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Task SA-EN.IM.10-T002-D002

*On application of γ -ray spectrometer for α -particles studies
in low-activation JT-60SA plasmas*

Motivation

- ❖ The α -particle studies in low-activation plasmas could help to develop optimal plasma conditions in the reactor burning phase.
- ❖ A harsh radiation environment in the D-T plasma phase makes realisation of this task extremely difficult since a restricted set of plasma diagnostics will be available.
- ❖ Experiments with low-activation plasmas could provide insights for the design and modelling of reactor-compatible diagnostic systems, as well as testing them in currently working fusion devices before their use in burning D-T plasma machines.

A possible scenarios for α -particle generation in low-activation JT-60SA plasmas

$D(^3\text{He},p)^4\text{He}$ ($E_\alpha = 3.6$ MeV) as used on JET

- D-NBI heating with ^3He seeding

$^{11}\text{B}(p,2\alpha)^4\text{He}$ ($E_\alpha < 6$ MeV)

- H-NBI heating with boron seeding

D³He α-particle generation: JET benchmark

❖ D-NBI heating

- up to ~**15 kW** of D³He fusion power at $P_{\text{NBI}} \sim 15$ MW ($n_{3\text{He}}/n_e \approx 30\%$)
($\sim 5 \cdot 10^{15} \text{ s}^{-1}$ α-particles) [Sharapov S.E. et al 2016 Nucl. Fusion **56** 112021](#)

❖ ³He-minority ICRF heating

- up to **140 kW** of D³He fusion power ($\sim 4.6 \cdot 10^{16} \text{ s}^{-1}$ α-particles) at $P_{\text{ICRH}} = 10$ MW
[Jacquinot J. and Sadler G., Fusion Technology **21** \(1992\) 2254](#),
[Mantsinen M.J. et al 2002 Phys. Rev. Lett. **88** 115004](#), [Sharapov S.E. et al 2016 Nucl. Fusion **56** 112021](#)

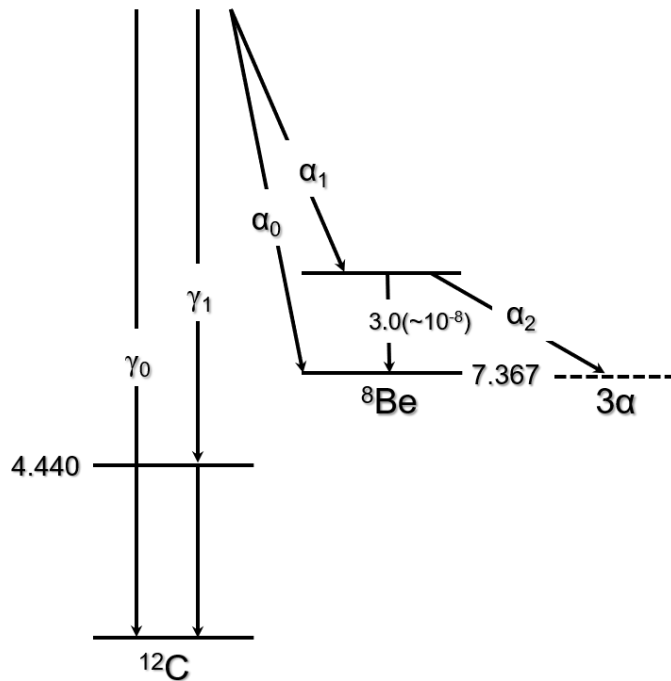
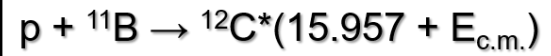
❖ D-beam ion accelerations with 3rd harmonic ICRF

- up to 10 kW of D³He fusion power at $P_{\text{ICRH}} \sim 3$ MW + 4.5 MW of NBI
[M.J. Mantsinen et al 2002 PRL. **88** 105002](#), [Kiptily V.G. et al 2002 Nucl. Fusion **42** 999](#)
[Sharapov S.E. et al 2016 Nucl. Fusion **56** 112021](#)

❖ 3-ion ICRH scheme, accelerating D- or ³He-ions

- up to **60 kW** of D³He fusion power at $P_{\text{ICRH}} = 6$ MW + 7 MW NBI and $n_{3\text{He}}/n_e \approx 22\%$
($\sim 2 \cdot 10^{16} \text{ s}^{-1}$ α-particles)
[Nocente M et al 2020 Nucl. Fusion **60** 124006](#), [Kazakov Ye.O. et al Phys. Plasmas **28**, 020501 \(2021\)](#),
[Kiptily V.G. et al Nucl. Fusion **61** \(2021\) 114006](#)

$^{11}\text{B}(p, 2\alpha)^4\text{He}$ reaction for α -particle production

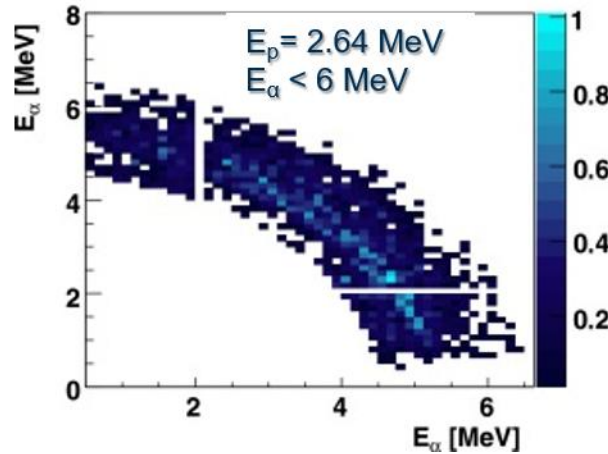
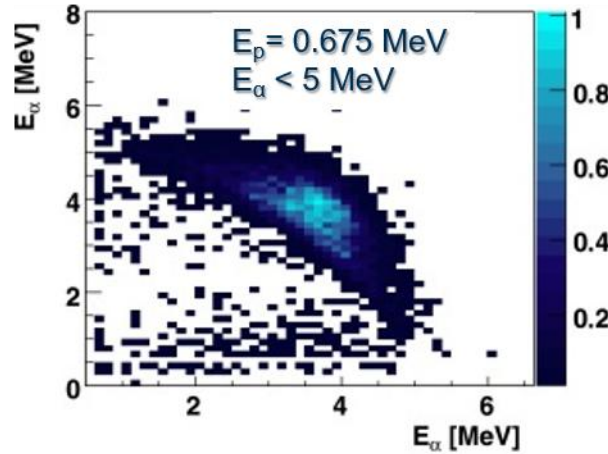


N.B. p - ^{11}B fusion reaction was observed in LHD; α -particles were detected.

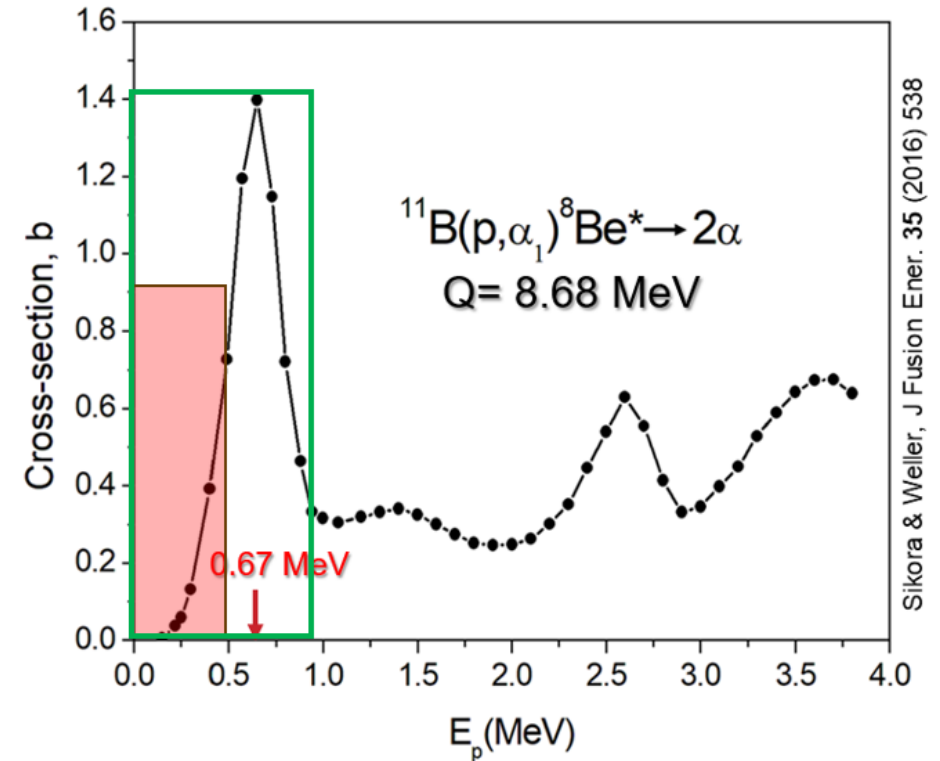
[Ogawa K. et al, 2024 Nucl. Fusion 64 096028](#)

[Kamio S. et al, 2026 Nucl. Fusion 66 036020](#)

Spraker M.C. et al J Fusion Energ. 31 (2012) 357



Normalised α -particle coincidence spectra



Sikora & Weller, J Fusion Energ. 35 (2016) 538

JT-60SA: $E_{\text{H-NBI}}(\text{max}) = 500 \text{ keV}$

ITER: $E_{\text{H-NBI}}(\text{max}) = 870 \text{ keV}$

H-ion ICRF heating for α -particle generation: JET benchmark

❖ 2nd-harmonic & H-minority ICRF heating in H- & D-plasmas

- α -particles production with ${}^9\text{Be}(p,d)2\alpha$ & ${}^9\text{Be}(p,\alpha){}^6\text{Li}$ reactions
- First α -particle observation in low-activation plasmas

[Krasilnikov A.V. et al 2018 Nucl. Fusion 58 026033](#)

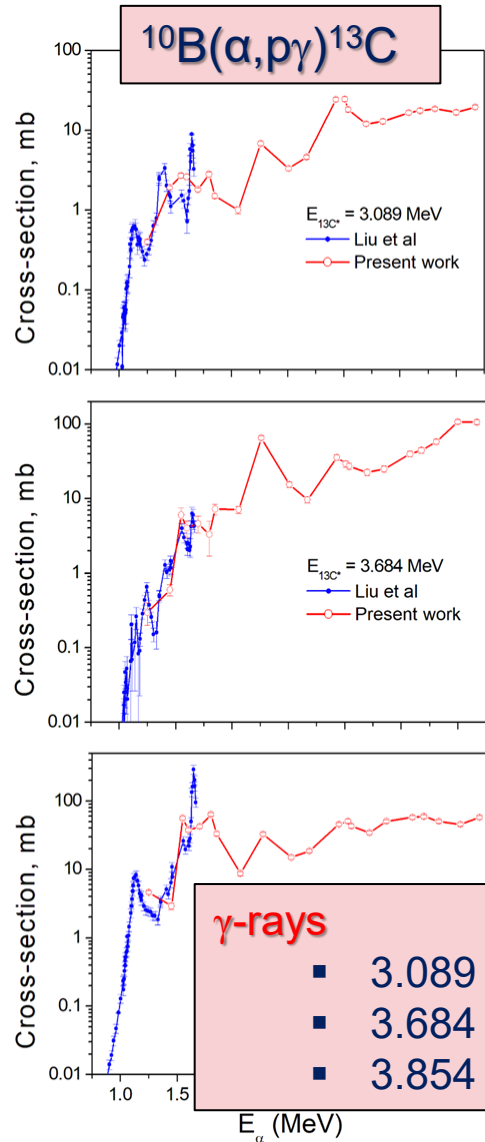
❖ H-minority ICRF heating in He- & D-plasmas

steady-state L-mode plasma with dominant p-Be fusion

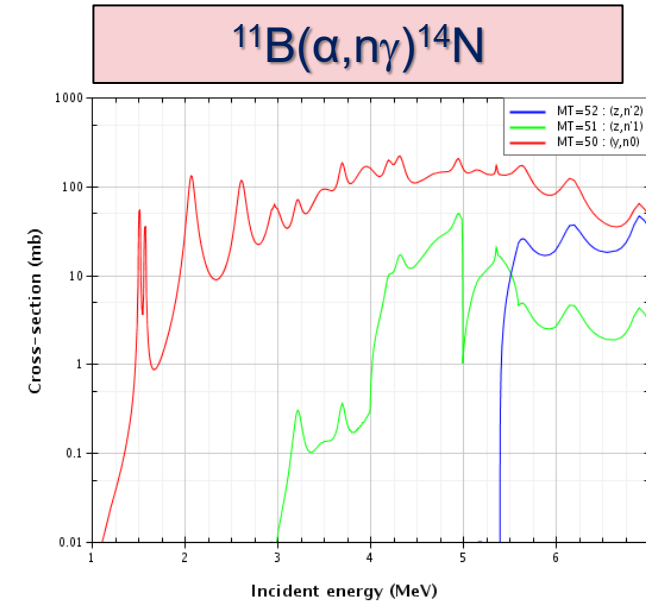
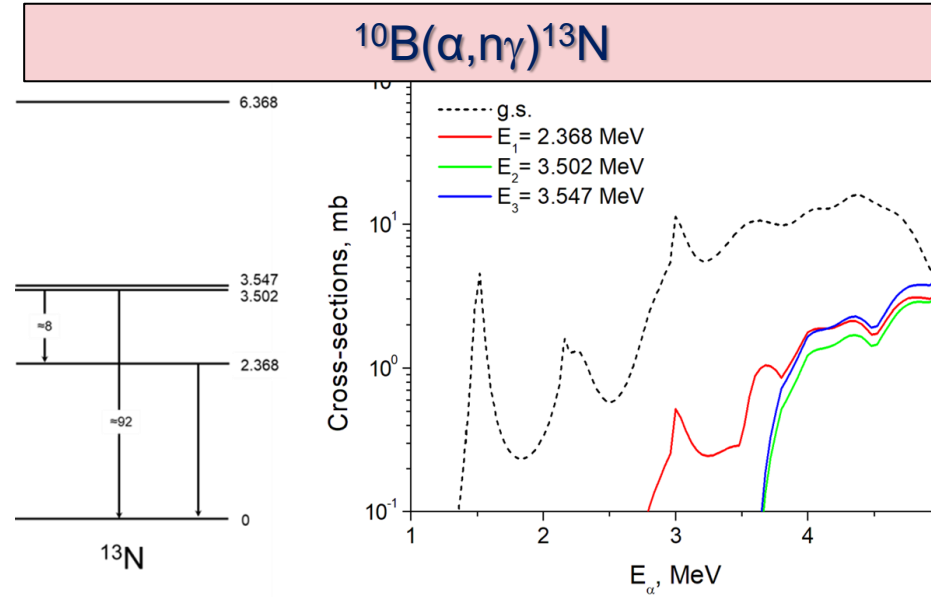
- γ -ray emission modelling was validated for both 3.56-MeV gammas from the ${}^9\text{Be}(p,\alpha\gamma){}^6\text{Li}$ reaction and 4.44-MeV γ -rays from the secondary ${}^9\text{Be}(\alpha,n\gamma){}^{12}\text{C}$ reaction.
- replacement Be $\rightarrow$ B leads to the ${}^{11}\text{B}(p,\alpha)2\alpha$ reaction rate $\sim 3.6 \times 10^{15} \text{ s}^{-1}$ estimated at JET Pulse No.101184 plasma conditions.
- it could be used as a benchmark for feasibility assessments p- ${}^{11}\text{B}$ α -particle measurements in low-activation plasmas

[Štancar Ž. et al 2026 Nucl. Fusion 66 096005](#)

α -particle diagnosis with γ -rays & neutrons



Kiptily V.G. 2025 Fusion Eng. Des. 215 114959



✓ γ -rays

- 2.368 MeV at $E_\alpha > 1.8 \text{ MeV}$
- + 3.50 MeV at $E_\alpha > 3.4 \text{ MeV}$

✓ neutrons

e.g. at $E_\alpha = 1.5 \text{ MeV} \rightarrow E_{n0} \approx 2 \text{ MeV}$

✓ γ -rays

- 2.313 MeV at $E_\alpha > 3 \text{ MeV}$
- + 1.635 MeV at $E_\alpha > 4.6 \text{ MeV}$

✓ neutrons

e.g. $E_\alpha > 3.6 \text{ MeV} \rightarrow E_{n0} > 2.6 \text{ MeV}$

Note: 2.5 MeV neutron emission from $D(D, n)^3\text{He}$ reaction could be an obstacle for α -particle studies

[Kiptily V.G. et al 2026 Nucl. Fusion 66 066004](#)

Kiptily et al, 19th TM EP, Lausanne, 2026

Characterisation of fast H- and D-ions with γ -rays

H-beam : $^{11}\text{B}(p,\gamma)^{12}\text{C}$, $^{10}\text{B}(p,\alpha_1\gamma)^7\text{Be}$

D-beam : $^{10,11}\text{B}(d,n\gamma)^{11,12}\text{C}$, $^{11}\text{B}(d,\alpha\gamma)^9\text{Be}$, $^{10}\text{B}(d,p\gamma)^{11}\text{B}$,
 $^3\text{He}(D,\gamma_{17\text{MeV}})^5\text{Li}$

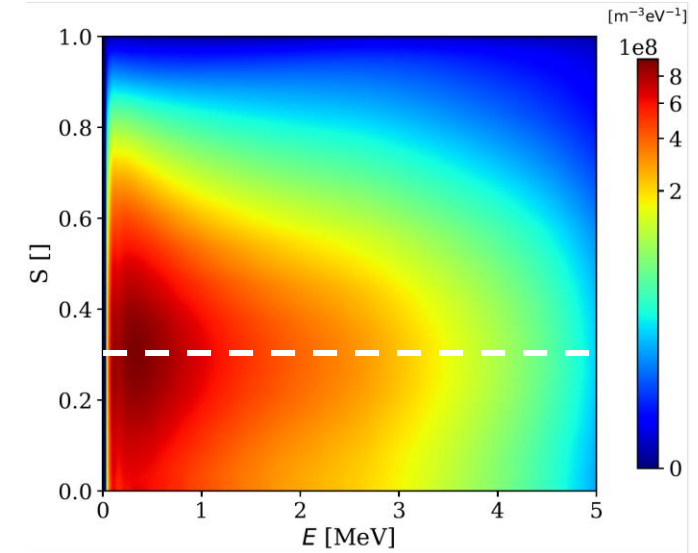
For more details see: [Kiptily V.G. *et al* 2026 *Nucl. Fusion* 66 066004](#)

D-NBI in D³He plasma for α-particle studies on JT-60SA

JT-60SA NBI heating system:

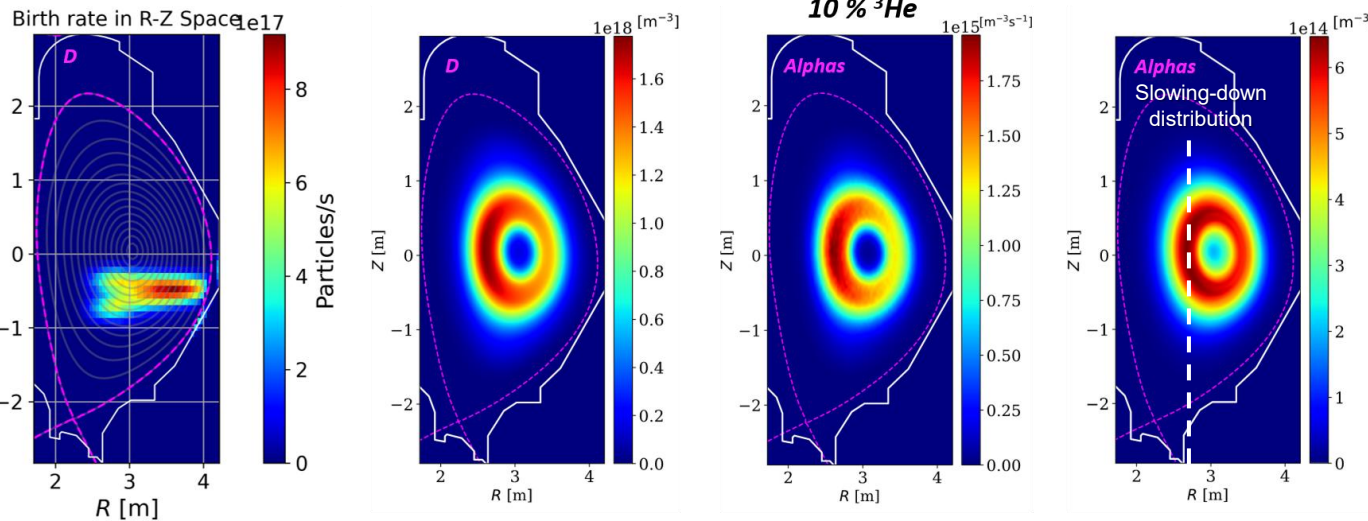
- 12 P-NBI, up to 24 MW in total at 85 keV
- 2 N-NBI, 10 MW at up to 500 keV

Slowing-down α-particle distribution



γ-ray emission rates, m⁻³ s⁻¹ (preliminary assessments)

E_γ , MeV	$^{10}\text{B}(\alpha, p\gamma)^{13}\text{C}$	$^{10}\text{B}(\alpha, n_1\gamma)^{13}\text{N}$	$^{11}\text{B}(\alpha, n_1\gamma)^{14}\text{N}$
3.09	$8.5 \cdot 10^8$		
3.685	$3 \cdot 10^9$		
3.854	$4 \cdot 10^9$		
2.368		$4.5 \cdot 10^7$	
2.313			$6 \cdot 10^8$



$P_\alpha^{D^3He} \sim 30 - 50$ kW is well-matched with 60-kW D³He-experiment on JET !

[Coelho R. et al Nucl. Fusion **66** \(2026\) 086029](#)

[Coelho et al, 19th TM EP, Lausanne, 2026](#)

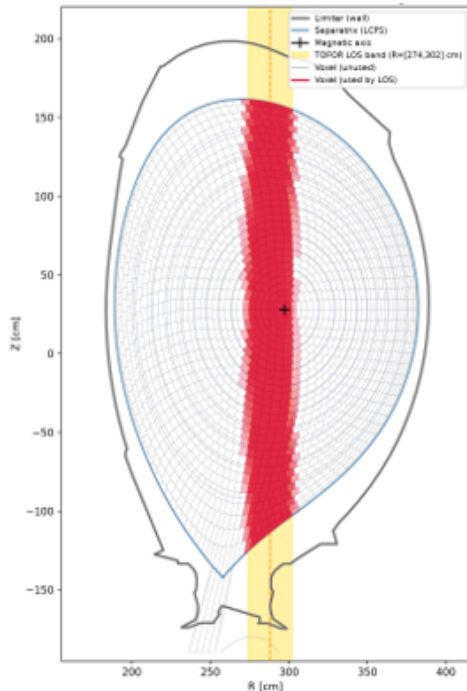
[Kiptily et al, 19th TM EP, Lausanne, 2026](#)

Thus, α-particle measurements
alike JET ones could be
feasible on JT-60SA

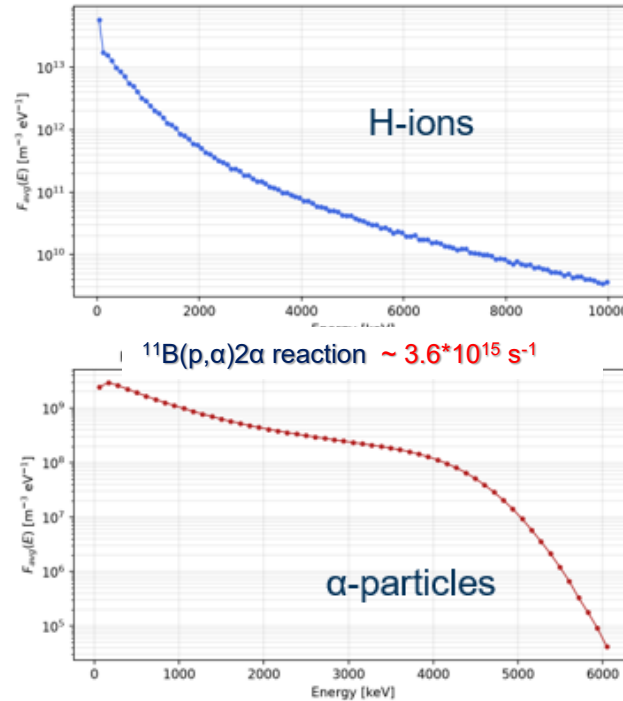


$^{11}\text{B}+\text{p}$ α -particle generation at conditions of JET Pulse No. 101184

LoS of γ -ray & neutron spectrometers



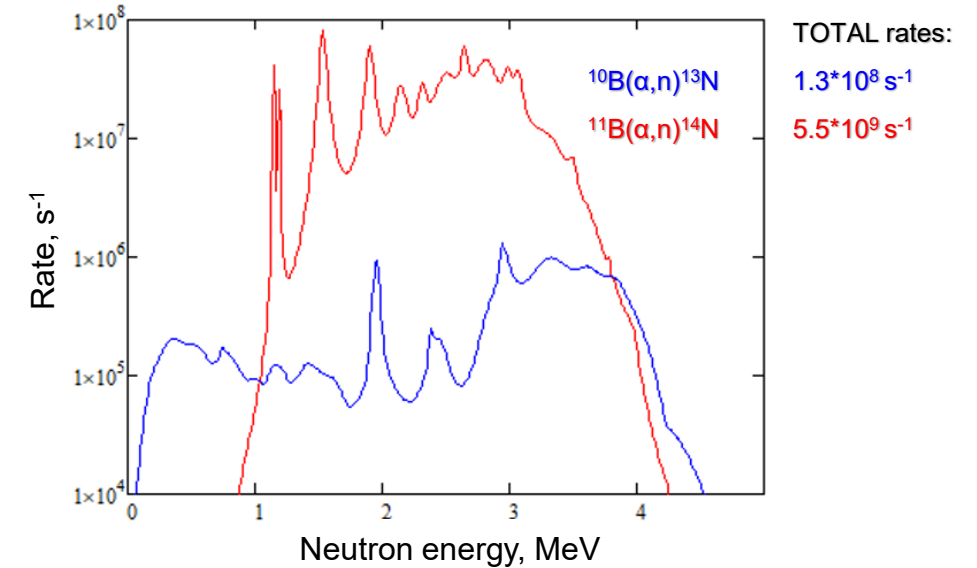
Distribution functions



Štancar Ž. et al 2026 Nucl. Fusion 66 096005

α -particle rate monitoring

Neutron emission rates (preliminary assessments)

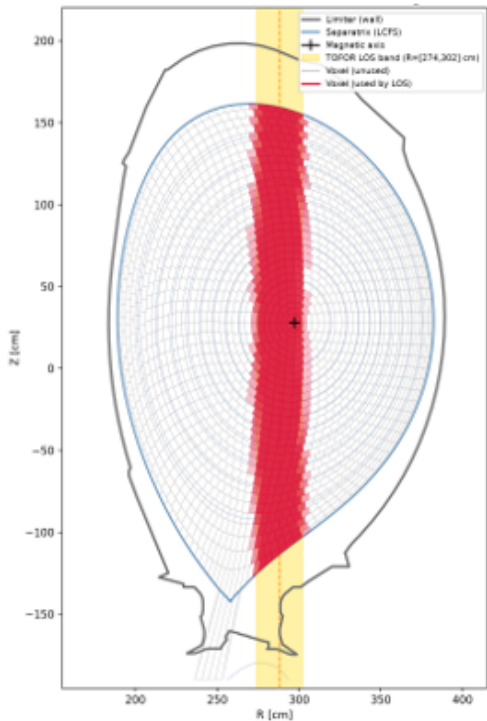


[Kiptily V.G. et al 2026 Nucl. Fusion 66 066004](#)

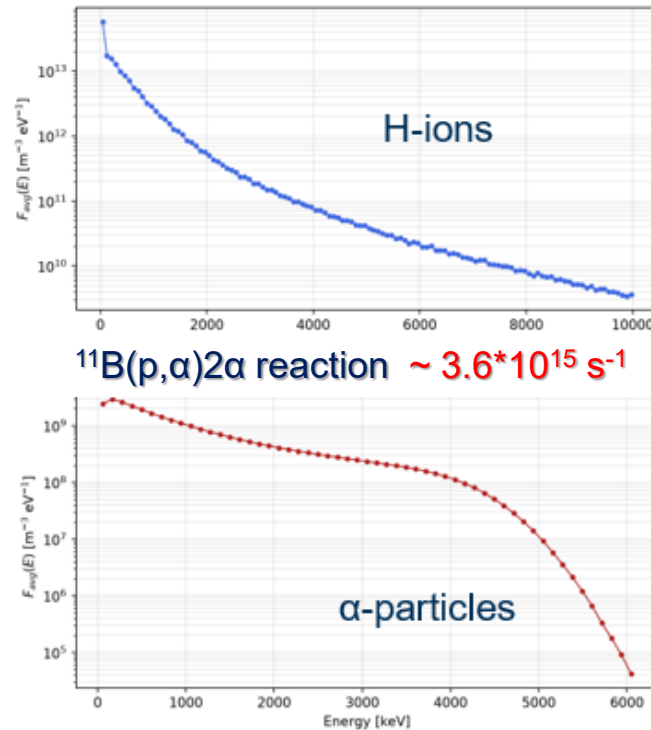
Kiptily et al, 19th TM EP, Lausanne, 2026

$^{11}\text{B}+\text{p}$ α -particle generation at conditions of JET Pulse No. 101184

LoS of γ -ray & neutron spectrometers



Distribution functions



[Štancar Ž. et al 2026 Nucl. Fusion 66 096005](#)

Confined α -particle measurements
 γ -ray emission rates, s^{-1} (preliminary assessments)

E_γ , MeV	$^{10}\text{B}(\alpha,\text{p}\gamma)^{13}\text{C}$	$^{10}\text{B}(\alpha,\text{n}_1\gamma)^{13}\text{N}$	$^{11}\text{B}(\alpha,\text{n}_1\gamma)^{14}\text{N}$
3.09	$1.9 \cdot 10^8$		
3.685	$6.6 \cdot 10^8$		
3.854	$8.8 \cdot 10^8$		
2.368		10^7	
2.313			10^8

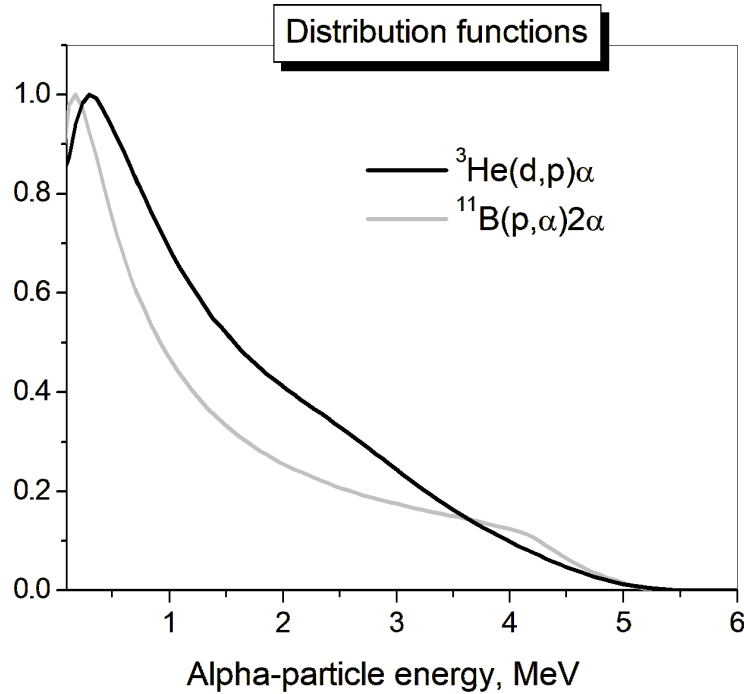
Kiptily et al, 19th TM EP, Lausanne, 2026

JT-60SA with H-NBI & 1% ^{11}B could generate more than $3.4 \cdot 10^{15} \text{ s}^{-1}$ alphas

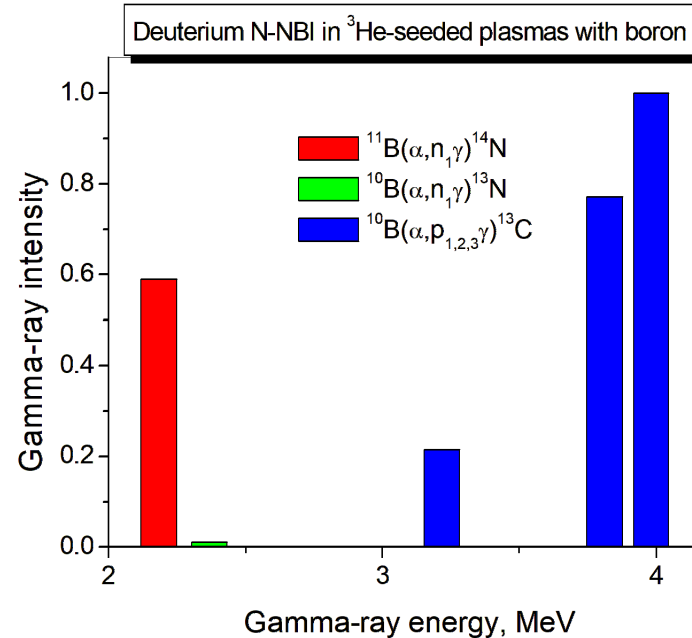
Coelho R. et al, talk at the 19th TM EP, Lausanne, Switzerland, 2026

Gamma-ray spectra generated by α -particles in D^3He & $p^{11}B$ experiments on JT-60-SA

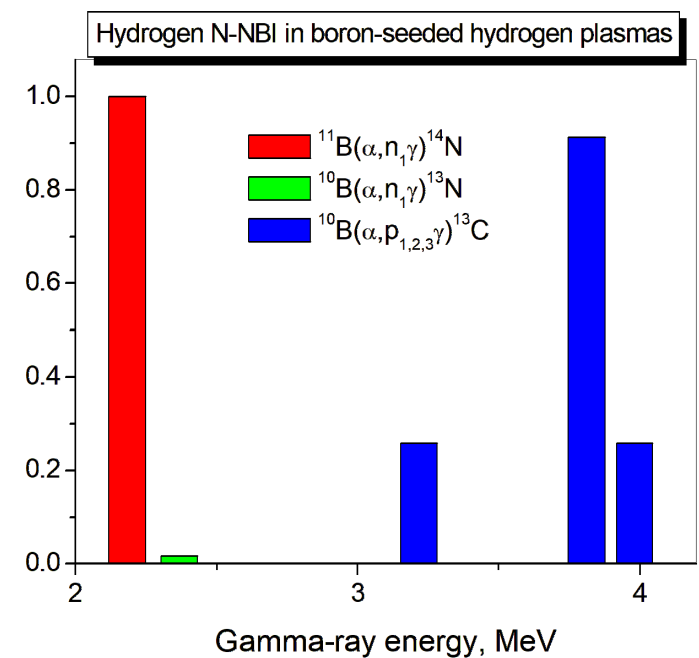
Expected γ -ray spectra in these experiments



Calculated α -particle distributions (plasma core) for D^3He & $p^{11}B$ experiments



$^{11}B(\alpha,n\gamma)^{14}N$ and $^{10}B(\alpha,p\gamma)^{13}C$ reactions could be used for the confined α -particle measurements in both cases



Summary & conclusions

- ❖ JET experiments have demonstrated feasibility of the α -particle studies in low-activation plasmas
 - ✓ JET studies could be a benchmark for the present and future fusion machines
 - to produce fast-ions with ICRH or/and NBI heating in D^3He , He -, D - and H -plasmas, using $D(^3He,p)^4He$ & $^{11}B(p,2\alpha)^4He$ reactions as α -particle generators
- ❖ Low-activation α -particle studies could be considered for JT-60SA
 - ✓ and in the pre-burning phases of forthcoming machines (SPARC, ITER, BEST etc.)
- ❖ γ -ray measurements of confined α -particles with $^{10}B(\alpha,p\gamma)^{13}C$ and $^{10,11}B(\alpha,n\gamma)^{13,14}N$ reactions are proposed
 - ✓ synergy of γ -ray & neutron diagnosis could be an advantage for the α -particle studies in the p - ^{11}B experiments