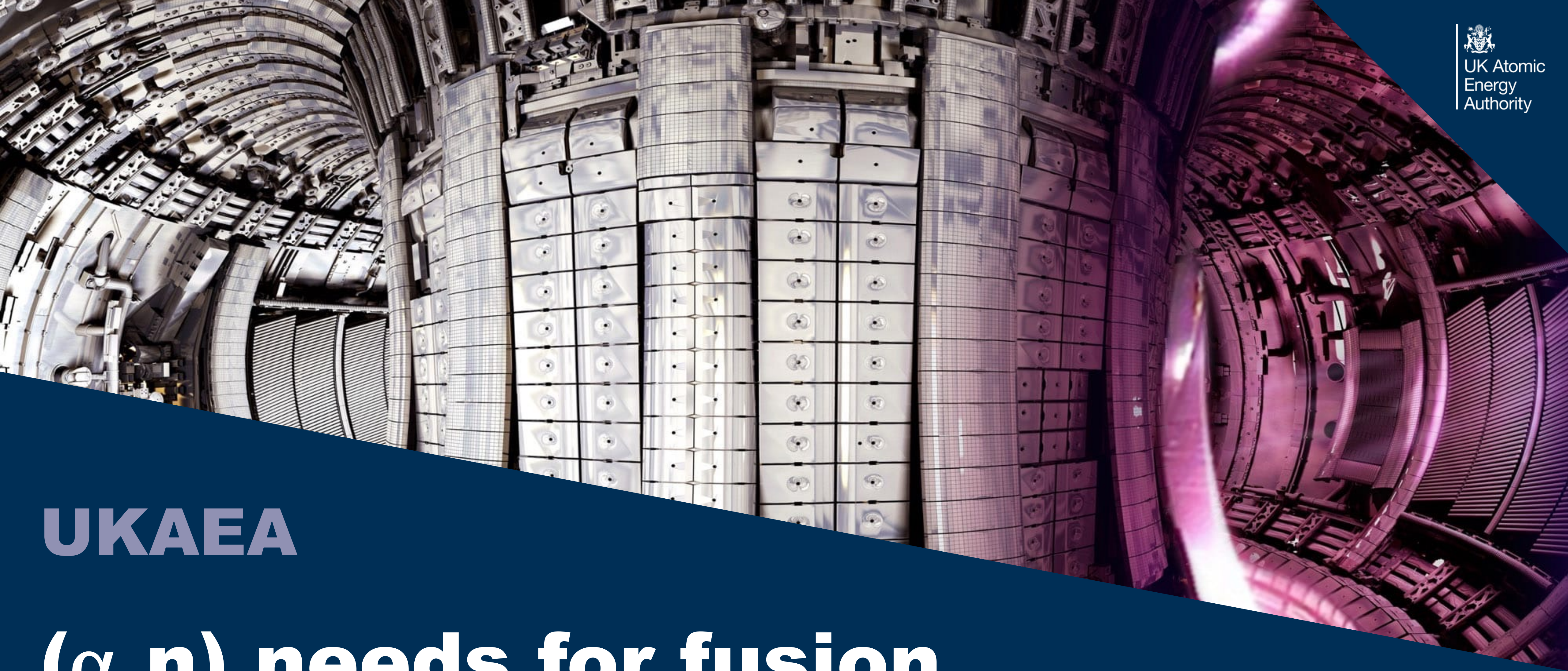

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(α,n) needs for fusion

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IAEA technical meeting on (α,n) nuclear data

8-12 November 2021

Introduction
Why fusion cares about α-particles

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- Sustaining a magnetically-confined plasma in a fusion reactor relies on α-particles delivering the heat (energy) they obtained when created in the deuterium-tritium reactions – plasma heating
- $D + T \rightarrow {}^{4}He$ (3.52 MeV) + n (14.1 MeV)
- $D + {}^{3}He \rightarrow {}^{4}He$ (3.66 MeV) + p (14.7 MeV)
- $P + {}^{11}B \rightarrow 3\ {}^{4}He$ (8.68 MeV)
- [advanced aneutronic fusion explored in some experimental reactors, including JET and theoretically for ITER, but also in private fusion companies such as TAE and Helion]
- If too many of the α-particles escape the plasma before transferring their energy, then the energy gain factor, Q – the ratio of fusion power to heating required to maintain the plasma – will be reduced
  - One of ITER's main objectives is to use this self-heating by α-particles to demonstrate ignition
- Thus, α-particles must be well confined
  - any losses during experiments on plasma control (particularly in ITER) must be well understood
- Requires accurate accounting of α-losses by measurement and monitoring
  - Both ITER and future demonstration fusion power plants need this
- α measurement can also be used as an alternative to neutron flux monitoring
  - Due to short range of α, they are not susceptible to scattering noise like neutrons

Measurement options

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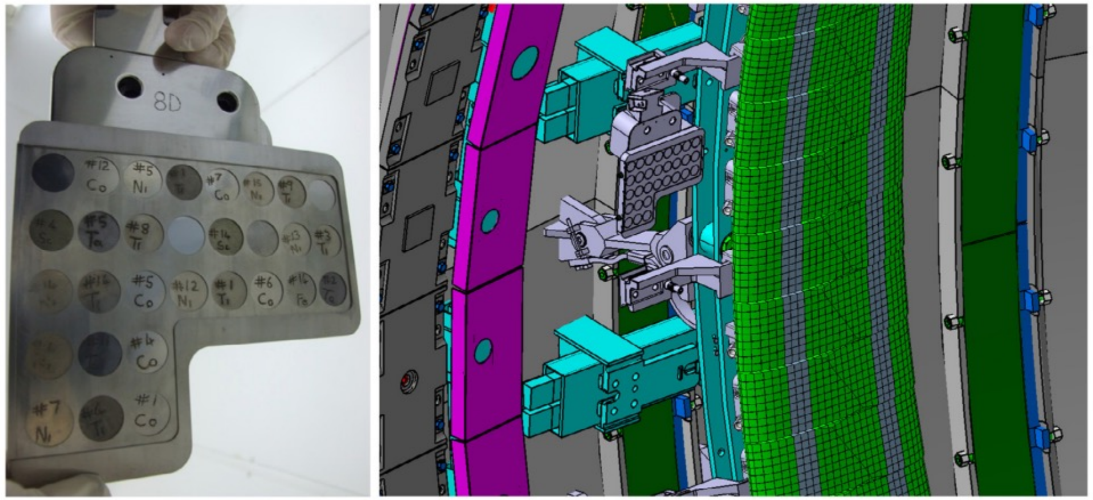
- ITER is not (currently) developing an α (or fast-ion) monitoring system based on activation foils, instead exploring combination of techniques that can offer real-time and per-pulse measurements:
  - Fast-ion Loss detector (FILD) using either Faraday cups, liquid scintillators of bolometry foils
  - Gamma ray α monitor (GRAM) – monitoring of gammas generated by interaction of α-particles with impurities in plasma – primary is $^{9}Be(\alpha,n\gamma)^{12}C$
  - Infrared techniques, Under dome detectors, etc.
- FILD is the primary choice
  - But has unproven radiation hardness
  - And will require characterization
- Potential role for a robust activation foil approach as a complementary technique to real-time measurements
  - back-up integral measure in case FILD fails
  - and can also provide characterization/benchmarking for real-time techniques

Activation foil measurements for α

- Activation foil measurements for neutrons is a well-established technique
- For α-particles the challenge is to identify reactions that will produce γ-signals that can be detected against the significant background of neutron-induced γ-activation
- Short penetration depth (μm) of α-particles creates an engineering challenge
- Foils must be very close to first wall (ideally with direct sight of plasma)
- If target real-time measurements with short-lived radionuclides, then must also engineer a rapid extraction system



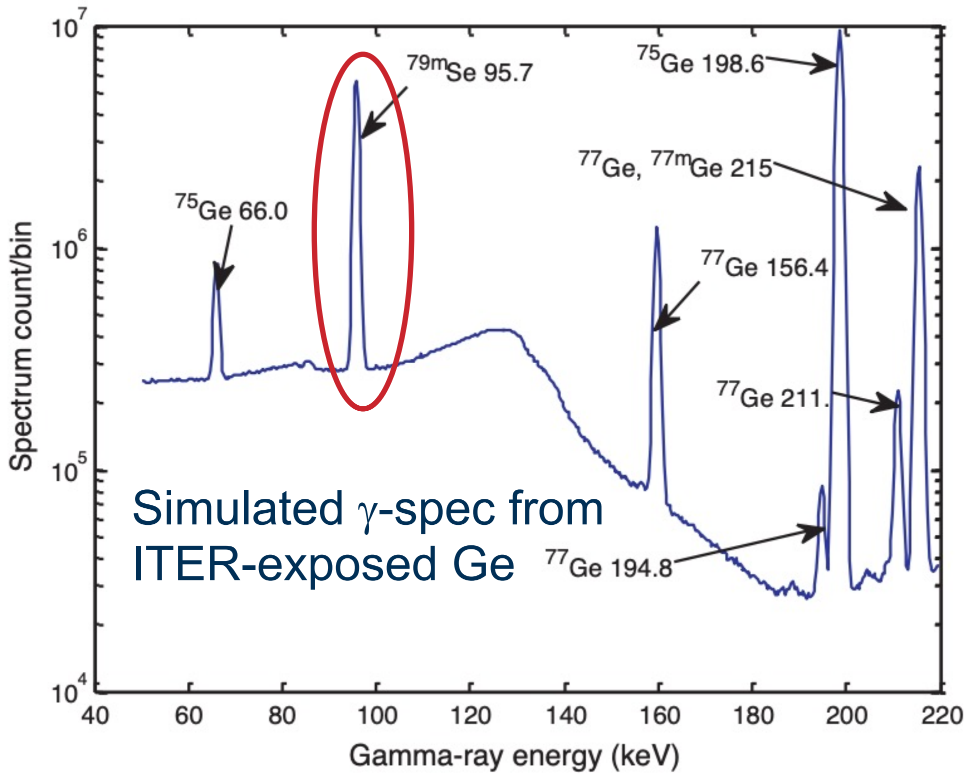
JET test of neutron foil diagnostics for ITER
(Packer et al. Nucl Fusion **58** (2018) 096013)

Foil based diagnostic investigations

- Previous work: Bonheure et al. Fus. Eng. Des. **88** (2013) 533
- Simulations show that ^{79m}Se peak would be detectable over “neutron noise”
- “The most important limitation of this work is the absence of measured data for the candidate reaction ^{76}Ge(α,n)^{79m}Se below the energy E = 6 MeV”

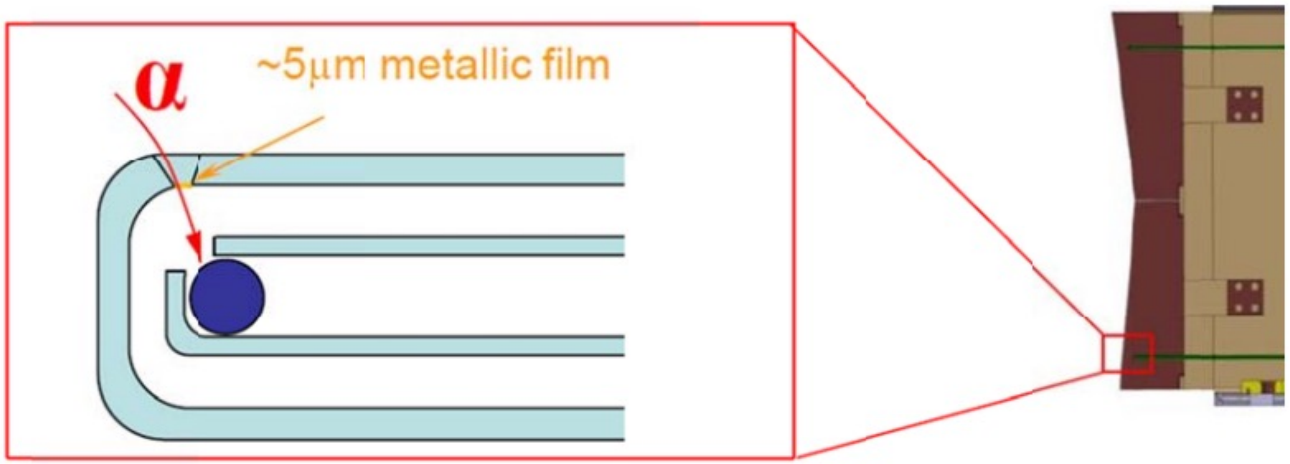
Reactions	Thr (MeV)	Isot. abundance (%)	Half-life	Photons energy (MeV)
^{25}Mg(α,p)^{28}Al	1.4	10	2.2 min	1.779
^{33}S(α,g)^{37}Ar	–	0.75	35 day	0.814
^{41}K(α,n)^{44}Sc	3.7	6.7	58.6 h	1.157
^{43}Ca(α,p)^{46}Sc	1.7	0.1	83.7 day	0.889, 1.120
^{44}Ca(α,p)^{47}Sc	2.2	2	3.34 day	0.159
^{48}Ca(α,p) ^{51}Ti	0.15	1.8	5.76 min	0.320
^{47}Ti(α,g) ^{51}Cr	–	7.44	27.7 day	0.320
^{53}Cr(α,p)^{56}Mn	3.5	9.5	2.5 h	0.988
^{54}Fe(α,p)^{57}Co	1.9	5.8	271 day	0.122
^{61}Ni(α,g)^{65}Zn	–	1.1	244 day	0.078
^{76}Ge(α,n)^{79m}Se	3.2	7.4	3.9 min	0.096
^{123}Te(a,g)^{127}Xe	–	0.9	36 day	0.202

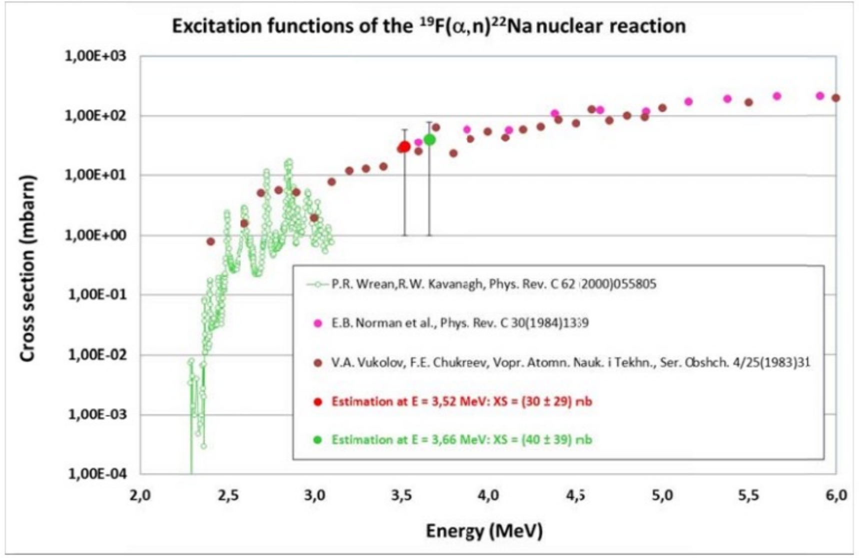
EXFOR doesn’t contain any data for this reaction



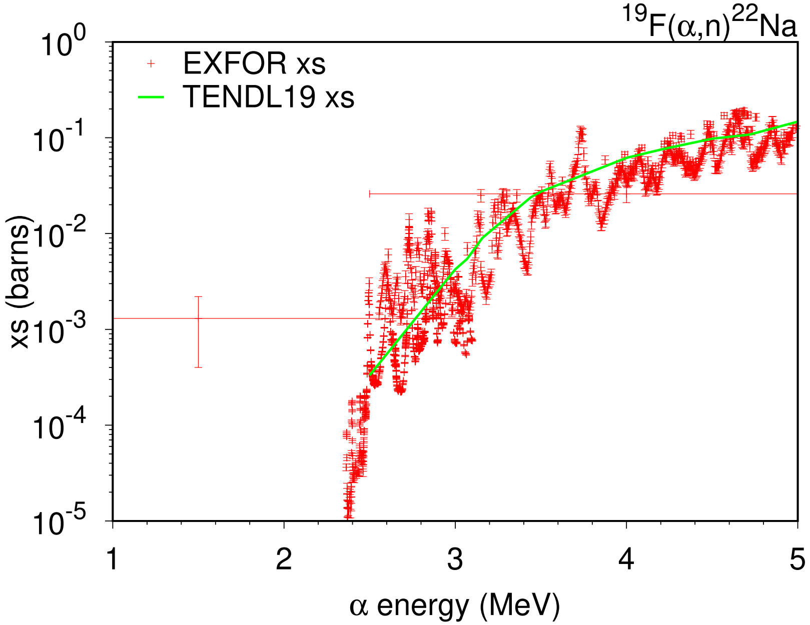
ITER feasibility work on activation foils

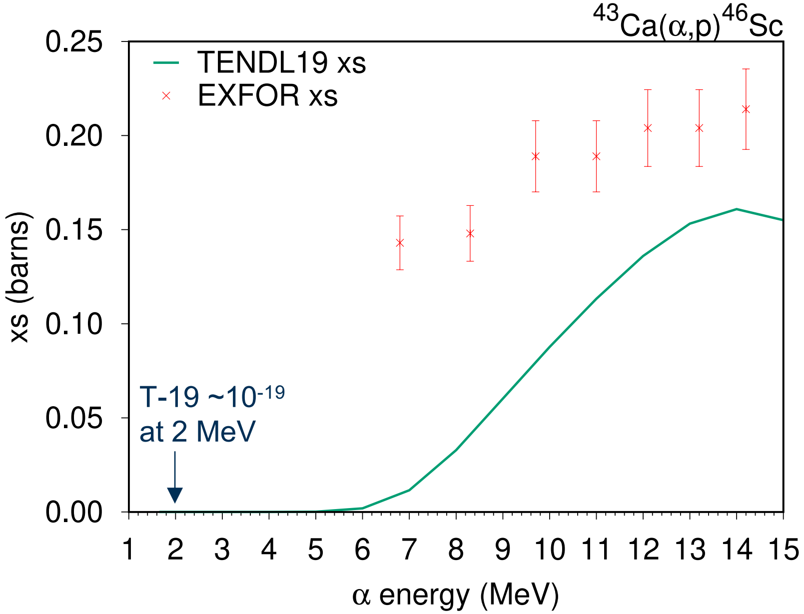
- Fenyvesi and Zoletnik (Hungary) proposed a system that would allow real-time alpha measurements with foils – commissioned by ITER in 2016
- Beryllium window to separate foils from plasma chamber, creating vacuum boundary and allowing extraction
  - means that 3.5 MeV alphas more like 2.6 MeV when they reach foils
- $^{19}F(\alpha,n)^{22}Na$ reaction proposed: has measured cross section data below 3 MeV

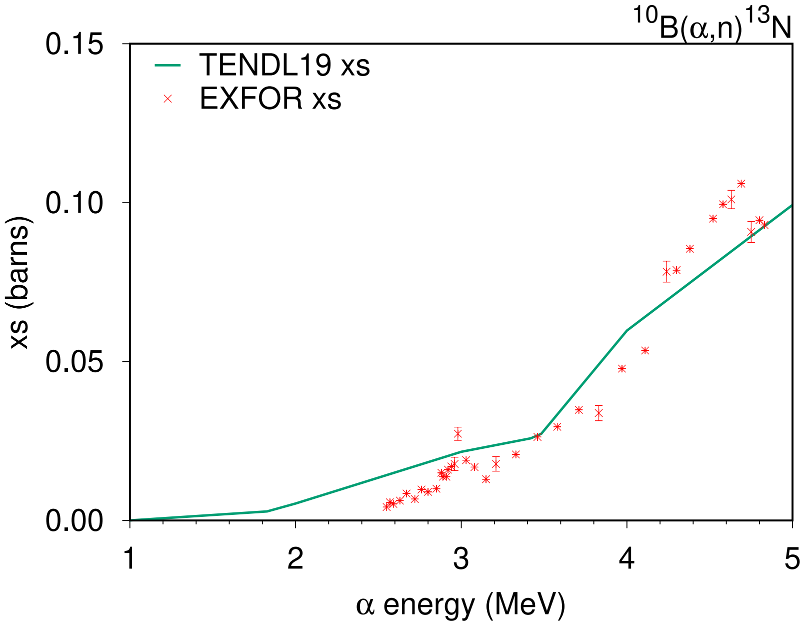


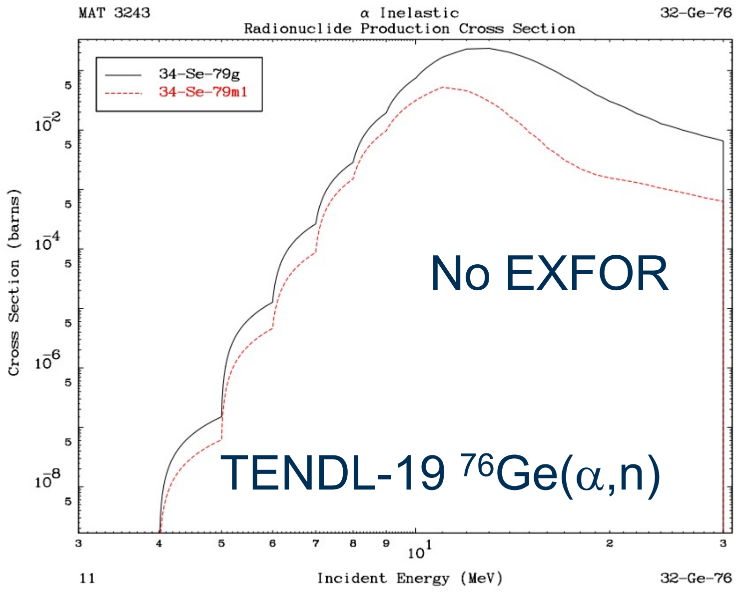


Candidate reactions









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Some of the candidates defined previously have poor experimental data & some threshold uncertainties

For D–T alphas	Thresholds (MeV)
$^{10}B(\alpha,n)^{13}N$	–
$^{14}N(\alpha,g)^{18}F$	–
$^{19}F(\alpha,n)^{22}Na$	2.4
$^{25}Mg(\alpha,p)^{28}Al$	1.4
$^{40}Ca(\alpha,p)^{43}Sc$	3.9
$^{41}K(\alpha,n)^{44}Sc$	3.7
$^{41}Ca(\alpha,p)^{44}Sc$	2.4
$^{43}Ca(\alpha,p)^{46}Sc$	1.7
$^{44}Ca(\alpha,p)^{47}Sc$	2.2
$^{45}Ca(\alpha,p)^{48}Sc$	1.3
$^{45}Sc(\alpha,n)^{48}V$	2.4
$^{46}Ca(\alpha,p)^{49}Sc$	1.6
$^{48}Ti(\alpha,n)^{51}Cr$	2.9
$^{51}V(\alpha,n)^{54}Mn$	2.4
$^{53}Cr(\alpha,p)^{56}Mn$	3.5
$^{55}Mn(\alpha,n)^{58}Co$	3.8
$^{76}Ge(\alpha,n)^{79m}Se$	3.1

Candidates from Bonheure et al. Fus. Eng. Des. 86 (2011) 1298

Discussion

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- Further work is needed to identify best candidate reactions and test feasibility
- But, given the uncertainties, gaps in the data it is difficult to make serious proposals for materials suitable for α detection in fusion
  - Need library of α-induced data that is reliable enough to allow scoping studies

To facilitate above need:

- Measurements in the range ~1-3.5 MeV
- Theoretical
  - Model development (e.g. optical)
  - Benchmark measurements for model-based library of evaluated α,n data
- Eventually will need validation via combined (14 MeV) neutron and (3.5 MeV) α experiments to benchmark simulations and prove that detection over neutron-induced γ-background is possible