PRISMAP
Medical Radionuclides

THE ISOL TECHNIQUE

Overview of the Isotope Separation OnLine technique

Leuven, Tuesday 28 May 2024

Recall from Riccardo

$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$

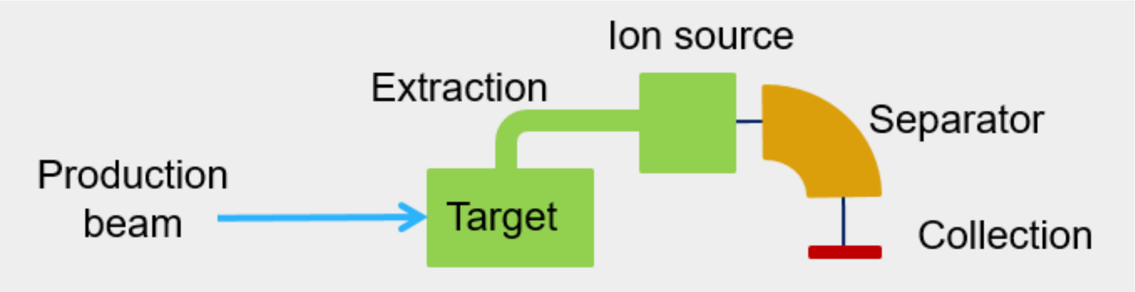
Yield

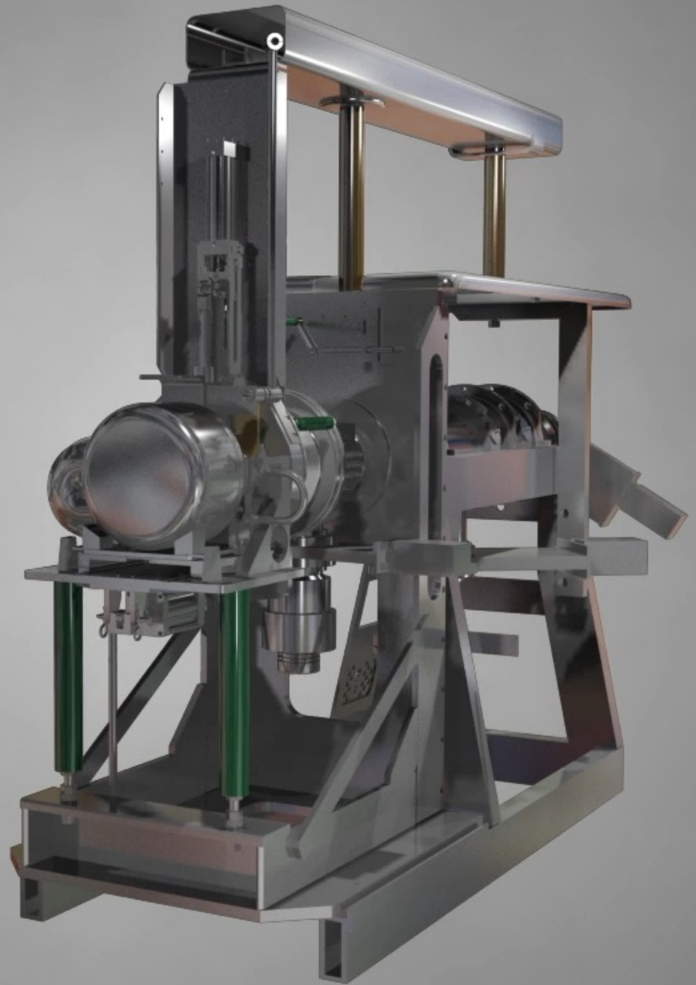
Beam intensity

Target

Cross section

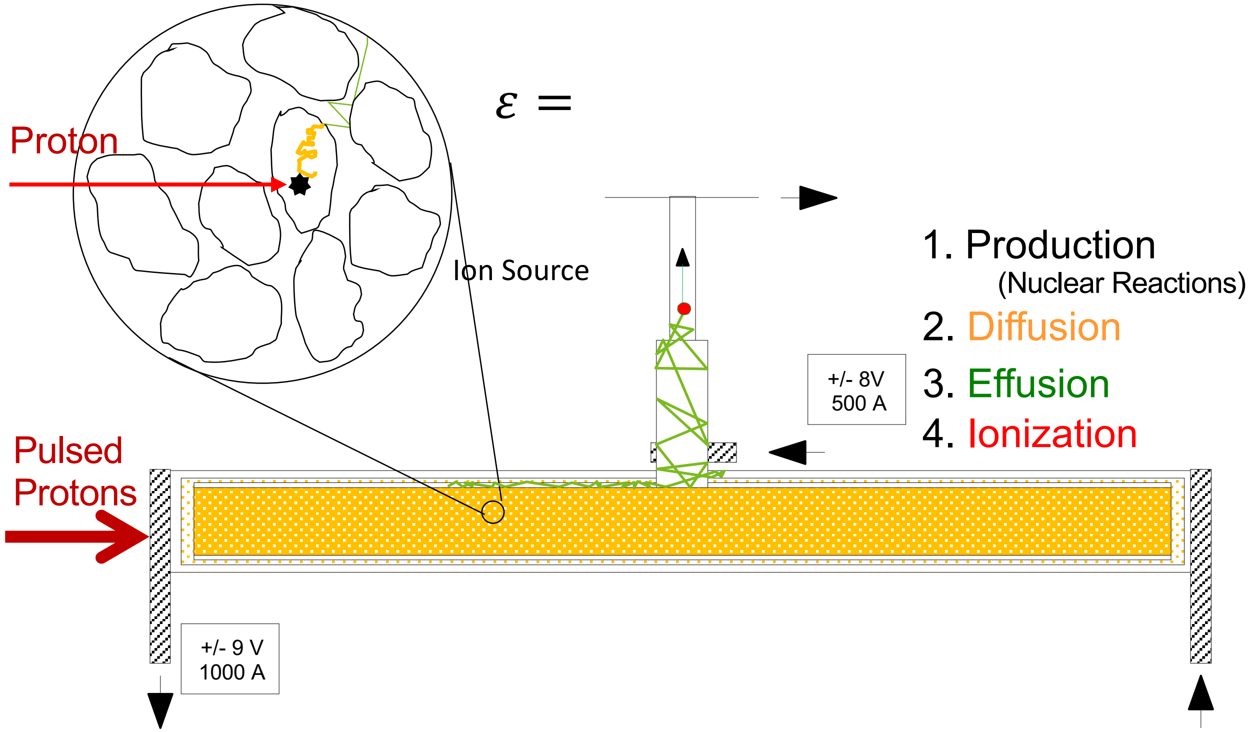
Efficiencies





The ISOL technique broken down

$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$



Animation by João Pedro Ramos, SCK CEN

Outline (of this lecture and of the day!)

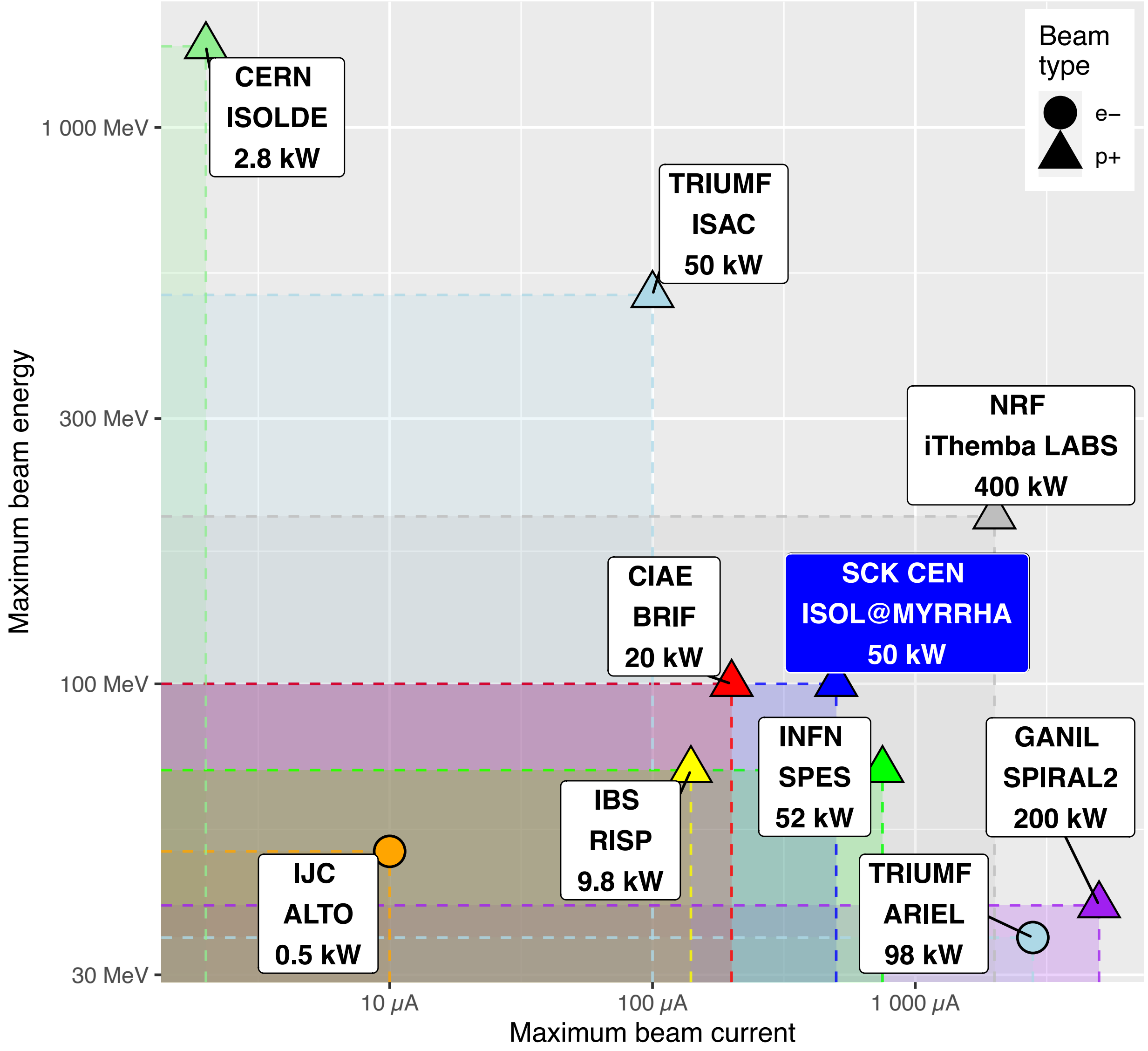
$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$

$$\varepsilon = \varepsilon_{diff}\varepsilon_{eff}\varepsilon_{ion}\varepsilon_{sep}\varepsilon_{trans}$$

- What beam does what? → Riccardo Raabe
- What target? → Stefano Corradetti
- What ion source? → Mia Au
- Mass separation? → Julien Michaud
- How does that work as a whole?? → Laura Lambert

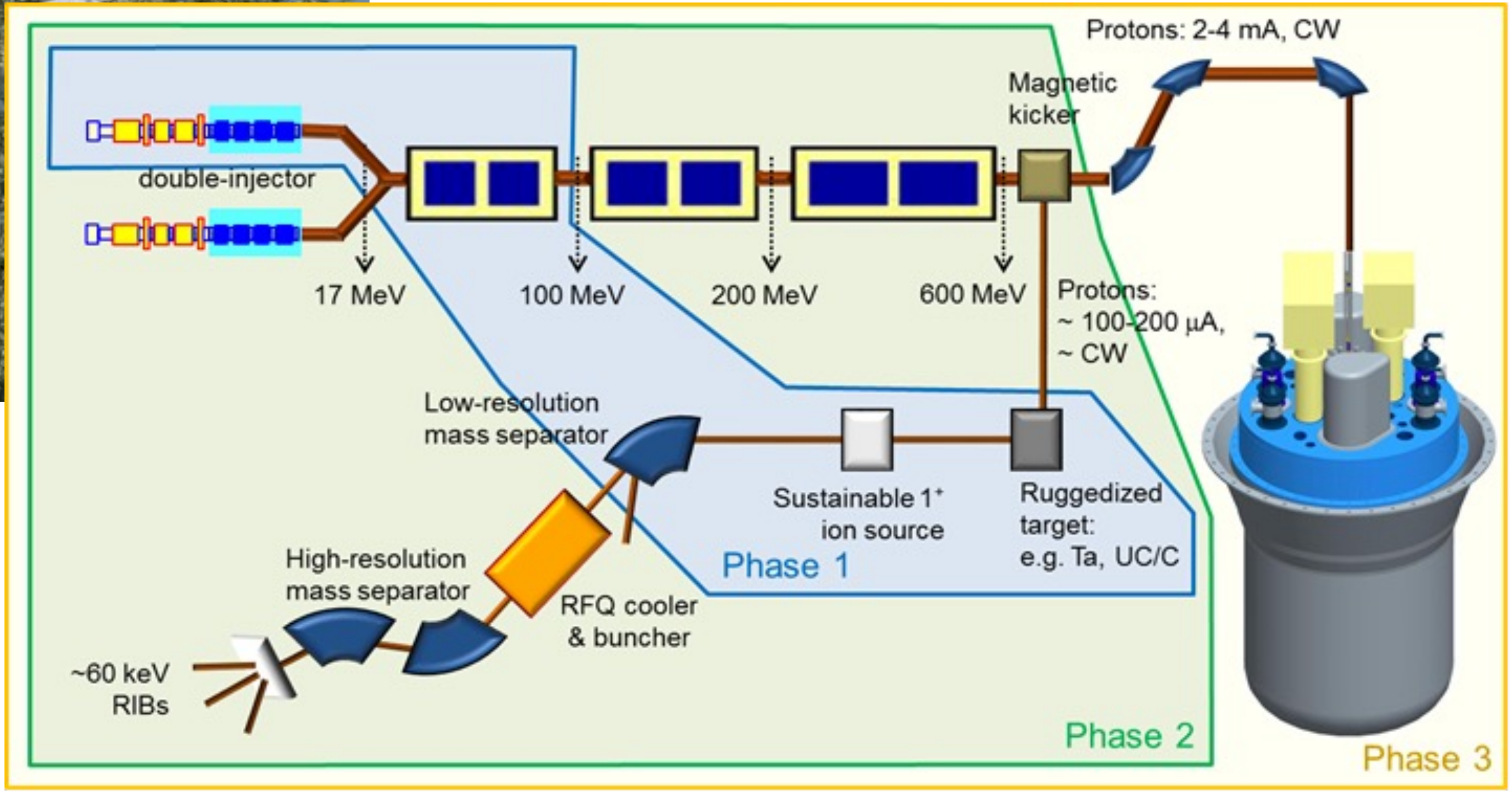
The ISOL landscape

Illustrations by Sophie Hurier, SCK CEN & KU Leuven



ISOL@MYRRHA

- ISOL@MYRRHA is a new ISOL facility being designed at the Belgian Nuclear Research Center SCK CEN in Mol, Belgium.
- Its Phase 1 will operate with 100 MeV protons, then phase 2 600 MeV protons, with up to 500 µA on target (200 µA on actinides).
- This high power and high-power deposition in the target present global challenges for the ISOL technique that are under investigation (target, ion source).



www.myrrha.be

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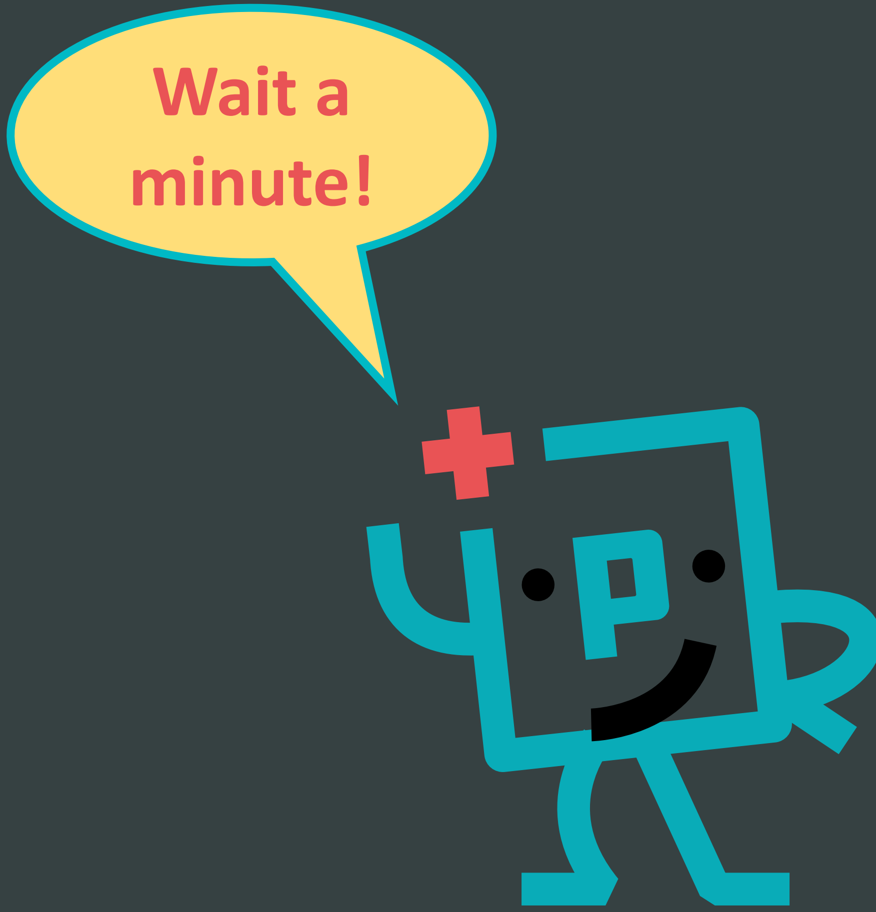

ZEE END!

WWW.PRISMAP.EU

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008571 (PRISMAP).

Can we really dissociate the different components?

$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$

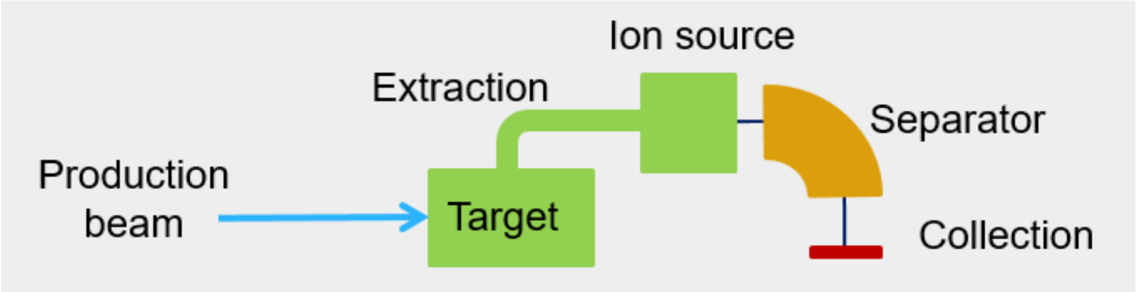
Yield

Beam intensity

Target

Cross section

Efficiencies



More beam = more RIB?

$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$

- More beam should yield more radioactive ion beam linearly.

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- More beam should yield more radioactive ion beam linearly.
- BUT more beam damages the target more rapidly, so that the release efficiency goes down and one ends up with LESS beam rather than more.
- Moreover, with too much influx, the ion source saturates and more radioactive atoms in the ion source do not translate to more radioactive ions.

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- Scaling up the primary beam intensity has been a dream for many decades
  - ask about EURISOL after a few beers – reactions may vary, from laughter to tears
- Some facilities are getting close to these limits already (e.g., MEDICIS and the ion source)
- New facilities are about to start or under design/construction which aim beyond this limit (e.g., ISOL@MYRRHA)

More target = more RIB?

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- More target should yield more radioactive ion beam linearly.

More target = more RIB?

$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$

- More target should yield more radioactive ion beam linearly.
- BUT more target means generally higher density, which is associated with poorer release, and in the end barely more beam yet a lot more radioactive waste.
- One should also not forget that the particles lose energy in the target material, irrespective of density (e.g., just using a longer target). Then, the question is whether the added target thickness is useful at all. Sometimes, it might be better to work with a thinner target that yields a higher purity – as it avoids producing other contaminants.
  - Maybe Nathalie Michel will tell us how they stack foils at ARRONAX to turn this into an efficiency advantage!

More energy = more choice of RIB?

$$Y = I \cdot N_t \cdot \int_{E_i}^{E_f} \frac{\sigma(E')}{S(E')} \cdot dE' \cdot \varepsilon$$

- Higher energy yields less sensitivity to energy loss and less energy deposition in the material – so less target damage.
- Higher energy also pushes further towards the edge of nuclear stability.

C. Duchemin et al. Applied Radiation and Isotopes 178 (2021) 109983

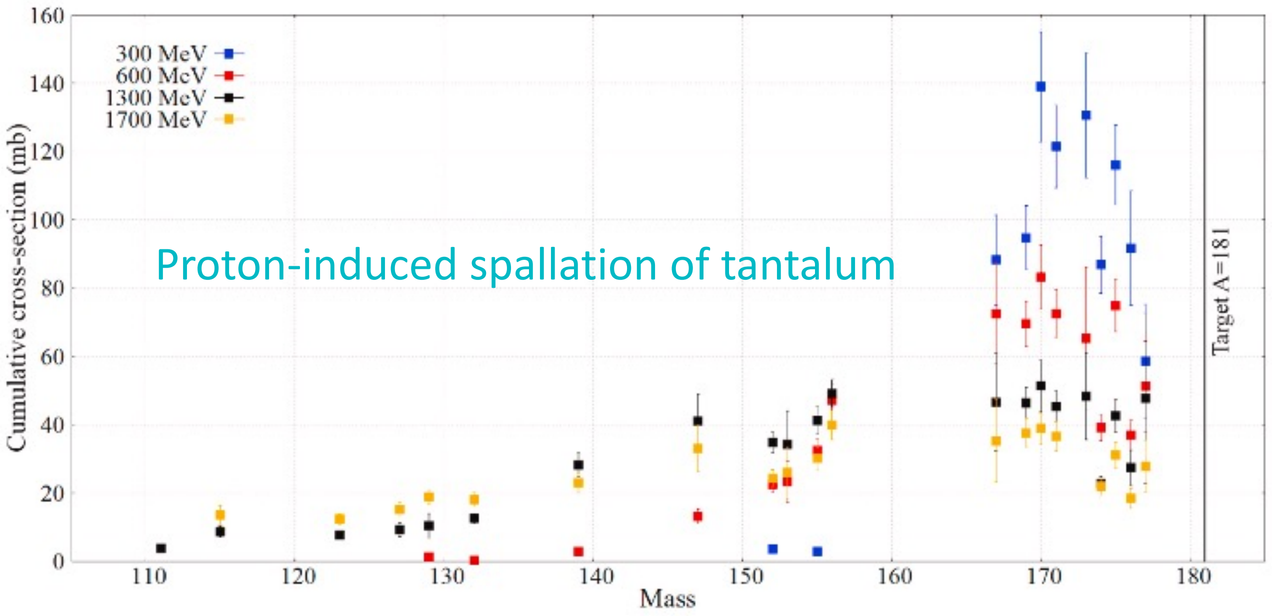

Fig. 7. Cumulative cross-sections for the last radionuclide of the decay chain as a function of mass and beam energy.

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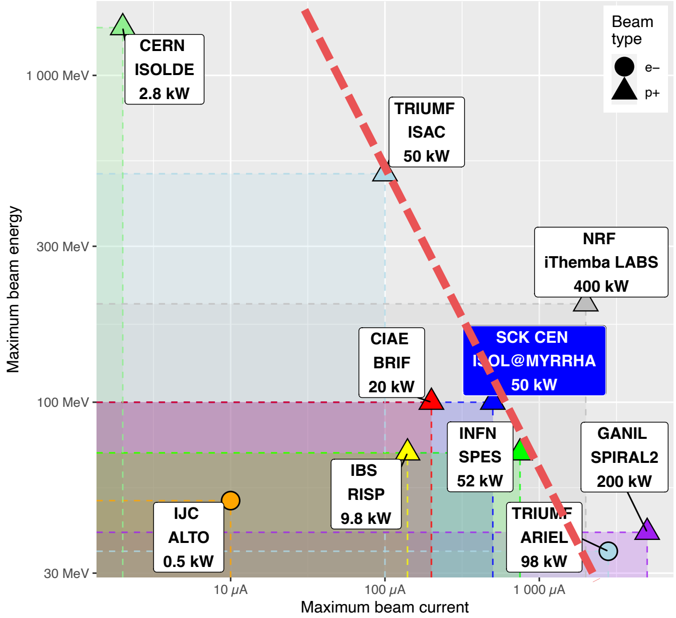
- Higher energy yields less sensitivity to energy loss and less energy deposition in the material – so less target damage.
- Higher energy also pushes further towards the edge of nuclear stability.
- BUT higher energy also means more contaminants – like $^{139}Ce^{16}O$ vs ^{155}Tb.
- Higher energy typically goes together with less beam.



Proton-induced spallation of tantalum

H. Verhoeven, et al. Nuclear Inst. and Methods in Physics Research B 463 (2020) 327–329

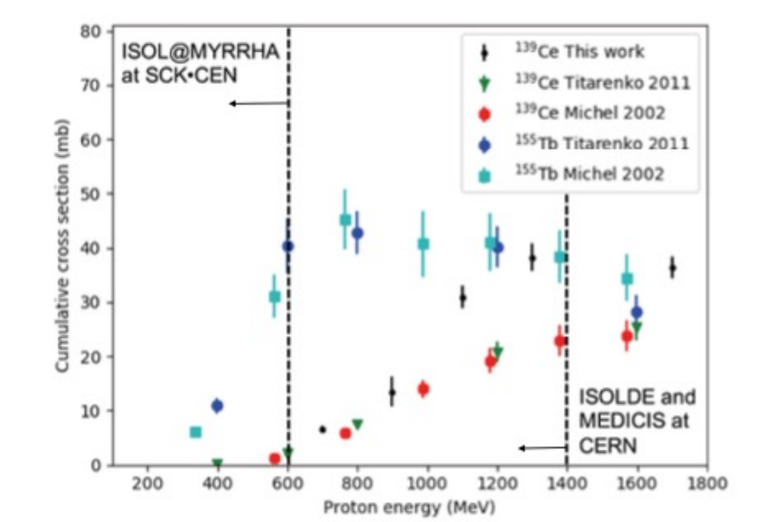
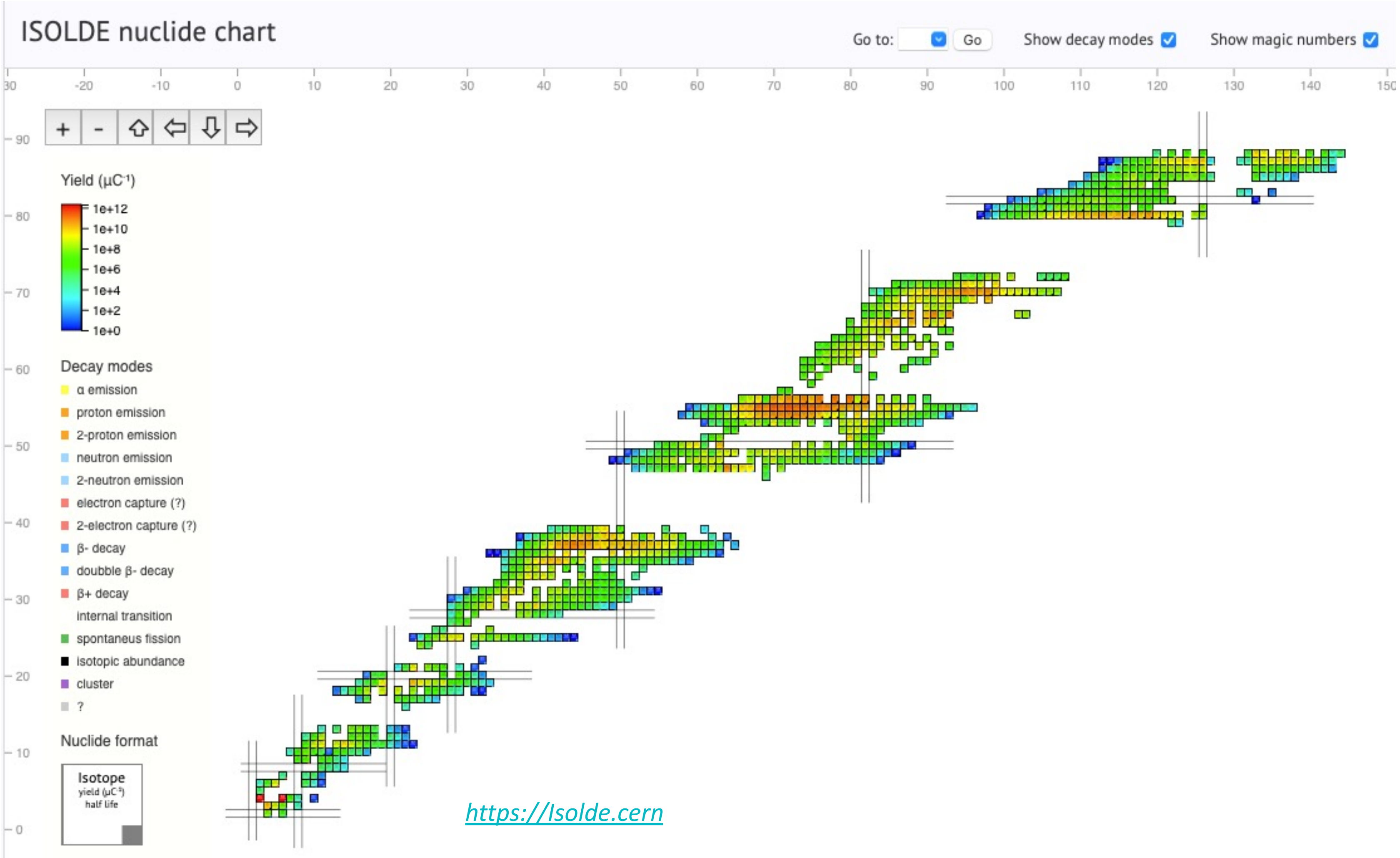


Fig. 3. Cumulative cross section for the production of ^{139}Ce in the spallation of Ta from this work compared to literature data for the same isotope and for ^{155}Tb [8,9]. The operation energy for ISOL@MYRRHA and CERN ISOLDE are indicated with dashed lines and the effective energy range with the arrow. This comparison shows that the purity of the produced ^{155}Tb sample can be increased by using a lower incident energy, such as foreseen at the ISOL@MYRRHA facility.

ISOLDE Yields



https://Isolde.cern

- Experimental RIB facilities like ISOLDE at CERN have access to a wide range of targets and to high energy (1.4 GeV), through which a large inventory of isotopes is available.
- There are gaps in the available beams because of in-target chemistry (but some are also simply not properly characterised to be reported in this table!)
- Advanced techniques can yield extreme purity, but often at the cost of efficiency. It is thus a trade-off between how much and how clean.
- ➔ For medical applications, one needs a lot AND high purity grade, which is a challenge for facilities like MEDICIS.

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AN ISOL FACILITY IS MORE THAN THE SUM OF ITS PARTS BUT DEEP UNDERSTANDING OF EACH STAGE IS REQUIRED TO BUILD A COMPREHENSIVE PICTURE.

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