Fusion Reactor Technology I
(459.760, 3 Credits)

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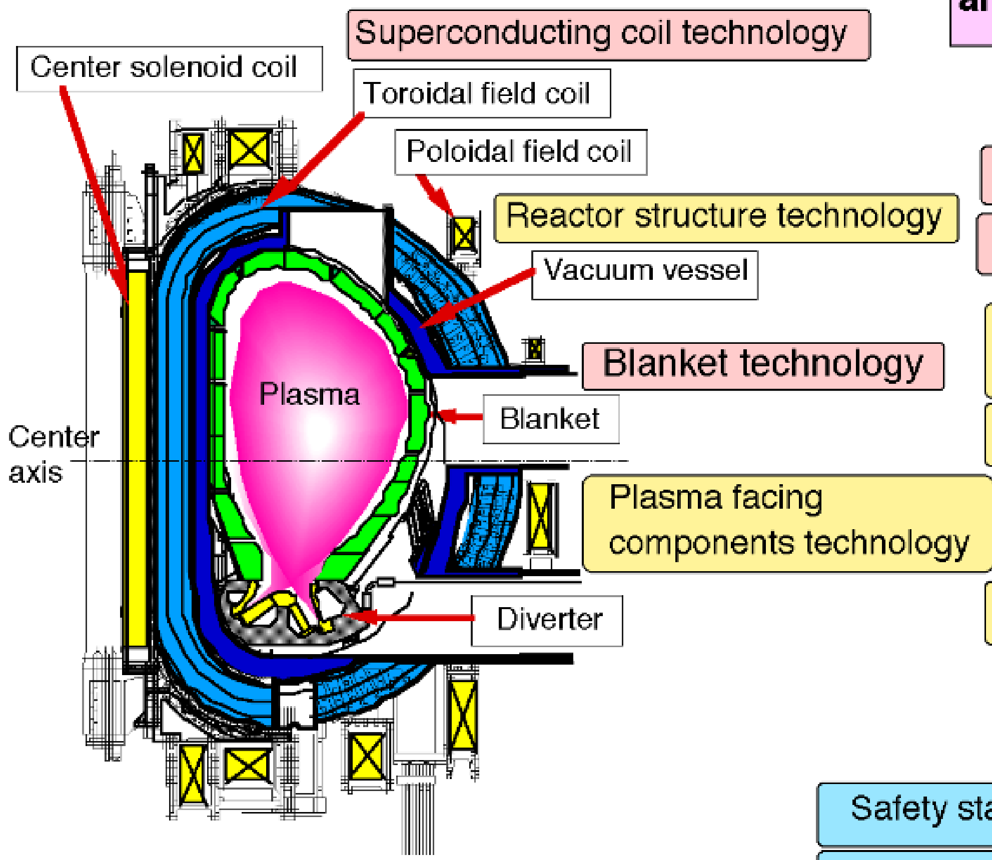
Contents

Development of component technology for tokamak type fusion reactor

Tokamak Machine Technology



Tokamak related components and system technology

Remote maintenance technology

Tritium engineering /safety technology

Auxiliary heating/current drive components technology

Plasma measurement technology

Fuel injection and exhaust technology

Safety standard/safety evaluation

Demo reactor Tritium Breeding blanket R&D

Material R&D

Development of component technology for tokamak type fusion reactor

- **Technologies of tokamak component**

- Blanket Technology:
  to develop the blanket that surrounds plasma and converts the kinetic energy of neutrons and other particles into heat and also shields the superconducting magnets from radiation
- Plasma Facing Components Technology:
  to develop the divertor that captures the high-energy particles and absorbs the heat load from plasma
- Reactor Structural Technology:
  to develop the vacuum vessel and support structures that will sustain the high vacuum for generation of plasma and contain the blanket and divertor
- Superconducting Magnet Technology:
  to develop the superconducting magnet that provide magnetic field to confine plasma, which is a magnetohydrodynamic fluid, and induces a current in the plasma by varying the magnetic field

Development of component technology for tokamak type fusion reactor

- **Component technologies related to the tokamak**
  - Auxiliary Heating and Current Drive Equipment Technology:
    to heat the plasma and drive the plasma current
  - Plasma Measurement Technology:
    to measure the temperature and density of plasma
    to form and control the plasma
  - Fuel Injection and Exhaust Technology:
    to inject and exhaust fuel
  - Tritium Engineering /Safety Technology:
    to recycle tritium safely, which is radioactive and do not exist naturally
  - Remote Maintenance Technology:
    to remotely maintain and repair the components that are radio-activated by neutrons generated from the plasma. Furthermore, toward the safety review for licensing and the future power reactor development

OXFORD TECHNOLOGIES

Development of component technology for tokamak type fusion reactor

- **Component technologies related to the tokamak**
  - Preparation of safety standards required for safety review for licensing, and data and evaluation methods required for safety evaluation
  - Research and development of the Tritium breeding blankets for the future power reactors
  - Development of first wall materials are required.

Fusion Plasma Technology

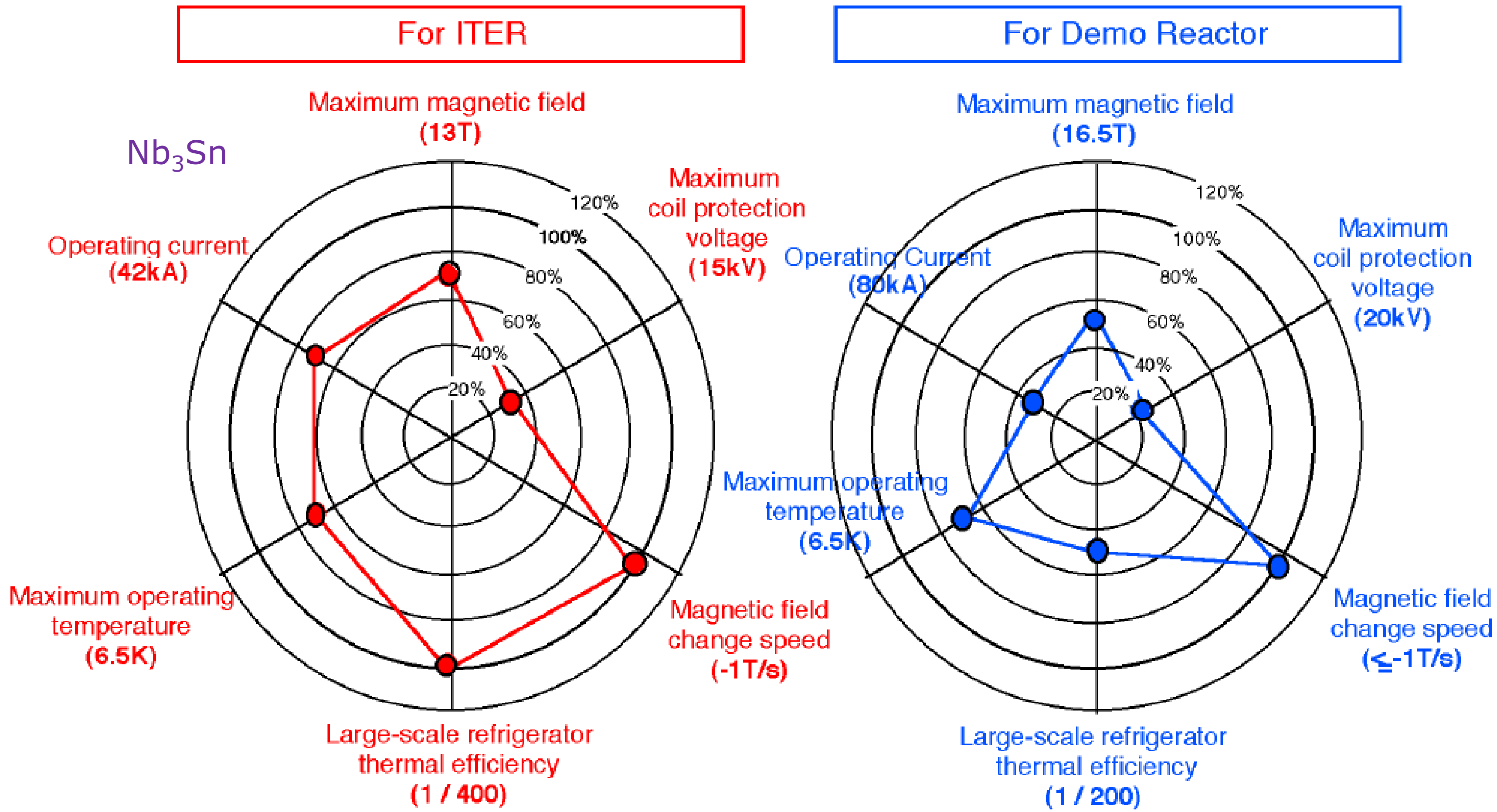
Reactor Technology

Blanket and Material Technology

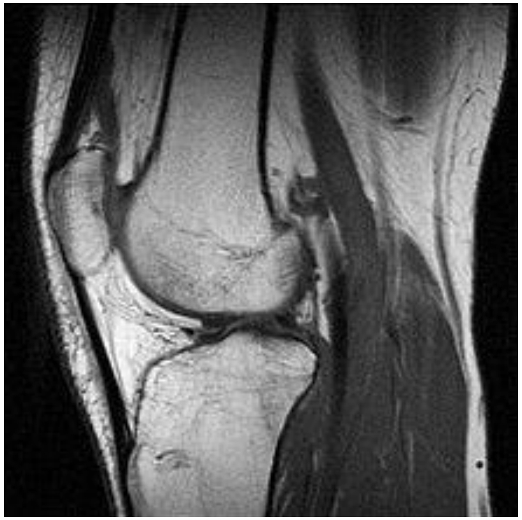
Safety Technology

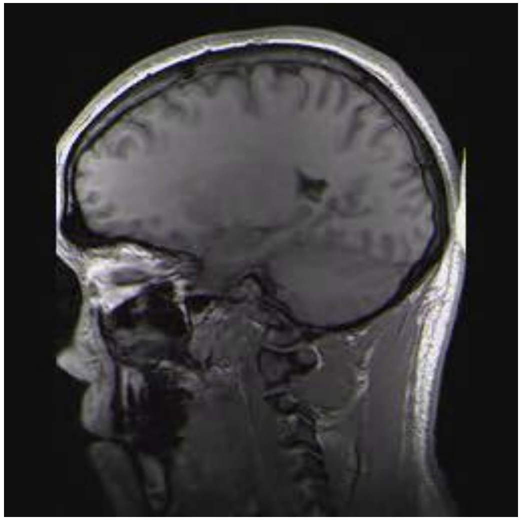
Operation and Maintenance Technology

Superconducting magnet technology



Superconducting magnet technology

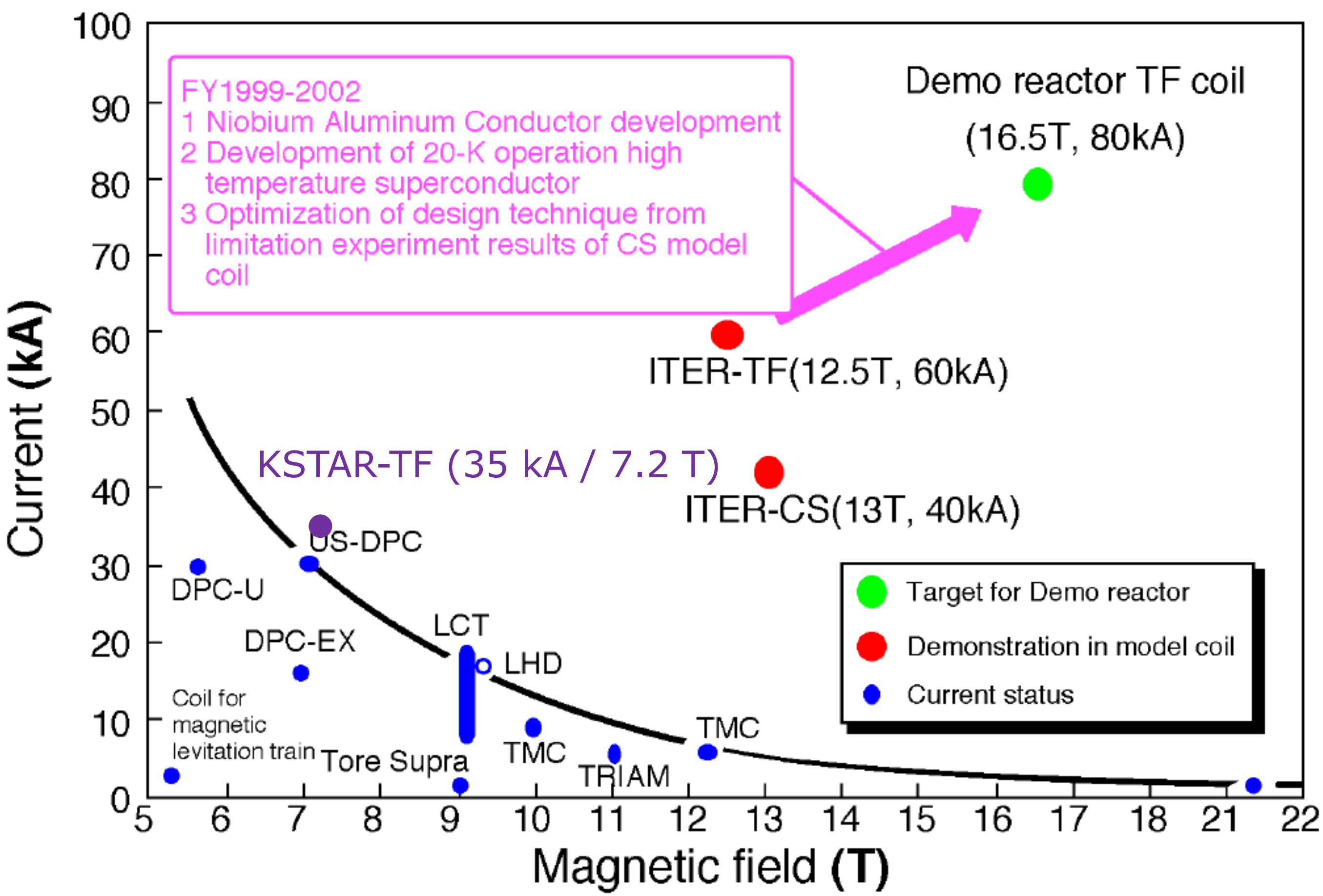


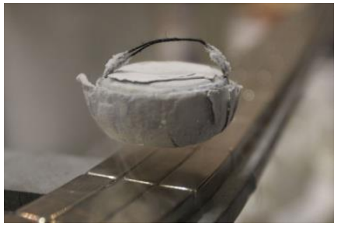


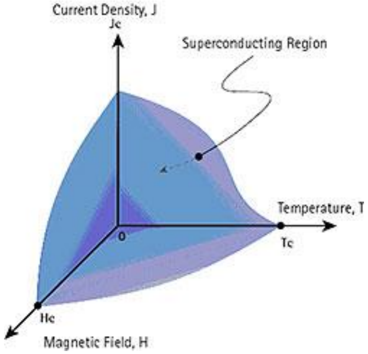
Magnetic Resonance Imaging (MRI) or
Nuclear Magnetic Resonance Imaging (NMRI),

http://www.thefullwiki.org/Magnetic_resonance_imaging

Superconducting magnet technology

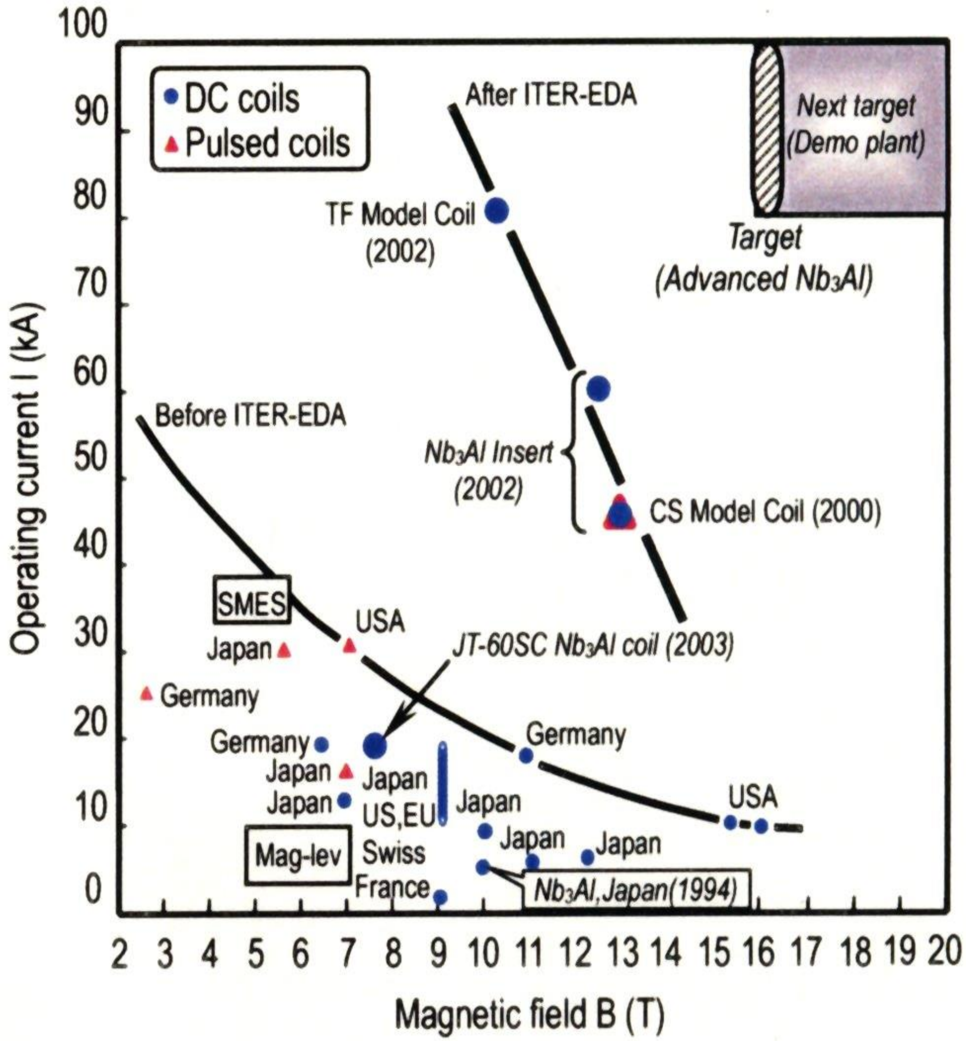






http://en.wikipedia.org/wiki/Superconductivity
http://www.amsc.com/aboutus/about_super.html

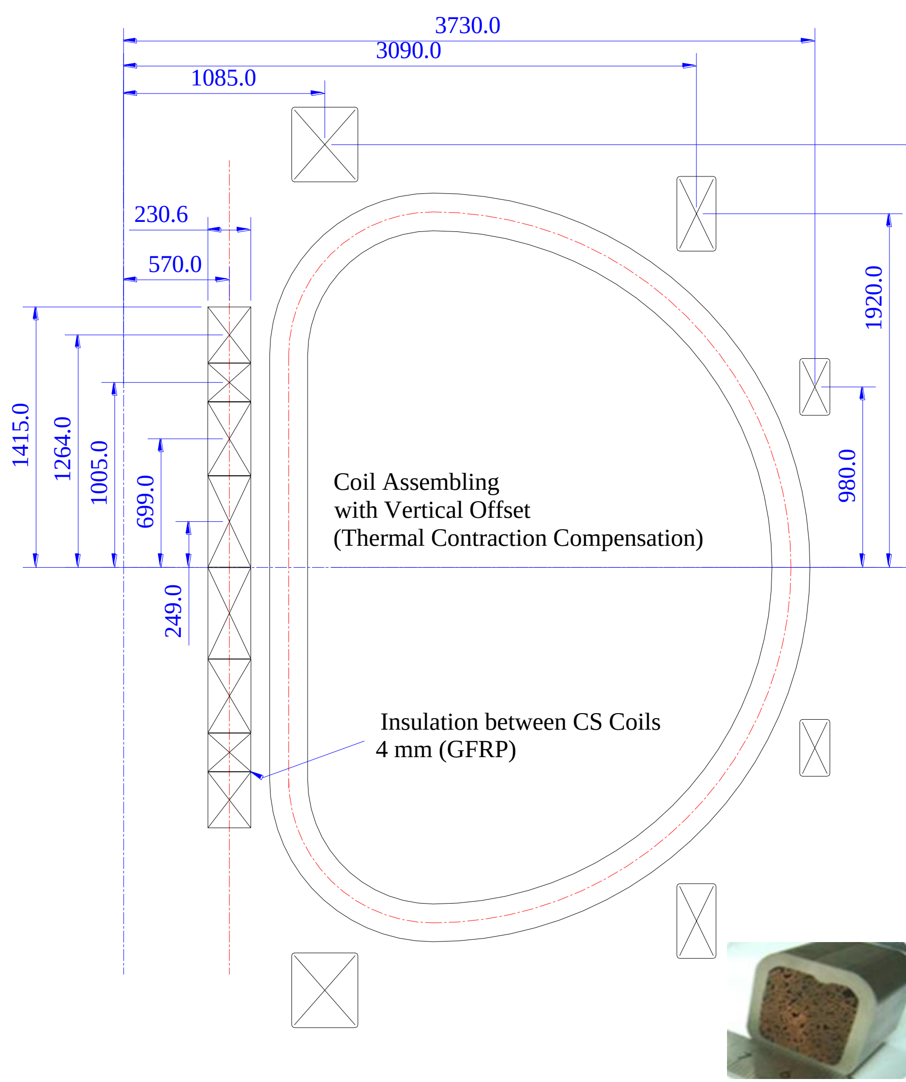
Superconducting magnet technology

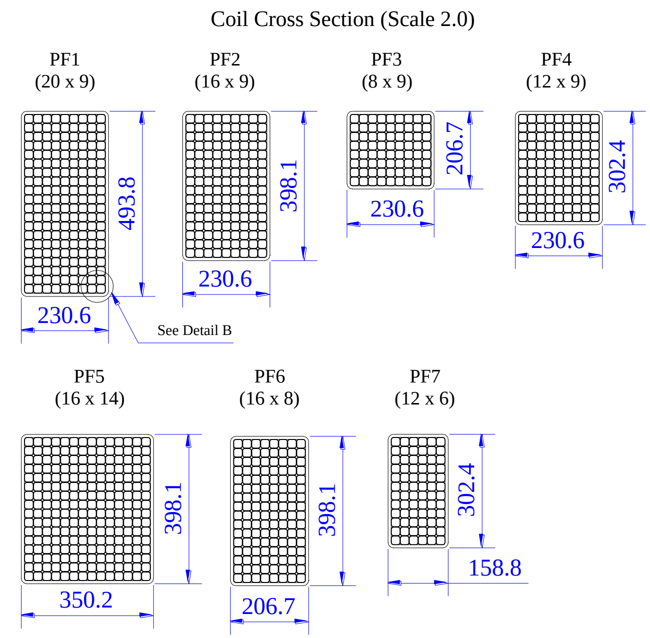


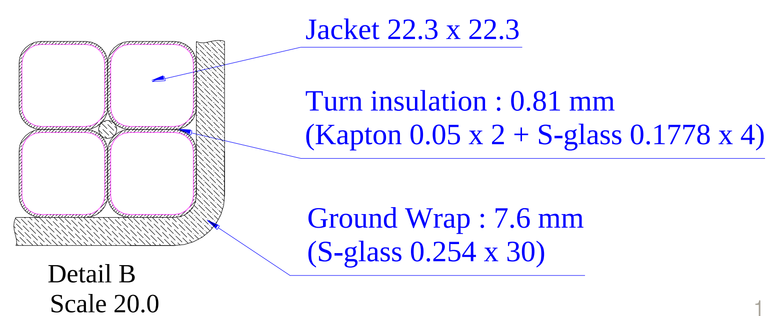
Operating points of superconducting coils constructed so far and the target for fusion demo plant,
N. Koizumi, et al., 20th IAEA FEC
IAEA-CN116-FT/P1-7 (2004)

Layout of the KSTAR magnet

Insulation Thickness :
Turn insulation : 0.81 mm
Ground wrap : 7.6 mm

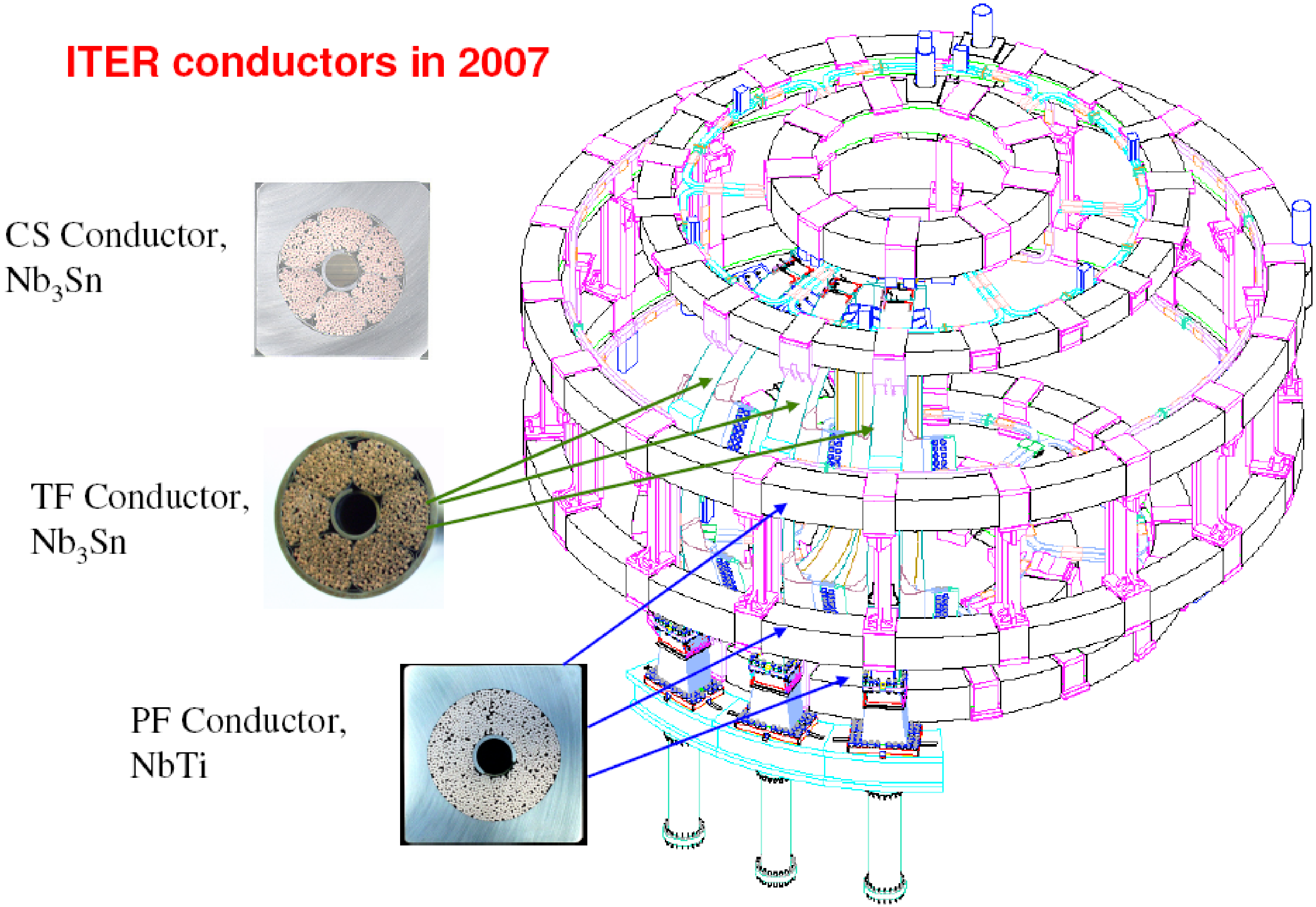






Superconducting magnet technology

ITER conductors in 2007

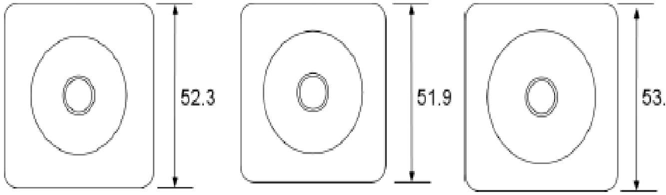


ITER conductor

Nb_3Sn conductor

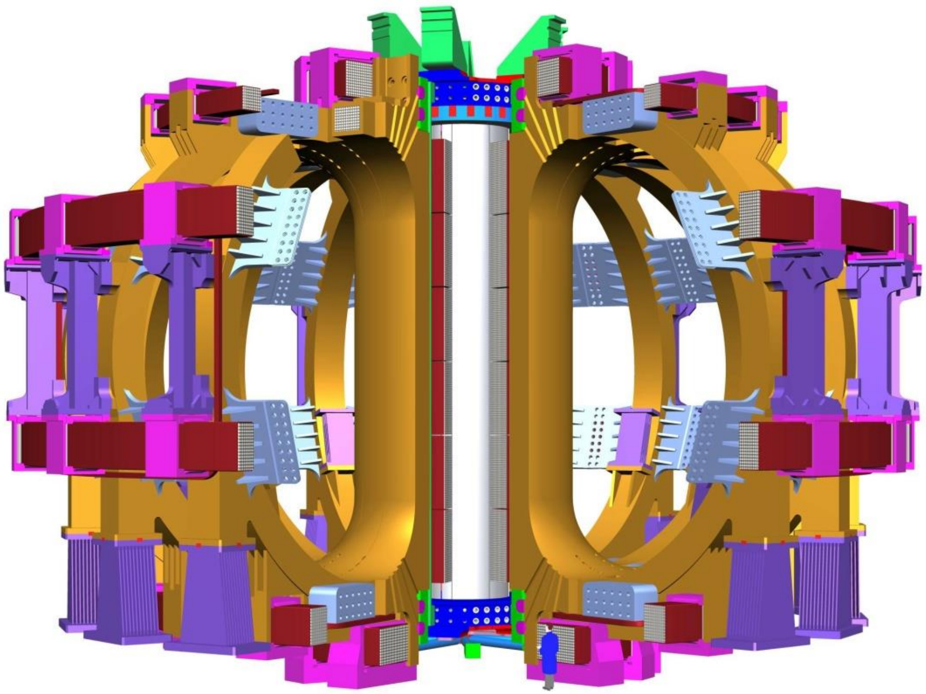
	TF	CS
Iop (kA)	68	40 (IM) 45 (EOB)
Bmin – Bmax (T)	10.5 – 11.8	12.4 - 13.0 (IM) 12.0 - 12.6 (EOB)
Top (K)	5.0	4.7
ε (%)	-0.77	-0.69
τ discharge (s)	11 + 2s delay	7.5 + 2s delay
sc strand diam. (mm)	0.82	0.83
sc strand Cu:nonCu	1	1
cabling layout	((2sc+1Cu) x 3 x 5 x 5 +core) x 6	(2sc+1Cu) x 3 x 4 x 4 x 6
core in 4th stage	3 x 4 Cu wires 0.82 mm	na
Cu strand in 1st triplet	1	1
sc strand Nr	900	576
local Vf (%)	33.2	33.2
cable diam. (mm)	40.5	32.6
central spiral od x id (mm)	9 x 7	9 x 7
flow area in annulus (mm^2)	406.5	252.3
total flow area (mm^2)	445.0	290.8

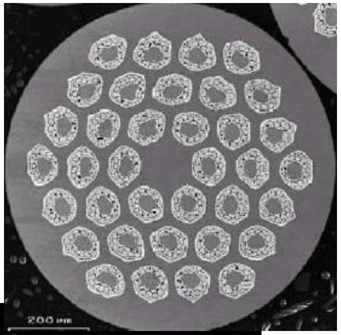
NbTi PF conductor



	PF2/3/4	PF5	PF1/6
Iop (kA)	45	45	45
Bpeak (T)	4	5	6
Top (K)	5.0	5.0	5.0
τ discharge (s)	14 +2s delay	14 +2s delay	14 +2s delay
sc strand diam. (mm)	0.73	0.72	0.73
sc strand Cu:nonCu	6.9	4.4	1.6
cabling layout	((3 x 3 x 4+1) x 4+1) x 6	((3 x 3 x 4+1) x 5+1) x 6	3 x 4 x 4 x 5 x 6
Cu core diam 2/3/4 stage (mm)	0.0/1.8/3.5	0/1.2/2.7	0.0/0.0/0.0
sc strand Nr	864	1080	1440
local Vf (%)	34.2	34.3	34.5
cable diam. (mm)	34.5	35.4	38.2
central spiral od x id (mm)	10 x 12	10 x 12	10 x 12

ITER's Magnet Coils





- **TF model coil (Nb_3Sn)**
  - 80 kA at 9.7 T (4.5 K liquid He)
  - 720 Nb_3Sn strands in 6 bundles (0.82 mm diameter)
  - Cable diameter: 37.5 mm

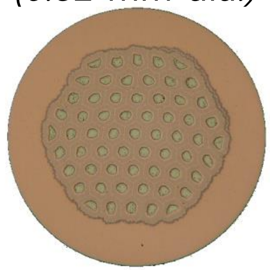
Preparation for ITER Procurement – Superconducting Magnets

Fusion Technology

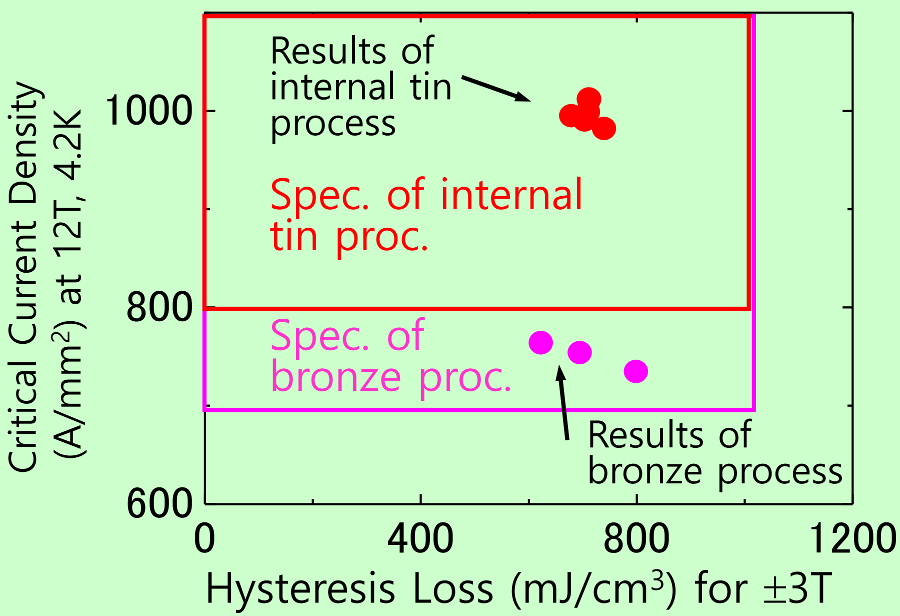
1. Development of Nb_3Sn Strands

- **Improvement of critical current density** (Jc) to 1.3～1.5 times higher than that in the model coils.
- **Increase of production capability** from 29 tons in the model coils to 540 tons in ITER.

Nb_3Sn strand (0.82 mm dia.)

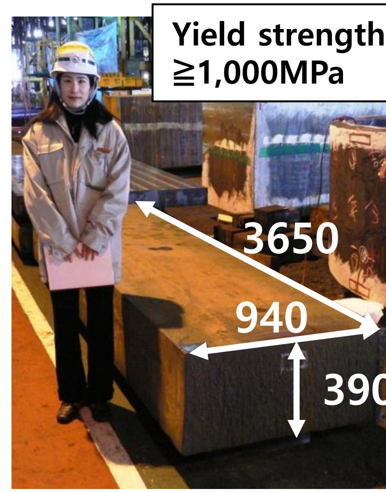


Results of fabrication demonstration

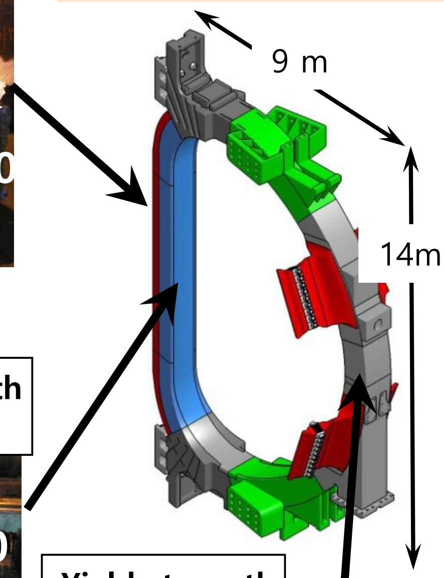


2. Development of Structures for TF Coil

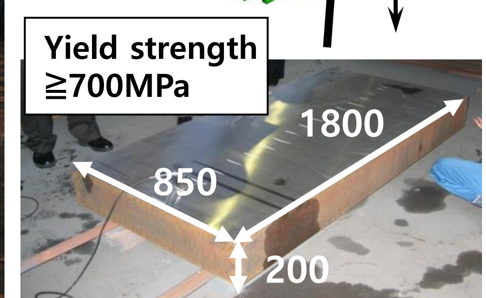
TF coil uses several kinds of structural materials depending on the requirements of mechanical strength.



JJ1 forging



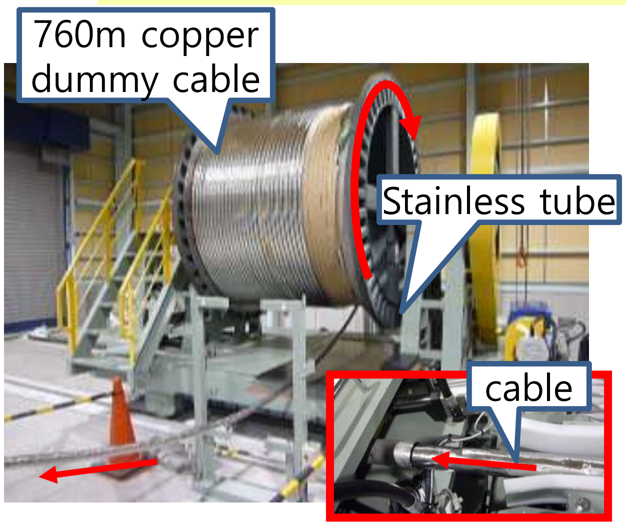
316LN forging

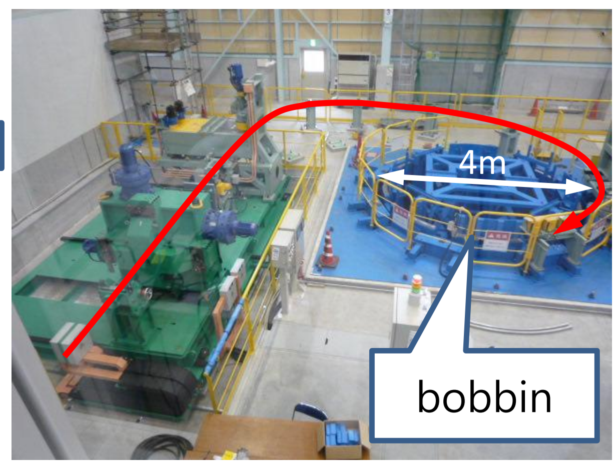


316LN hot rolled plate

Production of Super-Conducting Conductor

- **Building and facilities for jacketing of SC cables was complete in January 2010.**
- **A 760m trial conductor with dummy copper cable has been successful.**
- **The first SC conductor is now under fabrication.**

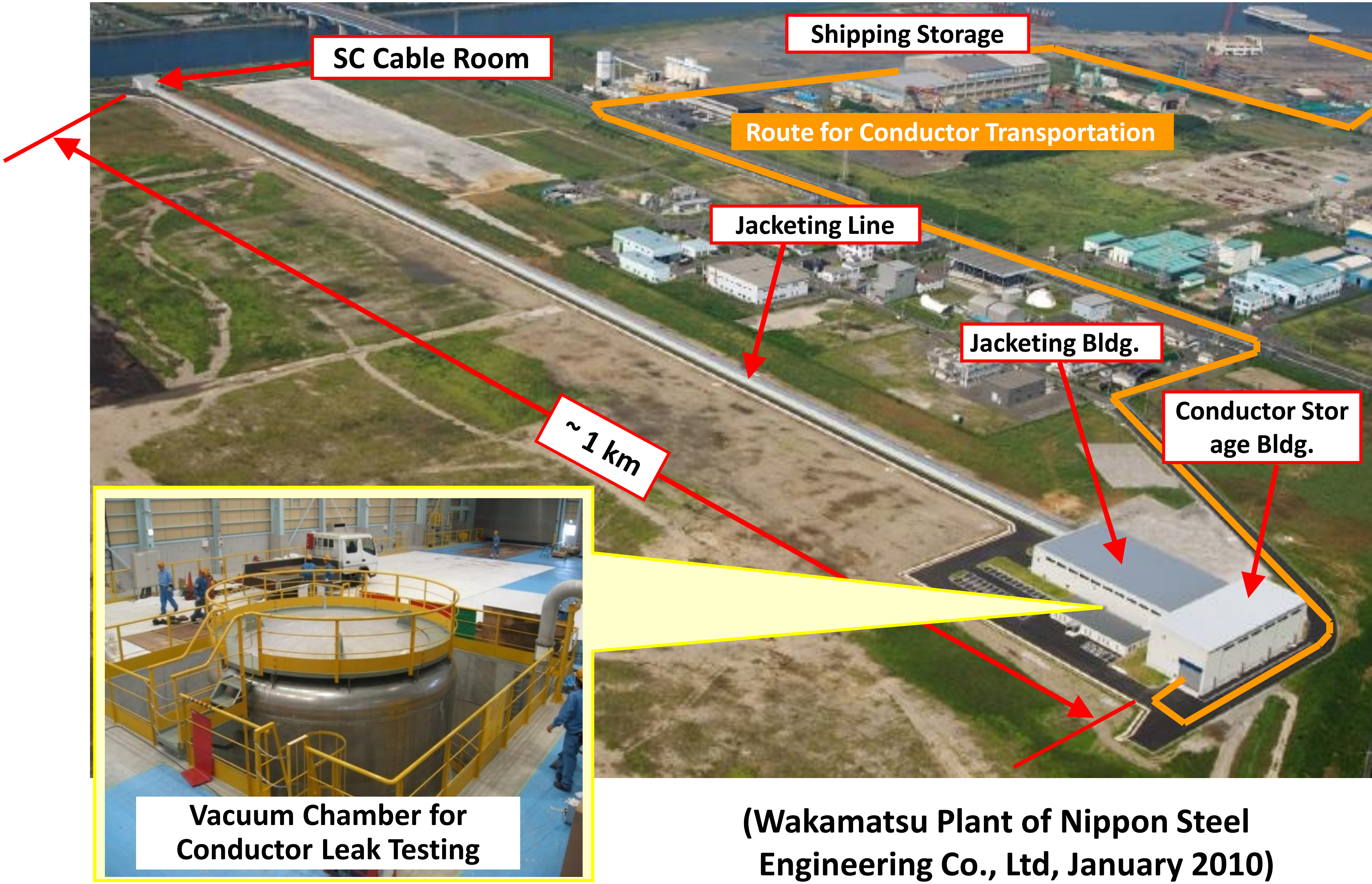




A 760m copper twisted cable is being inserted into a stainless steel jacket.

Compressed forming of a dummy conductor on to a 4m diameter bobbin

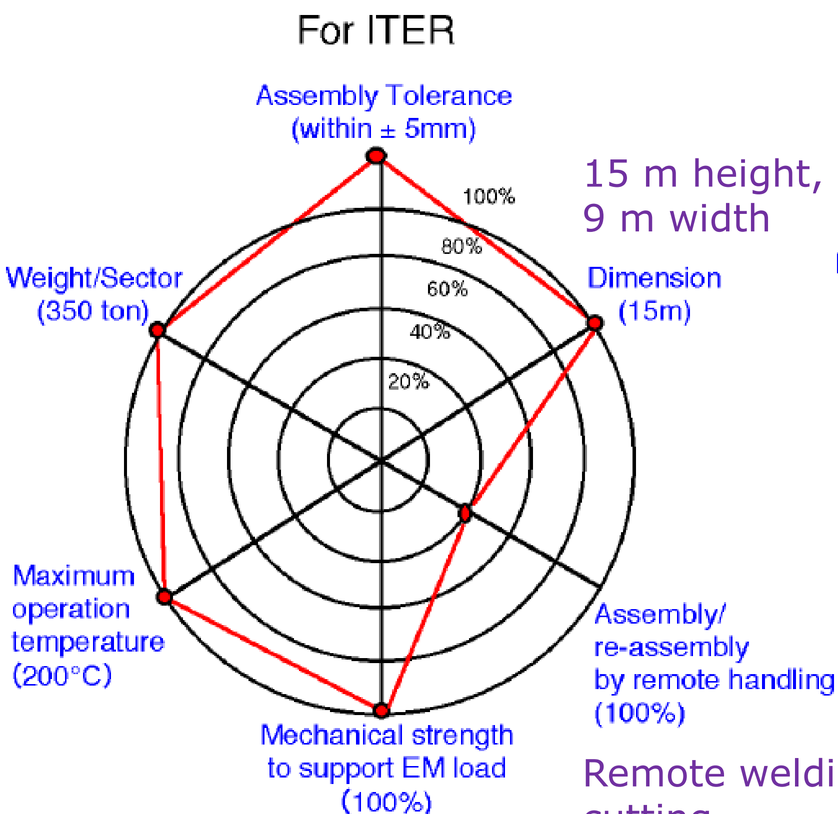
ITER Jacketing Line Facility



(Wakamatsu Plant of Nippon Steel Engineering Co., Ltd, January 2010)

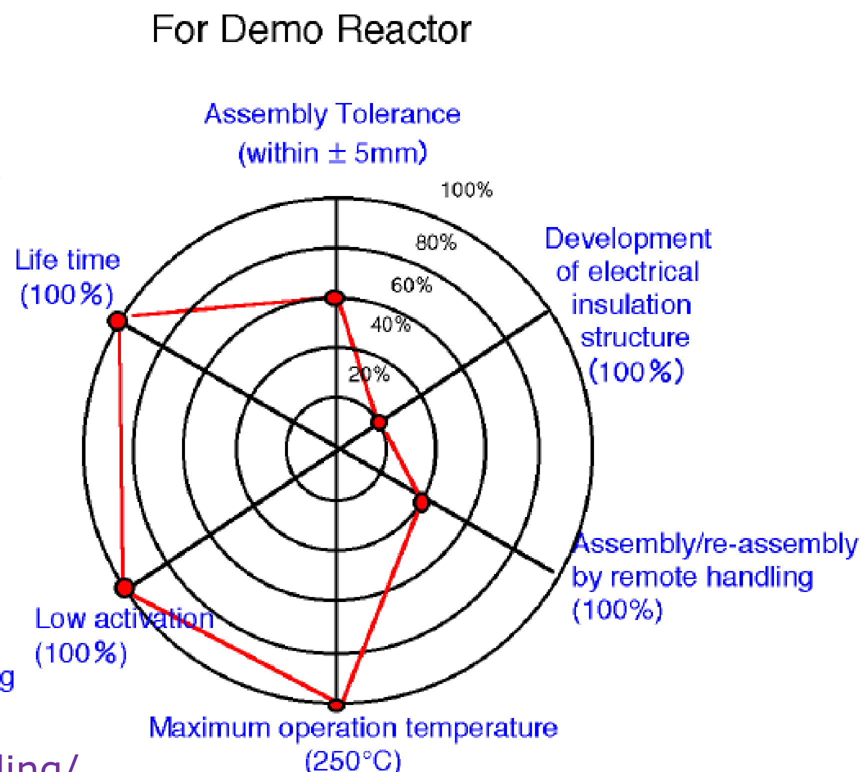
"Japanese fusion program and future DEMO reactor issues", S. Matsuda, Sept 23. 2011, SNU

Vacuum vessel technology

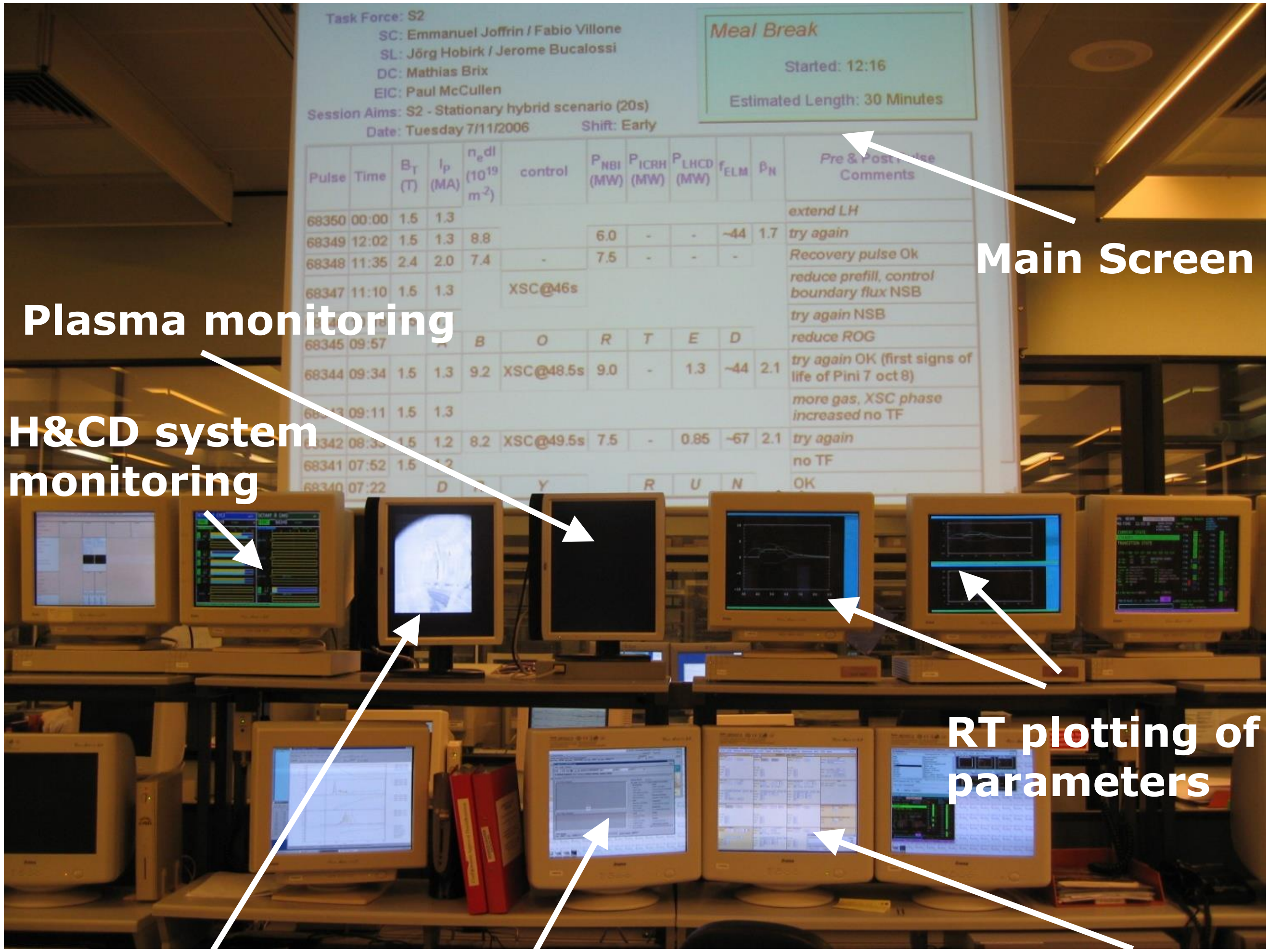


15 m height,
9 m width

Remote welding/
cutting



JET control room



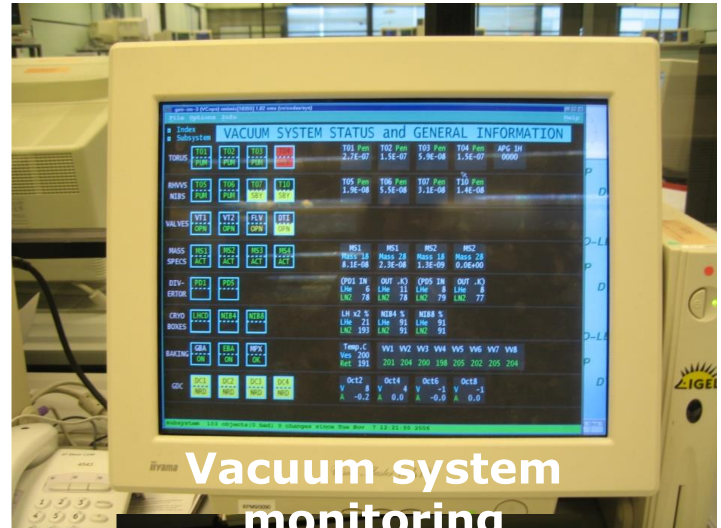
IR Camera (PFC monitoring)

Shot comments

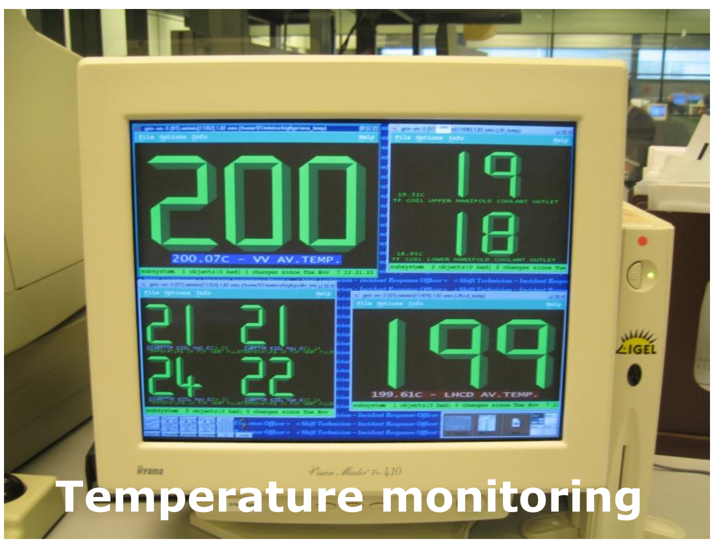
Shot editing

Session Leader

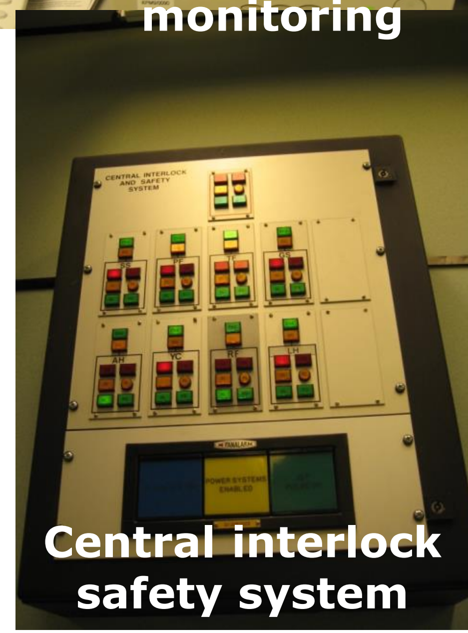
JET control room



Vacuum system monitoring



Temperature monitoring

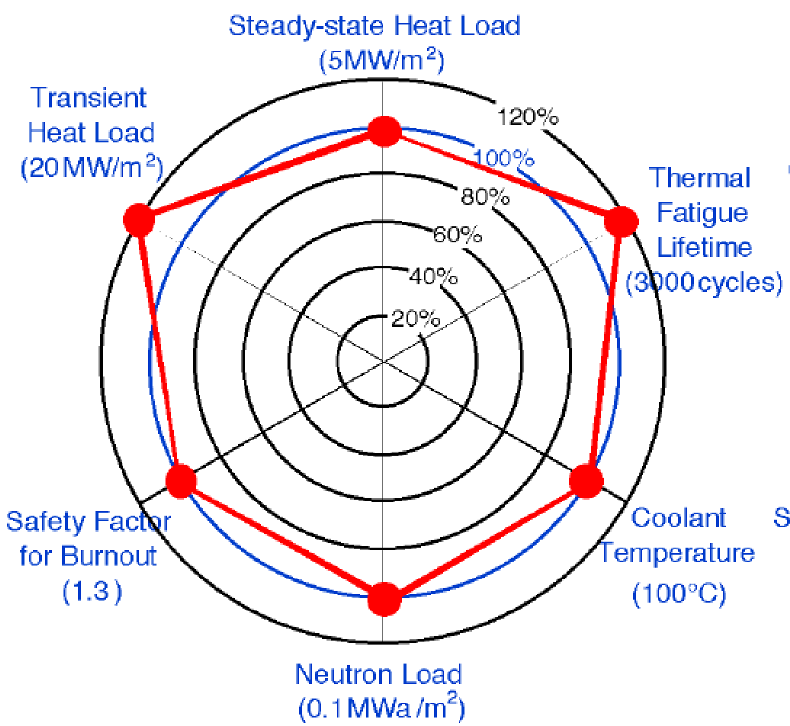


Central interlock safety system

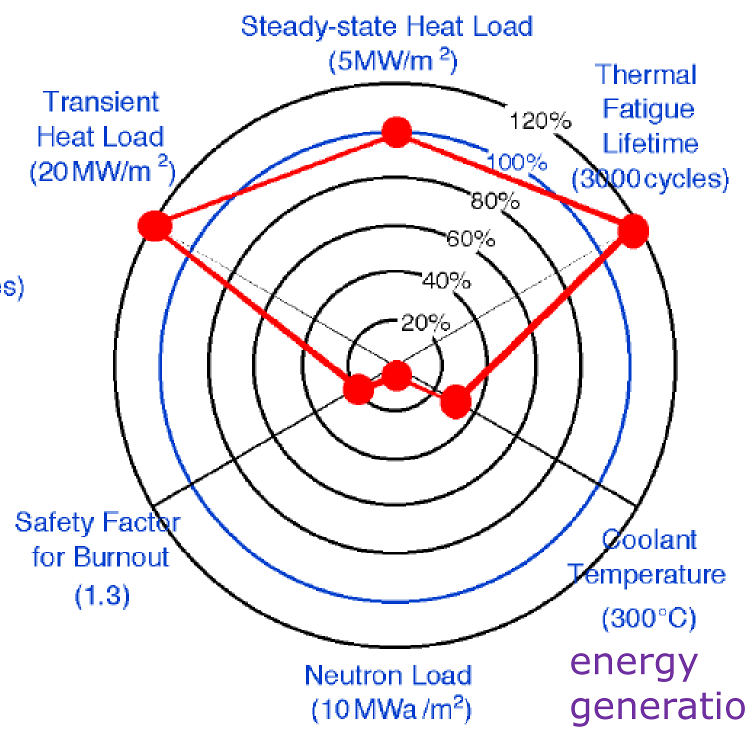
Divertor and high heat-flux component technology

- **ITER divertor requirements**
  - heat load: 5-20 MW/m^2
  - Coolant temperature: 100-150 °C
  - Neutron influence: 0.1 MWa/m^2

For ITER



For Demo Reactor



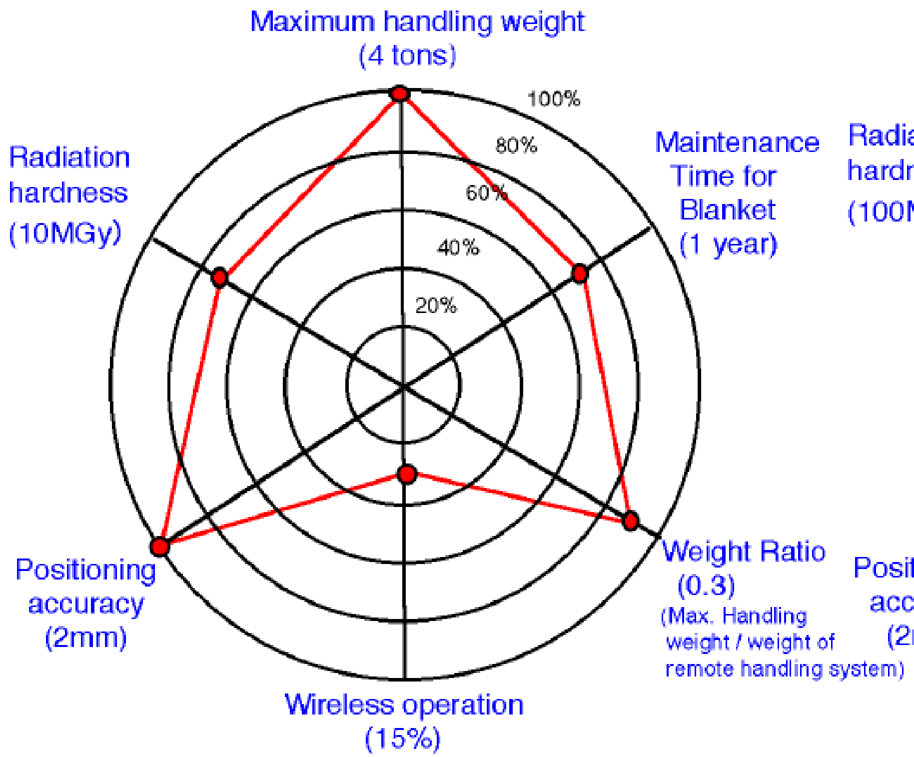
energy generation

Remote handling technology

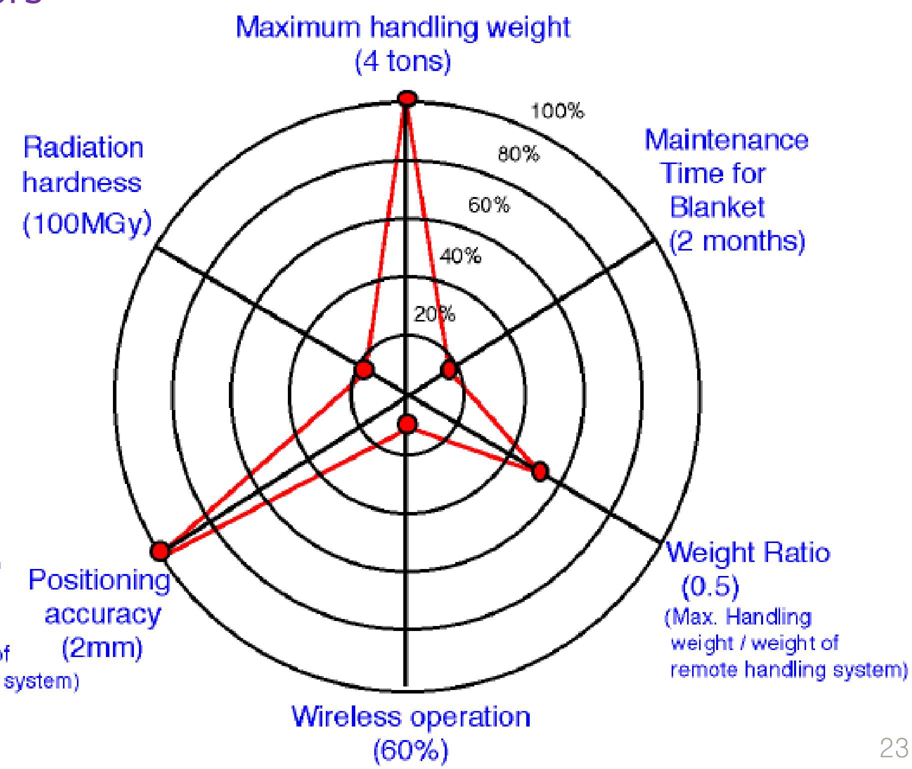
- Minimisation of the maintenance time
- Development of radiation-resistant components
  (radiation-resistant battery, signal transmitter for wireless control)

For ITER

4 tons for blanket,
15 tons for divertors

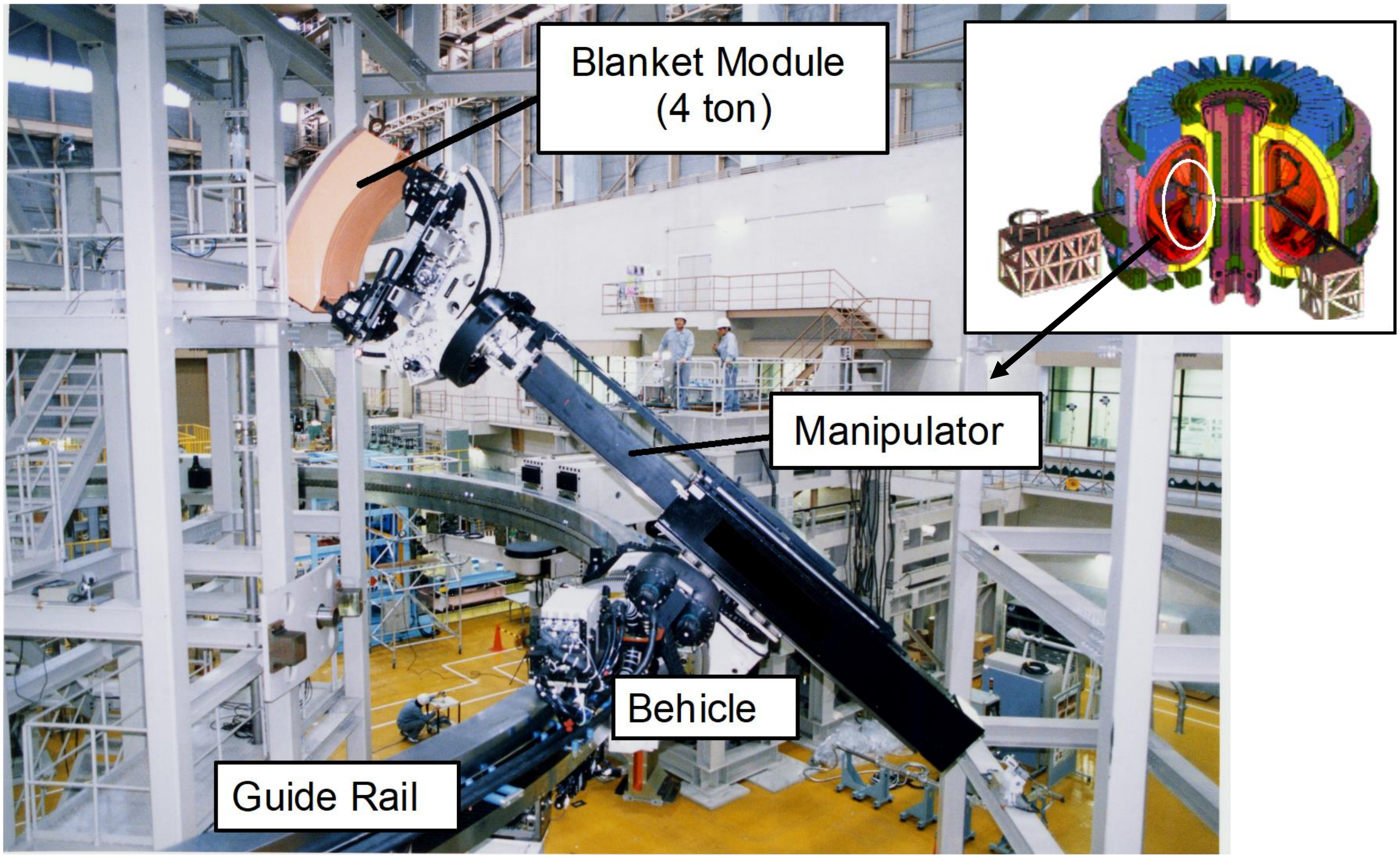


For Demo Reactor



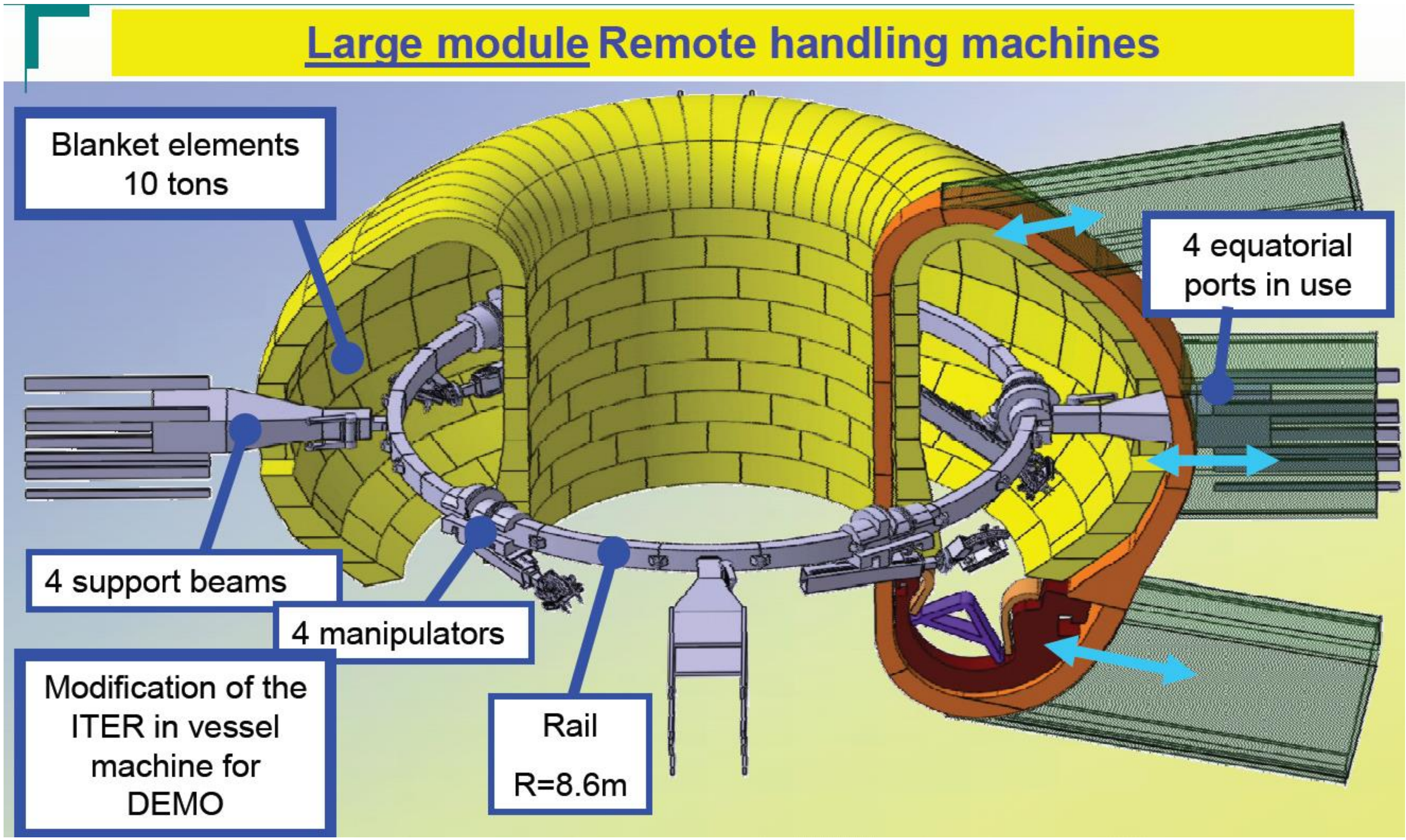
Blanket Remote Maintenance

Handling accuracy of 4 ton module : 0.25 mm



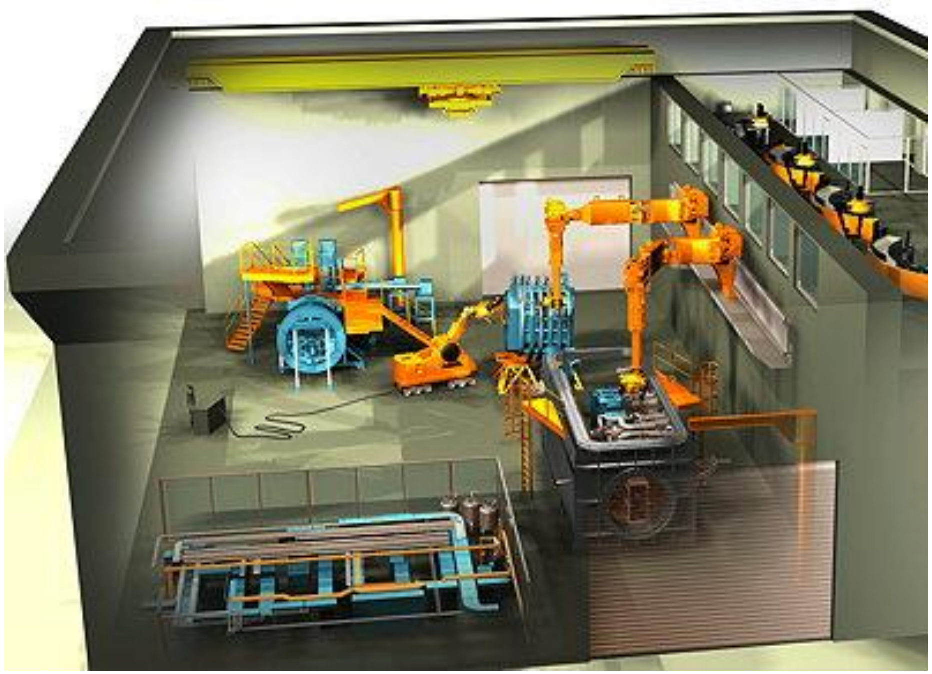
"Japanese fusion program and future DEMO reactor issues", S. Matsuda, Sept 23. 2011, SNU

Remote handling technology



"Fusion Technology Development for DEMO in Forschungszentrum Karlsruhe (FZK)", G. Janeschitz, Toki Conference 2005

Remote handling technology



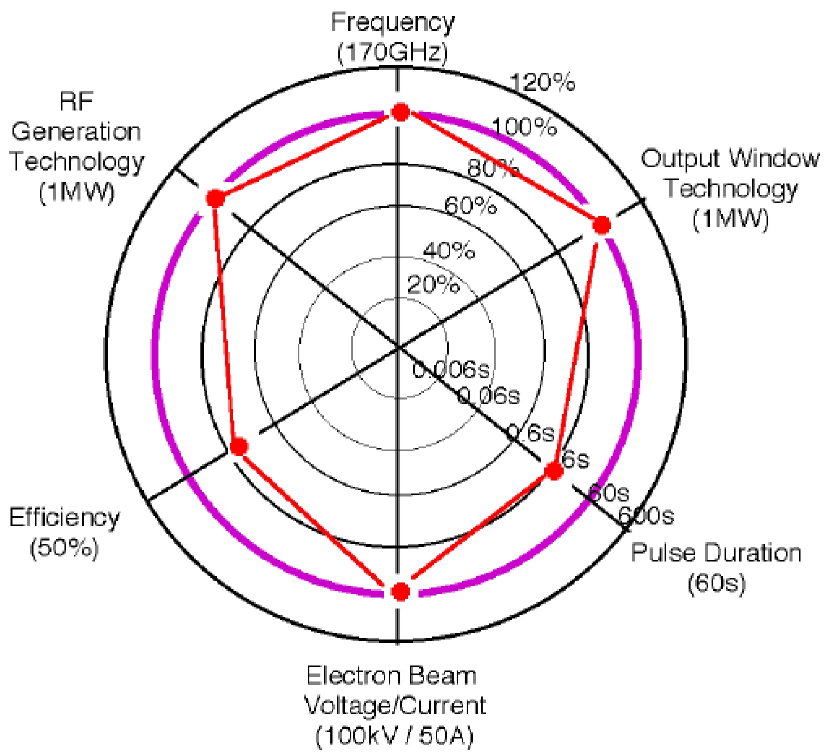
Race's planned facilities will be used to develop remote-controlled robotic handling equipment.

http://www.drivesncontrols.com/news/fullstory.php/aid/4565/Remote_handling_centre_opens_for_business.html

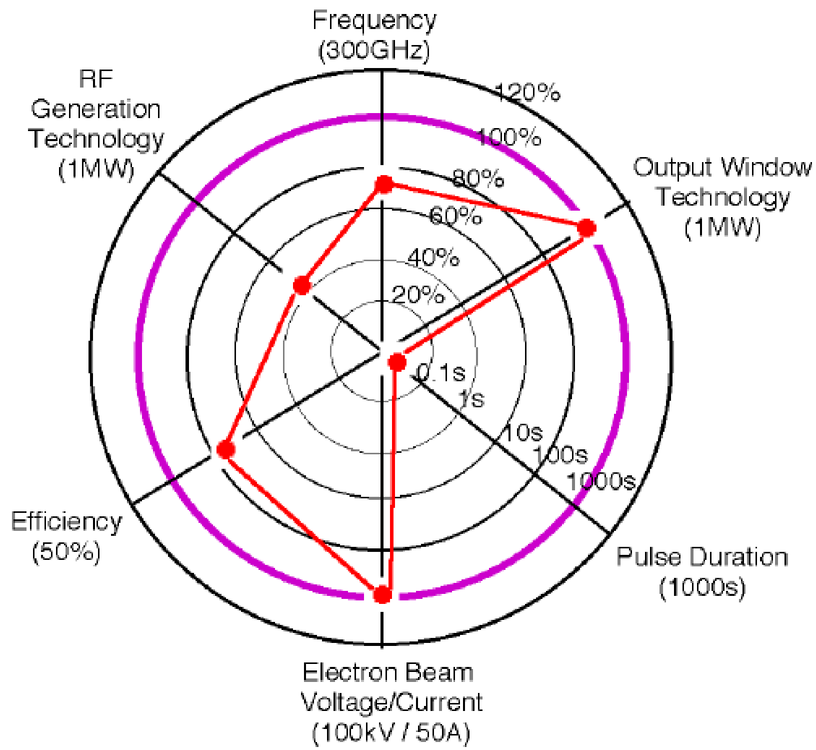
Heating and CD system technology

- **RF heating and CD technology in DEMO**
  - Frequency of 300 GHz heat load: 5-20 MW/m^2
  - Resonator enabling higher frequency oscillation, diamond window, frequency variable oscillator, etc.

For ITER



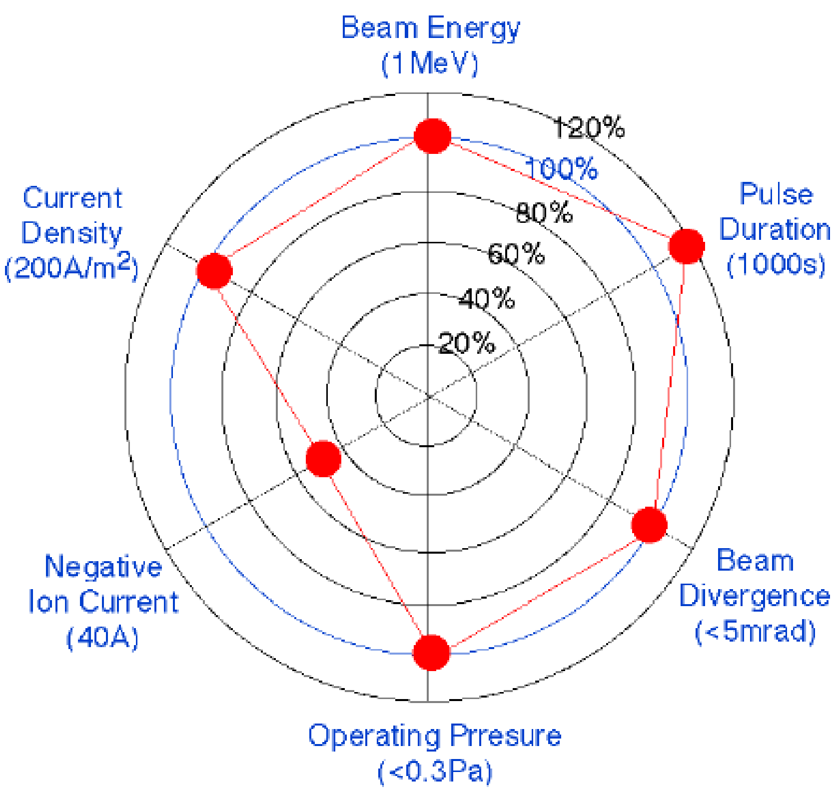
For Demo Reactor



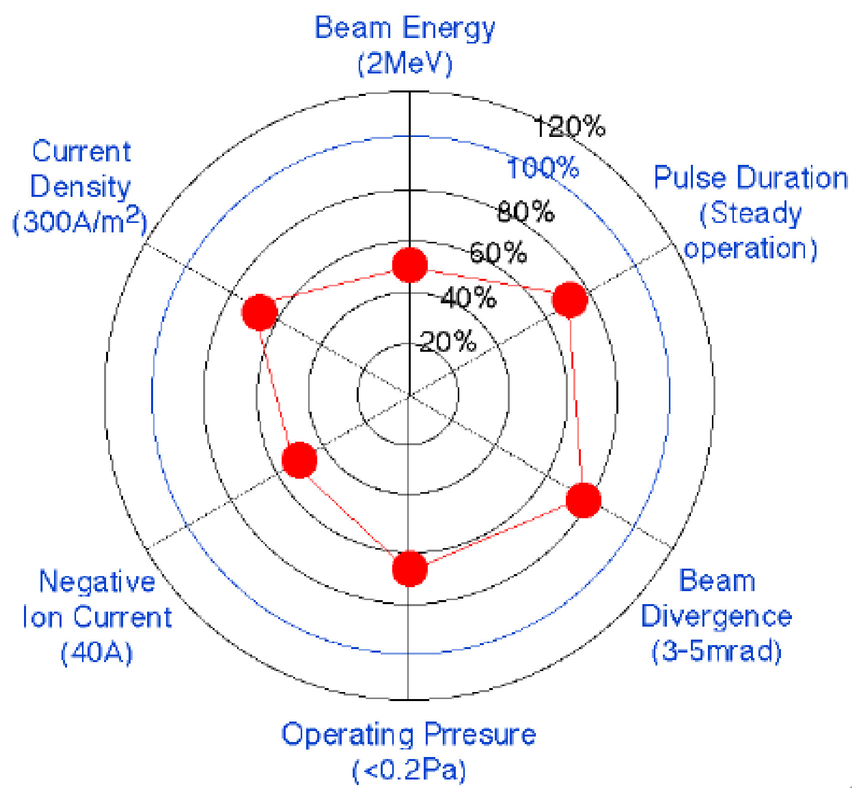
Heating and CD system technology

- **NBI technology in DEMO**
  - Beam energy of 2 MeV
  - Maintenance-free negative ion source, plasma neutraliser with higher efficiency

For ITER



For Demo Reactor

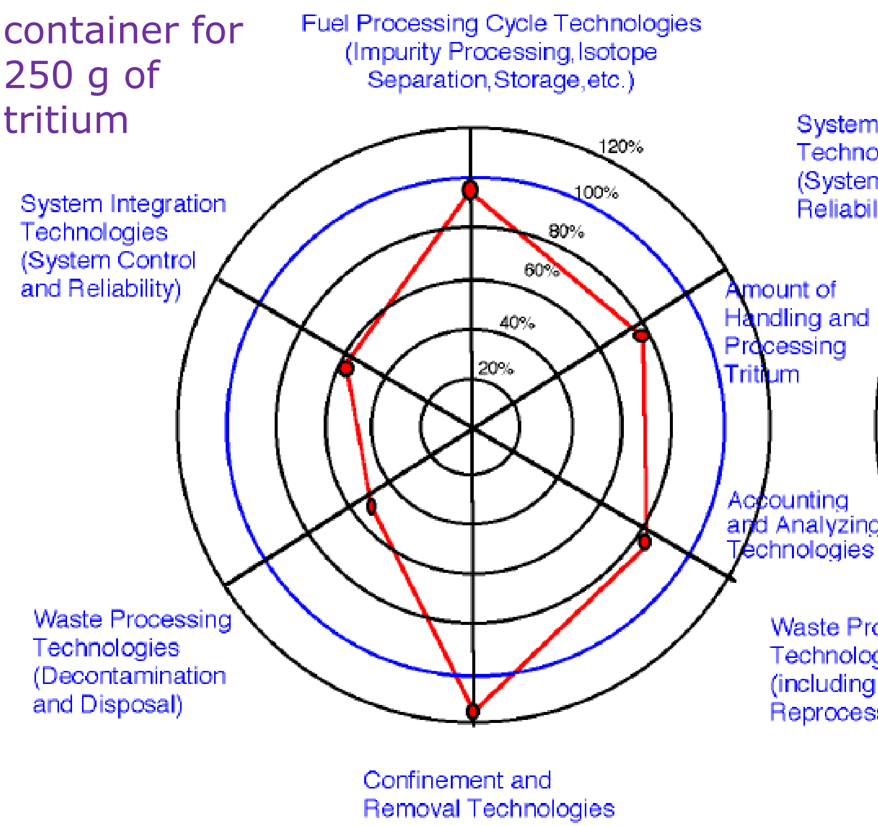


Tritium processing and safety technology

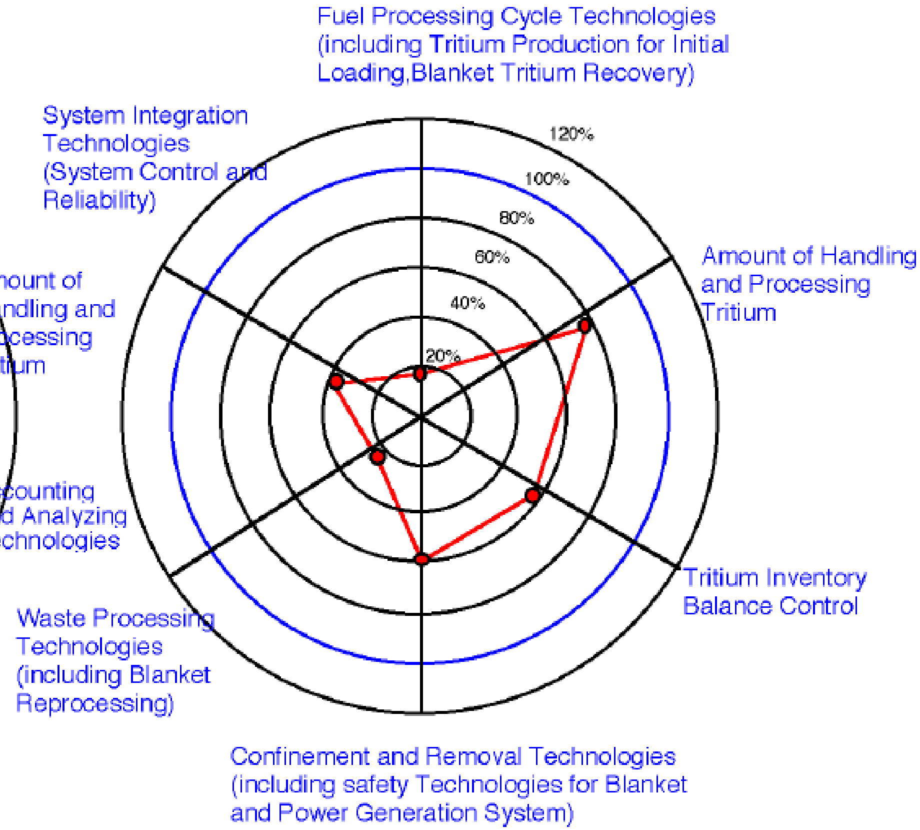
- Reliable tritium processing for steady and continuous long-term operation
- Safety for the power generation plant
- Production and security of necessary amounts of tritium
- Efficient tritium removal/recovery from contaminated wastes

container for 250 g of tritium

For ITER



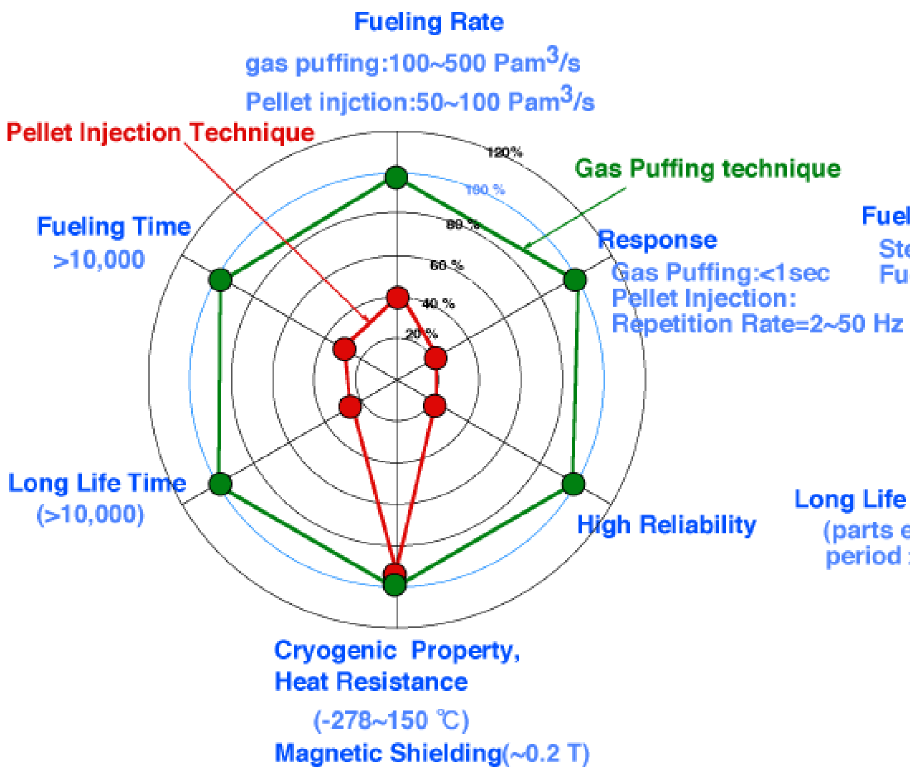
For Demo Reactor



Fuelling and vacuum pumping technology

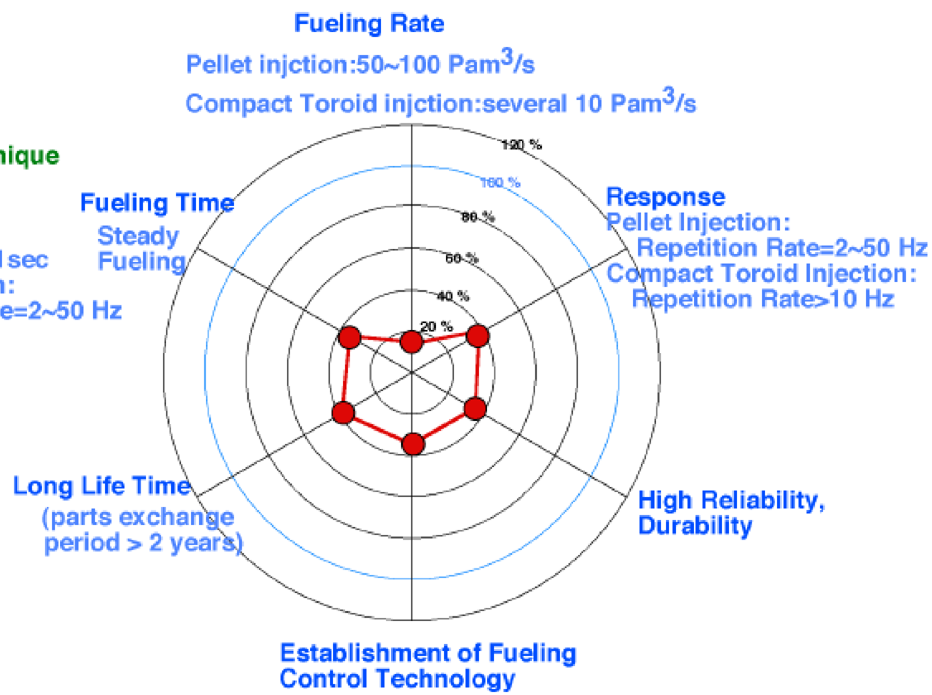
For ITER

* development of gas puffing technique
* development of pellet injection technique



For Demo Reactor

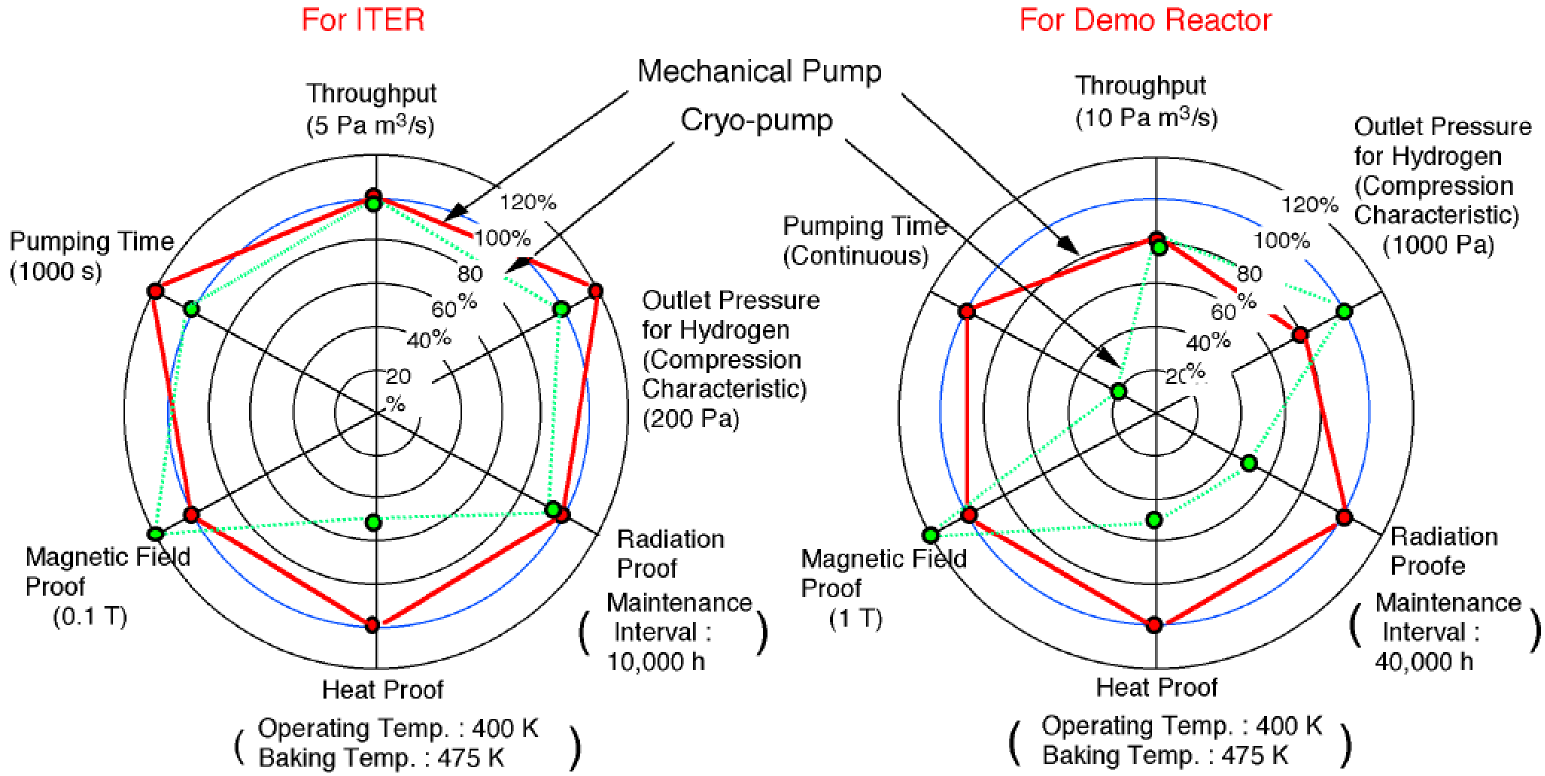
* development of centor fueling technique



HW: compact toroid injection?

Fuelling and vacuum pumping technology

- **Mechanical pump**: metallic rotors requring magnetic shield, low tritium inventory
- **Cryopump**: not disturbed by a magnetic field, operation has to be stopped periodically for regeneration of the cryopanel.



vacuum leak detection method

Assuming a ceramic pump driven by a compressed gas in a Demo reactor.

Diagnostics technology

For ITER

* **Development of Diagnostic Elements**

  Ceramics Insulatotion,
  Optical Elements (Mirror/Reflector, Windw Materials, Optical Fiber),
  Sensors (Magnetic Probe, Bolometor, Pressure Gauge, etc.),
  Electric Cable

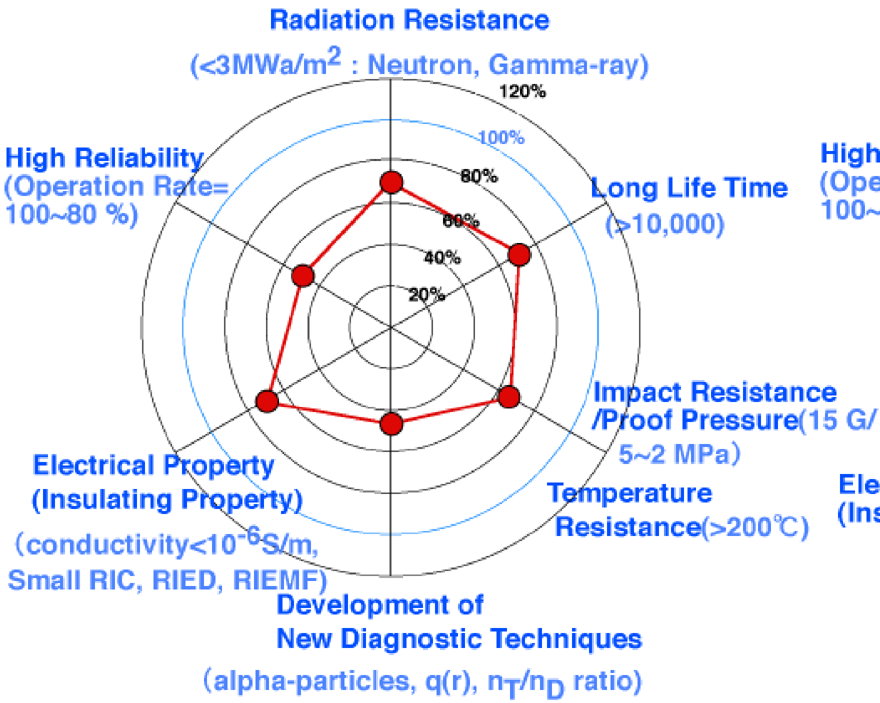
* **Development of Prototype**

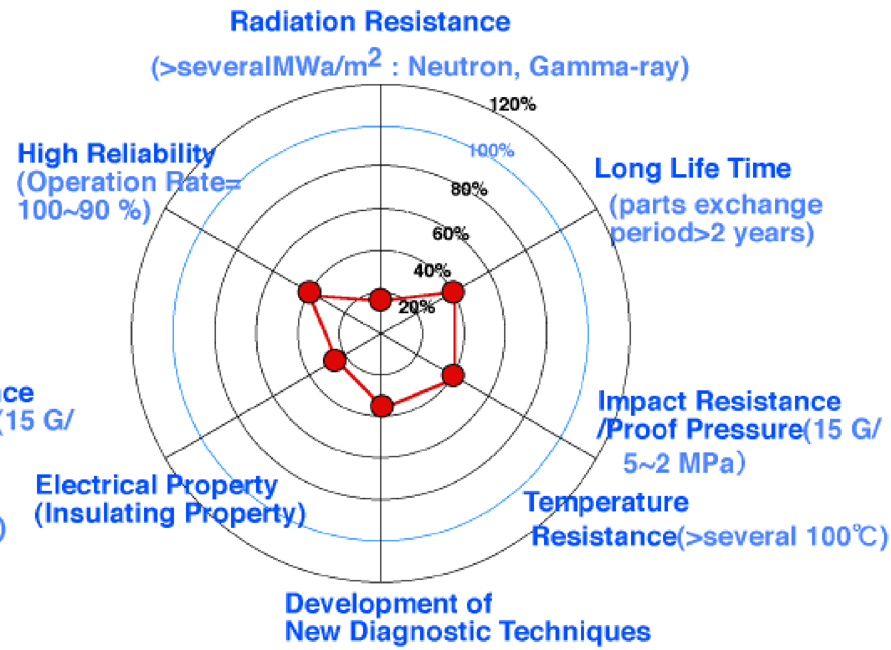
  Sensors, Vacuum Seals for Diagnostic Window,
  Optical fiber/ Electric Cable Feedthroughs, etc.

For Demo Reactor

* **Development of Diagnostic Elements/Prototype**

  Development of Advanced Materials,
  Heavy Irradiation Tests with <20 dpa

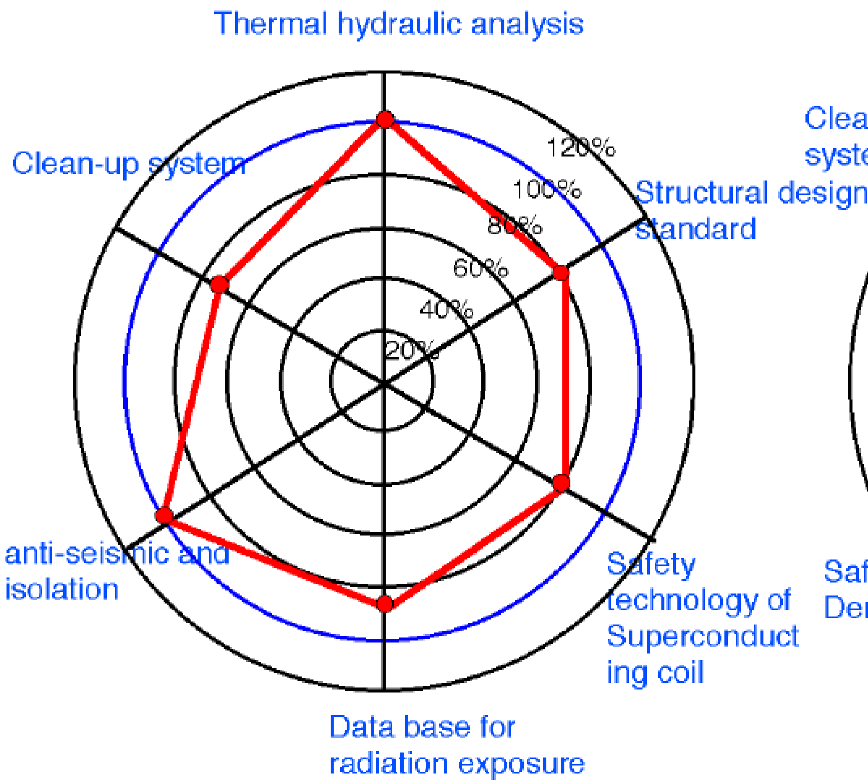




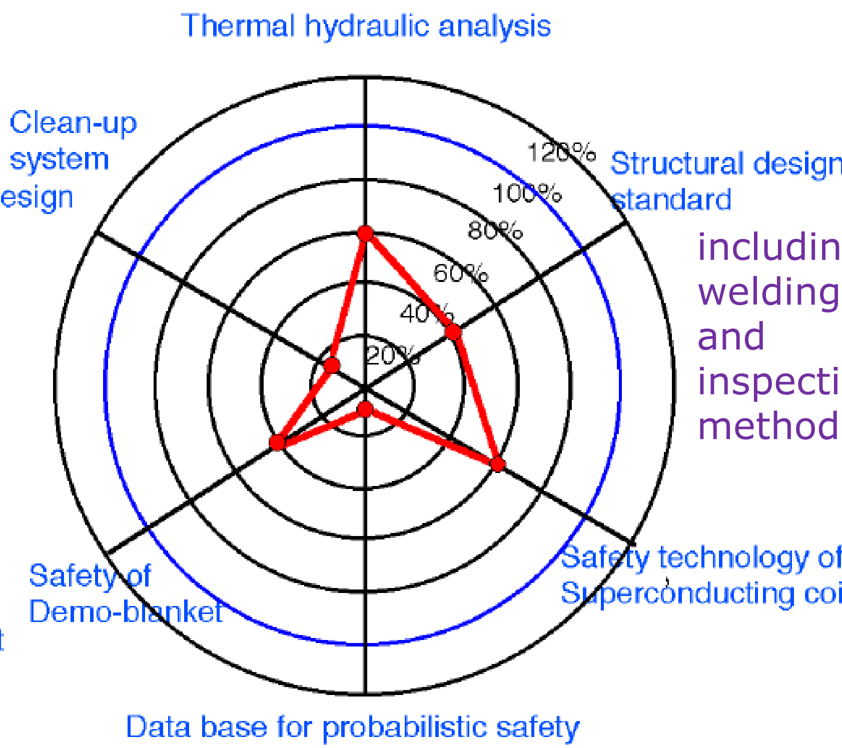
Safety technology

- Improvement of the safety system reliability for abnormal events of the cooling system due to high coolant temperature, high heat flux, and high neutron flux for power generation, and the improvement of social receptivity of the programme by rationalisation and passiveness.

For ITER

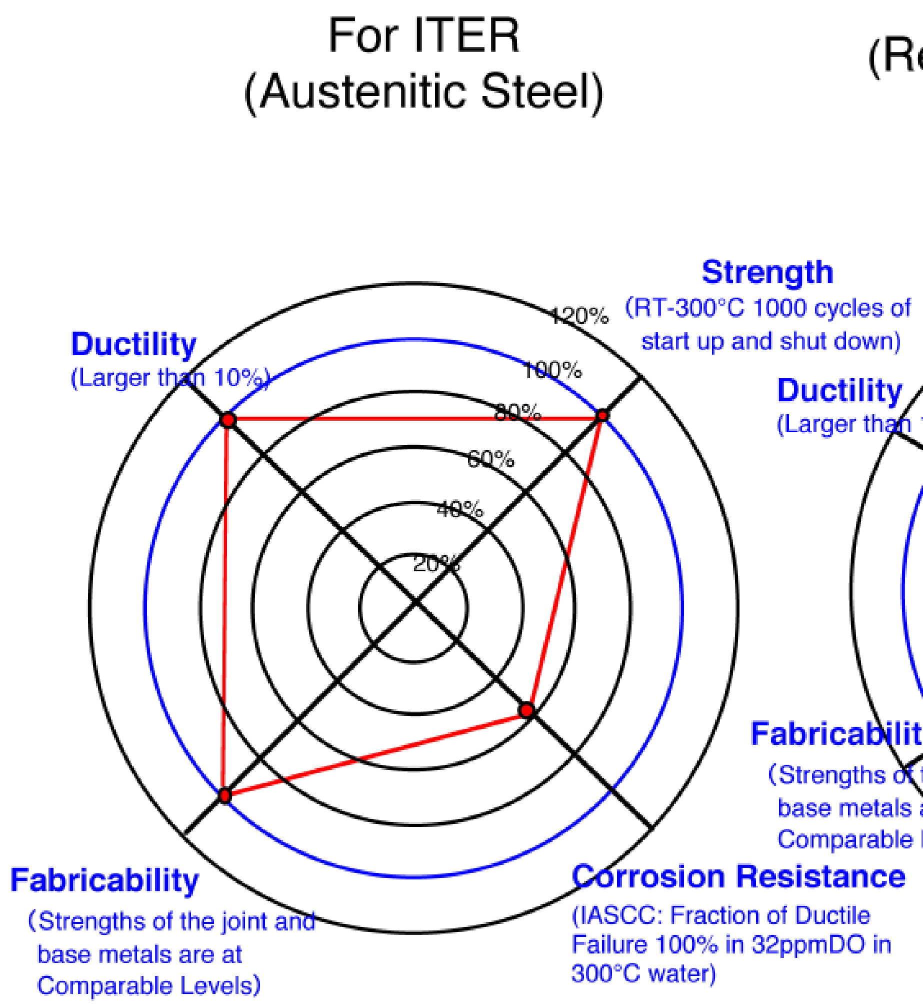


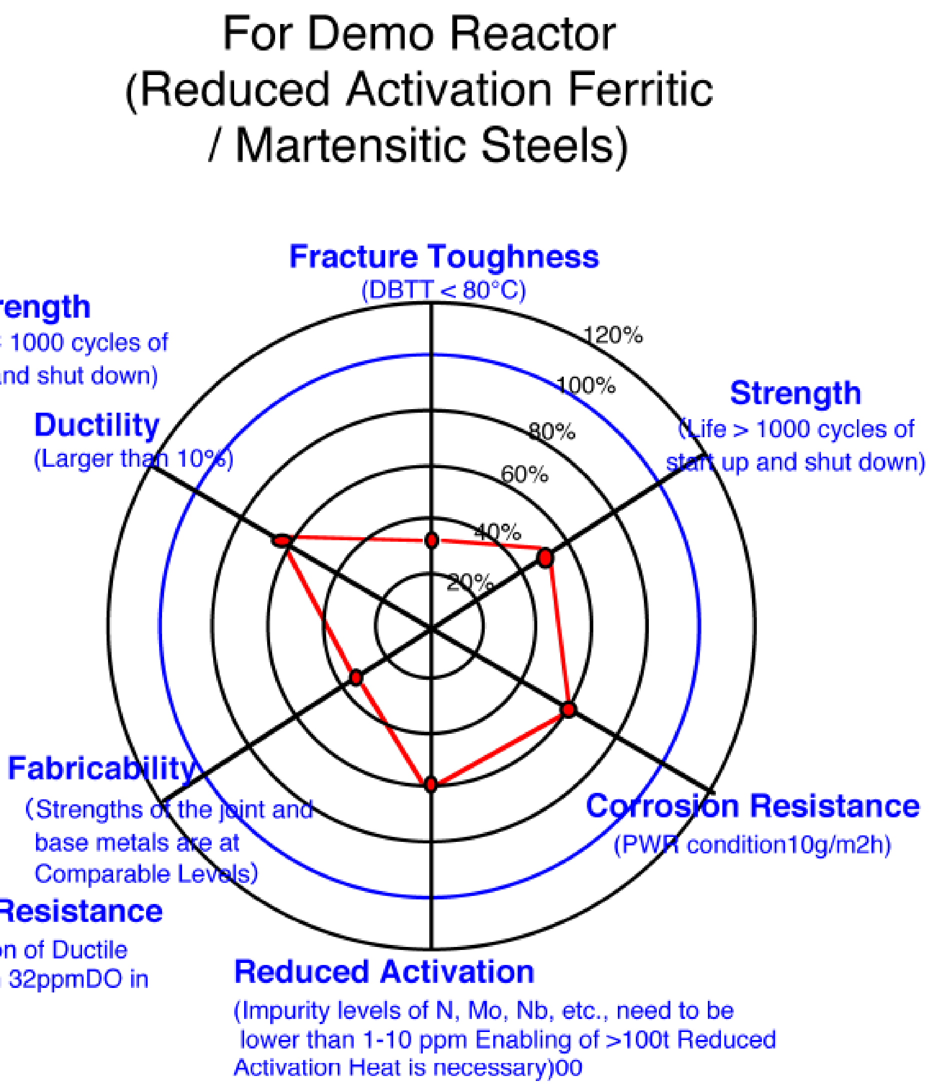
For Demo Reactor



including welding and inspection methods

Materials development





Blanket technology

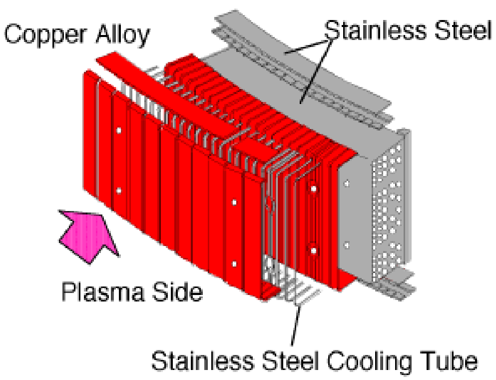
1. Shield Blanket for ITER

■ Requirements and Structure

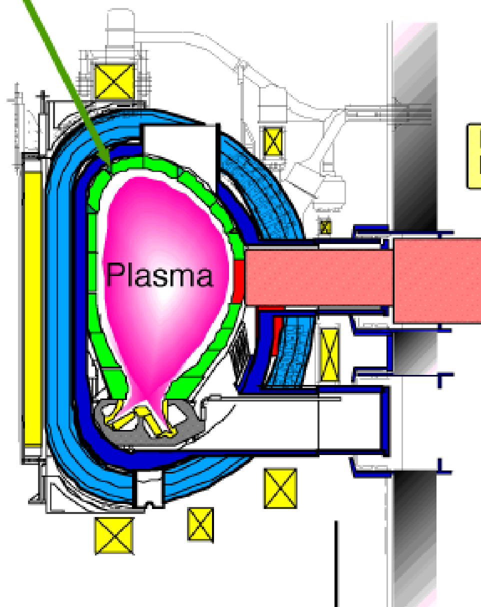
1) Withstand High Thermal Stress
2) Withstand High Electromagnetic Force
3) Provide High Shielding Capability

⇩

Copper Alloy for Heating Surface
Stainless Steel for Structure and Cooling Tubes



ITER Crosssection



■ Technology Challenge

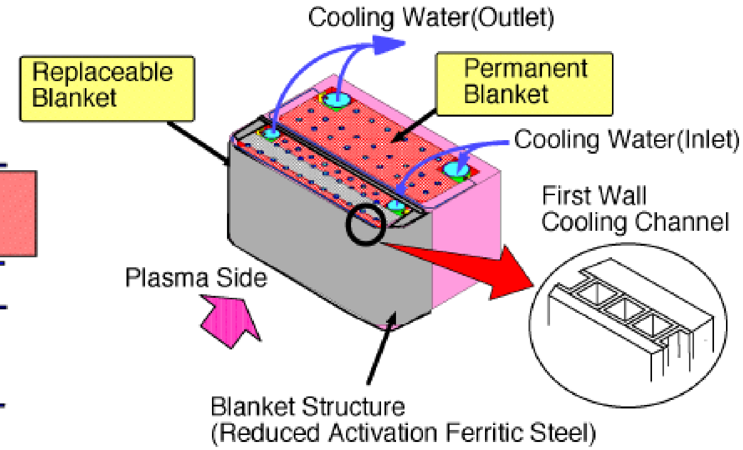
Simultaneous Hot Isostatic Pressing (HIP) bonding of SS/SS, Cu/Cu, and SS/Cu has been successfully developed at 1050°C,150MPa, and 2 hours holding time, and a prototype blanket module has been completed.

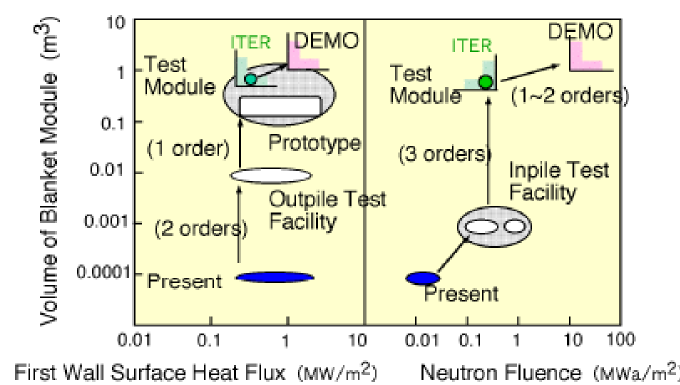
2. Blanket for Power Reactor

(Tritium Breeding and Power Generation)

Double Layered Structure with Replaceable and Permanent Blankets

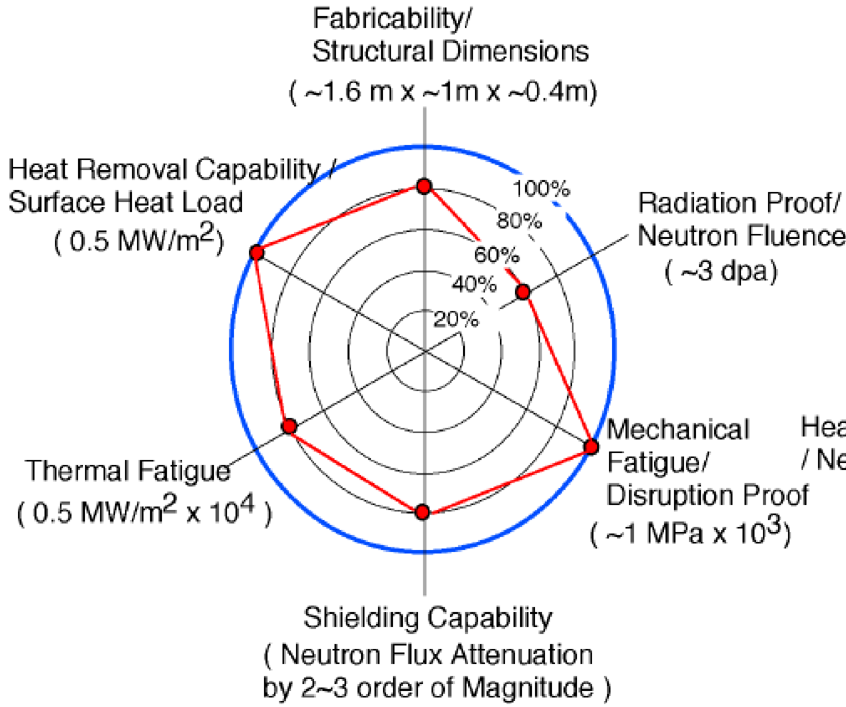
R&D Items: Development of a blanket structure capable of tritium breeding and high heat generation for power generation, under high heat load and neutron wall load





Blanket technology

For ITER



For Demo Reactor

(Reduced Activation Ferritic Steel)