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Overview of Reactor Design Studies at JAERI

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Outline

1. Low-A Compact Reactor, VECTOR
2. DEMO Plant Design
3. Reduction of Waste

1. Low-A Compact Reactor, VECTOR

References:

[1] S. Nishio et al., 19th Fusion Energy Conf., Sorrento, IAEA-CN-94/FT/P1-21 (2002).

[2] S. Nishio et al., 20th Fusion Energy Conf., Vilamoura, IAEA-CN-FT/P7-35 (2004).

[3] K. Tobita et al., Plasma Phys Contr. Fusion 46 (2004) S95.

[4] K. Tokimatsu et al., WEC 2004, Sydney.

Reactor Design Studies at JAERI

	concept	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04
SSTR	BS current-dominated SS reactor															
DREAM	Easy maintenance and low activation															
A-SSTR	Requirements to improve COE of SSTR															
A-SSTR2	Combined advantages of A-SSTR and DREAM															
DEMO 2001	DEMO to assess the prospect of pebble bed/water-cooled blanket															
VECTOR	Superconducting compact low-A reactor															
DEMO	Compact low-A DEMO															

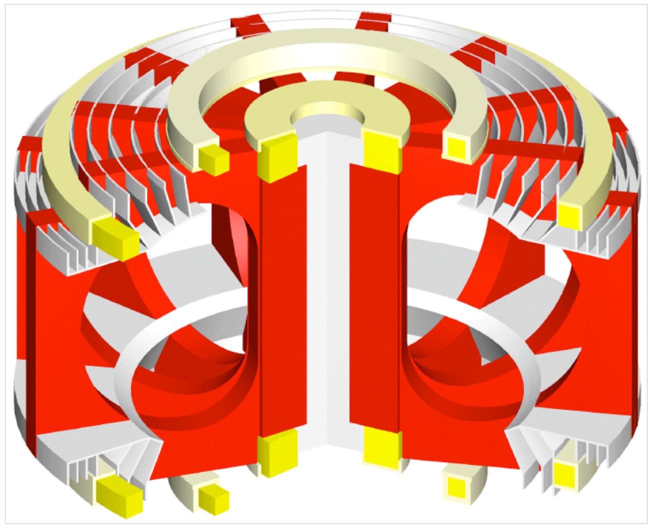
= SSTR series

= Low-A approach

SSTR series aimed at higher power density with high B_{max}, yet this does not always make the reactors compact

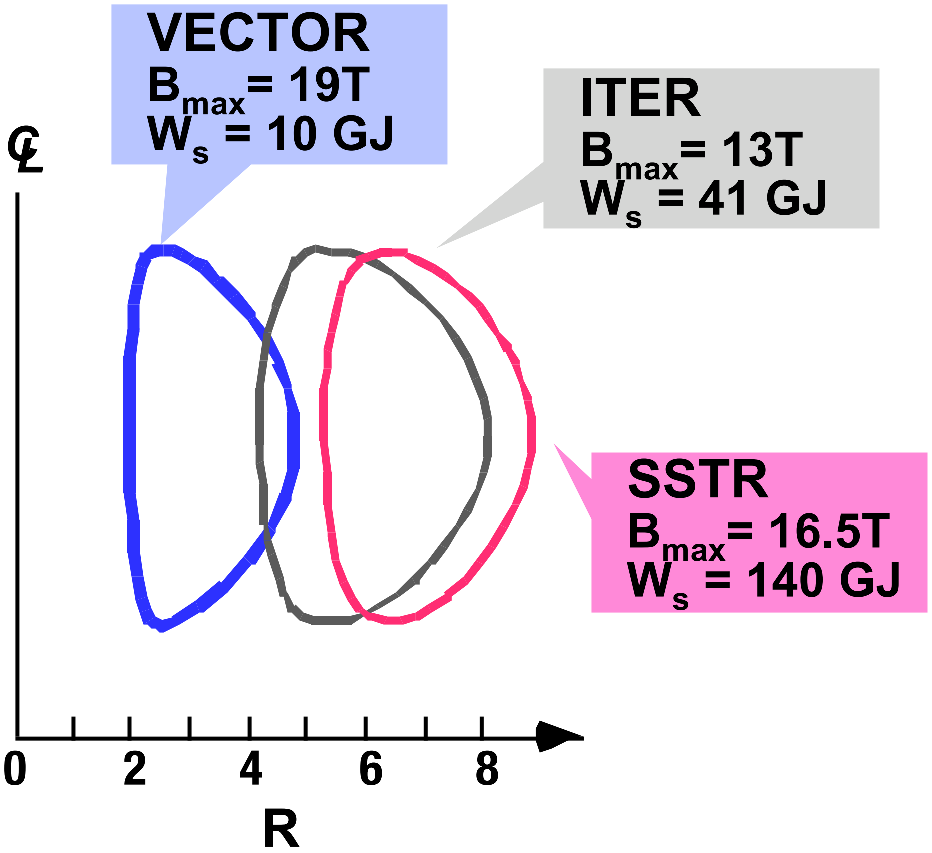
SSTR 16.5 T → **A-SSTR** 19 T → **A-SSTR2** 23 T

	SSTR	A-SSTR2
P_{fus} (GW)	3.08	4.0
R_p (m)	7.0	6.2
B_{max} / B_T (T)	16.5 / 9	23 / 11
W_{TFC} (GJ)	136	181
TFC Weight (t)	11,200	14,640



Coil system of A-SSTR2

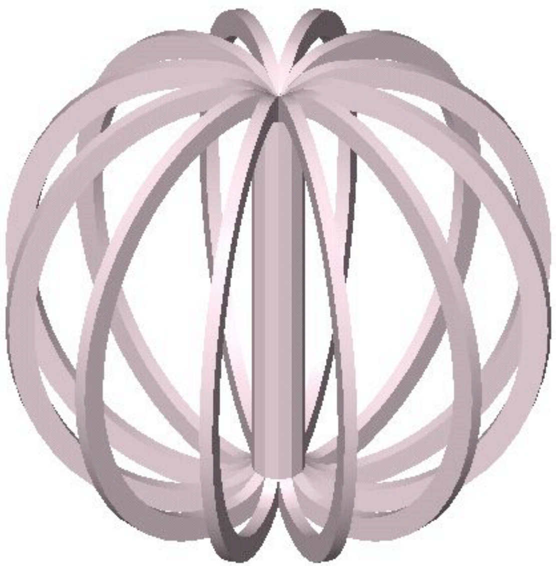
TF Coils of "VECTOR" concept



Small R leads to a reduction in W_s of TFC.

reducing

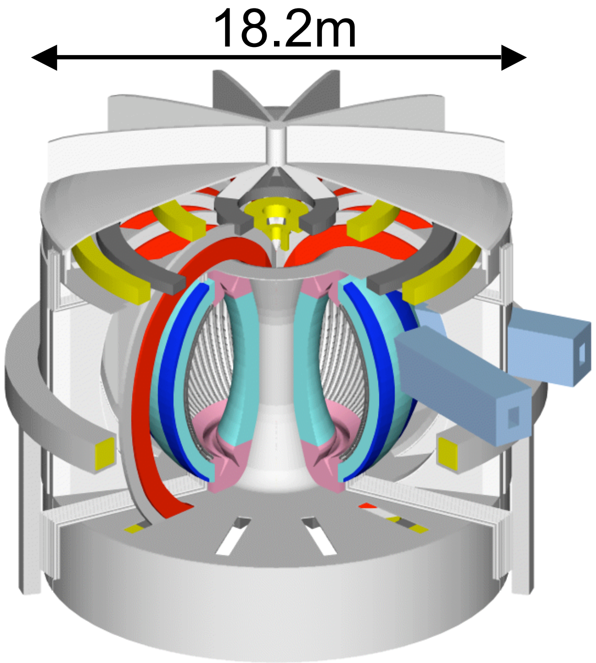
- supporting structure material
- stabilizing material



Slim TF coil system

Parameters of VECTOR

VEry Compact Tokamak Reactor



R_p	3.2 m	I_p	14 MA
a	1.4 m	β_N	5.5
A	2.3	HH	1.3
κ	2.35	n/n_{GW}	0.9
B_{max}	19 T	P_{fus}	2.5 GW
B_T	5 T	P_n	5 MW/m^2

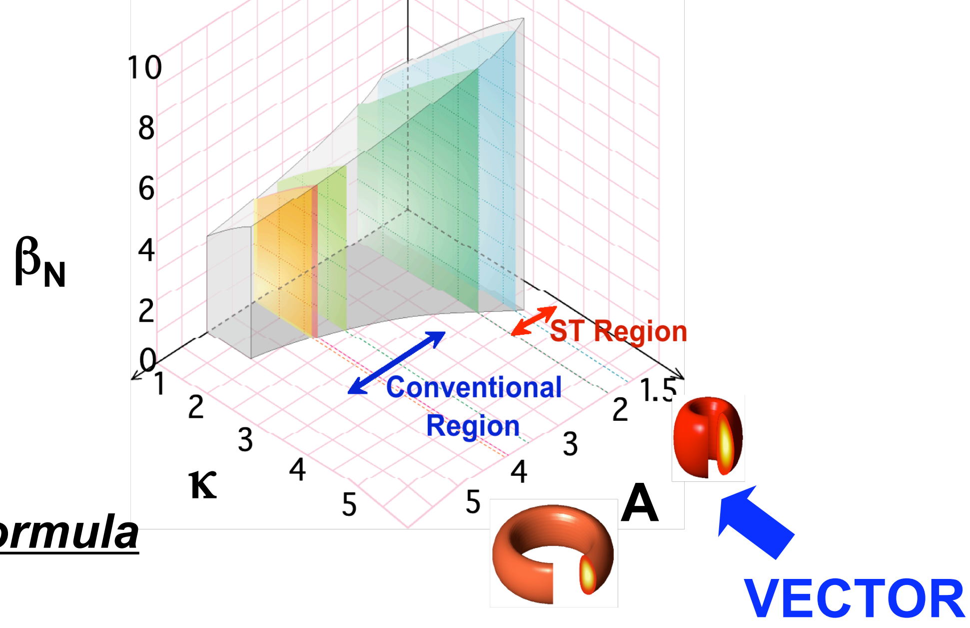
- No CS
- Structural material: SiC/SiC
- Breeding material: LiPb
- Superconductor: Bi-HTS

Considerations on A

- **Low-A**

  Advantages : high κ ⇨ $n_{GW} = I_p/\pi a^2$ ↗

  high β

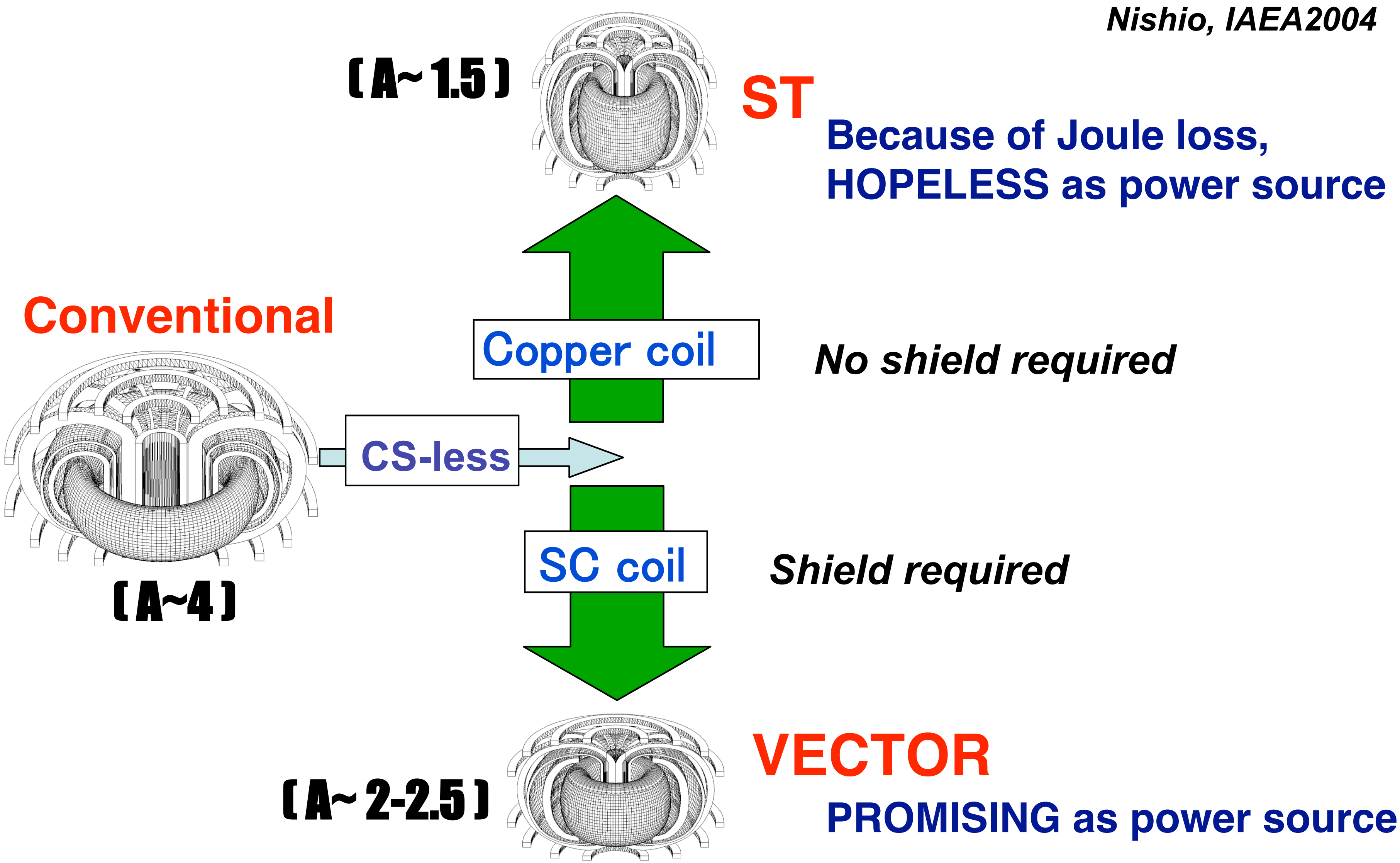


Plot of Wong's formula

- **To adopt superconducting TF**

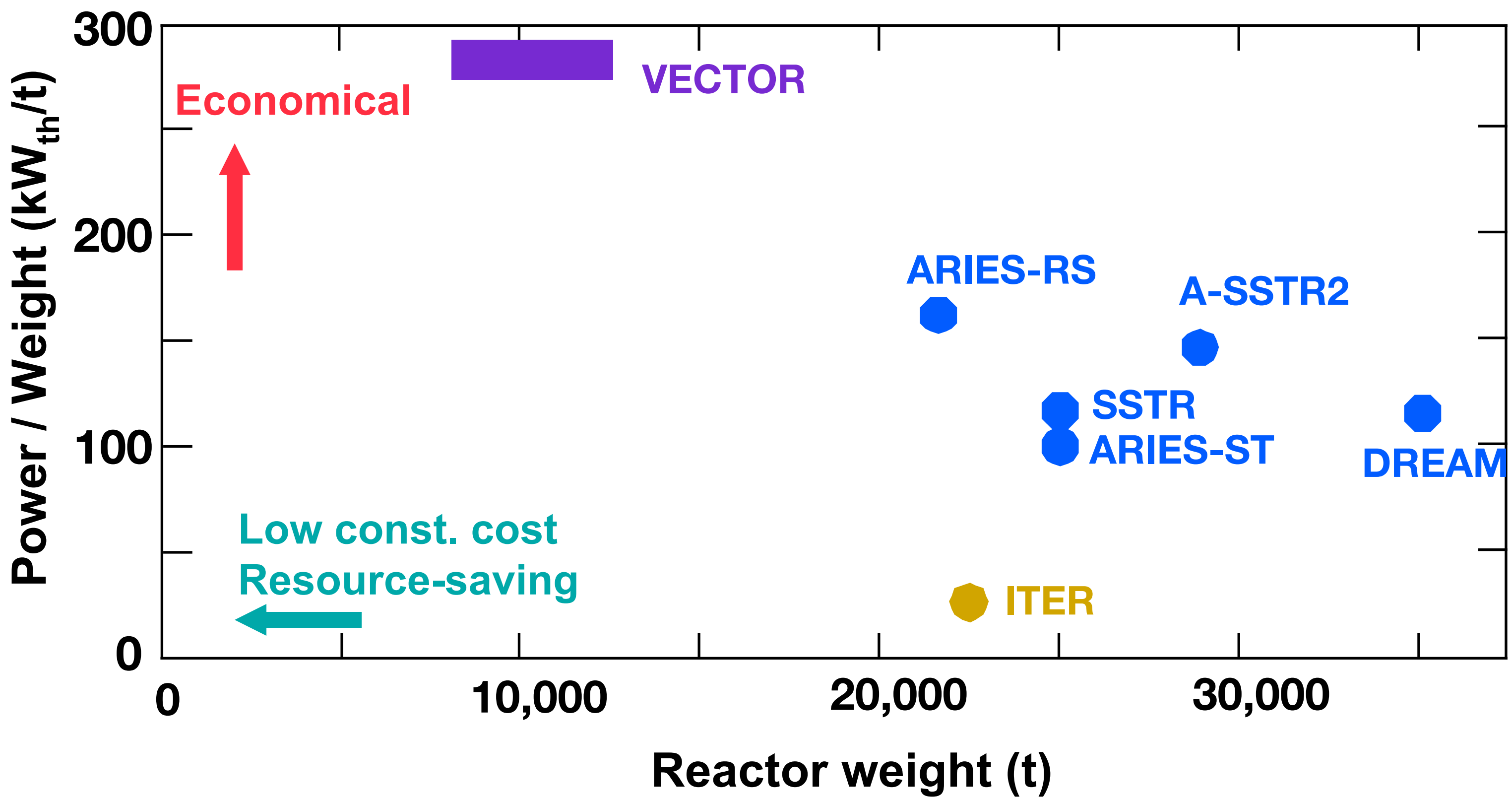
  Space needed to install shield, leading to A = 2-2.5

Difference between VECTOR and ST



Features of VECTOR

Likely to have economical and environmental advantages



Strategy on Waste of VECTOR

- **Introduce "clearance"** ⇨ **Can be put in recycle market**

  "Clearance" waste, regarded to have negligible waste hazard, would be treated as industrial waste.

- **Radwaste, less dependent on reactor size. To take advantage of "compactness", we must treat the radwaste as useful resource.**

"Recycling" **difficult**

Remote precision machining, installation, Impurities in recycle materials, cost.

"Reuse"

Use again in next reactors for the same purpose w/o recycle processes

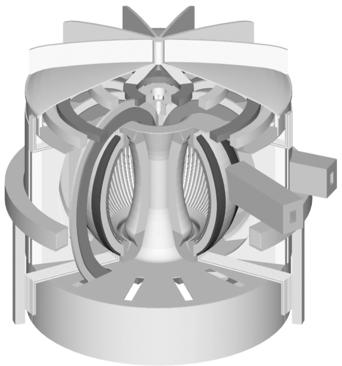
- ***Neutron shield (TiH_2)***
- ***Liquid breeder (LiPb)***

favorable

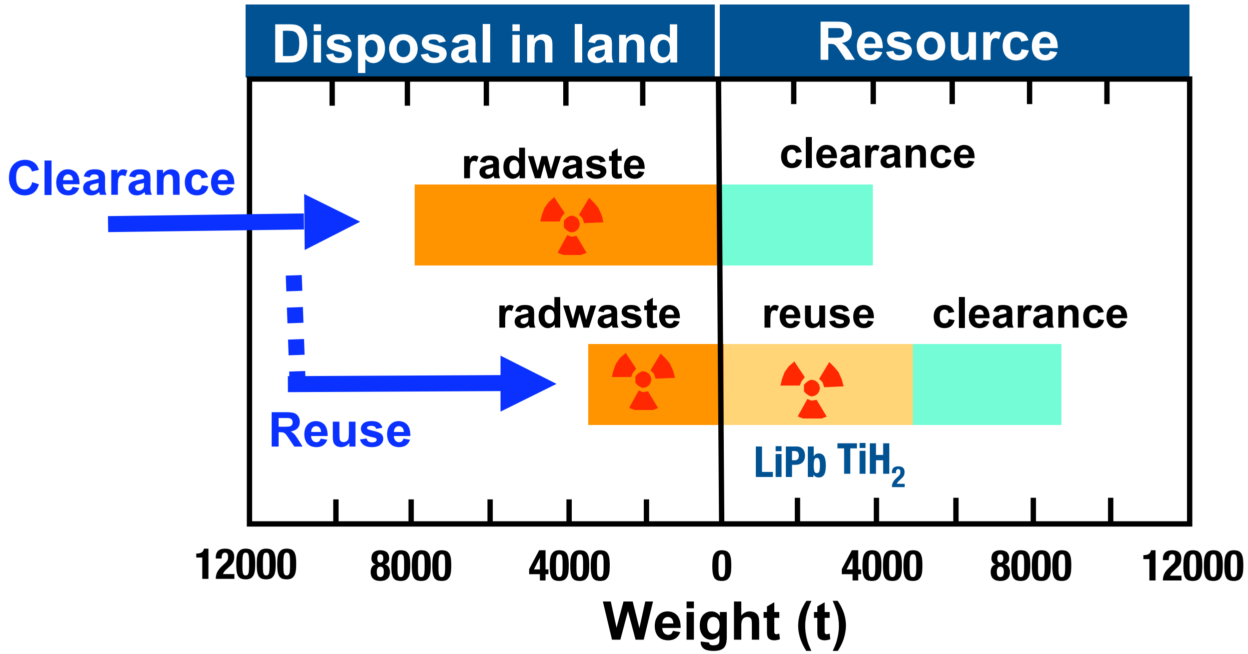
Reusable after several year-cooling

Impact of Reuse

Reuse of part of radwaste can reduce the amount of disposal waste to as low as ~4,000 t (PWR level).



12,100 tons



Other features of VECTOR

- Excellent α-particle confinement expected due to strong TF ripple damping

- Extremely low CO_2 emission in life cycle :
  3.2 g-CO_2/kWh (cf. DEMO2001: 5 g-CO_2/kWh)

Critical issues *Related with CS-less*

✓ Shaping (low δ)

✓ Controllability (I_p, separatrix)

2. DEMO Plant Design

References:

To appear in ISFNT-7 (Tokyo, 2005 May)

[1] K. Tobita et al., *Overview*

[2] M. Sato et al., *Core and divertor*

[3] T. Isono et al., *Magnet*

[4] S. Nishio et al., *Blancket and maintenance*

[5] K. Sakamoto et al., *ECH/ECCD*

[6] T. Inoue et al., *NBI*

[7] H. Nakamura et al., *In-vessel tritium inventory*

[8] M. Nishi et at., *Tritium accountancy*

[9] T. Hayashi et al., *Advanced shield materials*

Requirements on DEMO

— Discussions in subcommittee of AEC —

Technical requirements

- TBR > 1
- P_e^{net} ~ 1 GWe (P_{fus} ~ 3 GW)
- One-year continuous operation
- Power core as small as ITER's

Strategic requirements

- ~1 GWe power generation in 2030's
- Show a way for economical power production

VECTOR can be a key concept of DEMO but …

Needs compromises in technologies

- **Reconsider pros and cons of CS-less**

  CS-less plasma, unexplored experimentally

- **Available materials:**
  - **Ferritic steel (F82H)**
  - **Pebble bed breeder**
  - **Nb_3Al superconductor**

CS-less, seems problematic

- I_p ramp / control

  Y. Nakamura, this WS

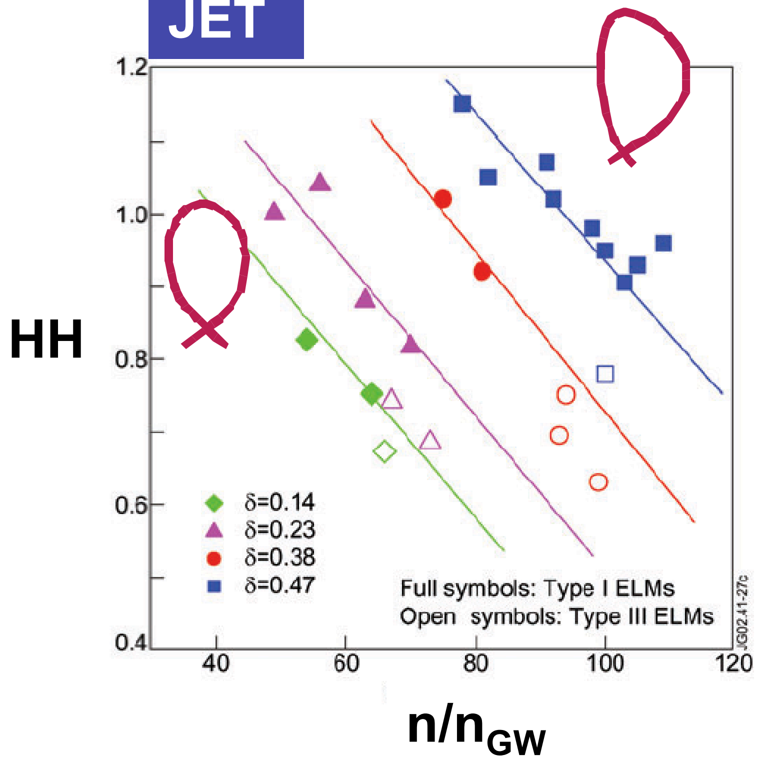
  Unproven but the technology developing (JT-60U, etc.)

- Plasma shaping, low δ (~0.1)

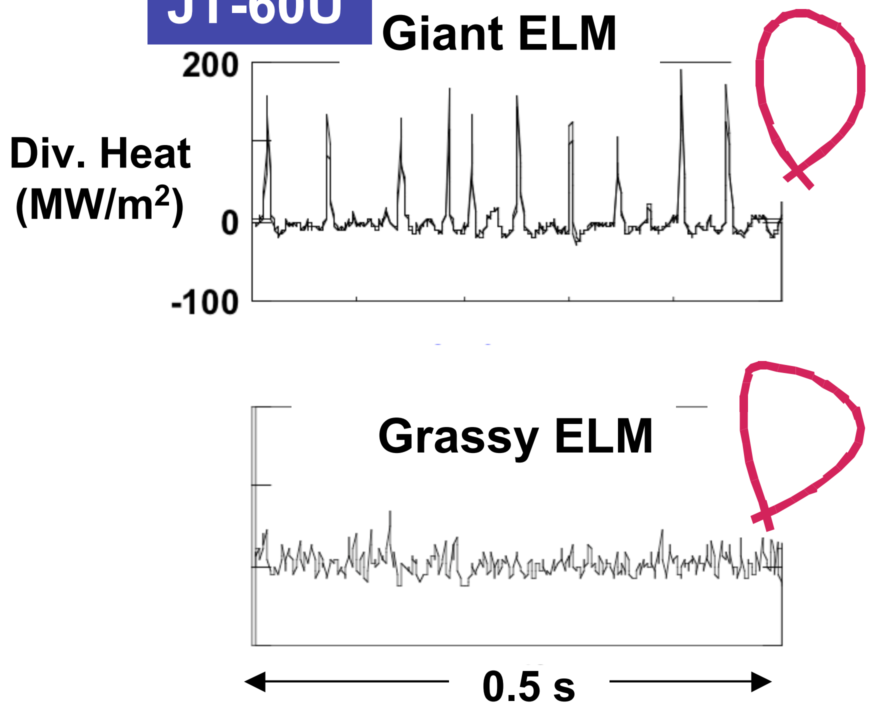
  Shinya, this WS

  Problematic in HH in high f_{GW} and ELM control

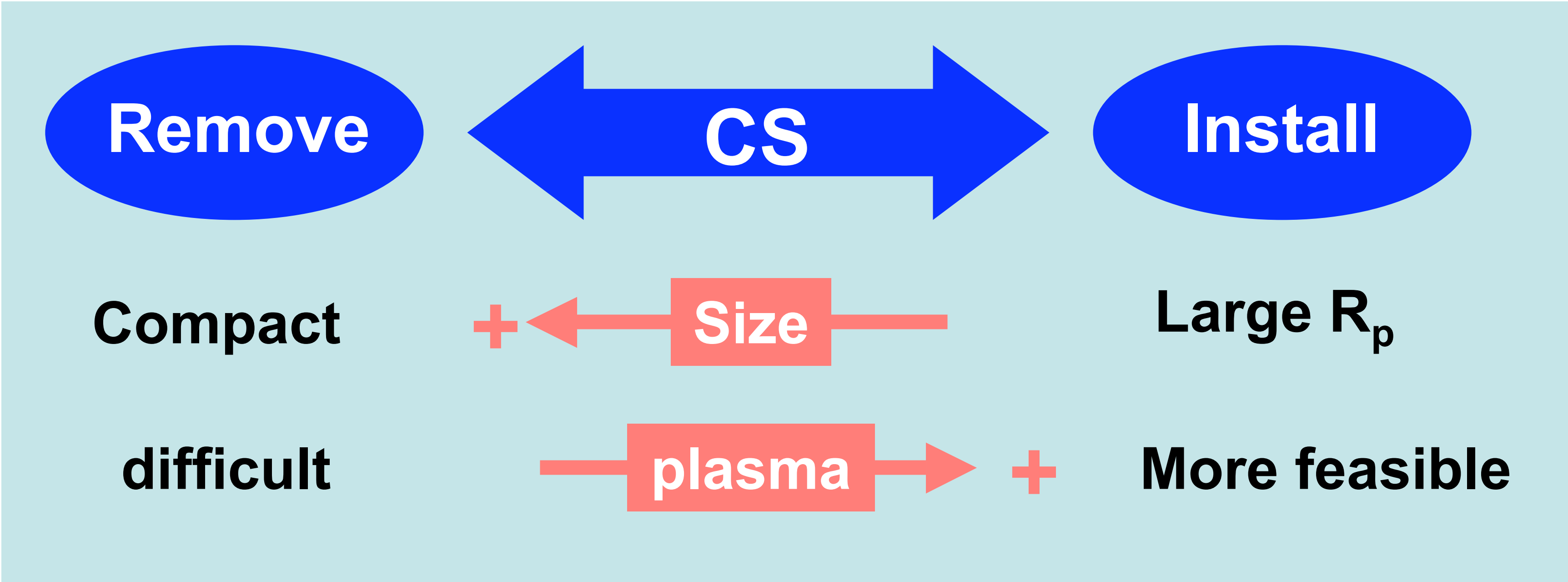
JET



JT-60U



Tradeoff on CS



Based on the roles of CS, three DEMO options are under consideration

Design Options

Option A

"CS-less"

R_p ~ 5.1m, A ~ 2.3
δ ~ 0.1

Option B

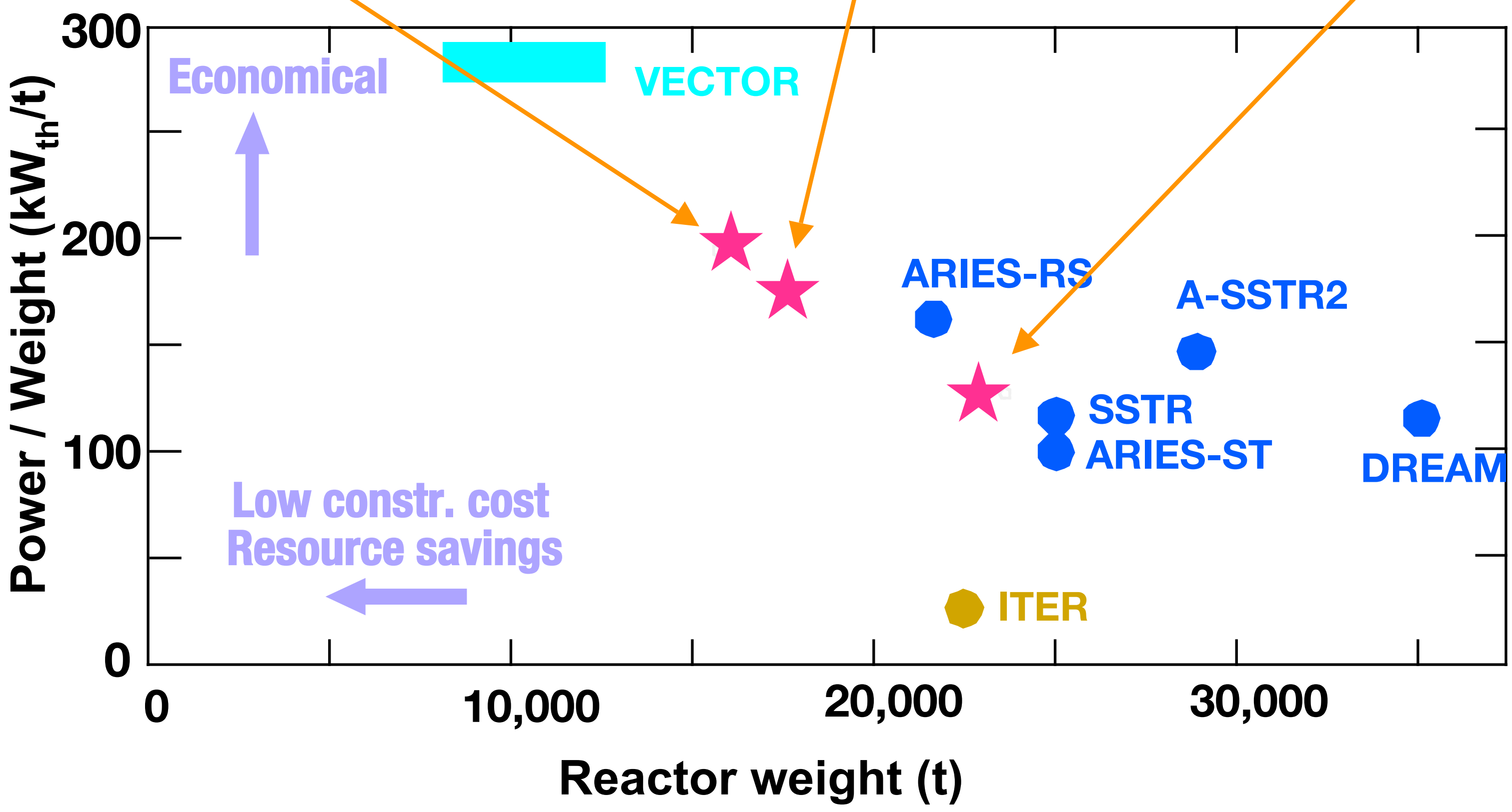
"Slim CS"

R_p ~ 5.5m, A ~ 2.4
10 Vsec, δ ~ 0.4

Option C

"Full CS"

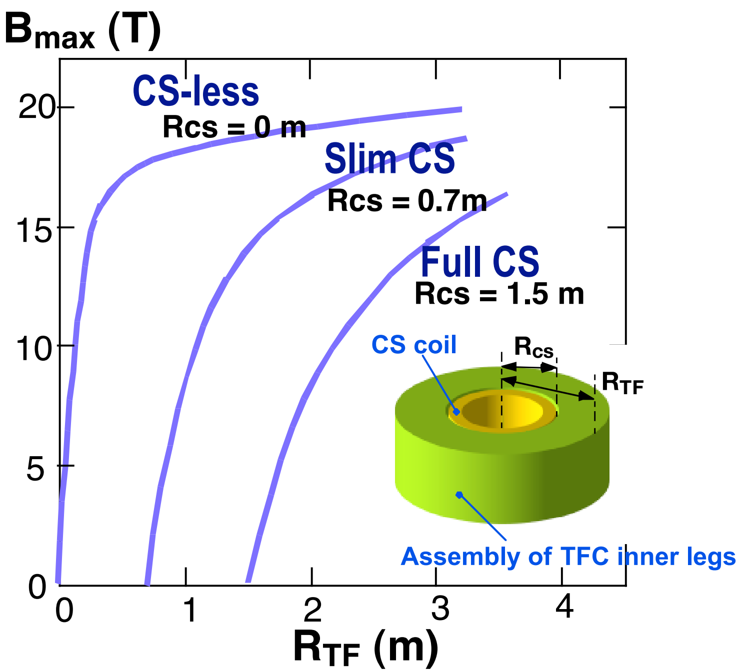
R_p ~ 6.4m, A ~ 2.8
CS: 30 Vsec



Parameter Selection

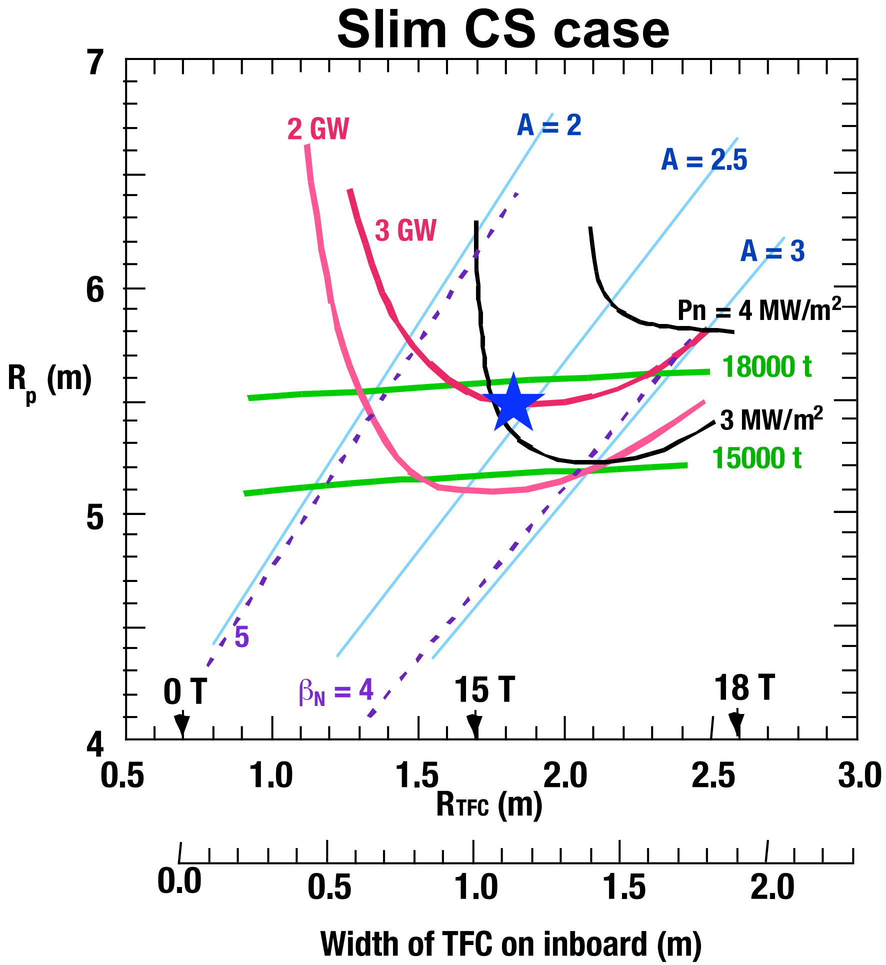
Sato, this WS

➢Gives $B_{max}(R_{TF})$
Determined for Nb_3Al



➢ Assumes
- conservative κ
- 78% of Wong's $\beta_N(A,k)$

➢Systems code analysis changing R_{TF} and R_p



Tentative Parameters

	CS-less	Slim CS	Full CS
	Option A	Option B	Option C
R_p (m)	5.1	5.5	6.4
a (m)	2.35	2.3	2.33
A	2.2	2.4	2.75
κ	2.15	2.07	1.95
δ	~0.1	0.4	0.4
B_T /B_{max} (T)	4.6 / 18.0	5.1 / 15.7	5.6 / 13.3
I_p (MA)	19.8	18.3	16.6
q_{95}	5.9	5.6	5.1
β_N	4.8	4.5	4.2
HH	1.3	1.3	1.3
n/n_{GW}	0.94	0.97	0.99
P_{fus} (GW)	3.1	3.1	2.9
P_n (MW/m^2)	3.2	3.1	2.6
Q	46	51	47
Weight (tons)	15,800	17,300	22,700

Key Issues in DEMO Design Study

- **TFC design based on the VECTOR concept**

  Achieve high current density by reducing structural and stabilizing materials

- **BLK design to withstand EM force of fast disruptions**

  Assembly of small BLK casings to withstand ~30ms disruption
  TBR expected to be critical

- **Reduction of T permeation in PFC**

  H. Nakamura, this WS

  W coating on all over the BLK surface

  Nishio, this WS

- **Maintenance scheme to foresee high availability**

  Sector transport and hot cell maintenance
  — challenging to adopt in DEMO

3. Reduction of Waste

References:

[1] K. Tobita et al., *J. Nucl. Mater. 329-333 (2004) 1610.*

[2] K. Tobita et al., SOFT 2004, Venice.

Why Waste Reduction?

	Fission (1.1GWe PWR)	Fusion
Catch phrase	Low environmental load	Environmentally more favorable than fission
High level waste	200 tons/30y	Nothing
Low level waste	4,100 tons *metal*	~9,000 tons (DEMO 2001)

Fusion is vulnerable to LLW.

Waste Assessment at JAERI

Not systematic, but various waste assessments carried out

SSTR	Introduced "clearance" to reduce radwaste
A-SSTR2	Investigated an impact of "reinforced shield" to reduce further
DEMO-2001	Assessed possible tailoring of chemical composition and impurity content of F82H to avoid deep land burial
VECTOR	Studied an impact of "compactness" of reactor and "reuse of radwaste"
D^3He	Compared disposal waste between DT and D^3He reactors

Waste Management Scenario

Decommission

50y cool

Classification

Reusable waste
Shield, breeder

Clearance waste

Radwaste
- Low level
- Medium level

Potential resources

Reuse in next generation reactors

Recycle market or disposal as industrial waste

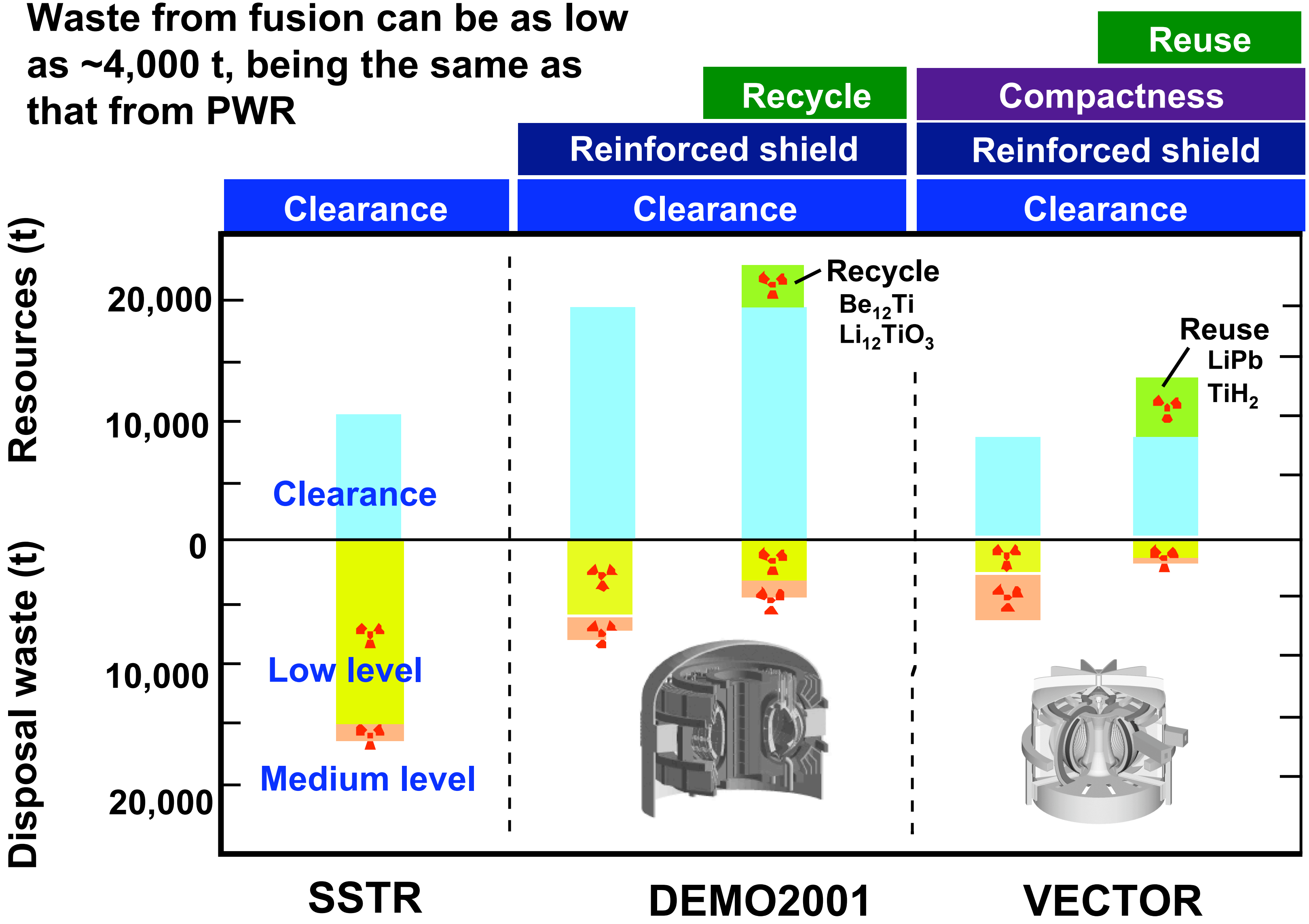
Disposal waste

Deep land burial

Shallow land burial

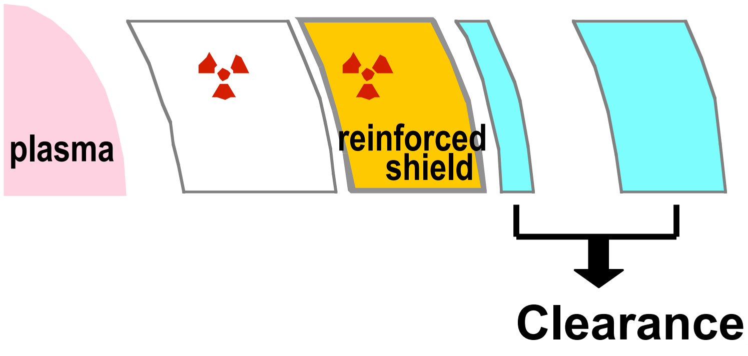
Summary of Waste Assessment

Waste from fusion can be as low as ~4,000 t, being the same as that from PWR



Strategies/Technologies for Waste Reduction

➢ Reinforced shield

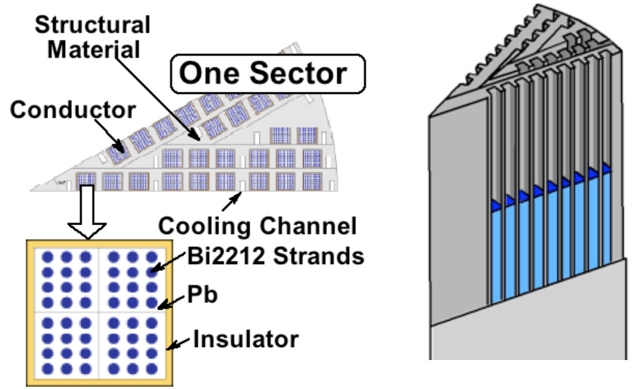


Reinforced shield

Shield thickness enough to clear the ex-shield components

➢ Separation technique of TF and PF coils

Inhomogeneous waste such as TFC does not qualify for clearance. This is to avoid an accumulation of a particular material contained in the waste beyond the clearance level in the recycle process.



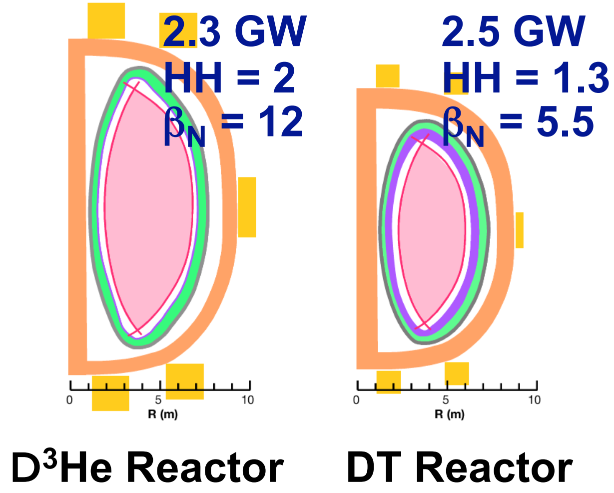
TFC of VECTOR

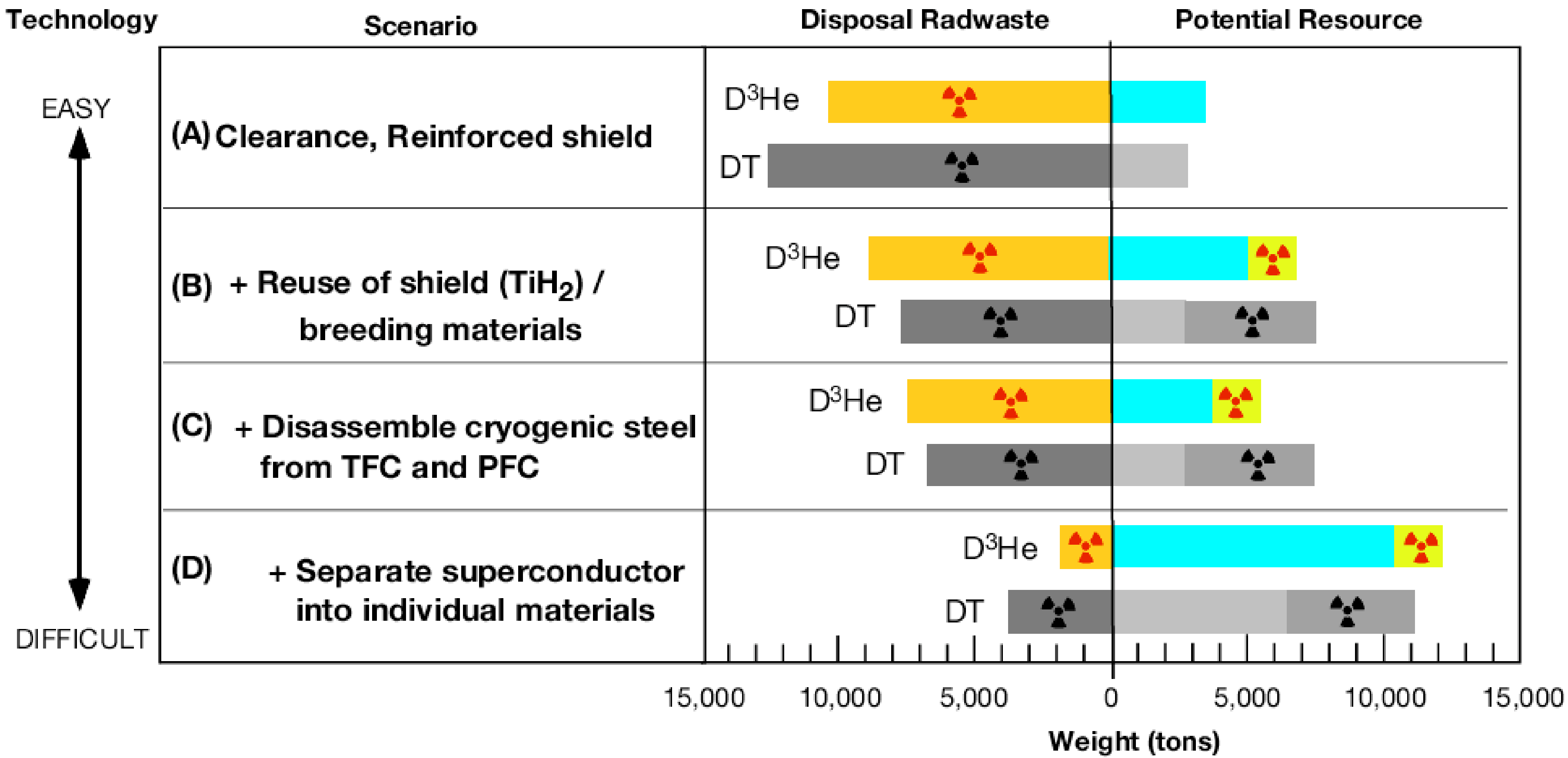
➢ Reuse of radwaste

Fusion reactor produces about 10,000 t of LLW. Reuse/recycle of radwaste will be necessary to improve PA.

Shield and liquid breeding material, reusable.

Comparison of waste from D^3He and DT reactors





Summary

- VECTOR has economical and environmental advantage over conventional reactors.

- DEMO design study at JAERI is in progress.

Prime option : “Slim CS” R_p = 5.5m, A= 2.4…

- Waste reduction assessed for different JAERI reactor designs. Waste could be as low as ~4000 t (PWR level) for VECTOR.