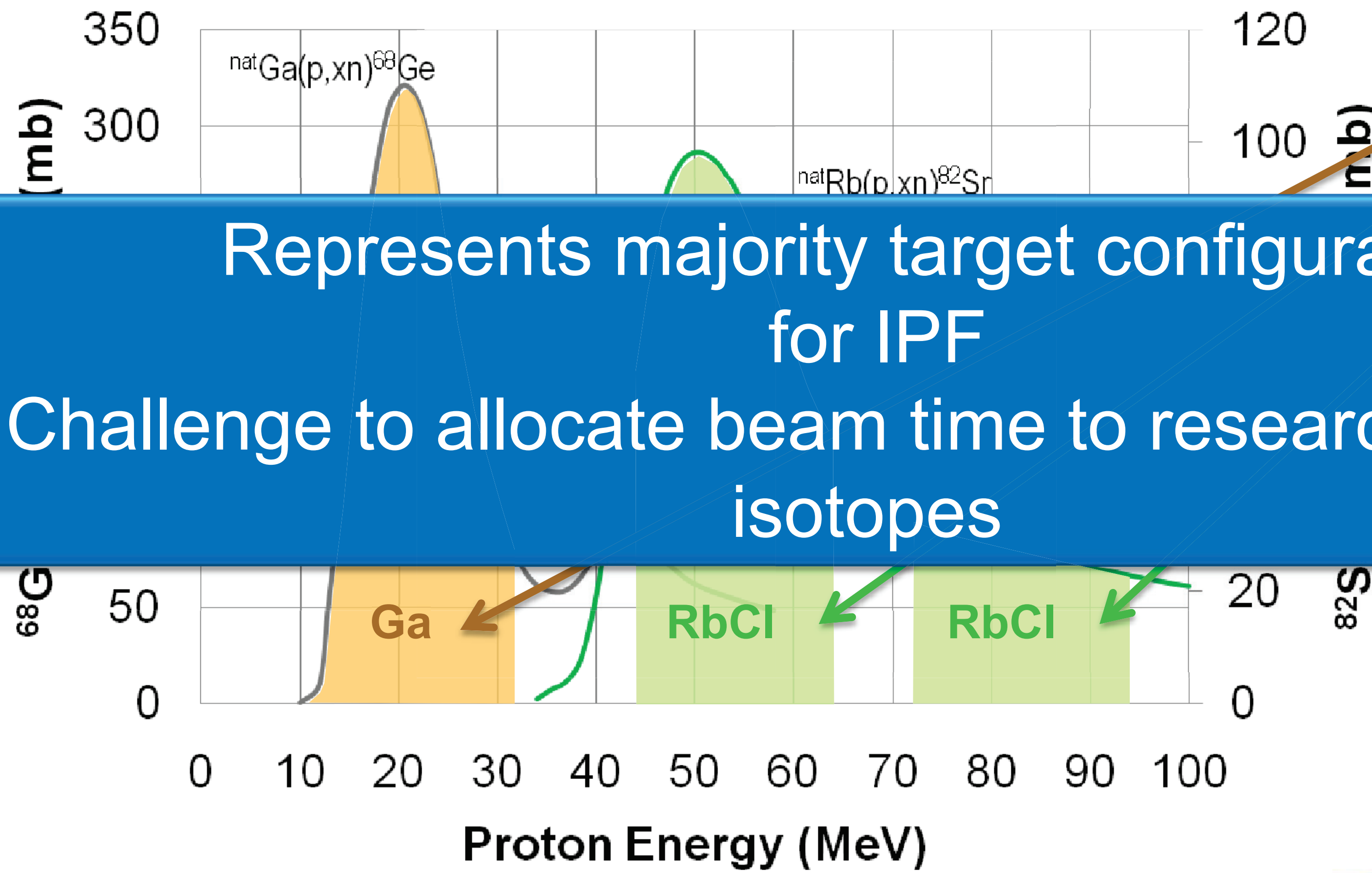


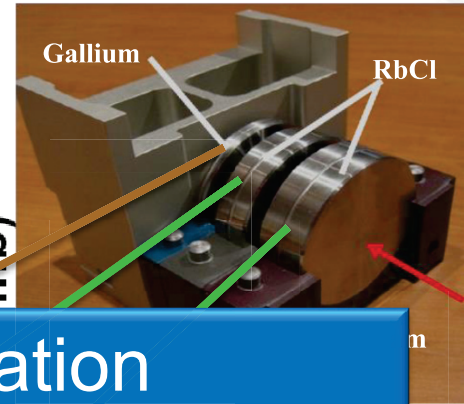






One Target Stack Tuned for ^{82}Sr and ^{68}Ge

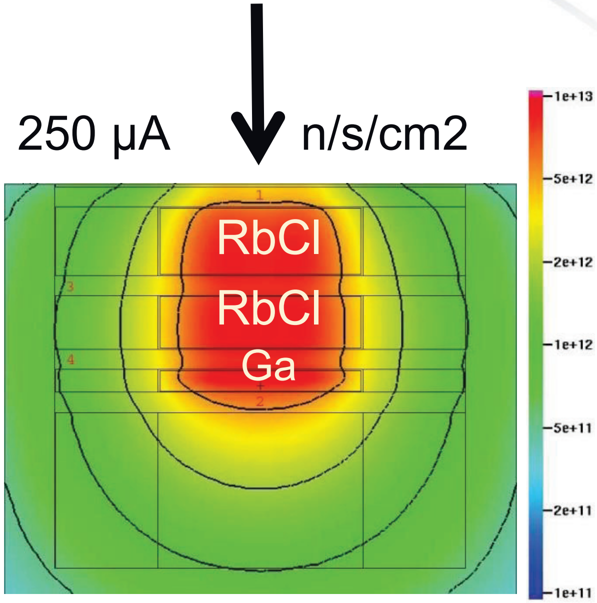




Represents majority target configuration for IPF

Challenge to allocate beam time to research and new isotopes

Lots of Secondary Neutrons



MCNPX prediction

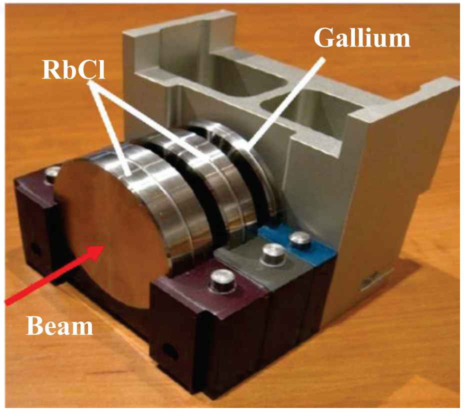
"nuisance" neutrons cause unwanted activation unwanted production of impurities

- For the $^{82}Sr/^{68}Ge$ production target stack
- Model calculations predict a secondary neutron flux of $\sim 10^{12}$ n/s/cm^2 around the targets

Comparable with that of a medium-flux research reactor

Parasitic Production of NCA Isotopes Utilizing Secondary Neutrons

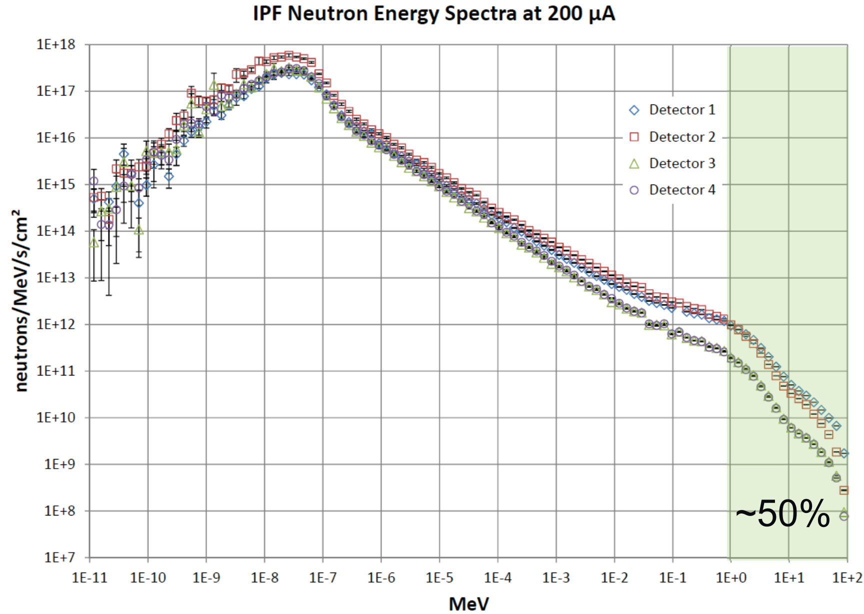
- Presents potential for useful production of No-Carrier-Added isotopes via (n,p), (n,2n) and (n,α) threshold reactions
- Candidate isotopes include ^{36}Cl, ^{63}Ni, ^{64}Cu, ^{67}Cu, ^{85}Kr, ^{89}Zr, ^{212}Pb, ^{225}Ac, ^{229}Th, ^{231}Pa, ^{237}Np
- Inspection of reaction thresholds on target nuclei over a wide mass range shows that thresholds generally vary in the range 0-10 MeV

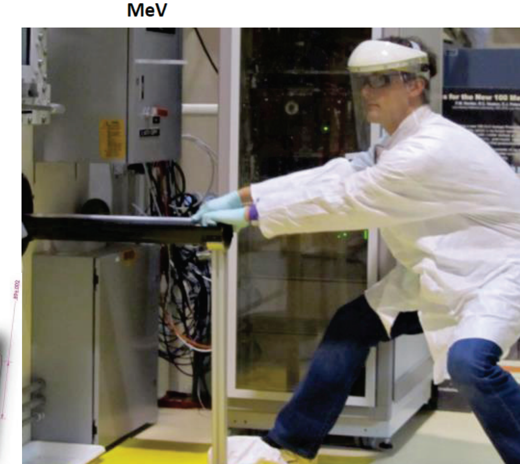


Target Nucleus	(n,p)	(n,2n)	(n,α)
^{16}O	10.2	16.6	2.3
^{36}Cl	0	8.8	0
^{70}Zn	5.8	9.3	0.2
^{148}Nd	4.1	7.4	0
^{226}Ra	2.9	6.4	0

Parasitic Production of NCA Isotopes Utilizing Secondary Neutrons

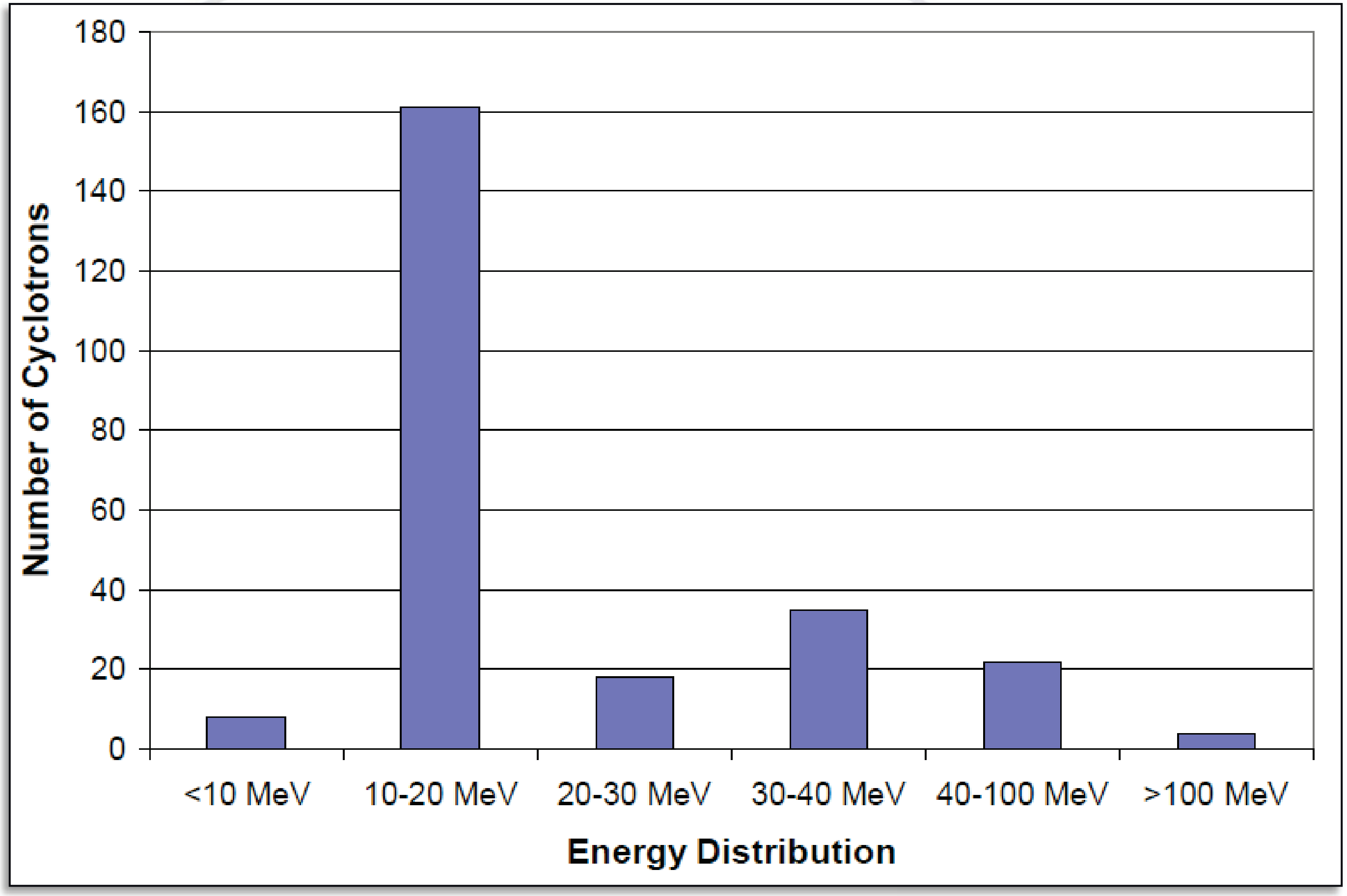
- Approximately 50% of the neutrons have energies >1 MeV (25% > 5 MeV, 15% > 10 MeV)
- This high energy component is very suitable for inducing (n,p), (n,2n) and (n,α) type reactions
- MCNPX model calculations and experimental verification measurements suggests small scale production is feasible
- Work is championed by Post Doctoral Fellow, Jonathan Engle





J.W. Engle et al., AIP Conf. Proc.,1509 (2012)

2006 - Cyclotrons energy distribution

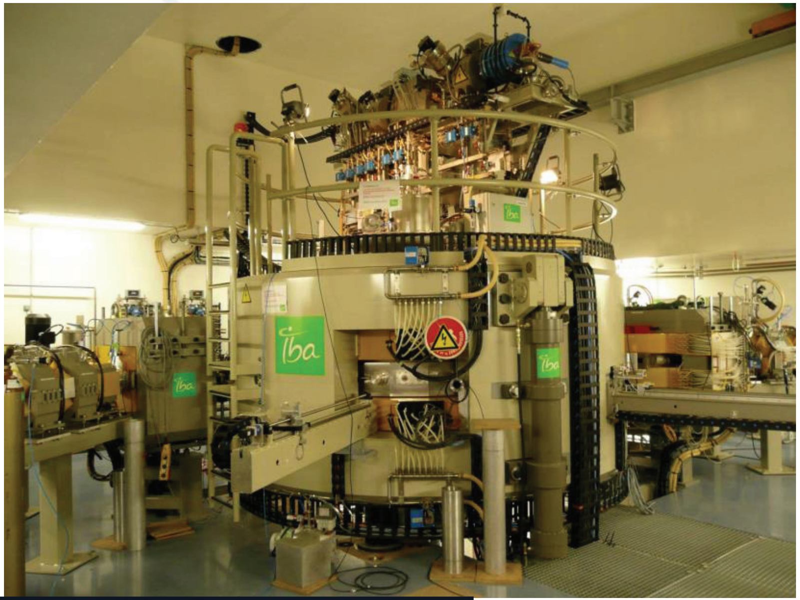


IAEA - DCRP, 2006

Intermediate energy cyclotrons can take advantage

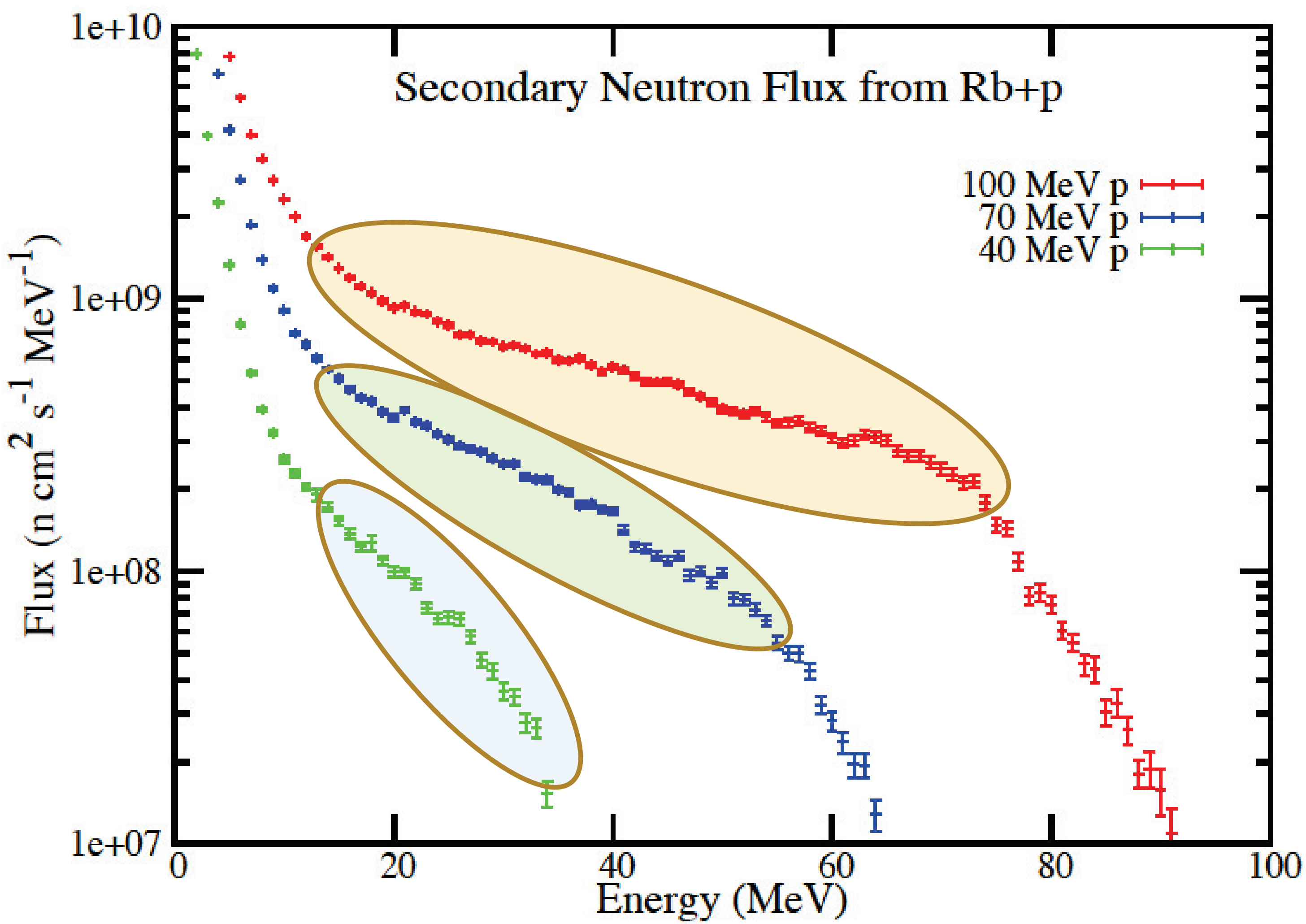
Commercial 70 MeV cyclotrons for large-scale production

ARRONAX machine, France

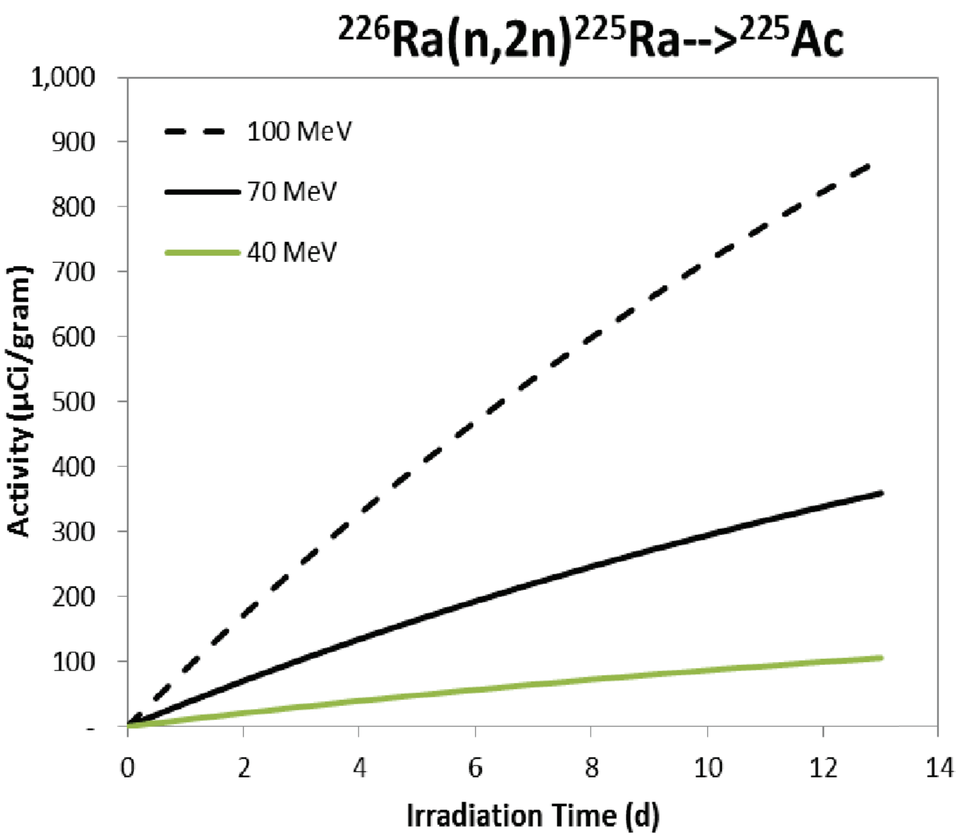


Beam	Particle	Energy (MeV)	Current (µAe)	Dual beam
Proton	H-	30-**70**	**<375**	**Yes**
	HH+	17.5	<50	No
Deuteron	D-	15-35	<50	Yes
Alpha	He++	68	<70	No

Secondary neutron flux comparison



Example of small-scale production of NCA ^{225}Ac



- Production approaching mCi scale is possible at 100 MeV, 250 µA
- Sufficient to support pre-clinical research efforts
- 70 MeV and 40 MeV potential is lower

  but
- High current of emerging commercial machines can still take advantage

Advantages are compelling

- Production is parasitic with no impact on proton beam schedule
- No proton beam heating of targets
  - Allows a wide range of target material
  - Containment of target material is greatly simplified
- Recycling of expensive highly enriched target material is much simpler
  - Target mass can range from ***mg*** to ***g*** scale and beyond
  - No sophisticated hot cell based target fabrication capability required

Summary

- Several isotope production facilities are operating at intermediate energies, including high power cyclotrons
- Often primary beam time is consumed for production of one or two isotopes (Sr-82, Ge-68 at LANL)
- Challenge to allocate beam time for small quantities of research isotopes
- At LANL parasitic utilization of secondary neutrons shows promise for research scale production via threshold reactions such as (n,p), (n,2n) and (n,α)
- This approach can benefit other facilities, especially high power cyclotron facilities such as iThemba, ARRONAX and TRIUMF

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