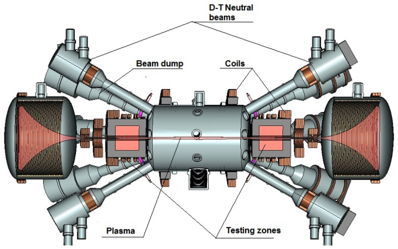
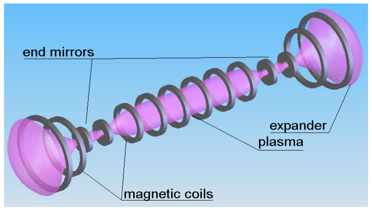
Axisymmetric magnetic mirror applications –

neutron source to fusion power plant





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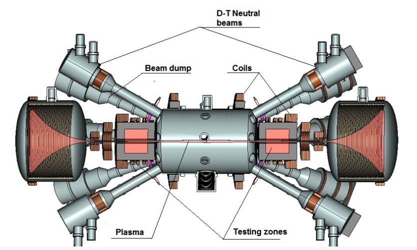
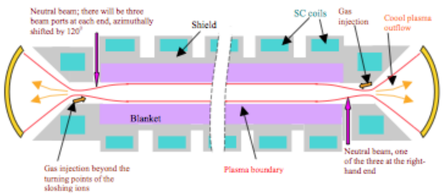
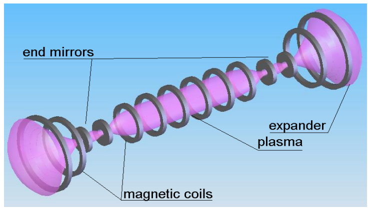
Outline

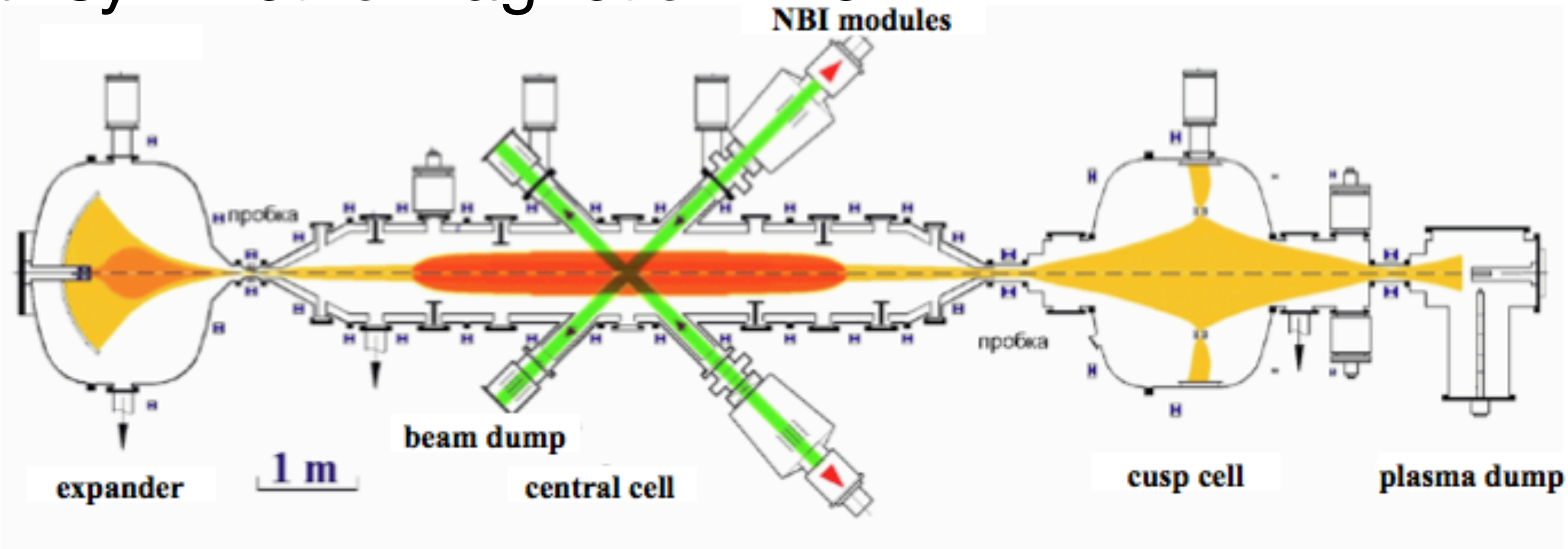






	Neutron source	Fusion-fission hybrid	Pure fusion
Risk:	Minor extension of tested physics	Q≤0.7 low risk – test line-tied stability	Test MHD & micro-stability
$\frac{\text{Fusion power}}{\text{Drive power}}$	$Q \sim 0.07$	$0.2 < Q \leq 10$	$Q > 10$
Motivation	Materials/component R&D for MFE, IFE DEMO	Q>4 (tandem) competes with fission breeders	Simpler fusion power. Perhaps thick-liquid walls

Gas Dynamic Trap (GDT) at Novosibirsk – stable, axisymmetric magnetic mirror



Mirror-to-mirror distance	**7 м**
Magnetic field at the mid-plane	**up to 0.35 T**
in mirrors	**up to 14 T**
Mirror ratio	**up to 35**
Time of neutral beam operation	**5 ms**
Total neutral beam power	**up to 5 MW**

Warm plasma:

10^{19}-10^{20} m^{-3}, $T_e \sim 200$ eV

Fast ions (H^+,D^+):

~5 x 10^{19} m^{-3} , <E>≈10 keV

$\beta \leq 60\%$

Long-pulse to steady-state 5 MW GDT could test plasma-materials interactions (PMI) to 400 MW/m^2, to simulate diverter heat loads. – R. Goldston

Performance of various neutron sources

	RTNS 1982-87 D-T	IFMIF D+Li	DTNS (FNSF) D-T	FNSF (FDF/CTF) D-T
Neutron Power (MW)	20 W	0.1	2	100-300 30-160
Flux (MW/m^2)	0.2	2/5	2	2 - 3 1 - 3
Availability goal		≥0.7	≥0.7	0.3
Area (m^2) Depth (cm)	.0001	0.01 5/1	1	70 /15
Tritium (kg/FPY) [Full-Power Year]	~0	0	0.1	~2 to 20 without breeding

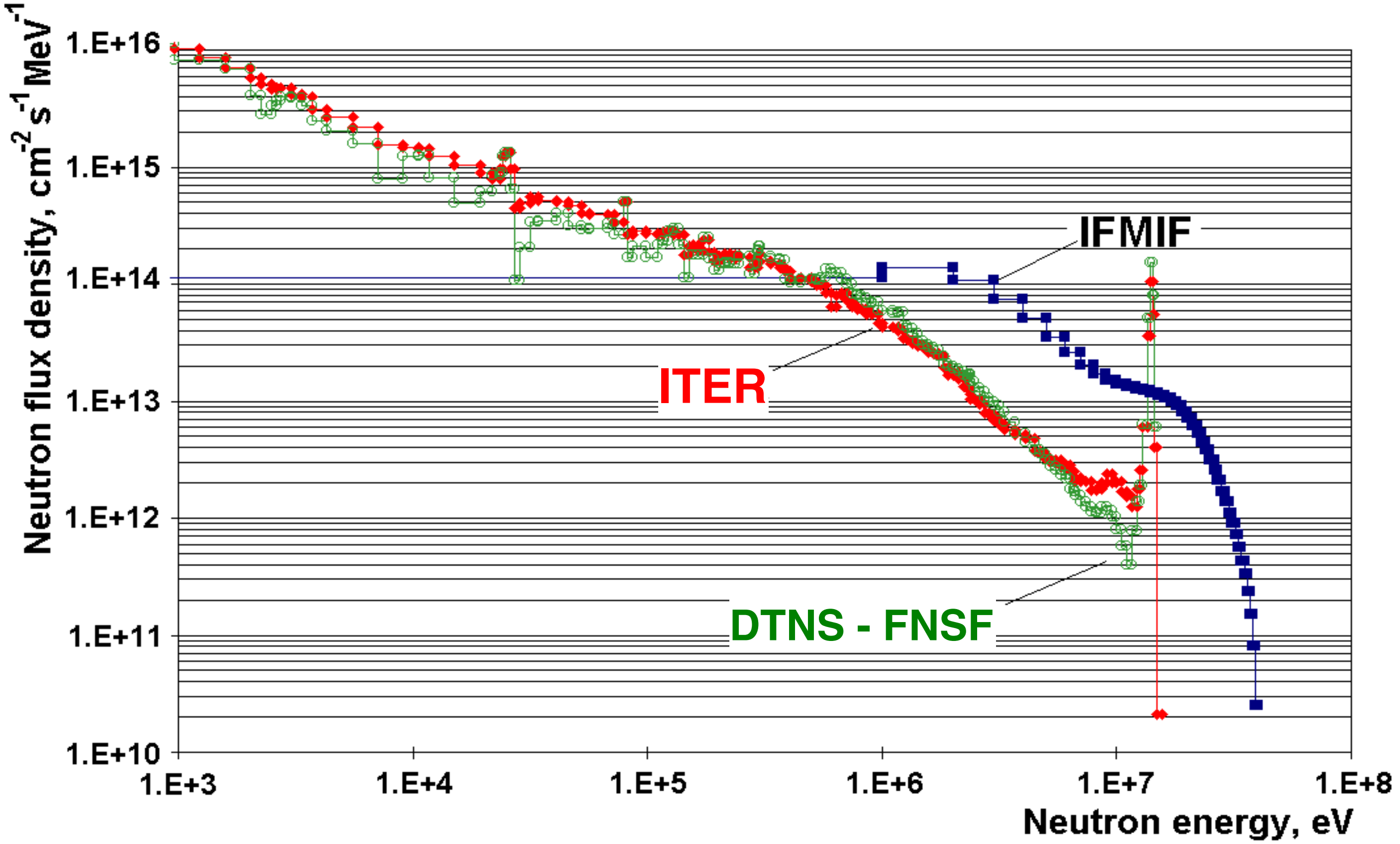
RTNS – Rotating Target Neutron Source

IFMIF – International Fusion Materials Irradiation Facility – D$^+$ beam onto flowing liquid lithium target yields cone of neutrons.

FNSF – Fusion Nuclear Science Facility (FDF & CTF are small D-T burning tokamaks for component development)

Neutron spectrum of DTNS – similar to ITER

- No spectrum conversion for displacements per atom (dpa), He/dpa, and H/dpa, or activation
- Activation data – no false positives from neutrons above 14 MeV

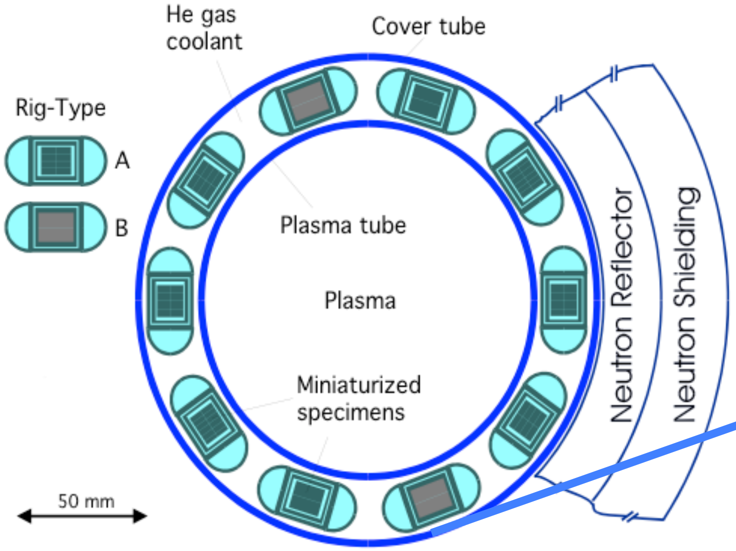


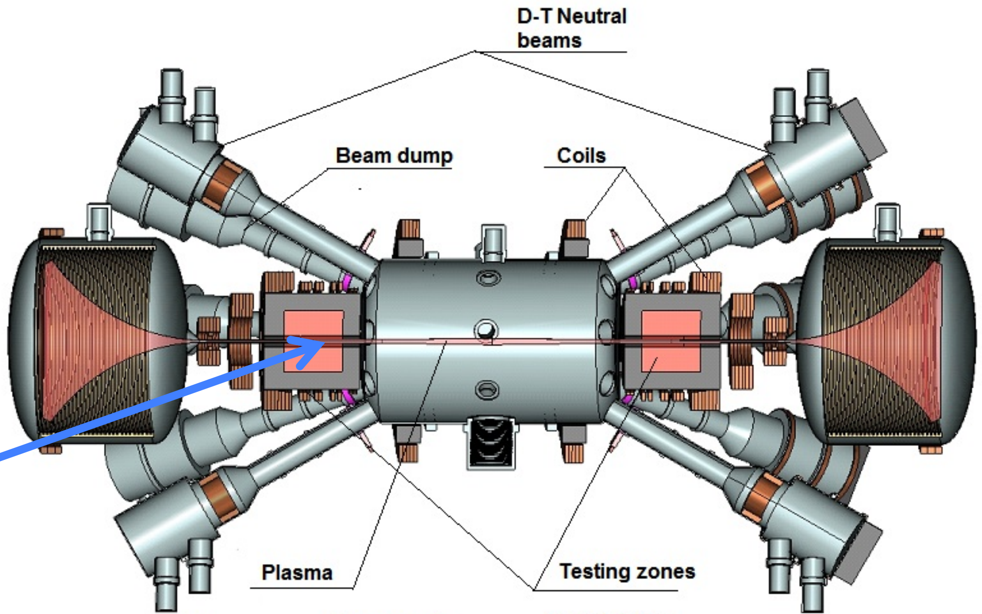
U. Fischer, A. Möslang, and A.A. Ivanov, "Assessment of the gas dynamic trap mirror facility as intense neutron source for fusion material test irradiations," Fusion Engineering and Design **48,** 307 (2000).

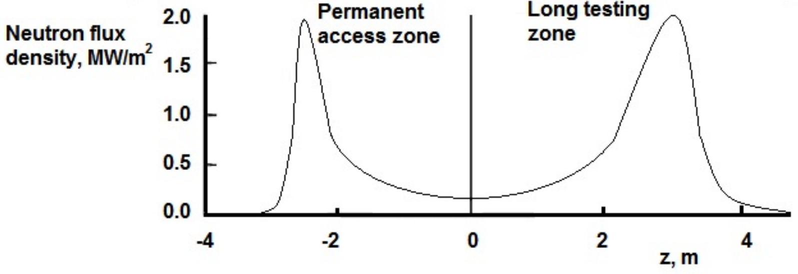
Dynamic-Trap Neutron Source (DTNS)

Optimized for materials test +
significant subcomponent tests

DTNS







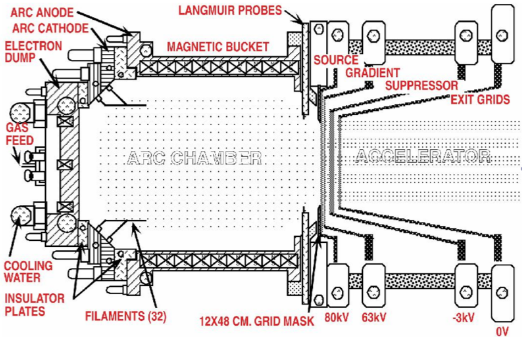
U. Fischer, A. Möslang, and A.A. Ivanov, FED **48,** 307 (2000).

Axisymmetric linear facility is maintainable, flexible, reconfigurable

Development needed for FNSFs

Steady-state neutral beams: DTNS – 30 MW at ~80 keV

- **Neutral beams reliable on tokamaks: TFTR (120 keV, 1 s [➔1000 s])[1] & DIII-D (80 keV, 5 s)[2]. Power 20-24 MW, availability 90-95%.**
- **Lifetimes uncertain. Ion source filament lifetime >2 weeks; sputter lifetime of accelerator electrodes similar order. Need ~1yr.**
- **Leverage NBI development from China, Korea, India?**



Long-Pulse-Source Neutral beams[3]

Steady-state cryopumps

- **All FNSF need cryopumps regenerated during full-power operation**

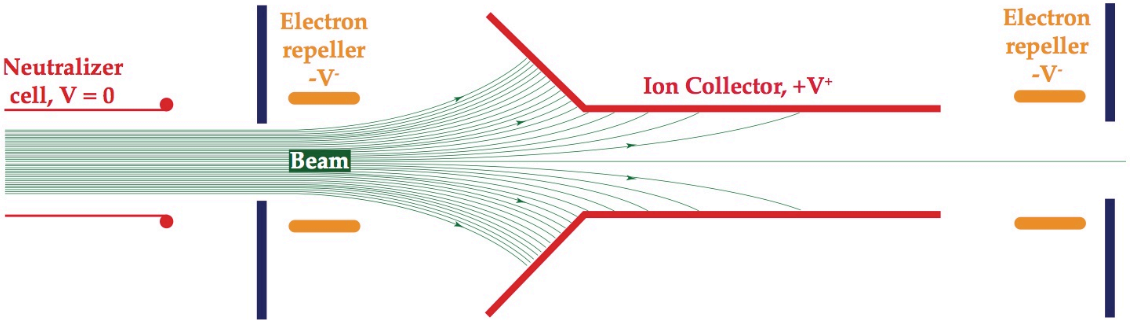
Remote handling

1. L. R. Grisham, et al., Fusion Engin. and Design **26**, 425 (1995).
2. J. Kim, et al., 12th SOFE (1987), p. 290.
3. M. Vella, et al., *Rev. Sci. Instrum.*, **59**, 2357 (1988).

Direct conversion of NBI residual ion beam – option

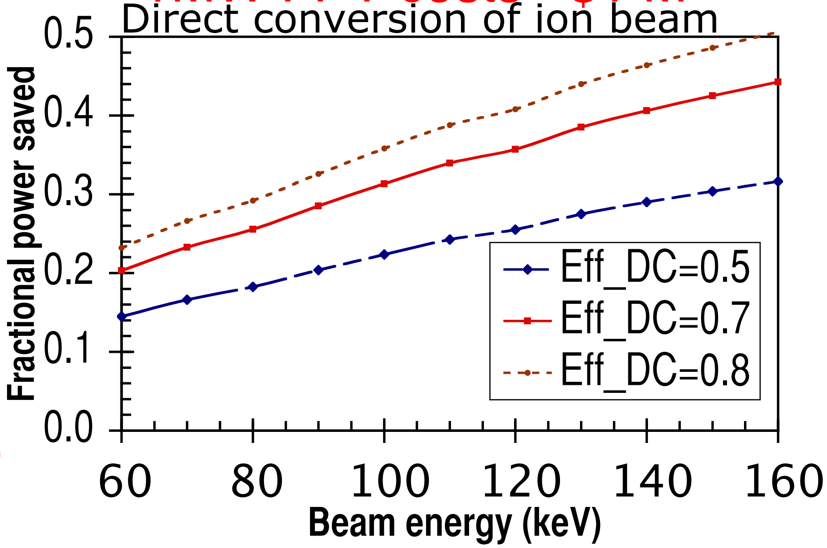
Efficiency ~65% achieved, ~75% if mostly full-energy ions [1]

100 keV, 2 A NB



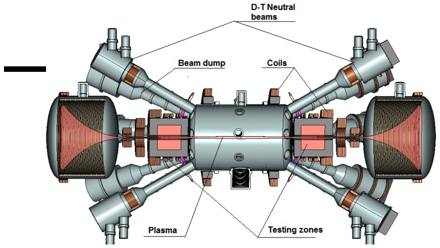
- Efficiency of ~70% possible
- Nearly eliminates decrease in efficiency at high-beam-energy
- Direct conversion (DC) can be added, or deleted; depends on R&D success.
- Save $5-10 M/yr at $0.10/kW hr

1MW FPY costs ~$1 M



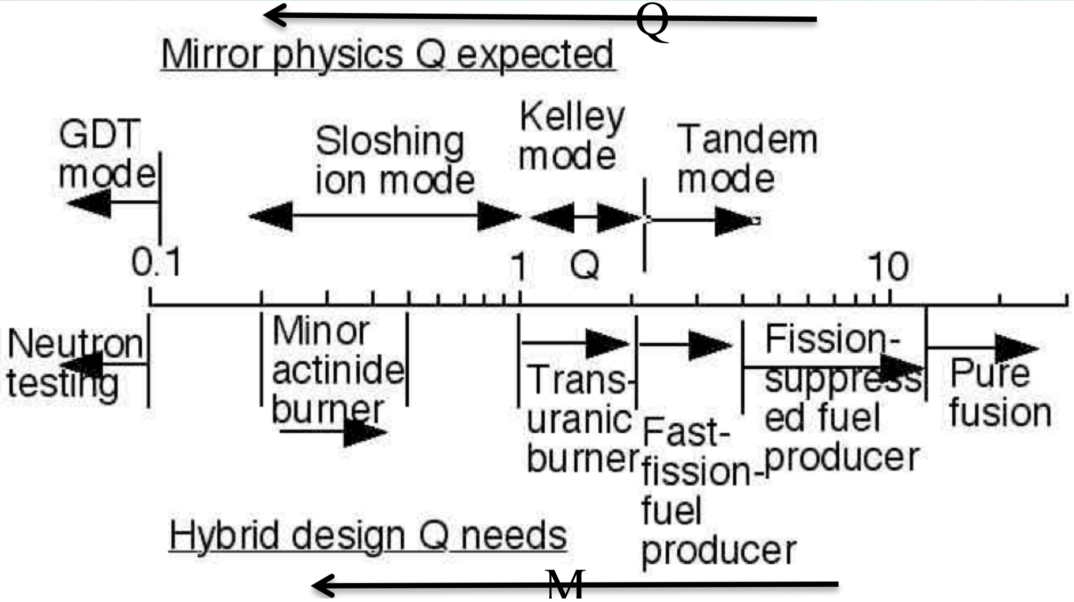
1. W. L. Barr, R. W. Moir, G. W. Hamilton, J. Fusion Energy **2**, 131 (1982).
2. W. L. Barr, et al., "Engineering of beam direct conversion for a 120 kV, 1 MW ion beam," 7th SOFE (1977), p. 1.

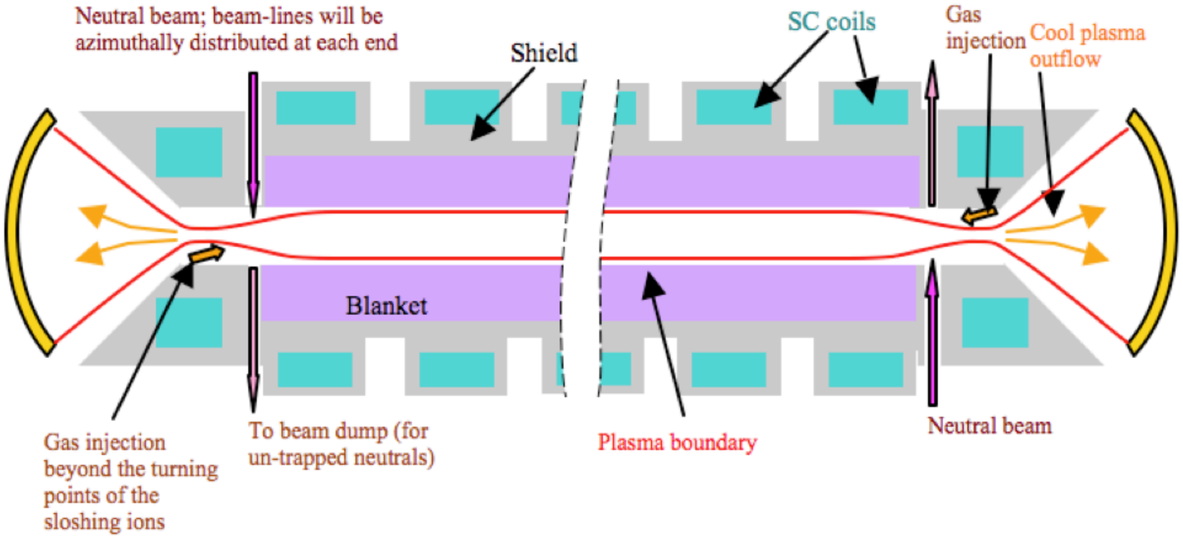
Dynamic-Trap Neutron Source DTNS – low risk



- **DTNS is extrapolation of successful GDT – low scientific risk**
  - **Neutral-beam energy x4 [to DIII-D level]**
  - **Neutral-beam current x1.5**
  - **B_{min} x 6**
  - **Same plasma length, radius, and B_{peak}**
  - **$T_e \sim 0.8$ keV from scaling law**
- **DTNS not part of test – low technology risk**
  - **Power densities low on DTNS**
  - **Tritium-breeding blankets not required for fueling (burns ~0.1 kg/yr)**
  - **Samples outside vacuum wall, change wall during maintenance**
  - **Insert samples thru airlock: expose to α's, PMI, neutrons >2 MW/m^2?**
- **DTNS differs from tokamak FNSF:**
  - **Superconducting magnets – lower operating power/costs**
  - **Maintainable without individual magnets separating into 2 pieces**

Mirror fusion-fission hybrid: burn waste or compete with fission breeder [Moir 1.4.3]

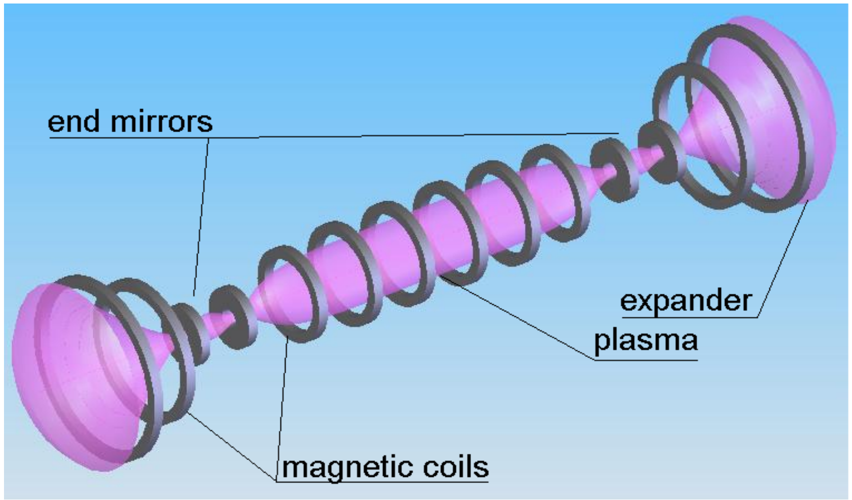


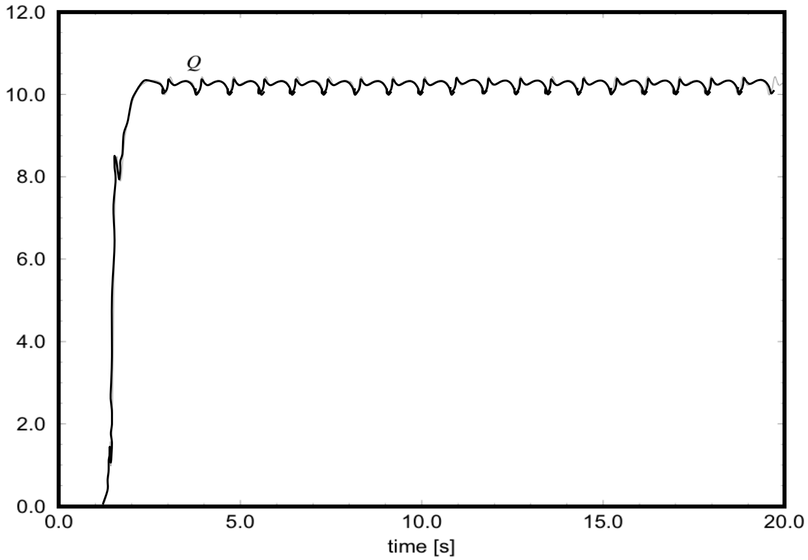


Detailed report is available – Moir, Martovetsky, Ryutov, Molvik, Simonen

Can axisymmetric mirrors provide pure fusion with Q>10?

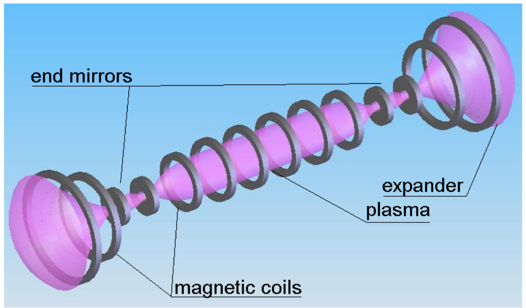
- Need to demonstrate MHD and micro-stability with low end-loss, several mechanisms to test – at low cost on GDT.
- Power/particle balance computations: Q=10 solution (below)*, Q>10?
- Q=10 sufficient with direct conversion of end loss and neutral-beams?
- Helium-ash accumulation?





* D. Hua and T. K. Fowler, “SYMTRAN – A Time- dependent Symmetric Tandem Mirror Transport Code,” LLNL Report: UCRL-TR-204783 (2004). Run 8, Figs. 24-27.

Axisymmetric tandem mirrors – potential for attractive pure-fusion power



Strengths

- **All mirrors eliminate**
    a. Disruptions (no significant plasma current)
    b. High power density to diverter strike points (large area for end loss).
- **Axisymmetric mirrors**
    a. Eliminate neoclassical and resonant radial transport
    b. Allow high-B tandem mirror end cells, don't need thermal barriers
    c. Easy to maintain or modify
    d. Low costs for stability tests, on GDT
    e. Technologies within ITER range
    f. Thick liquid walls of 0.5-1m thick molten-salt flibe eliminate most materials issues (dpa, He/dpa, H/dpa)[1]

1. R. W. MOIR and T. D. ROGNLIEN, "Axisymmetric Tandem Mirror Magnetic Fusion Energy Power Plant with Thick Liquid-Walls," *Fusion Sci. Technol.*, **52**, 408 (2007).

Conclusions – Axisymmetric mirrors have attractive applications

- Long-pulse GDT could test PMI to 400 MW/m^2 to simulate extreme diverter heat loads
- DTNS can test materials & subcomponents for a tokamak FNSF and a fusion DEMO
- Mirror fusion-fission hybrid: burn waste (single-cell) or compete with fission breeder (tandem mirror)
- Axisymmetric tandem mirrors have potential for attractive pure-fusion power

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