Fusion Reactor Technology I
(459.760, 3 Credits)

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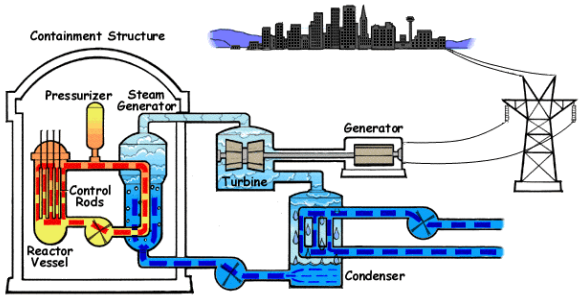
Present status of operation and maintenance technologies and future issues

Operation and maintenance conditions of commercial LWRs as a reference

Items	Working results
Start-up test	The output of 100% was confirmed within a year after the completion of individual equipment tests
Capacity factor	> 60-83%
Operator	6-7 persons/unit (10-11 persons/2 units)
Periodic inspection	< 50-70 days/unit/year (worker's exposure ~ 2-3 persons Sv/unit, 1 mSv for one worker)
Unplanned stop/trouble	< 0.2-4.0 times/unit/year (< 0.5 times/unit/year in Japan)

- 4 year construction



http://www.answers.com/topic/light-water-reactor

Projected operation and maintenance conditions in fusion reactors

Items	Large tokamak JT-60	ITER	DEMO (e.g. SSTR)	Prototype/Commercial reactor
Plasma current	< 5 MA	13 – 17 MA	12 MA	12 MA
Major radius	~ 3 m	6.0 – 6.5 m	~ 7 m	~ 7 m
Toroidal magnetic field	4 T (10 T max.)	< 6 T (12 T max.)	9 T (16 T max.)	9 T (16 T max.)
Fusion output power	~ 10 MW equivalent	> 0.5 GW	~ 3 GW	3-5 GW
Neutron wall load	-	> 0.5 MW/m^2	~ 3 MW/m^2	~5 MW/m^2
Pulse length / S-S	15 s	300-500 s	Steady	Steady
Normal / Superconducting	Normal	Super	Super	Super
Blanket	None	Use (test)	Use	Use
Tritium	No use	Use	Use	Use

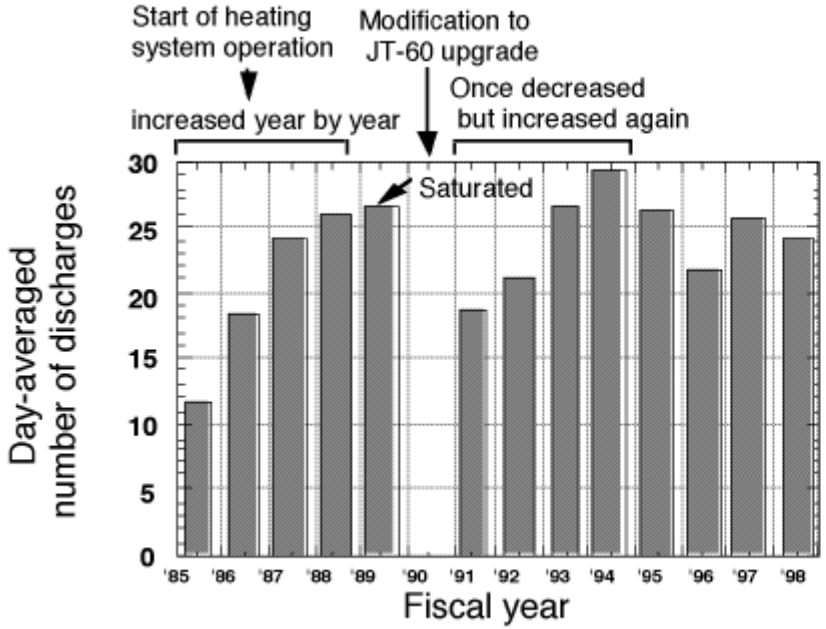
Projected operation and maintenance conditions in fusion reactors

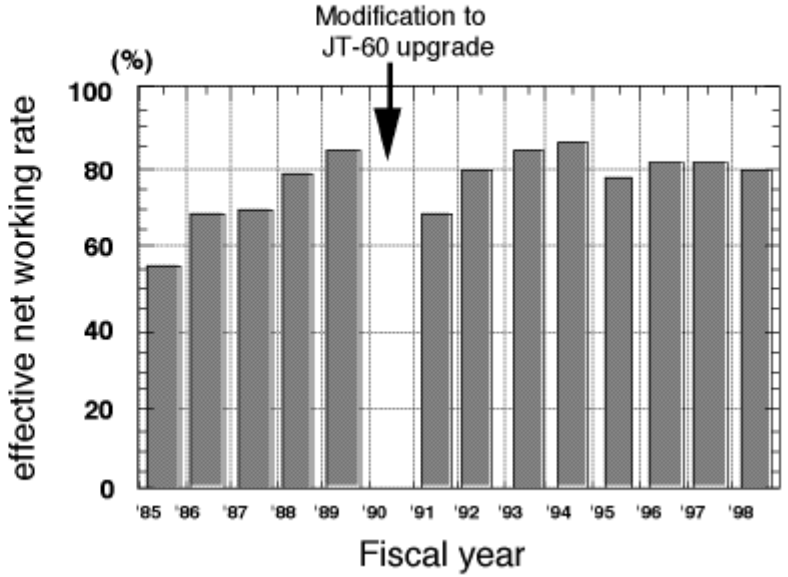
- **Startup tests (commissioning)**

- Commissioning without plasma:
  The number of the test items is about 30.
  The period is about one year.
- Commissioning with plasma:
  After completion of comprehensive tests of all systems as a fusion reactor, the first plasma is produced and commissioning proceeds with plasma.

Projected operation and maintenance conditions in fusion reactors

- **Capacity factor**
  - The percentage of time when the reactor producing power
  - Not including the period in which power generation stopped due to periodic inspections or troubles, etc





- Effective net working rate: defined as the ratio of "effective operating time" to the "sum of the effective operating time and troubleshooting time"

Availability increased

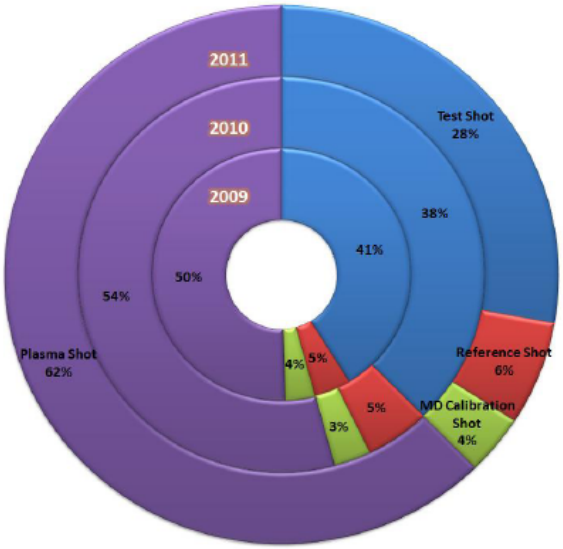


Fig. Type of Shots and their ratios by year

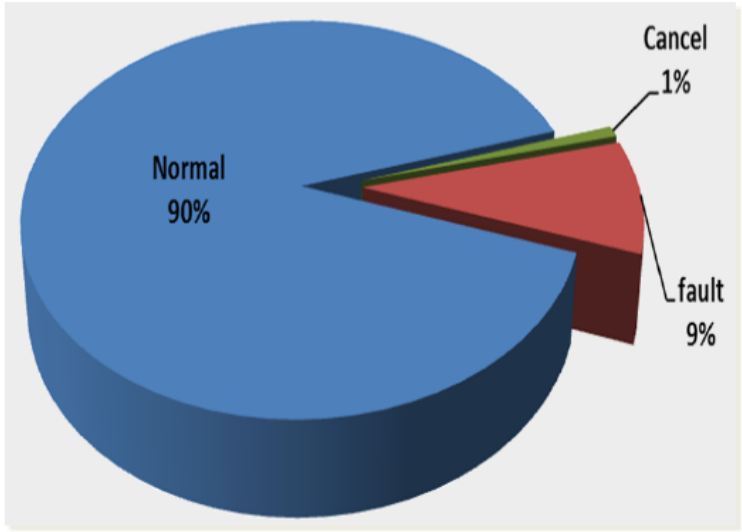
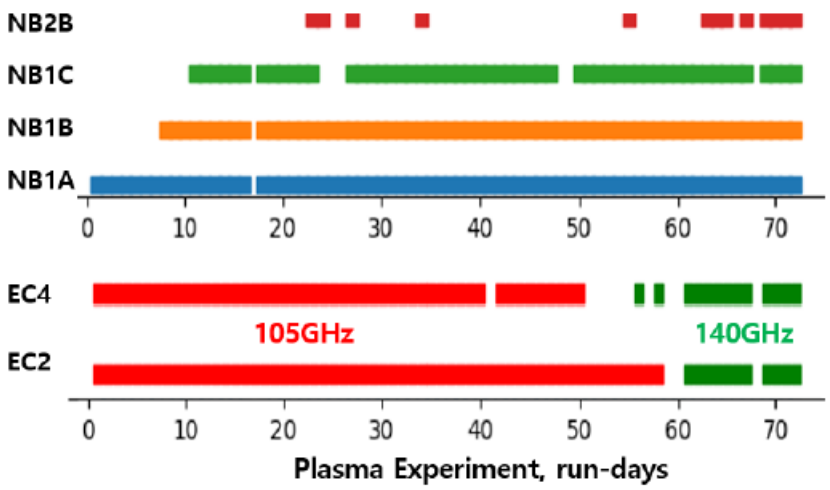
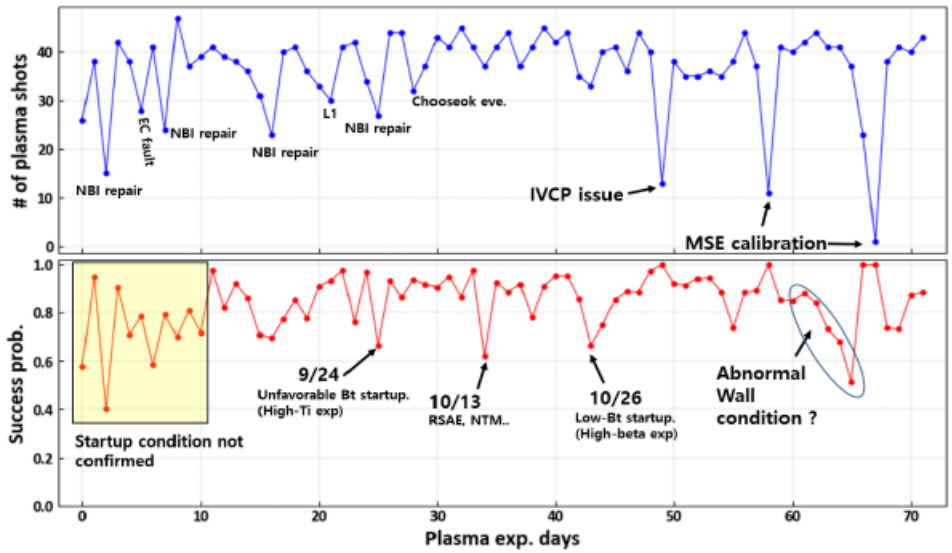


Fig. Shot success ratio in plasma shots

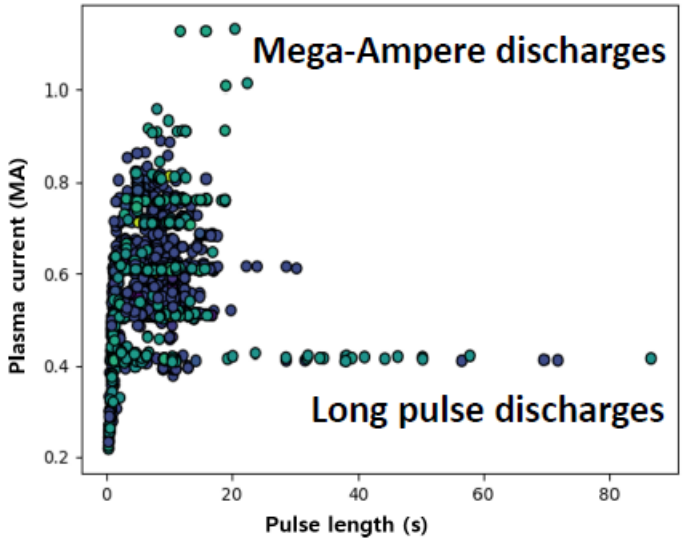
- Availability of the KSTAR machine for the plasma experiment has been increasing year by year, where the percentage of plasma shots is increasing, and the fault of plasma shots is decreasing.
- The number of KSTAR exp. shots in 2011 is 1234.
- The averaged shots per day is 28.4 shots/day, the plasma shots is about 24.6 shots/day, which has also been increasing.

Overall status of 2020 KSTAR experimental campaign





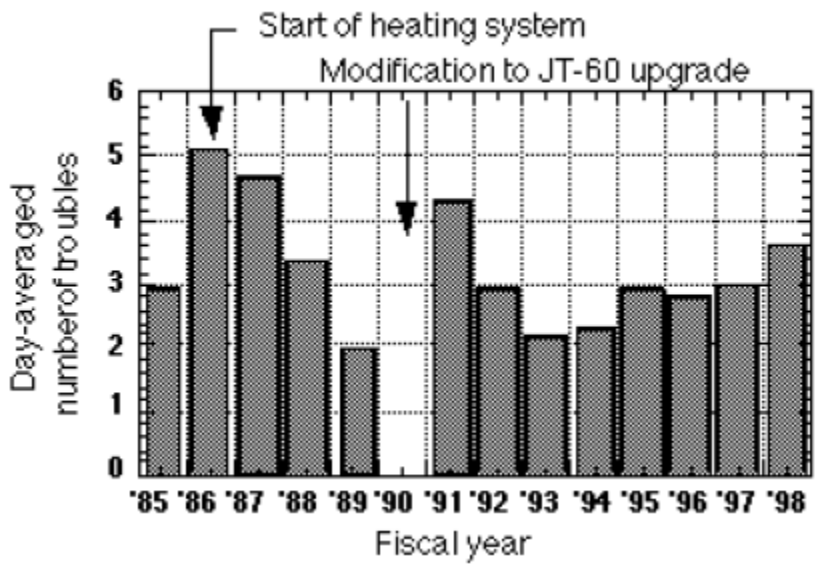
- Former campaign had a well-functioning heating system. P_{NB}~4.0 (3 beams) - 5.0 (4 beams) MW, P_{EC}~1.3 MW
- Overally we had ~40 shots and ~90% shot success rate per run-day.
- Most of shots had I_P=0.4-0.8 MA and B_T=1.8-2.5T (due to EC frequency) range with pulse length of less than 20 seconds.

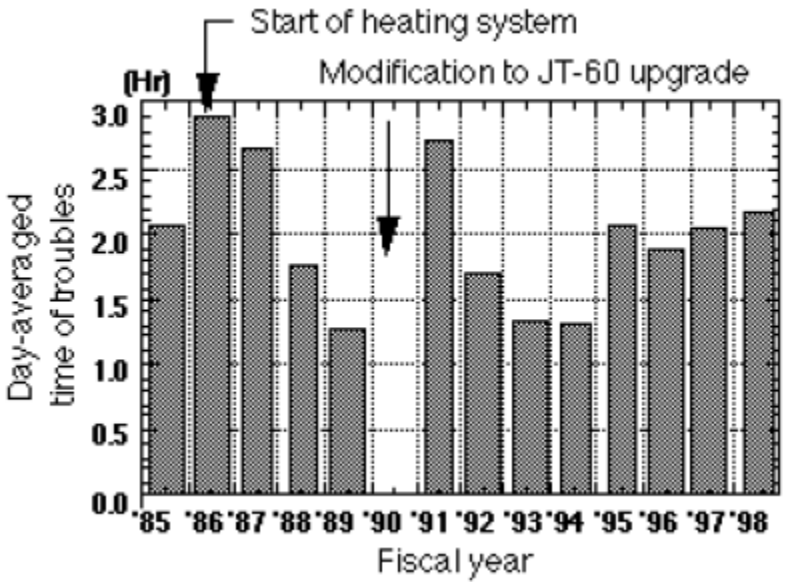


Projected operation and maintenance conditions in fusion reactors

- **Unplanned shutdown (trouble occurrence rate)**

- Trouble (JT-60U): failure or malfunction of equipment that interrupts the experiment discharge for one shot, namely, more than 15–20 minutes
- The most frequent time troubles occur is just before and just after a discharge.
- The second most frequent time troubles occur is at plasma disruptions.





Projected operation and maintenance conditions in fusion reactors

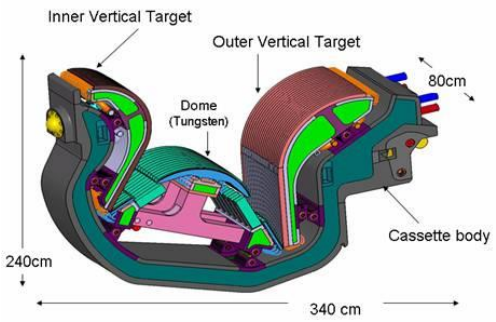
- **Operators**

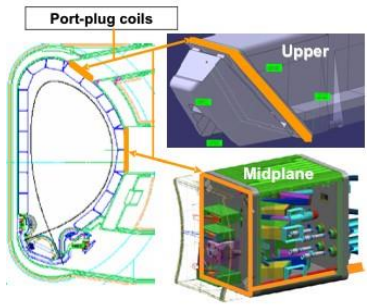
- JT-60U: One operating group consists of a JAEA staff of 14 and consigned industry members.
  Tasks of the consigned members include operation, start-up and shutdown of equipment at the local control room, and inspection.
- Fusion reactor: operating in the S-S mode.
  Startup/shutdown operations as performed everyday in large tokamaks like JT-60U will not be required.

Projected operation and maintenance conditions in fusion reactors

- **Periodic inspection (ITER)**

Items	Frequency	Units	Total period
Divertor cassette	1 time / 1.5 year	60 cassettes	112 days
Shield blanket	-	730 modules	349 days
Test blanket	-	Several assemblies	-





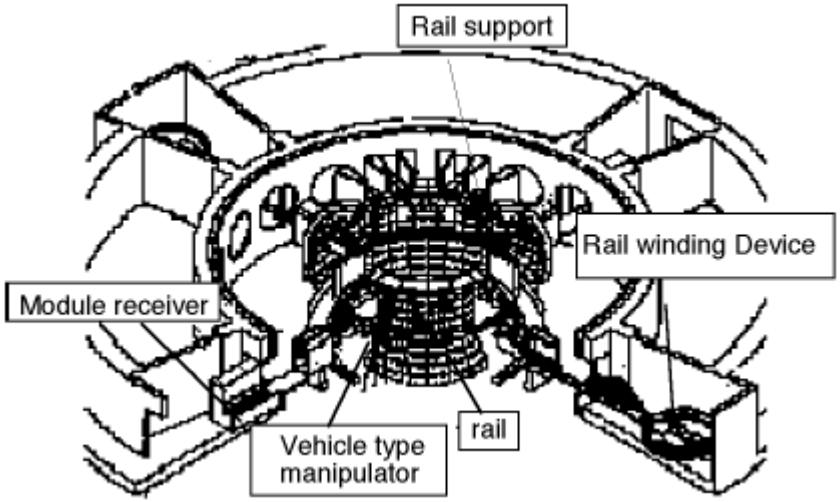
Projected operation and maintenance conditions in fusion reactors

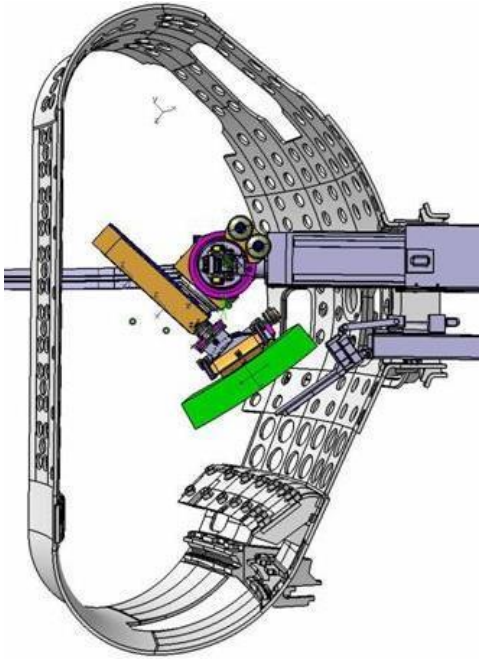
- **Blanket exchange work of ITER (FDR)**

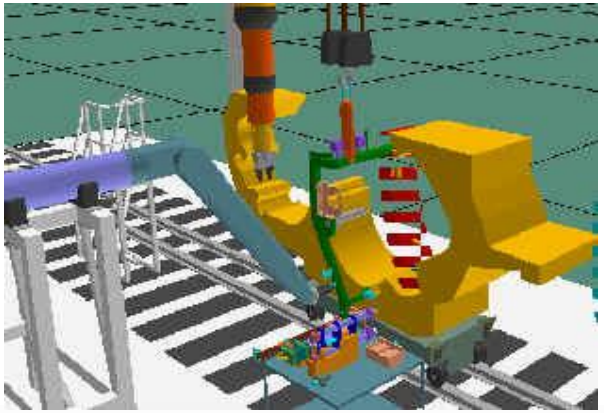
- The preparation time such as for baking, etc., before and after the exchange work is not considered as working time.
- Four vehicle type manipulators are installed (1 unit per quadrant).
- Sixteen units of pipe cutting/welding/inspection tools are installed (4 units per quadrant).
- A blanket weighs 4 tons.
- The number of bolts for fixing a blanket is 14 per four blankets, and 4 bolts are simultaneously mounted/dismounted.
- The working time for 4 days is 16 hours.
- The operating speed of the remote manipulation equipment is assumed to be the actual value obtained by a full-scale vehicle-type maintenance equipment test performed in the engineering R&D of ITER.
- Considering the uncertainty in the working time, 30% is added to the total exchange time.

Projected operation and maintenance conditions in fusion reactors

Modular-unit system,
Vehicle type manipulator for ITER

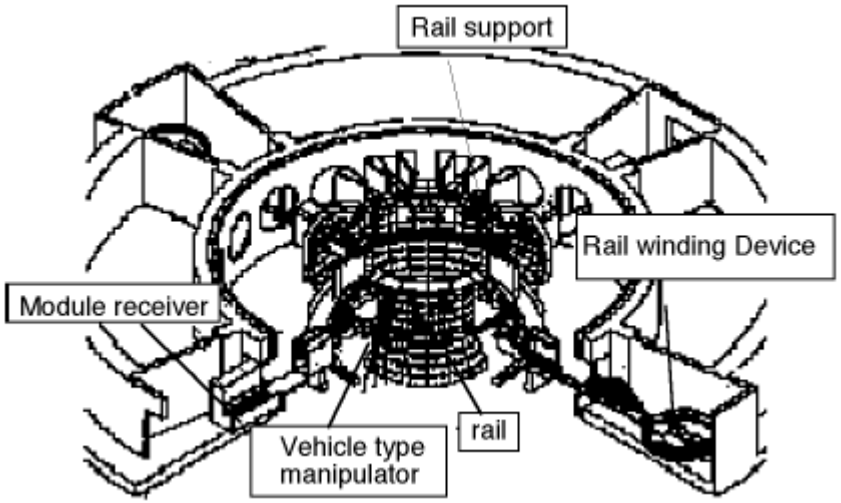


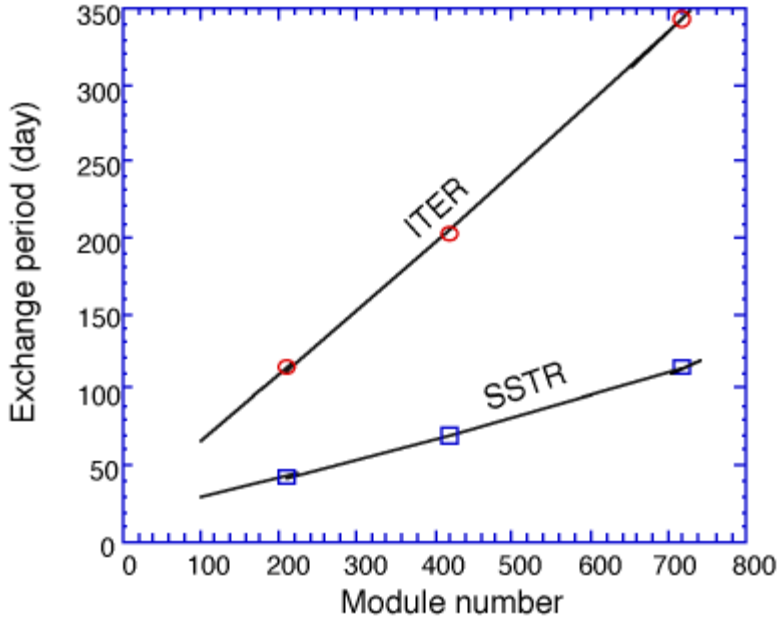




Projected operation and maintenance conditions in fusion reactors

Modular-unit system,
Vehicle type manipulator for ITER



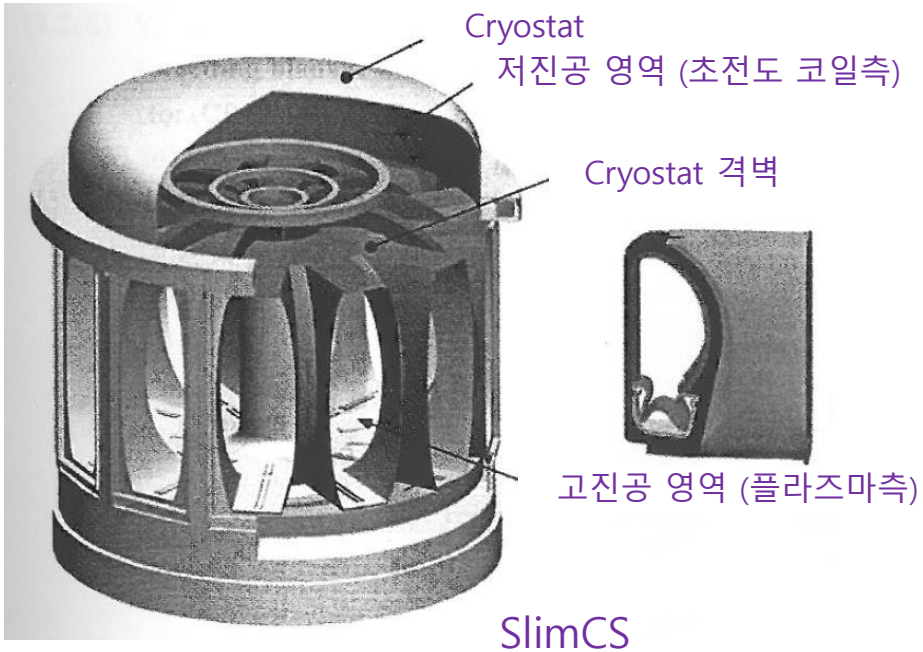


- **Blanket exchange work of SSTR**
  - The number of fixing bolts is four per blanket. Mounting/dismounting of 4 bolts is performed in parallel using the tool installed at the top of the manipulator.
  - The available work time per day is 24 hours.
  - The operating speed of the remote manipulation equipment is improved by 30%.

노의 구조 및 크기 결정

- **보수 방식과 노구조**

- Poloidal coil의 설치 위치, Toroidal coil의 비틀림 힘 지지 구조 외 노내 기기의 segmentation, 노내 기기의 열 설계, 냉각 배관의 처리 등 노 구조와 보수 방식은 밀접한 관계가 있음.

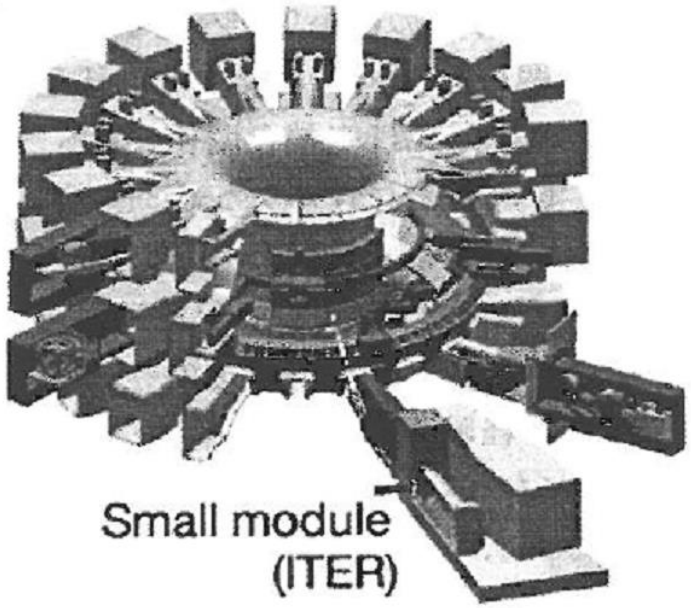


SlimCS

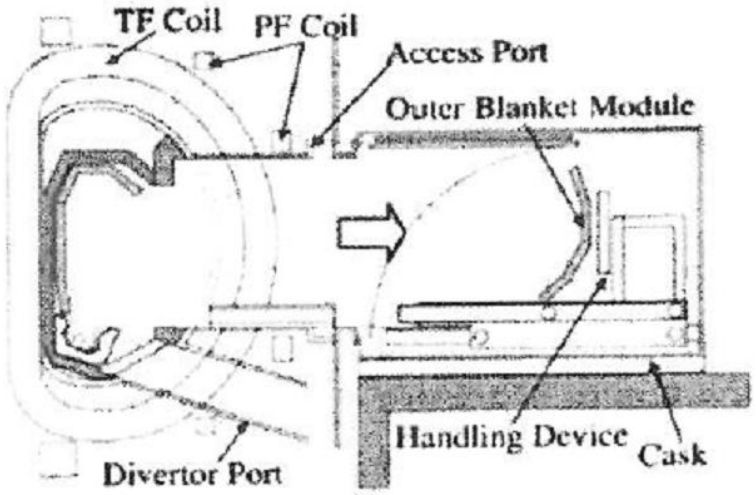
노의 구조 및 크기 결정

대모듈 노내 보수 방식: Blanket module을 대형화하여 절단, 재용접의 공수를 줄여 availability 개선

- **보수 방식과 노구조: In-vessel maintenance**



Small module (ITER)

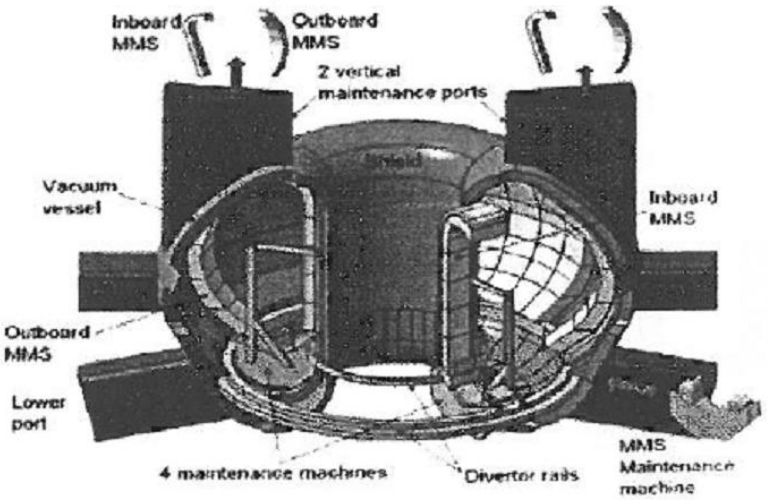


Large module (Demo-CREST)

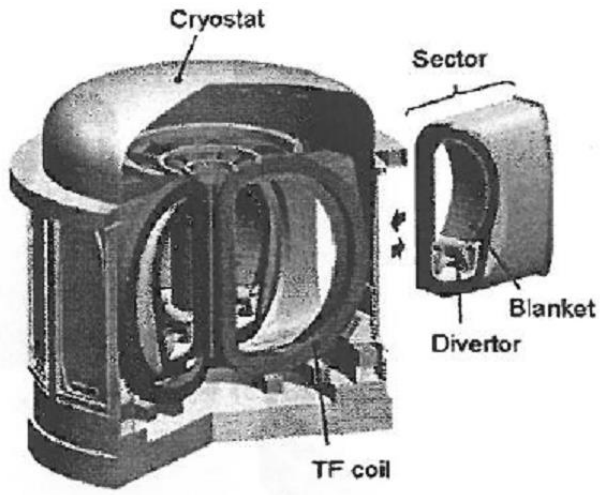
- Module의 부착 볼트부는 중성자에 의한 많은 조사를 피하기 위해 그 전면에 충분한 차폐를 설치해야 함 (팔이 긴 공구를 이용한 설치 정밀도의 확보가 요구됨)
- 핵발열로 인해 지지부에 온도차가 생기면 풀림 등이 생길 수 있음.

노의 구조 및 크기 결정

- **보수 방식과 노구조: Hot cell maintenance**



Vertical transport (EU-DEMO)



Horizontal transport (SlimCS)

- 사용 완료 unit을 Hot cell에 반송한 후, spare unit을 노 본체에 장착하고 즉시 핵융합로의 운전을 개시할 수 있음 → 유지보수 소요 시간 대폭적 단축
- Blanket 교환 작업, 검사는 Hot cell에서 로의 운전과 병행하여 실시
- 대구경 보수 port가 필요하고, PF coil 설치 위치에 대한 제약, TF coil의 비틀림 힘에 대한 지지 제약(코일 간 지지 구조물의 설치 영역 제약)의 해결책이 필요함.

노의 구조 및 크기 결정

- **보수 방식과 노구조**

	노내 보수 방식		Hot cell 보수 방식	
	소모듈	대모듈	수직 인발	수평 인발
보수 소요 시간	최장	Hot cell 방식보다 떨어짐	짧음	최단
Blanket 탈착	Front access 만	Front access 만	Hot cell 내에서 다방면으로부터 access 가능	
부착 신뢰성	시간 제약이 크기 때문에 문제가 됨		시간을 들인 조정/검사가 가능	
원격 보수의 수월성	고도의 로봇이 필요		비교적 단순한 보수 기기	
반송 중량	최경량	경량	중량	최중량
건물에 대한 영향	적음		Hot cell 외에 보수 회로가 필요	건물이 다소 큼. 수직 인발보다는 작음.
TF 코일 치수	-		-	대형화가 필요
EF 코일 설치 자유도	자유도가 큼	한정적	한정적	한정적
단점 트러블 대책	한정적		자유도가 큼	자유도가 가장 큼
개수 자유도	한정적		자유도가 큼	Sector 별 개조 가능 가장 큰 자유도

Assessment of the feasibility of operation and maintenance of fusion reactor

Items	Present status of fusion devices	Prospect	Performance of LWR
Starting test	< 3.5 years (until initial experiment) (ITER)	2	< one year (100% output)
Operators	< 14 JAEA's staff + consigned staff (JT-60)	1	6 or 7 persons/unit
Periodic inspection	~ 70 days (ITER/SSTR)	2	50-70 days / unit year
Trouble occurrence rate	~ 2.5 events/day (JT-60)	2	< 0.5-4.0 events / unit year
Net working rate	> About 64% (JT-60)	2	> 60-80 %

1: Possibility of realisation is large.
2: Possibility is increased if operation scenario of the S-S operation is established, if disruption avoidance techniques are developed, and if redundant systems are adopted.