Neutron-rich Rare Isotope Production in ^{238}U Projectile Fission at 20 MeV/nucleon

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ΚΑΠΟΔΙΣΤΡΙΑΚΟ
ΠΑΝΕΠΙΣΤΗΜΙΟ
ΑΘΗΝΩΝ

3rd Workshop of the Hellenic Institute of Nuclear Physics (HINP)
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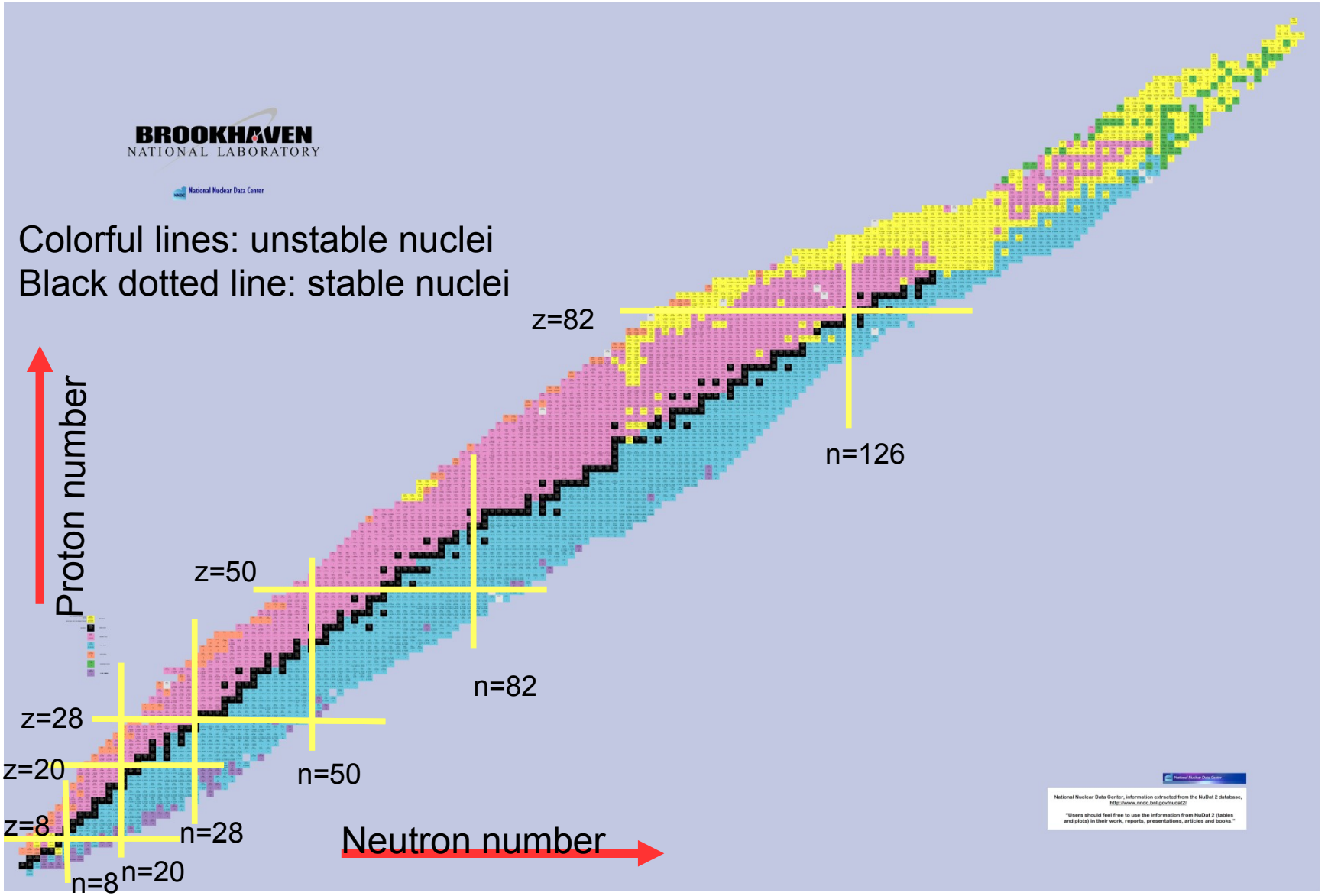
The Nuclear Landscape



https://en.wikipedia.org/wiki/Table_of_nuclides#/media/File:NuclideMap_stitched_small_preview.png
National Nuclear Data Center, information extracted from the NuDat 2 database, http://www.nndc.bnl.gov/nudat2/

288 nuclei are stable
~ 3300 short-lived (radioactive) nuclei synthesized to date
large region of neutron-rich nuclei is still unexplored (~4000 nuclei)

Rare isotope production study: Why?

Investigation of very neutron nuclei offers:

- Understanding of the **nuclear structure** with increasing N/Z

- Insight in nucleosynthesis processes (i.e. rapid neutron capture process, **r-process**)

- Reactions induced by n-rich nuclei:
  isospin dependence N-N interaction, equation of state of asymmetric nuclear matter.

- Study of the nuclear landscape toward the astrophysical **r-process** path and the **neutron drip-line**.
- Production of very neutron-rich nuclides which is a central issue in current and future **rare isotope beam facilities (GSI, Ganil, NSCL/FRIB, TRIUMF)**.

RIB facility @ S. KOREA: Raon

Raon: 라온 meaning happy/joyful in Korean

Raon: Heavy ion accelerator planned to be constructed by 2021 in South Korea

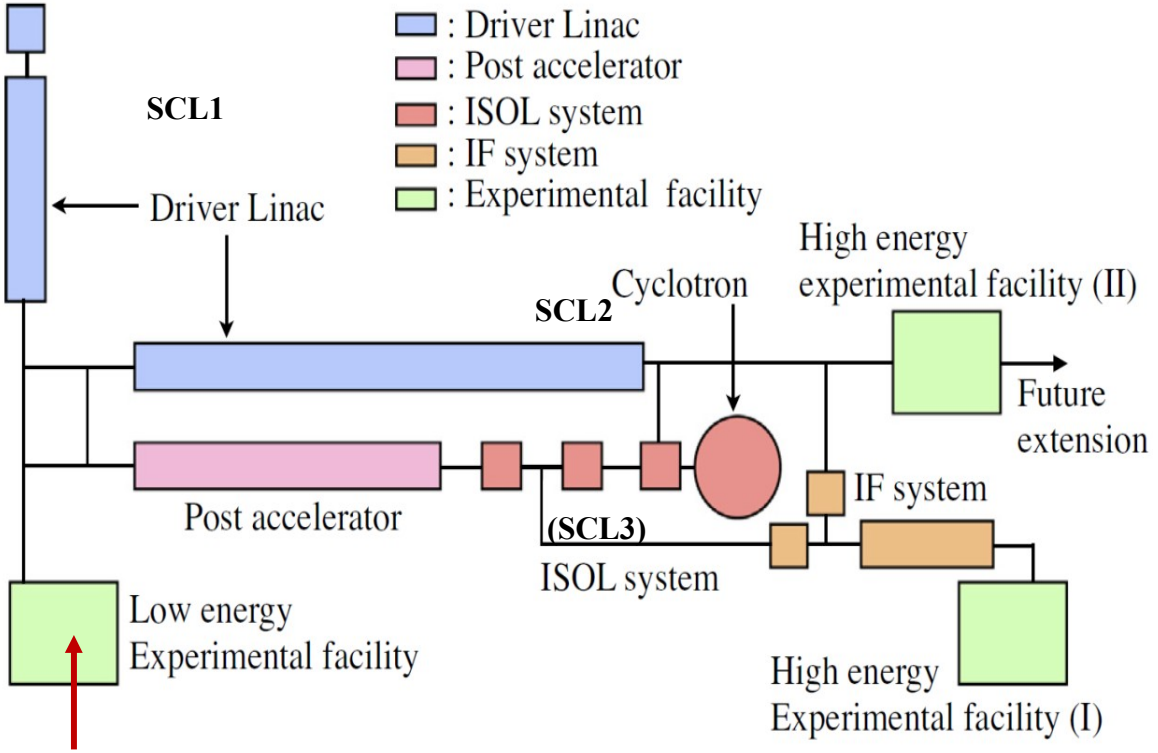
RISP (Rare Isotope Science Project): Research facility of the **IBS** (Institute for Basic Science), Daejeon, South Korea

https://www.ibs.re.kr/eng/sub01_05

Future Accelerator complex in RAON

Innovative feature: **ISOL + IF facilities** (ideally coupled)

SCL: Superconducting linear accelerator



KOBRA

Korea Broad acceptance Recoil spectrometer and Apparatus

http://risp.ibs.re.kr/eng/orginfo/info_blds.do

Initial phase of operation: stable beams 15-25 MeV/nucleon

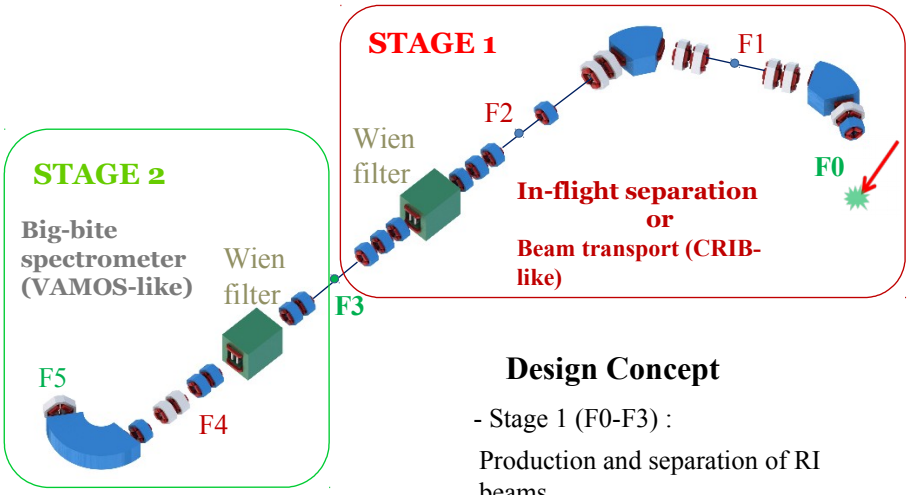
KOBRA separator

KOBRA

(KOrea Broad acceptance Recoil spectrometer and Apparatus)

Main facility for nuclear structure and nuclear astrophysics studies with low-energy stable and rare isotope beams

- **Research guidelines:**
  1) Nuclear structure of exotic nuclei near the drip lines
  2) Nuclear reactions (important in Astrophysics)
  3) Rare event study - Super Heavy Element (SHE)



Associate equipments

F0	RI production target,
F3	gas-jet target, gamma-array, detection system
F5	Focal plane detection system

Design Concept

- Stage 1 (F0-F3) :

  Production and separation of RI beams.

- Stage 2 (F3-F5) :

  Separation of the fragments following reactions of the RI beams on a secondary target.

- Main Specification

Maximum magnetic rigidity (Tm)	~3
Mass resolution ($m/\Delta m$) @ stage 1	~700
Dispersion (cm/%) @ stage 1	4.2
Momentum acceptance (%) @ stage 1	±4
Angular acceptance (mrad) @ stage 2	40 (H) and 200 (V)

Design status of KOBRA for rare isotope production and direct measurements of radiative capture cross sections
DOI: 10.1016/j.nimb.2015.12.025
Tshoo et al. Nucl. Instr. Meth. B in press

Production of Rare Isotopes: How?

- Spallation reactions for ISOL-type techniques
- Projectile fragmentation (beam energies typically >100MeV/nucleon)
- High energy projectile fission (light and heavy fission fragments)

What is our MOTIVATION?

Production of intense rare isotope beams @ 15-25 MeV/nucleon in upcoming RIB facilities worldwide

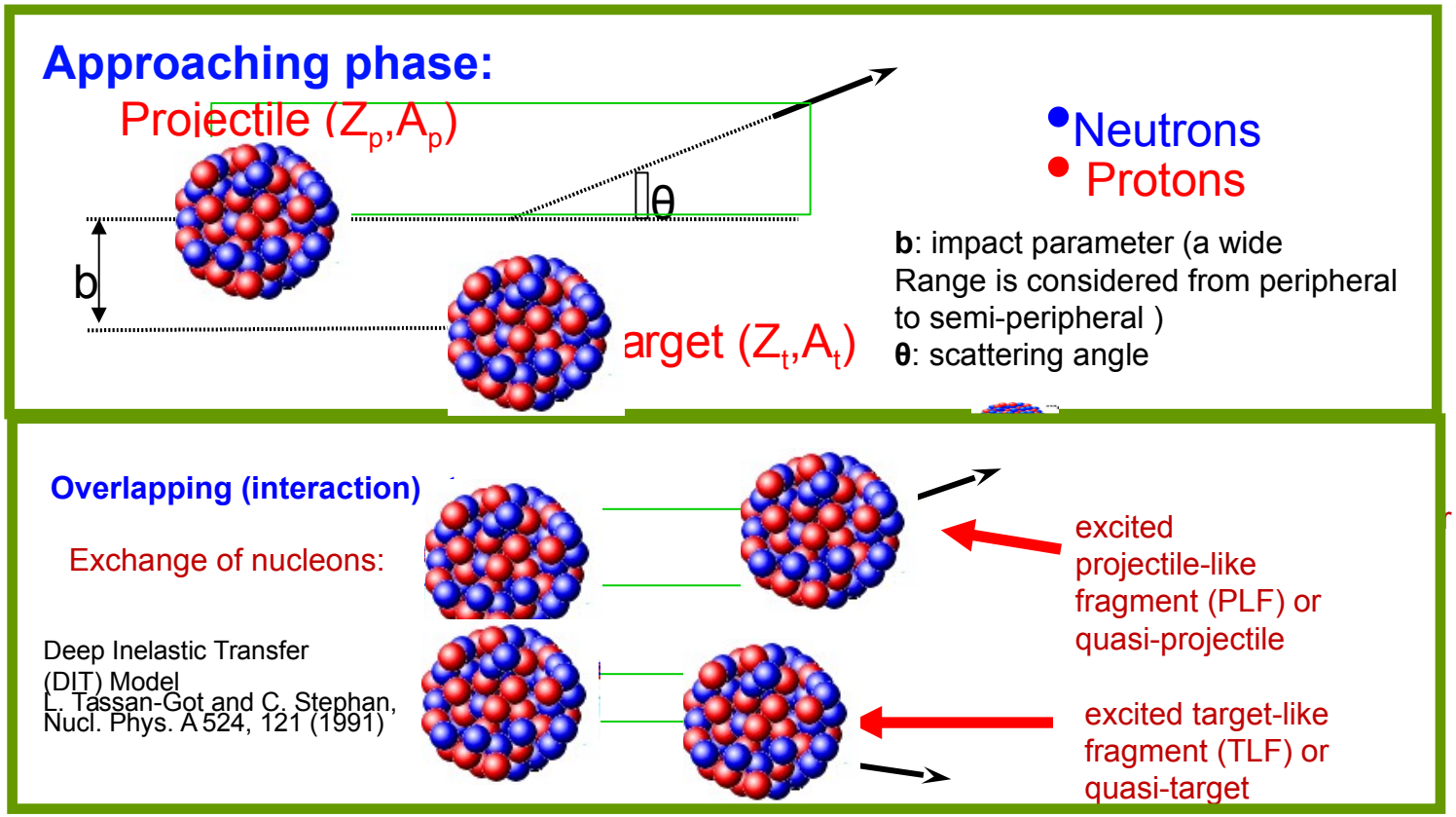
What is our METHOD?

Projectile fission following multinucleon transfer in 15-25 MeV/nucleon

The process: **quasi-projectile (QP) fission or simply QPF**

QPF: fission of a heavy quasi-projectile that results from extensive interaction of the heavy projectile with a heavy target

Multinucleon transfer in peripheral collisions



***DIT : Phenomenological model (Monte Carlo implementation) that simulates the stochastic nucleon exchange in peripheral collisions**

- 2 fermi gases in contact
- Formation of a di-nuclear configuration
- Exchange of nucleons through a "window" formed by the superimposition of the nuclear potentials in the neck region
- After the interaction: quasi-projectile and quasi-target are excited
- Nucleon exchange : the only source of energy dissipation
- Dissipation of Kinetic energy into internal degrees of freedom

De-excitation of the fragments: ***SMM (Statistical Multifragmentation Model)

****CoMD : model, full microscopic description**

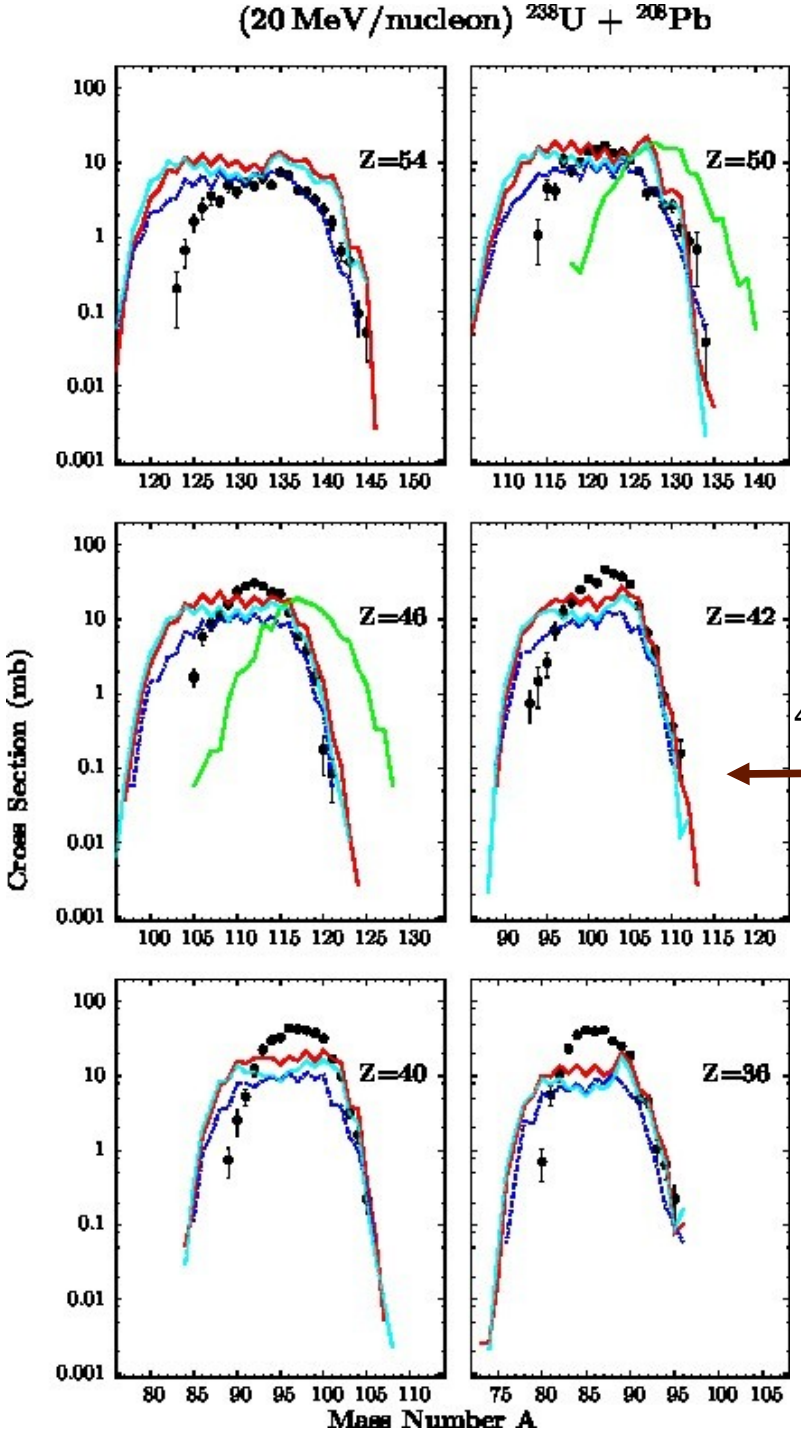
*DIT : L. Tassan-Got, C. Stephan, Nucl. Phys. A 524, 121 (1991)
DIT(modified): M. Veselsky, G.A. Souliotis, Nucl. Phys. A 765, 252 (2006)

** M. Papa, A. Bonasera et al., Phys. Rev. C 64, 024612 (2001)

***A. Botvina et al., Phys. Rev. C 65, 044610 (2002)

Comparison: Data, Calculations: ^{238}U (20 MeV/nucleon) + ^{208}Pb

Mass distributions of selected isotopes



^{238}**U** (N/Z= 2.59)

Experimental data: NSCL Experiment
G. A. Souliotis, W. Loveland, et al.,
Phys. Rev. C 55,2146 (1997)

Calculations:
Red lines: DIT/SMM [solid (red) line]
Blue lines: CoMD/SMM
Green ines: for Z=46,50: hot fission fragments from DIT/SMM
light blue lines: 238 U (20 MeV/nucleon) + 64 Ni

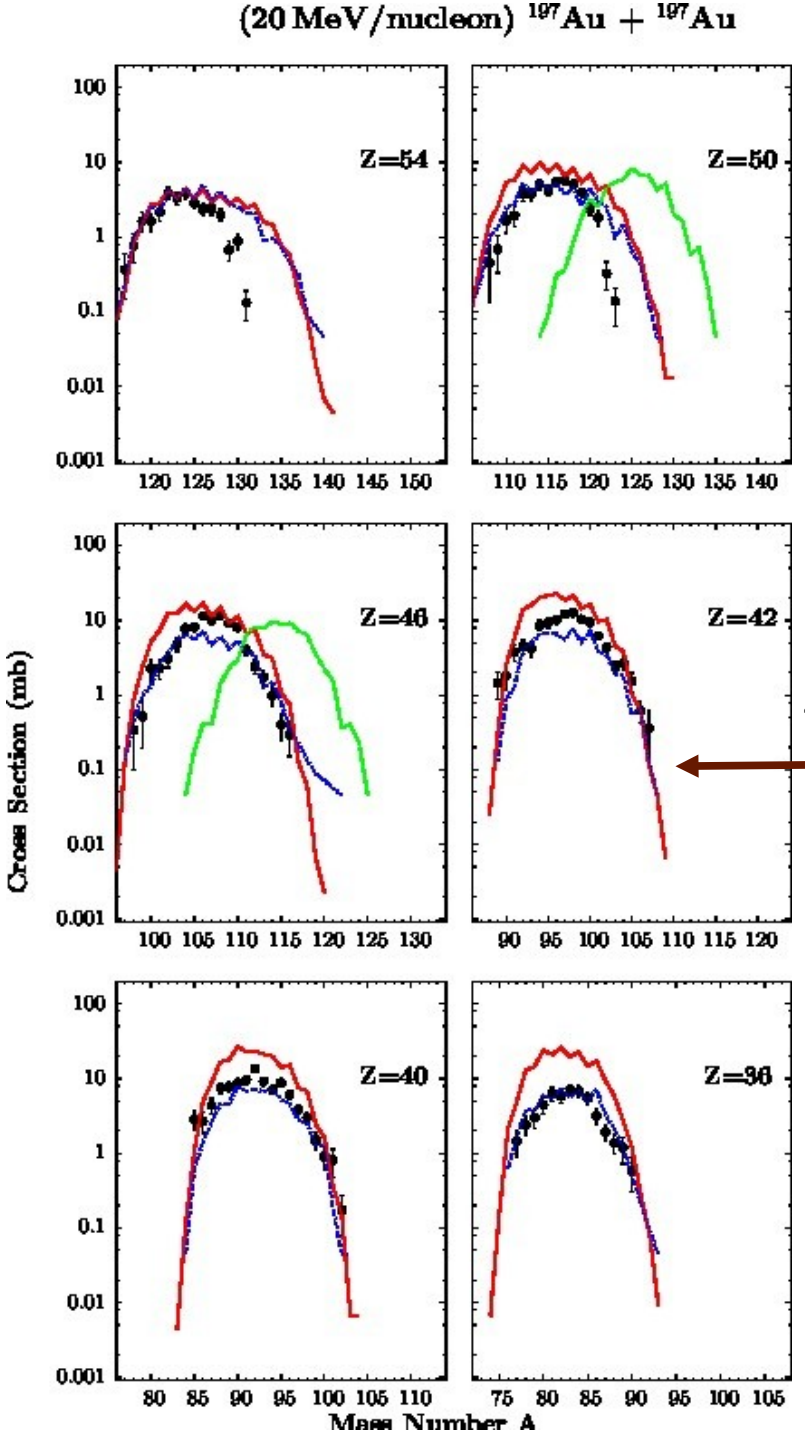
^{42}Mo

Neutron rich side successfully described by our calculation framework

N. Vonta, G. A. Souliotis. M. Veselsky et al.
To be submitted in Phys. Rev. C

Comparison: Data, Calculations: ^{197}Au (20 MeV/nucleon) + ^{197}Au

Mass distributions of selected isotopes



^{197}Au (N/Z= 2.49)

Experimental data: NSCL Experiment
G. A. Souliotis, W. Loveland, et al., Nucl. Phys. A 705,279 (2002)

Calculations:
Red lines: DIT/SMM [solid (red) line]
Blue lines: CoMD/SMM
Green ines: for Z=46,50: hot fission fragments from DIT/SMM

^{42}Mo

Neutron rich side successfully described by our calculation framework

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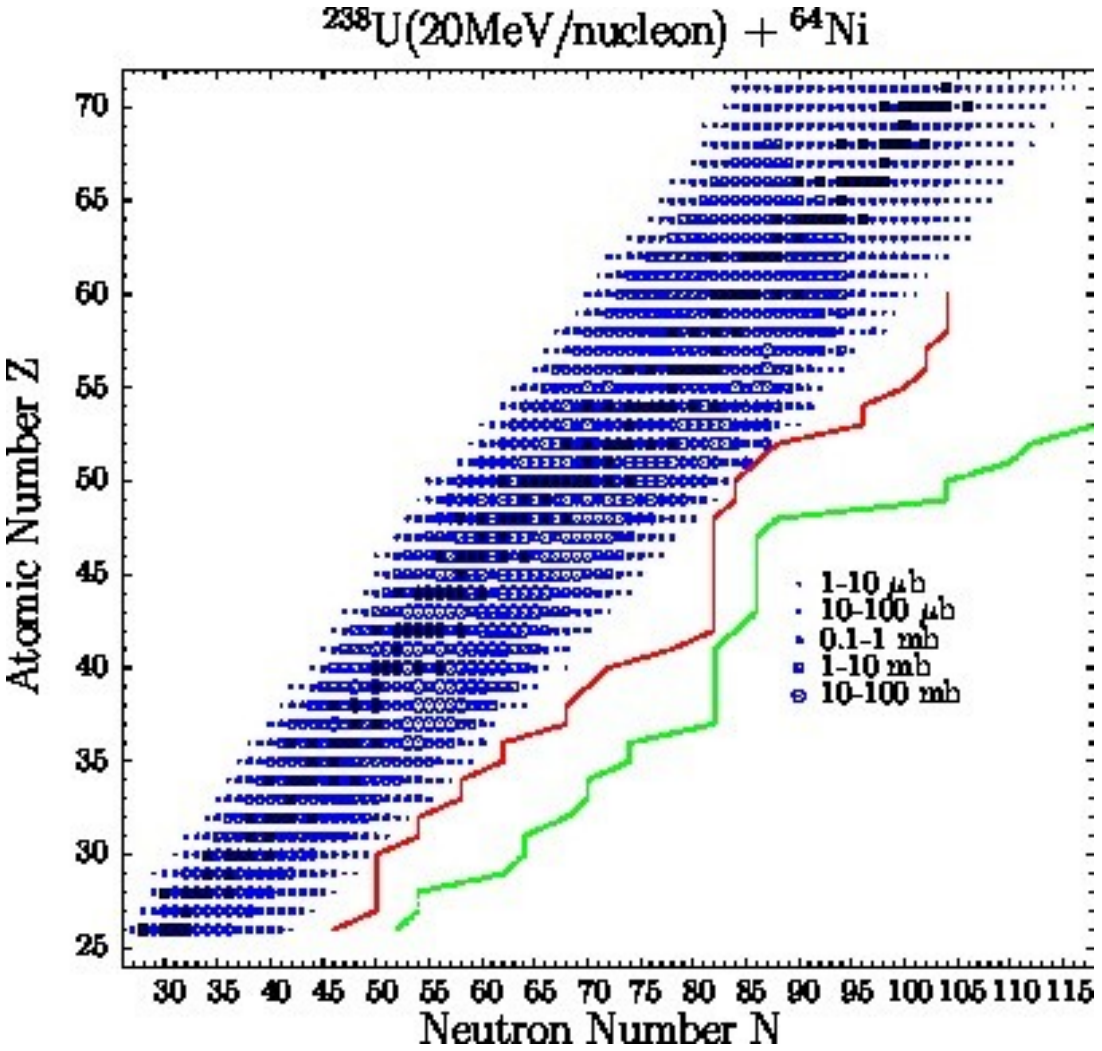
Calculations: ONLY DIT/SMM: ^{238}U (20 MeV/nucleon) + ^{64}Ni

Production cross sections and rates of accessible neutron-rich nuclides



^{64}**Ni** (N/Z=1.29)

Black: stable nuclei
Blue points: calculations DIT/SMM
Red: r-process
Green: expected neutron drip line

Current model framework predicts the production of nuclides toward r-process

N. Vonta, G. A. Souliotis. M. Veselsky et al.
To be submitted in Phys. Rev. C

Discussion – Future plans

- **CoMD calculations** on full dynamics*
- Projectile fission measurements: ^{238}**U (12 MeV/nucleon**) MARS recoil separator at Texas A&M Cyclotron Institute
- Experience and preparation for future experiments at the **KOBRA separator at RAON**

Acknowledgements

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- **S. J. Yennello** and group (contribution and preparation for future experimental work)

- ***N. Vonta, G. A. Souliotis. M. Veselsky et al.**
- **To be submitted in Phys. Rev. C**

***N. Vonta, G. A. Souliotis, M. Veselsky, and A. Bonasera**
Phys. Rev. C 92, 024616

THANK YOU!