How to produce scandium-44 efficiently ?

Research studies at SUBATECH laboratory and GIP ARRONAX (France)

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2. GIP ARRONAX, 1 rue Aronnax, 44817 Saint Herblain, France.

1. Introduction

- 3 isotopes of scandium present physical characteristics compatible with nuclear medicine purpose:

  - Sc-47 ($T_{1/2}$ = 3.351 days, β- = 100 %, γ = 68 %) → targeted radiotherapy.

  - Sc-43 ($T_{1/2}$ = 3.891 hours, β+ = 88.1 %) → diagnosis.

Katharina A. Domnanich talk.

  - Sc-44g ($T_{1/2}$ = 3.97 hours, β+ = 94 %, γ = 99.9 %) → diagnosis.

Jerzy Jastrzębski talk (with α) and this talk (with p and d). (available as ^{44}Ti/^{44}Sc generator.)

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- Theranostic approach possible with scandium.

Special emphasis on Sc-44 characteristics :

- Sc-44g is a positron emitter with a half-life between that of Ga-68 and Cu-64.
  → good candidate for PET imaging.

- Two states : Sc-44m ($T_{1/2}$ = 58.6 hours)

  Internal Transition 98.8 % *γ 270 keV*

  Sc-44g ($T_{1/2}$ = 3.97 hours)

  - Possibility to produce the Sc-44m/Sc-44g generator.
  - Production in cyclotron.

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- An isomeric state Sc-44m exists and mainly decays to Sc-44g through IT.

  → Huclier S. et al (Nantes) have demonstrated that Sc-44m/Sc-44g ***in-vivo* generator (3)** is feasible.

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→ Our selected target: calcium-44.

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→ Our selected target: calcium-44.

- Data for Ca-44(p,n)Sc-44 reaction are available in literature.
- No data for the deuteron route

→ Exp. cross section measurements has been carried out at the ARRONAX cyclotron.

3. The ARRONAX cyclotron

3.1 Study of the Ca-44(d,2n) reaction

Accelerator for the **R**esearch in **R**adiochemistry and **O**ncology at **N**antes **A**tlantique **X**

Reaction: Ca-44(d,2n)Sc-44

$E_{threshold}$ = 6.9 MeV

Delivered particles	Energy (MeV)	Max. intensity (μA)	Dual beam
Protons	30-70	2 x 350	Yes
Deuterons	**15-34**	2 x 50	Yes
α particles	67.4	70	No

→ Deuterons beam energy delivered by ARRONAX permits to cover all the energy range of interest

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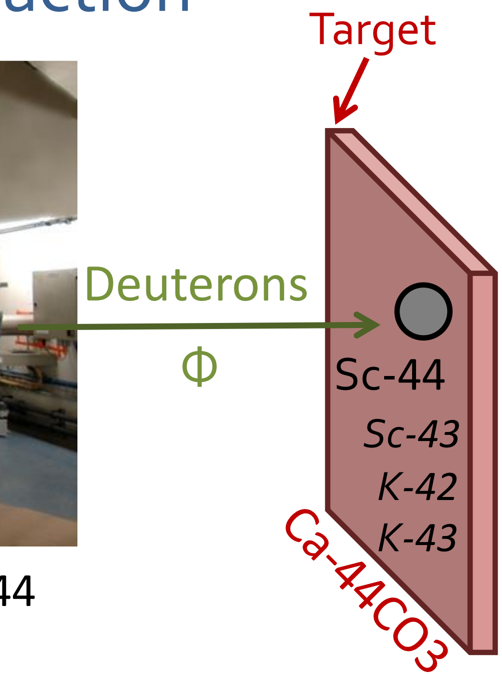

Target form:
$Ca\text{-}44CO_3$ deposit on Al foil

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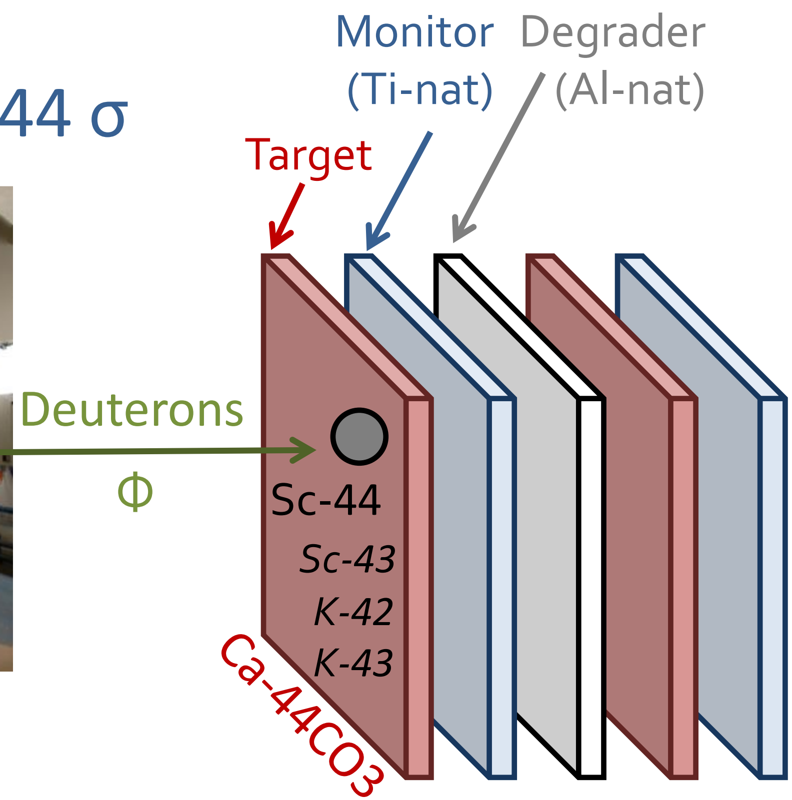
3.2 Experimental method for Sc-44 σ



- For prod. cross section determination → "stacked-foils" technique

Condition : Φ = Φ'

$$\sigma = \sigma' . \frac{Act \,.\, A \,.\, \chi' \,.\, \rho' . ef' . \,(1 - \exp(-\lambda' . t_{irr}))}{Act' \,.\, A' \,.\, \chi \,.\, \rho \,. ef \,. \,(1 - \exp(-\lambda . t_{irr}))}$$

Cross section recommended by the IAEA (refers to σ')

In our case Ti-nat(d,x)V-48

International Atomic Energy Agency Nuclear Data Services Provided by the Nuclear Data Section

Produced radionuclide

Target characteristics

Irradiation conditions

4. γ spectrum analysis

High purity Ge detector

- High purity Ge detector used to determine the activity in each foils.
- HPGe calibrated in energy and efficiency with certified Eu-152 γ source.

- Three different counting measurements, in the same conditions, to validate the activity values.

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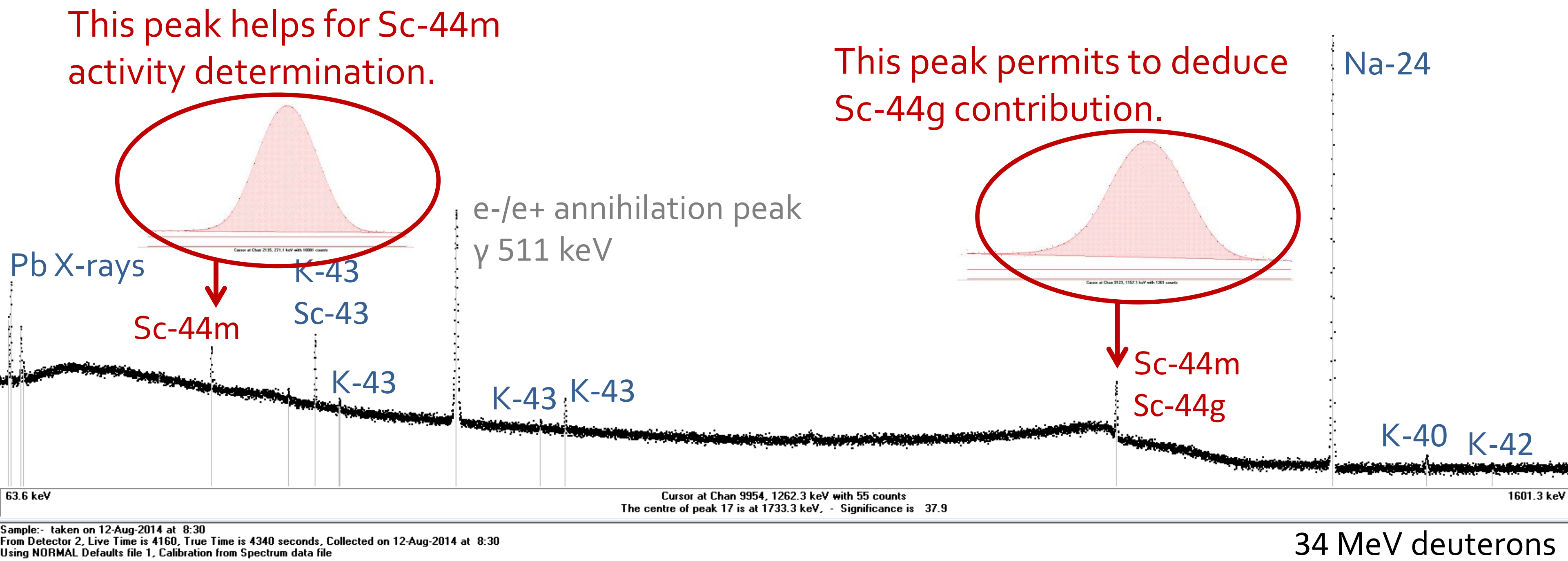
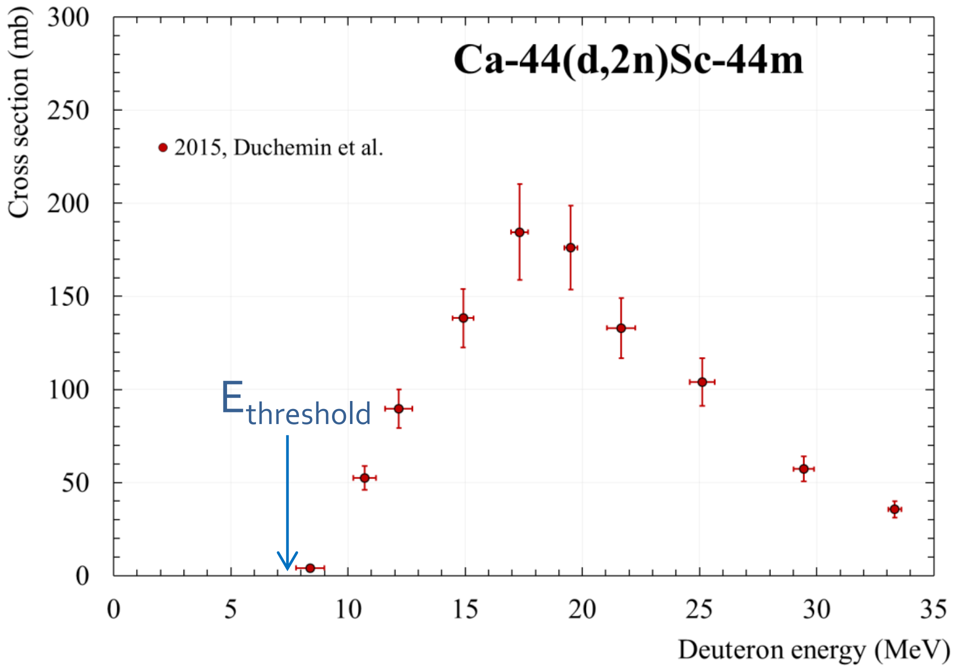
High purity Ge detector



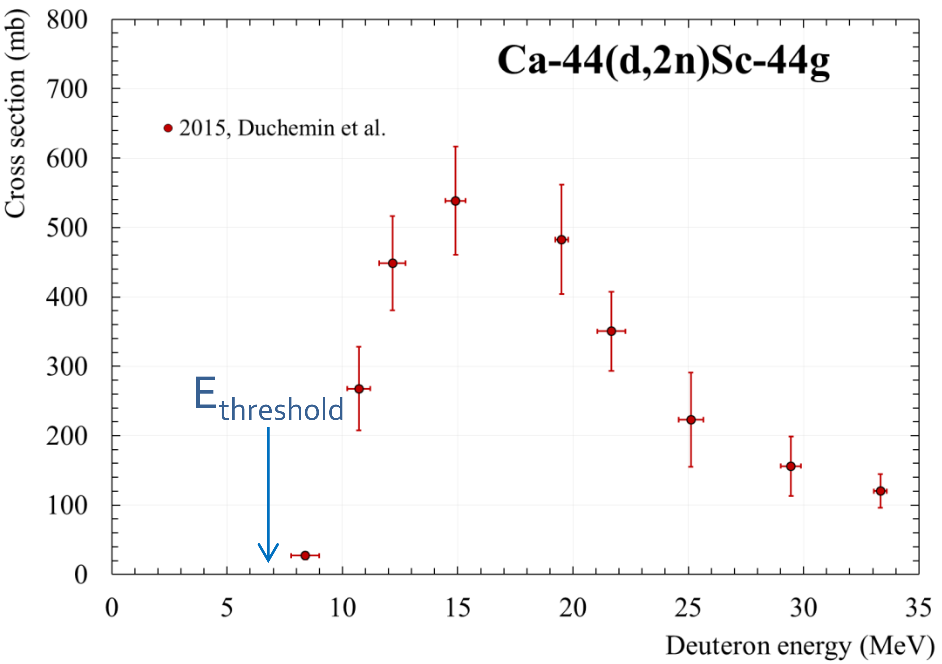
34 MeV deuterons

5. Sc-44 production cross sections

→ Sc-44m : $T_{1/2}$ = 58.6 hours



→ Sc-44g : $T_{1/2}$ = 3.97 hours



→ First data available in the literature for the Ca-44(d,2n) production route.

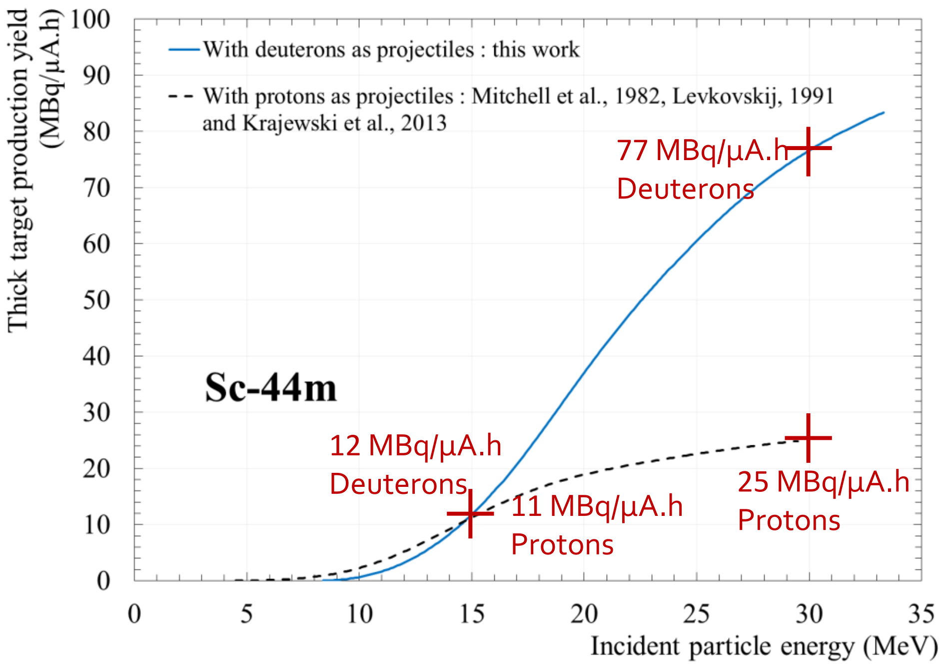
→ In addition, data on Sc-43, K-42 and K-43 have been obtained.

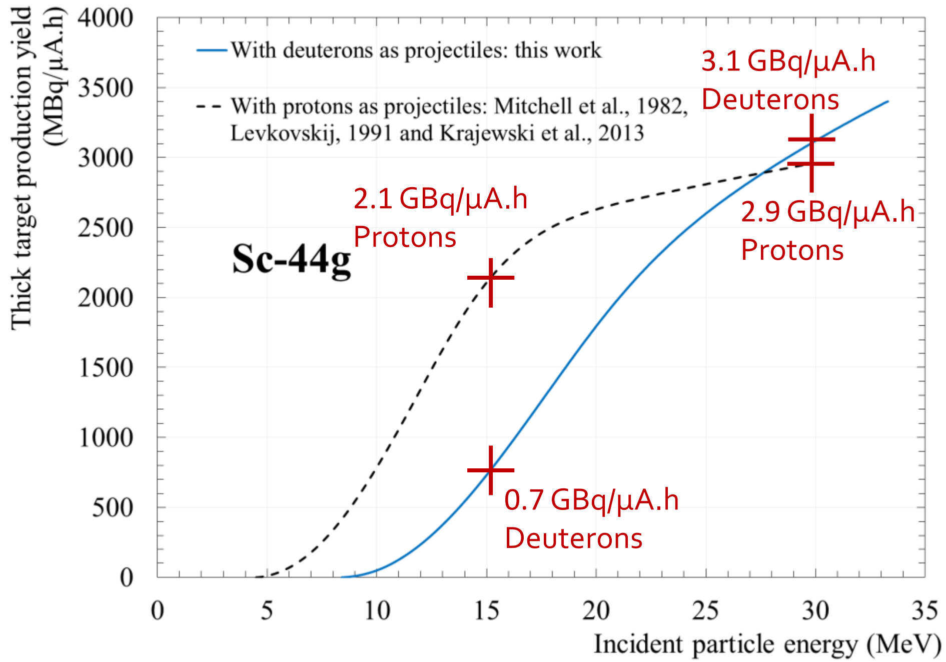
Results published in *Physics in Medicine and Biology* **60** (2015) **6847-6864**

6. Sc-44 Thick Target production Yields (TTY)

→ Comparison with Ca-44(p,n) production route

N.B.: in the case where the target is entirely composed by Ca-44 atoms.





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7. Conclusion on the best Sc-44 production routes with protons and deuterons.

Scenario / Cyclotron type	Sc-44g for PET using small molecules as vectors Needs: - High Sc-44g activity - Limit the Sc-44m act. *(additional dose to the patient)*	Sc-44g for 3 γ imaging developed at SUBATECH laboratory (Xenon group) Needs: - Limit Sc-44m and Sc-43 act. (*dose + background)*	Production of the Sc-44m/Sc-44g in-vivo generator paired with antibodies as vectors Needs: - High Sc-44m activity - Limit Sc-44g and Sc-43 act.
15 MeV protons	++	++	-
15 MeV deuterons	-	+	+
30 MeV protons	+	--	-
30 to 35 MeV deuterons	--	-	++

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Thank you for your attention

Special thanks to the members of the PRISMA group (SUBATECH) and of the GIP ARRONAX.

The ARRONAX cyclotron is a project promoted by the Regional Council of Pays de la Loire financed by local authorities, the French government and the European Union. This work has been, in part, supported by a grant from the French National Agency for Research called "Investissements d'Avenir", Equipex Arronax-Plus n° ANR-11-EQPX-0004 and Labex n° ANR-11-LABX-0018-01.

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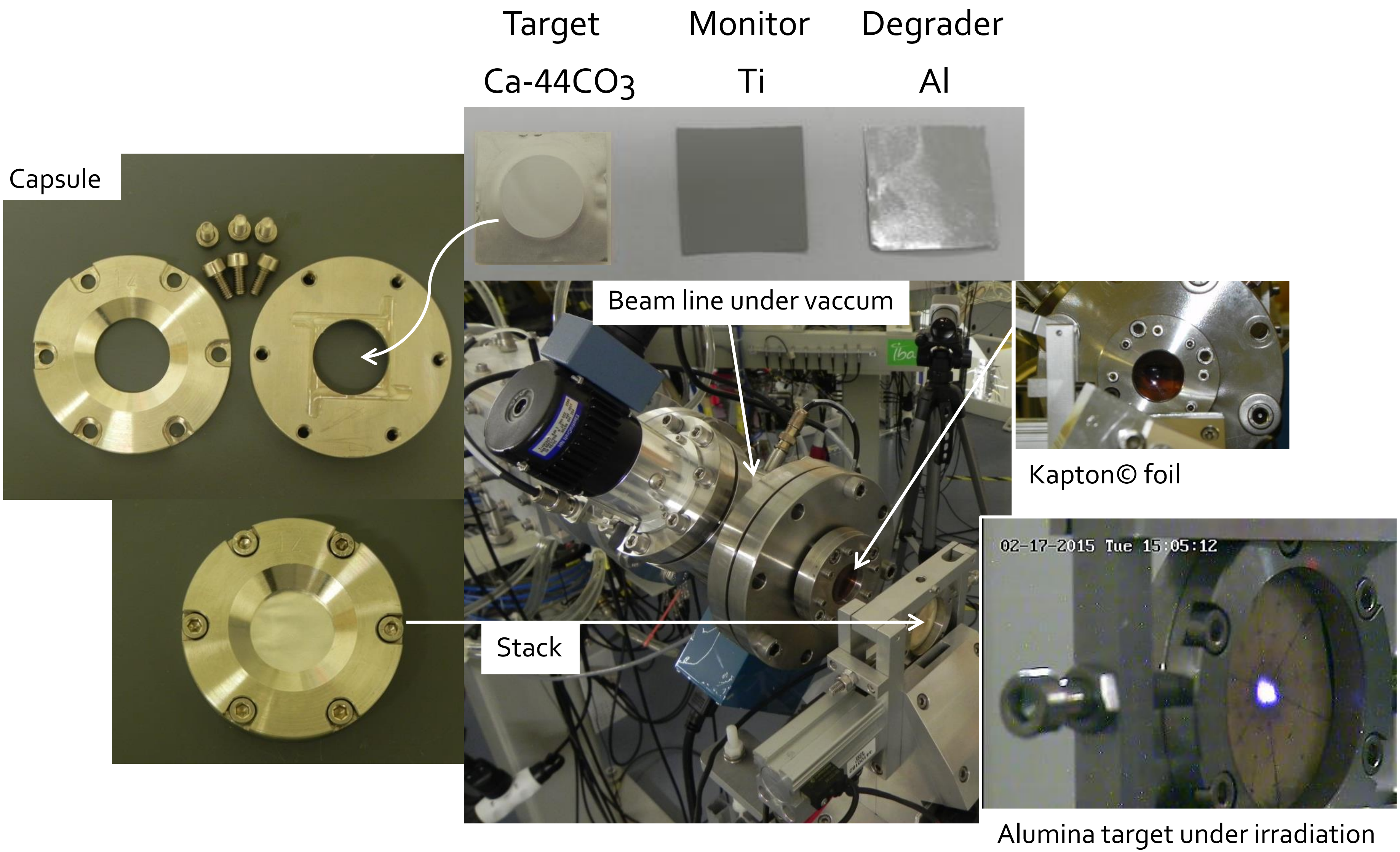
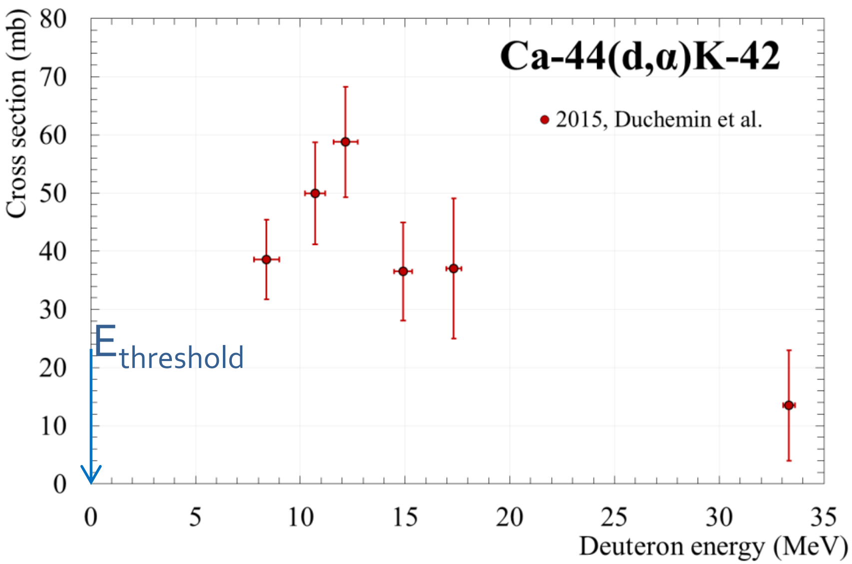
The experimental set-up



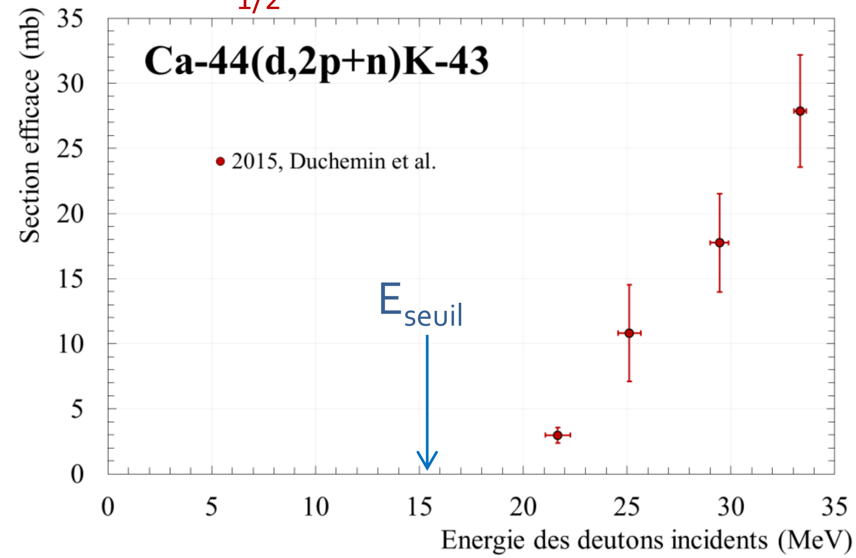
Production cross sections

Others radionuclides detected

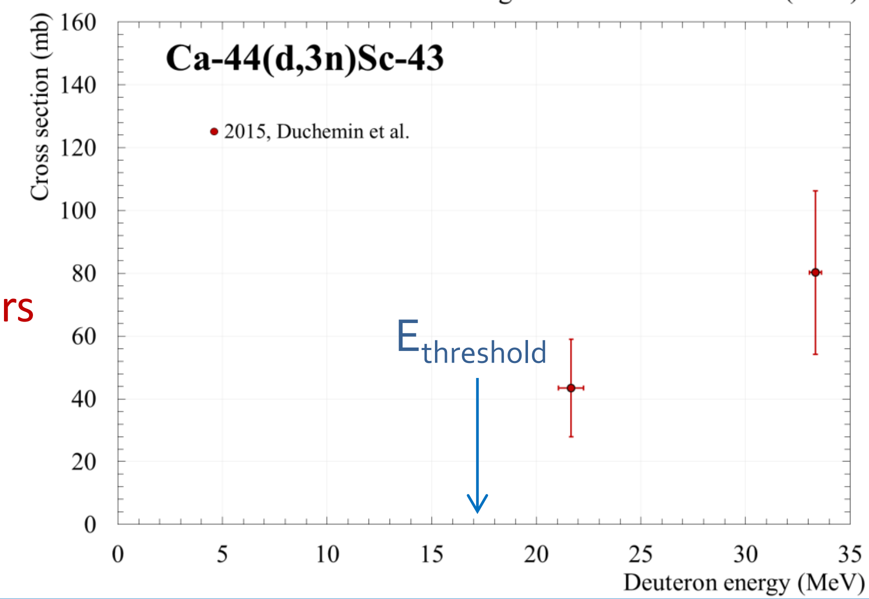
→ K-42 : $T_{1/2}$ = 12.26 hours



→ K-43 : $T_{1/2}$ = 22.3 hours



→ Sc-43 : $T_{1/2}$ = 3.89 hours



→ Sc-43 no chemically separable from Sc-44

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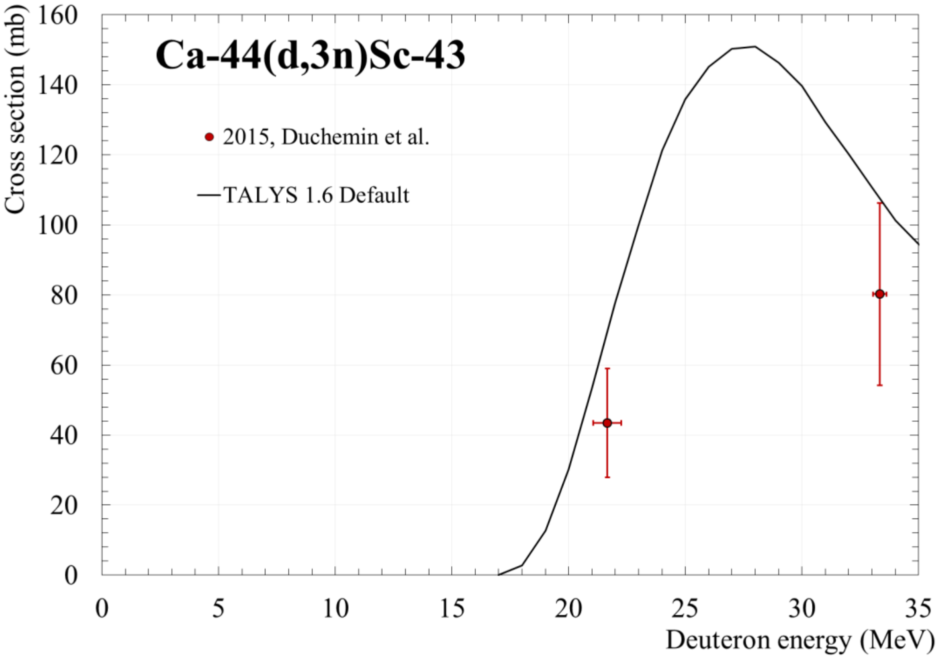
Sc-43 Thick Target production Yields (TTY)

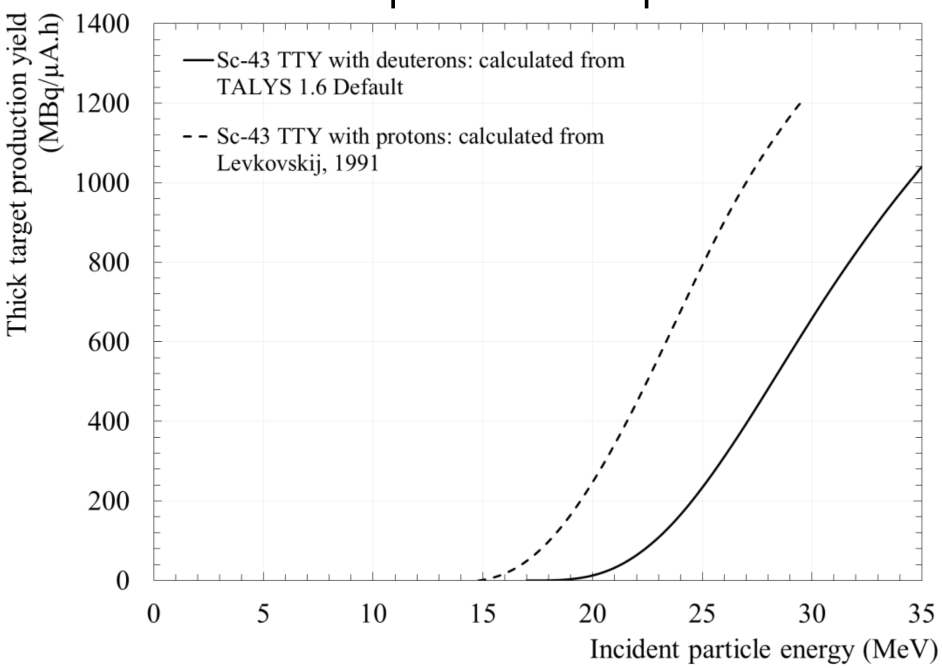
→ Sc-43 can not be chemically separated from Sc-44. Its production has to be controlled.

→ Ca-44(d,3n)Sc-43 production cross section data.



**The TALYS code is nuclear reaction program that included theoritical models by default.*

→ TTY comparison with proton route.



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