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Reaction Cross Section Measurements of $^{nat}Se(d,xn)^{75,76,77,78,82}Br$ Processes in the Energy Range 41 → 17 MeV

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Radioisotopes for medical applications

^{75}Br	^{76}Br
1.5 h	16 h
β^+ 76%	β^+ 57%
β_{max} 1.7 MeV	β_{max} 3.4 MeV

molecular imaging (PET)

^{77}Br	^{80m}Br
57 h	4.42 h
EC > 99%	IT 100%

Auger therapy / ^{77}Br for SPECT

Production routes for radiobromine

Target material	Nuclear reaction
natural bromine (*via* β^+-active krypton precursors)	$^{nat}Br(p,xn)^{76,77}Kr \rightarrow$ $^{nat}Br(d,xn)^{76,77}Kr \rightarrow$
enriched $^{78,80}Kr$-gas	$^{*}Kr(p,\alpha)$ / $^{*}Kr(p,\alpha n)$ $^{*}Kr(d,\alpha)$
natural arsenic	$^{75}As(\alpha,xn)$ $^{75}As(^{3}He,xn)$
natural selenium	$^{nat}Se(p,xn)$
enriched selenium	$^{*}Se(p,xn)$ $^{*}Se(d,xn)$

*enriched material

Choice of energy range

➡ primarily focus on $^{nat}Se(d,xn)^{76,77}Br$ for radiochemical studies

Br 75	Br 76 16 h	Br 77 57 h	Br 78	Br 79 50.69	Br 80	Br 81 49.31	Br 82	Br 83
Se 74 0.89	Se 75	Se 76 9.37	Se 77 7.63	Se 78 23.77	Se 79	Se 80 49.61	Se 81	Se 82 8.73

$^{78}Se(d,4n)^{76}Br$ $E_{thr} = 26.5$ MeV

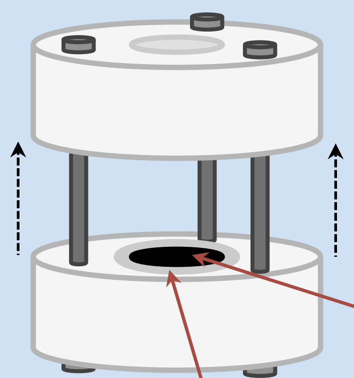
$^{78}Se(d,3n)^{77}Br$ $E_{thr} = 15.3$ MeV

➡ **energy range 41 → 17 MeV deuterons**

Target preparation

Sedimentation cell for preparation of thin targets

➡ Sedimentation of ^{nat}Se powder from ethanolic suspension



^{nat}Se-layer

- 10 mm diameter
- 5 - 15 mg/cm^2 Se
- protecting layer with 10 µm Al-cover

Al-backing

- 13 mm diameter
- 100 µm thickness

Irradiation parameters

Jülich Isochronous Cyclotron (JULIC)

➡ deuterons up to 76 MeV

- irradiation of Al – Se – Al sandwiches in stacked-foil arrangement
  - → Al and Cu foils as degraders
  - → Al and Ti foils as monitors
- energy range 41 → 17 MeV deuterons
  - → calculation of energy degradation with computer code STACK
- 30 min irradiation time; 100 nA beam current
- beam monitoring by
  - → current integration
  - → monitor reactions ^{27}Al(d,x)^{24}Na (41 → 20 MeV)
    ^{nat}Ti(d,x)^{48}V (< 20 MeV)

Methods of analysis

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Measurement of radioactivity by γ-counting

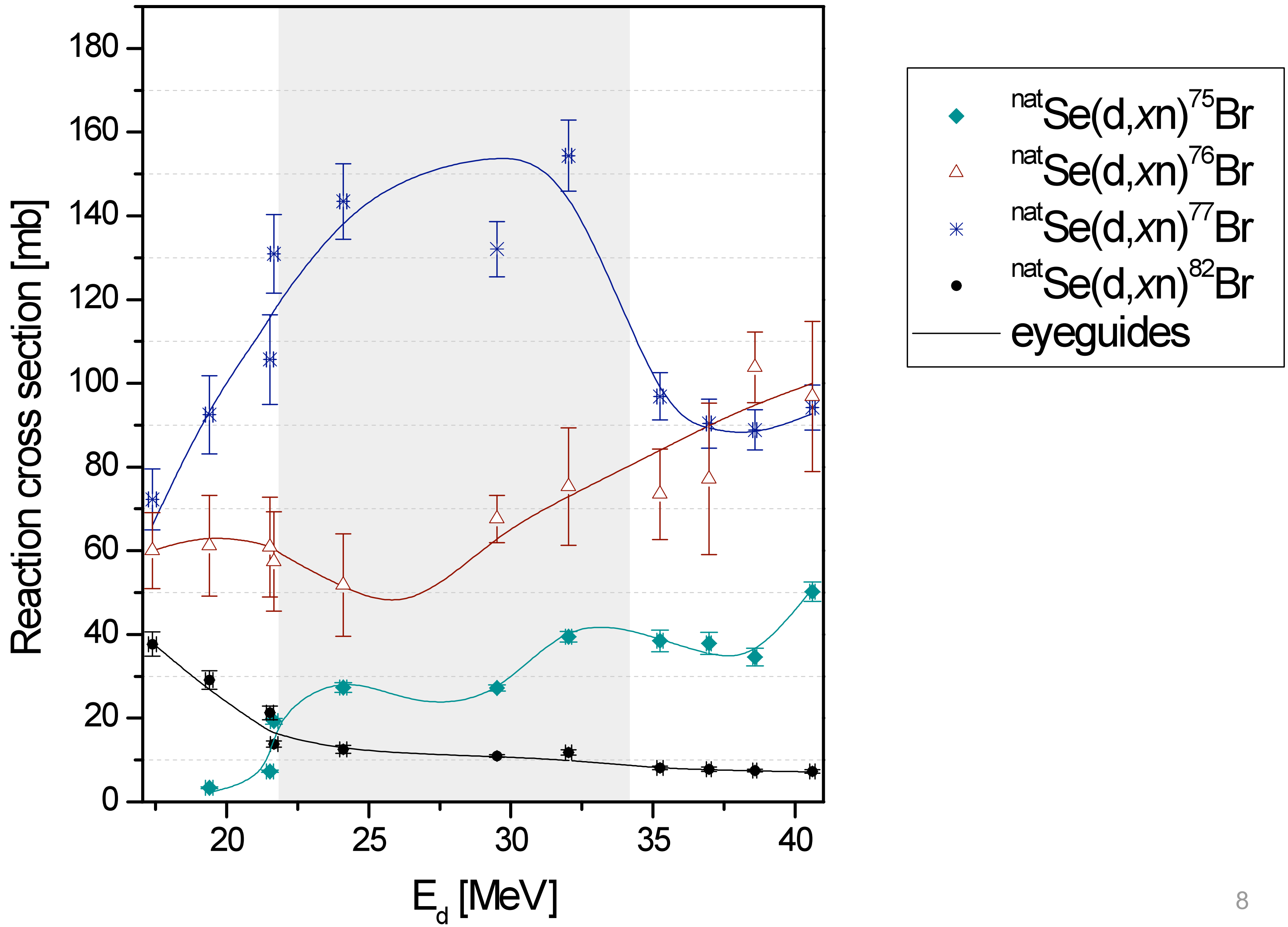
- well-calibrated HPGe-detectors
- distances 20 - 50 cm
- peak area analysis (Gamma Vision 6.01)

Overview of measured bromine isotopes and analysed γ-rays.

Radionuclide	Half-life	Analysed γ-ray [keV] (% abundance)
^{75}Br	1.5 h	286.6 (88)
^{76}Br	16.2 h	1853.7 (14.7)
^{77}Br	57 h	297.2 (4.2)
^{82}Br	35.34 h	554.3 (70.8)
^{78}Br	6.46 min	613.7 (14)
^{78}As	1.5 h	613.7 (54)

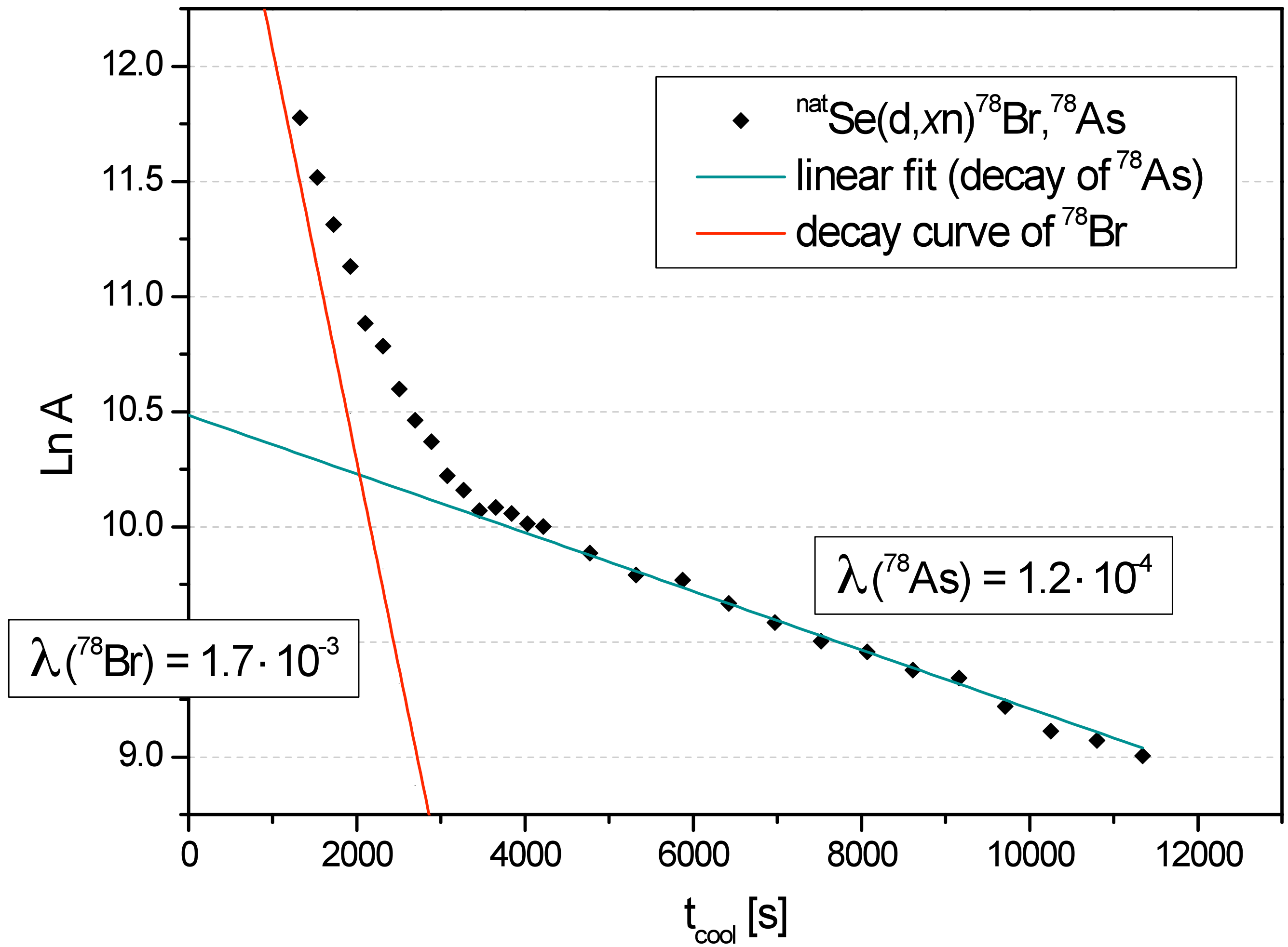
→ **Analysis of complex decay curves**

Cross sections for $^{nat}Se(d,xn)^{75,76,77,82}Br$

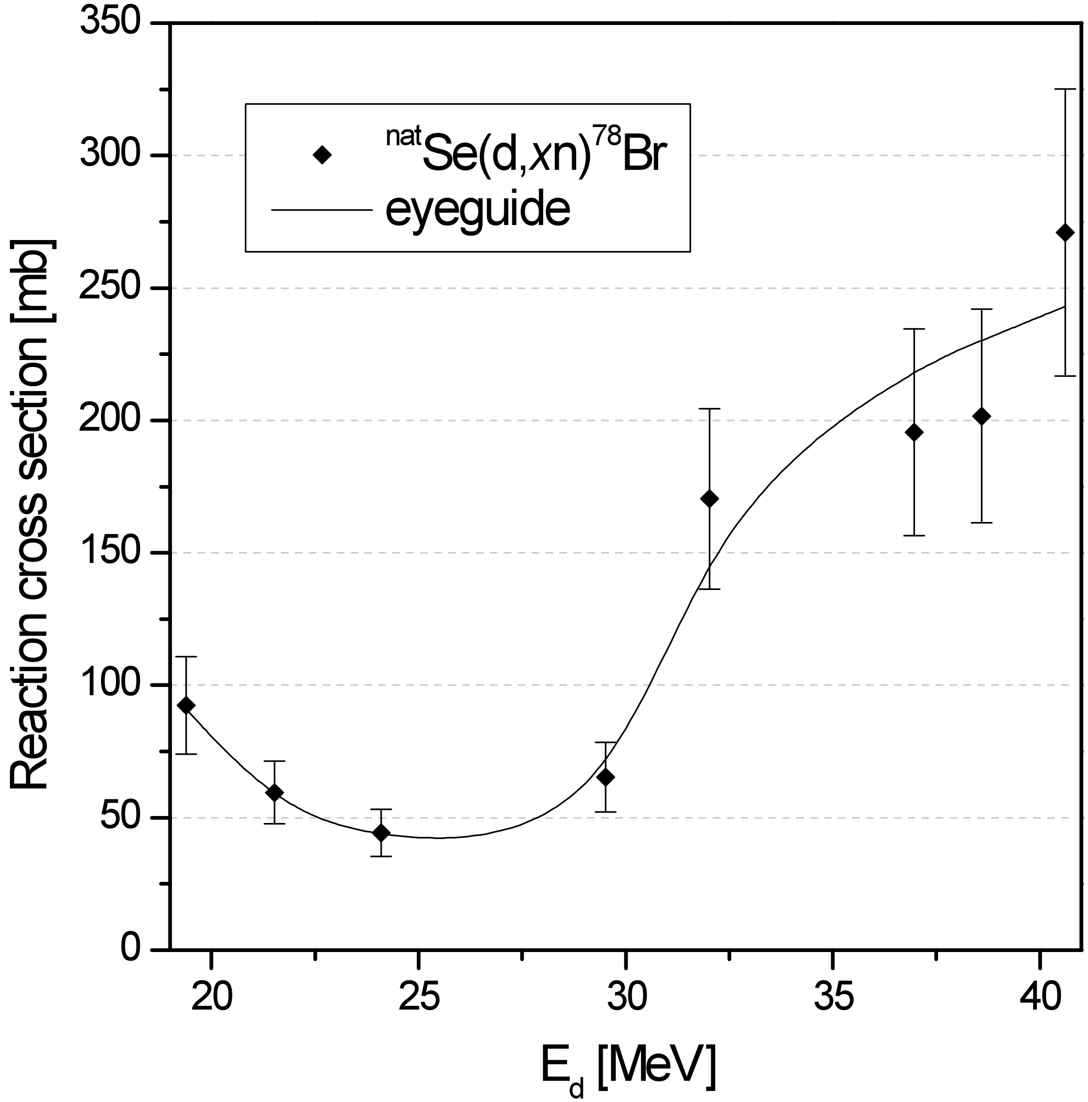


Complex decay curve of ^{78}Br / ^{78}As

➡ **target irradiated at E_d = 40.6 MeV**



Cross sections for $^{nat}Se(d,xn)^{78}Br$ after decay curve analysis



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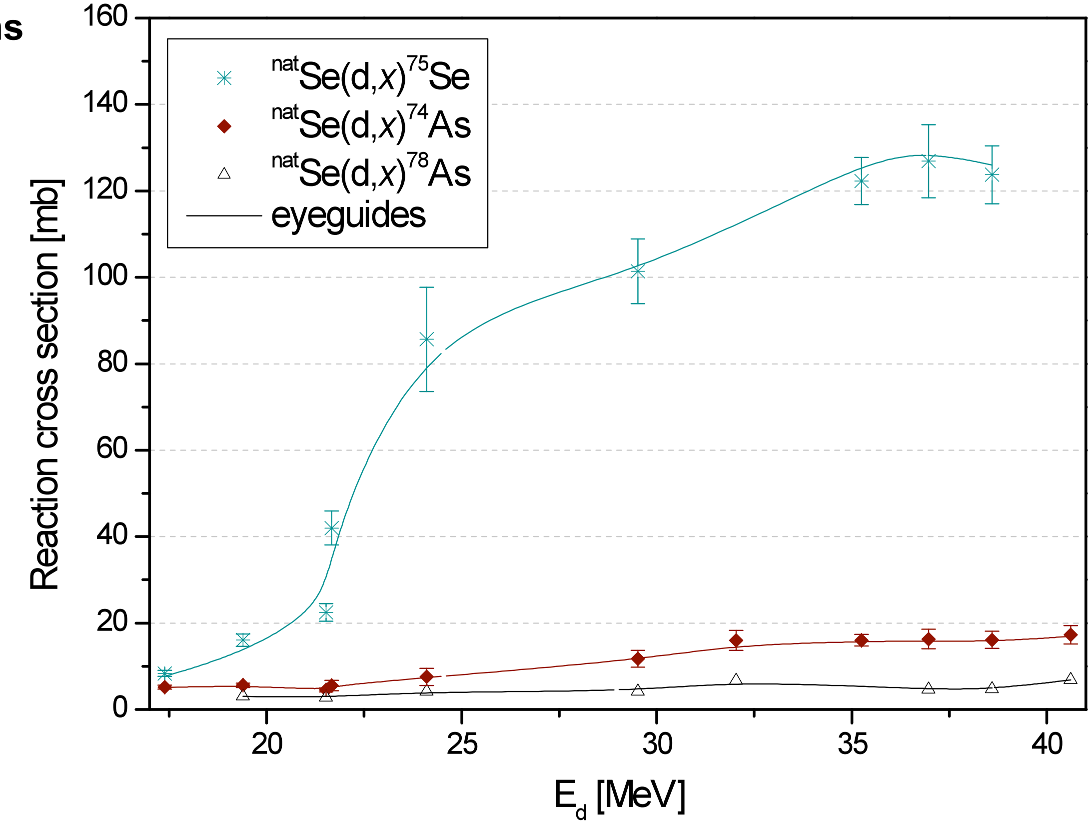
Calculated production yields

Nuclear reaction **(E_d = 41 → 17 MeV)**	**Calculated yield at EOB** **[MBq μA^{-1} h^{-1}]**
^{nat}Se(d,*x*n)^{75}Br	601 : 13
^{nat}Se(d,*x*n)^{76}Br	167 : 3
^{nat}Se(d,*x*n)^{77}Br	81 : 3
^{nat}Se(d,*x*n)^{82}Br	12 : 0.5
^{nat}Se(d,*x*n)^{78}Br	7 285 : 240

Non-isotopic impurities: ^{75}Se, ^{74}As, ^{78}As

Cross sections



Calculated production yields.

Radionuclide	Half-life	Analysed γ-ray [keV] (% abundance)	Calculated yield at EOB [MBq μA^{-1} h^{-1}]
^{75}Se	119.64 d	264.7 (58.9)	1.20 ± 0.02
^{74}As	17.77 d	595.8 (59)	1.13 ± 0.01
^{78}As	1.5 h	613.7 (54)	0.43 ± 0.02

Summary

- radioisotopes of bromine are very attractive for nuclear medical applications
  - → various decay properties
  - → advantageous bromine chemistry

- various production routes possible

- new nuclear reaction data of deuteron induced processes an natural selenium
  - → measurement of reaction cross sections for **^{nat}Se(d,*x*n)^{75,76,77,78,82}Br** and **^{nat}Se(d,*x*)^{75}Se,^{74}As,^{78}As** in the energy range 41 → 17 MeV
  - → calculation of production yields in the considered energy range
  - → cross sections, however, ca. 10 - 30% lower than ^{nat}Se(p,*x*n)^{75,76,77}Br

- further measurements in progress to extend the determined data on energy ranges above and below 41 → 17 MeV

Thank you for your attention!

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