Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Fusion-Fission Hybrid reactors based on Tokamak neutron sources

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Fusion-Fission Hybrid Reactors : WHAT FOR?

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FFHR AIM	ALTERNATIVE SOLUTION	
WASTE MANAGEMENT	REPOSITORY	
ENERGY PRODUCTION	FISSION	FUSION
TRITIUM PRODUCTION	FISSION	

WASTE MANAGEMENT I.E. BURNING LONG TERM ISOTOPES CAN BE AN EXCLUSIVE APPLICATION OF FFHR

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TECHNOLOGY READINESS LEVEL (TRL) CLASSIFICATION

Nucl. Fusion **56** (2016) 026009

Table A1. Readiness level definitions.

TRL 1	Basic principles observed and reported.
TRL 2	Technology concept and/or application formulated.
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept.
TRL 4	Technology basic validation in a laboratory environment.
TRL 5	Technology basic validation in a relevant environment.
TRL 6	Technology model or prototype demonstration in a relevant environment.
TRL 7	Technology prototype demonstration in an operational environment.
TRL 8	Actual technology completed and qualified through test and demonstration.
TRL 9	Actual technology qualified through successful mission operations.

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NUCLEAR FUSION 2016

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IS THERE A MARKET FOR THE FFHR ?

- AT MOMENT THERE IS NO MARKET FOR FFHR SINCE TRL<<9
- TECHNOLOGY READINESS LEVEL FOR FFHR SYSTEM BASED ON TOKAMAK ANALYZED AND CLASSIFIED ON AVERAGE AT THE TRL=4-5

- POSSIBLE APPLICATION FOR **WASTE MANAGEMENT** AND TRITIUM PRODUCTION
- MUST BE TESTED ON PROTOTYPE OR PROOF OF PRINCIPLE EXPERIMENTS

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WHY TOKAMAKS AS NEUTRON SOURCES FOR A FFHR ?   pros and cons

- PROS
- NON-THERMAL PLASMA SCENARIO TESTED ON JET IN 2021/ 2022 DTE2/DTE3 EXPERIMENTS   WITH ACHIEVEMENT OF FUSION RECORD (M MASLOV ET AL NUC FUS 2023)

  NON-THERMAL SCENARIO TESTED ON ST40 WITH RECORD

  ION TEMPERATURE ACHIEVED (S McNAMARA ET AL NUC FUS 2023)
- TRL OF THE SCENARIO IS 5
- TRL OF MOST SUBSYSTEMS BETWEEN 4- 5
- **FFHR BASED ON TOKAMAK READY FOR PROTOTYPE CONSTRUCTION AND TESTING to get TRL>5**
- **CONS**
- THE TOROIDAL GEOMETRY TO BE OPTIMIZED FOR BLANKET

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EVALUATED TRL FOR TOKAMAK (F P ORSITTO AND T N TODD FUNFI2 HEFEI CHINA 2018)

Subsystem	TRL
Superconducting magnets	5
NBI(100keV) NEUTRAL BEAM INJECTION SYSTEMS FOR PLASMA HEATING	4
ECRH (1MW gyr) RADIO FREQUENCY HEATING AT THE ELECTRON CYCLOTRON FREQ.	5
ICRH (1MW) RADIO FREQUENCY HEATING AT THE ION CYCLOTRON FREQ.	4

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TRL AND CONCEPT VALIDATION

The technology readiness level of the various subsystems of a tokamak can be determined and

TRL≈4 can be given to the plasma heating systems and superconductor magnets ,

while only to the electron cyclotron resonance heating can be given TRL≈5-6 .

From the point of view of the validation of the concept, the coupling of a fusion device to a multiplying fission medium (FFH) can be seen as one very specific case of the coupling of an intense high energy neutron source to a fission system(*).

(*) M SALVATORES ET AL ANNALS NUCLEAR ENERGY 2021

VALIDATION BY COMPONENTS

In the recent past the case of Accelerator Driven Systems (ADS) was considered, in particular in the frame of waste management strategies.

In order to validate the concept, an experimental validation strategy was set up and several relatively large experiments were realized in a European frame.

The same strategy of “validation by components” can be applied to FFH concept: apart from the realization of a fusion source , the validation concerns the subcritical region (with a “standard” fuel),

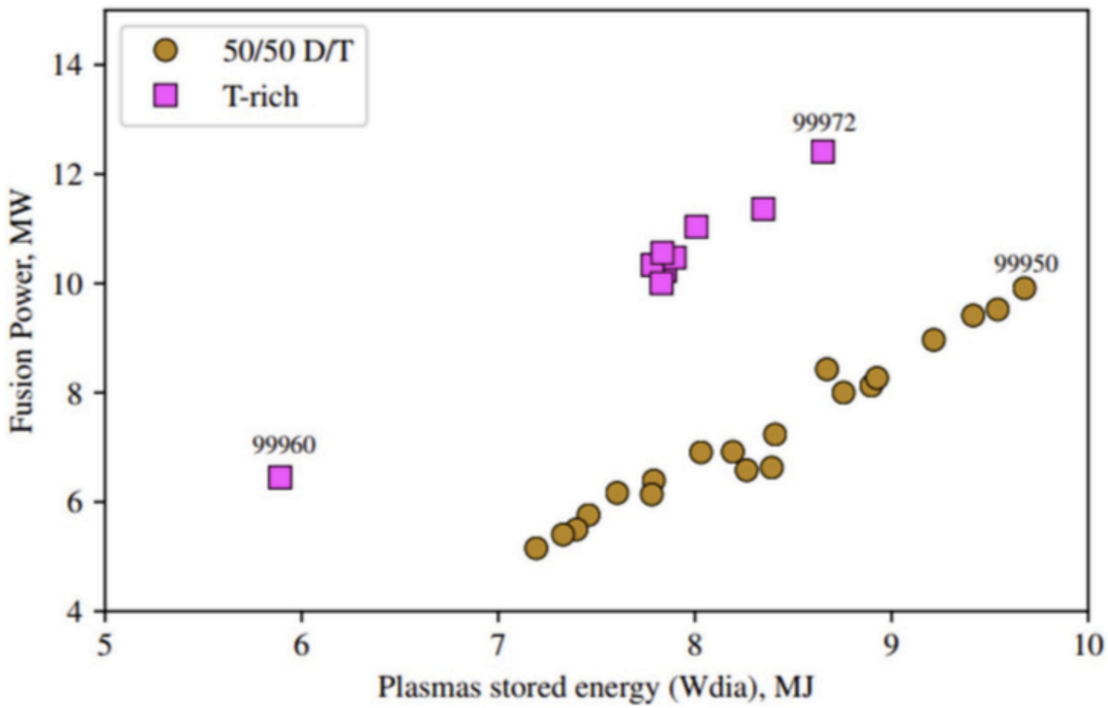
The eventual presence of buffer regions between the fusion source and the fission blanket, the presence of specific shielding zones.

The experimental program should be devoted to

- the study of the sub criticality,
- of the power distributions, and
- of some significant transmutation rates of key isotopes.

NON THERMAL FUSION SCENARIO AS SOLID EXPERIMENTAL BASIS FOR A TOKAMAK BASED FFHR

NON-THERMAL FUSION SCENARIO CONSISTS IN HAVING TRITIUM RICH PLASMA (D:T /25:75) AND DEUTERIUM NEUTRAL BEAMS INJECTED INTO PLASMA PRODUCING DIRECT FUSION REACTIONS ON TRITIUM



JET DTE2 CAMPAIGN
yr 2022

M MASLOV ET AL
NUC FUS 2023

NEW ENERGY CONFINEMENT SCALING LAW FOR NON-THERMAL TOKAMAK PLASMA SCENARIO

NEW SCALING LAW BASED ON TFTR SUPERSHOTS

The scaling law of confinement time in TFTR supershots (τ_{TFTR}) was given in [4]:

$$\tau_{TFTR} \propto Ip^{0.22}\, Bt\ Wbeam^{-0.56} \qquad (2)$$

Where Ip is the plasma current , Bt the magnetic field on axis and Wbeam the energy of the heating neutral beam, additional dependence on the density peaking (not shown in (2)) was also reported. An extension of the scaling law (2) to arbitrary geometry is proposed in the following form :

$$\tau_{TFTR} \propto Ip^{0.22}\, Bt\ Wbeam^{-0.56}\, R^{1.83}\ A^{0.06}\ k^{0.64} \left(\frac{n}{\langle n \rangle}\right)^{1.5} n^{0.4} \qquad (3)$$

Where the geometry (major radius R, elongation k , aspect ratio A) , density dependence (n) and peaking (n/<n>) are added

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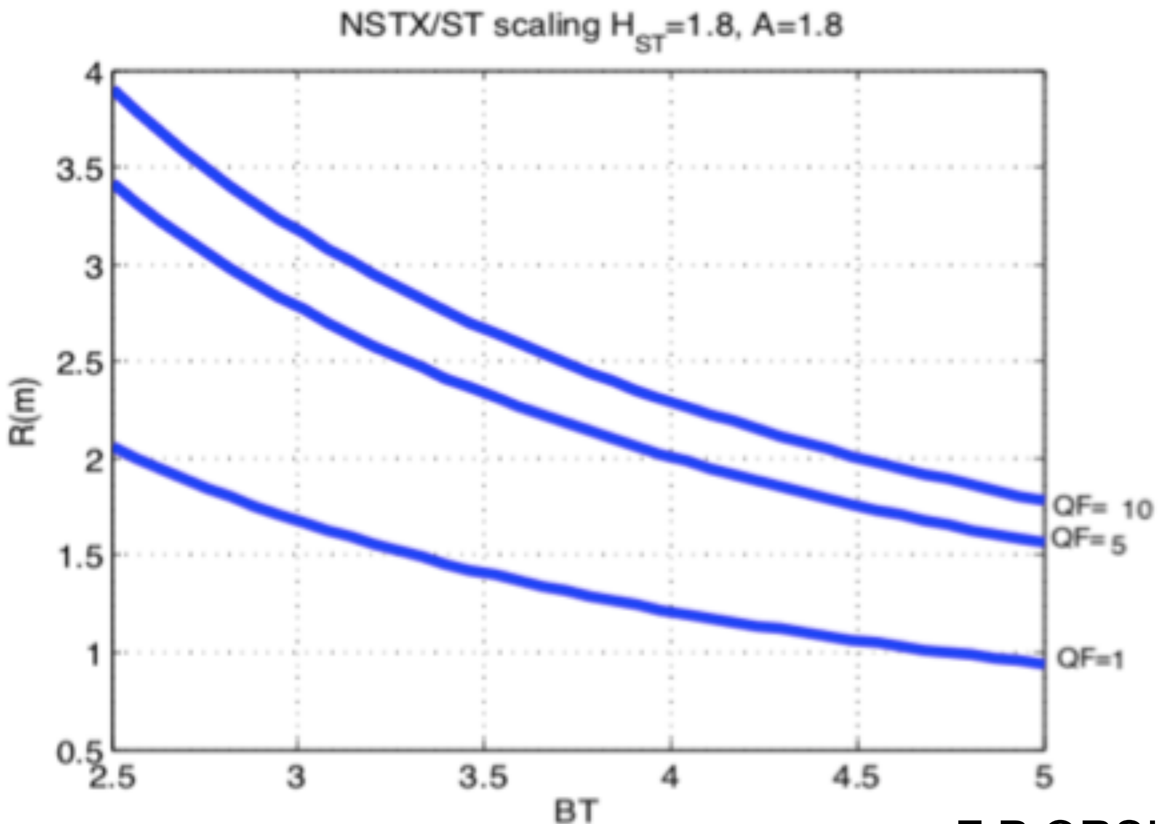
MAJOR RADIUS VS MAGNETIC FIELD FOR ST USING THE SCALING LAW OF ENERGY CONFINEMENT OF THE NSTX ST



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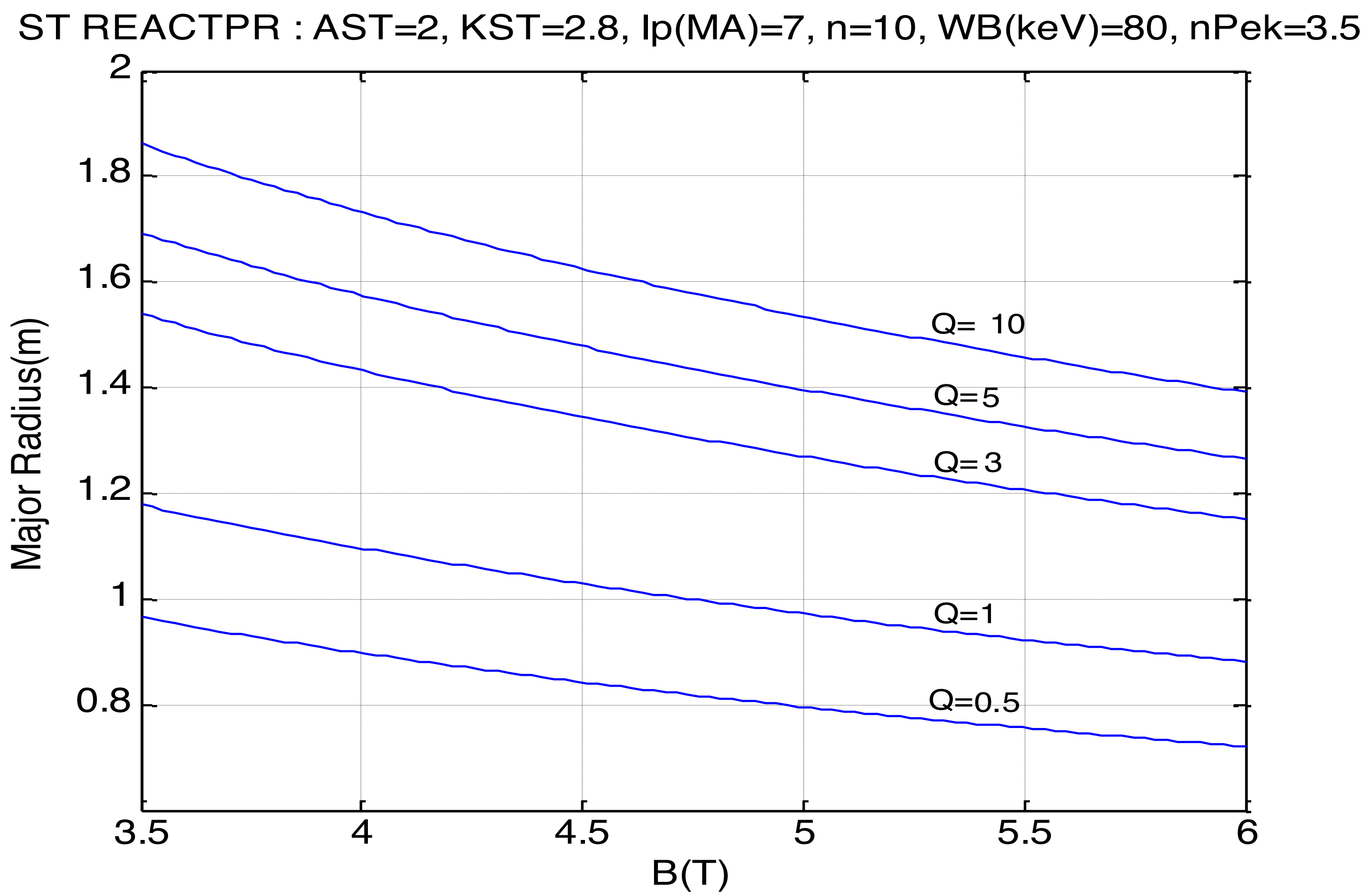
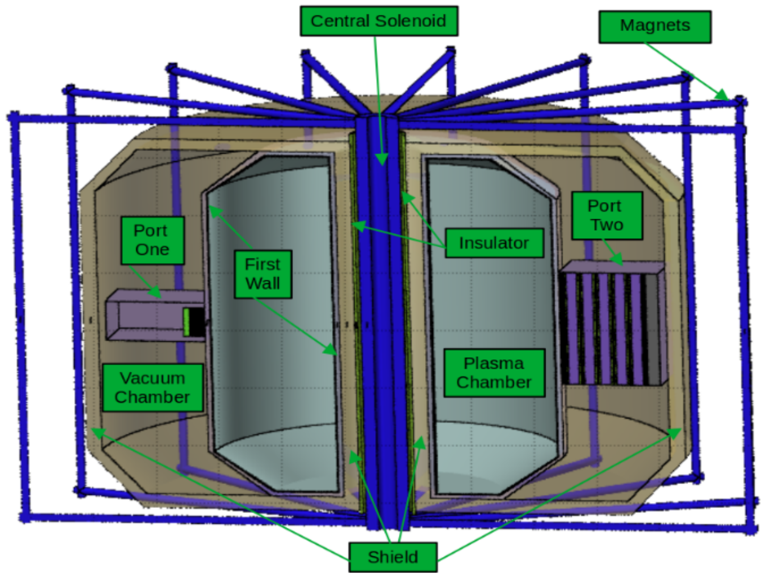
Major radius vs magnetic field for a ST USING THE NEW SCALING LAW FOR NON THERMAL SCENARIO ASPECT RATIO A=2



LOAD ASSEMBLY OF FFHR WITH ST NEUTRON SOURCE



F P ORSITTO , N Burgio,
M Ciotti, F Panza,
A Santagata
IAEA FEC London 2023
CN 1708

ST180	Plasma Parameters	Ip(MA)	4	Radial Build-Up	
		$n/10^{19}\ m^{-3}$	8	gap LCMS-VV(m)	0.05
Q	2	W_B(keV)	40	Vacuum Vessel thick.	0.1
R(m)	1.8	Pfus(MW)	15	Neutron shield(m) (Zr(BH4)4,W)(m)	0.25
A(aspect ratio)	1.8	neutr(n/s)1e18	5	Thermal Insulator(m)	0.05
B(T)	4.28	PBeam(MW)	7.5	total inboard thickness(m)	0.45

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CONCLUSIONS

1. A solid plasma scenario for FFHR based on tokamak has been tested on JET DTE2/DTE3
2. Tokamak subcomponents have a Technology Readiness Level TRL ≤ 6
3. FFHR based on tokamak as neutron source need a program for concept ‘validation by component’
4. Tokamak non-thermal scenario need to be tested for long pulses