Design Study Of Low-power Fusion Reactor Aiming For “42 Yen/kWh”

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MOTIVATION OF THE WORK

Fast-Track Of Fusion Energy

↓

Small fusion power

↓

High CoE, but affordable scale

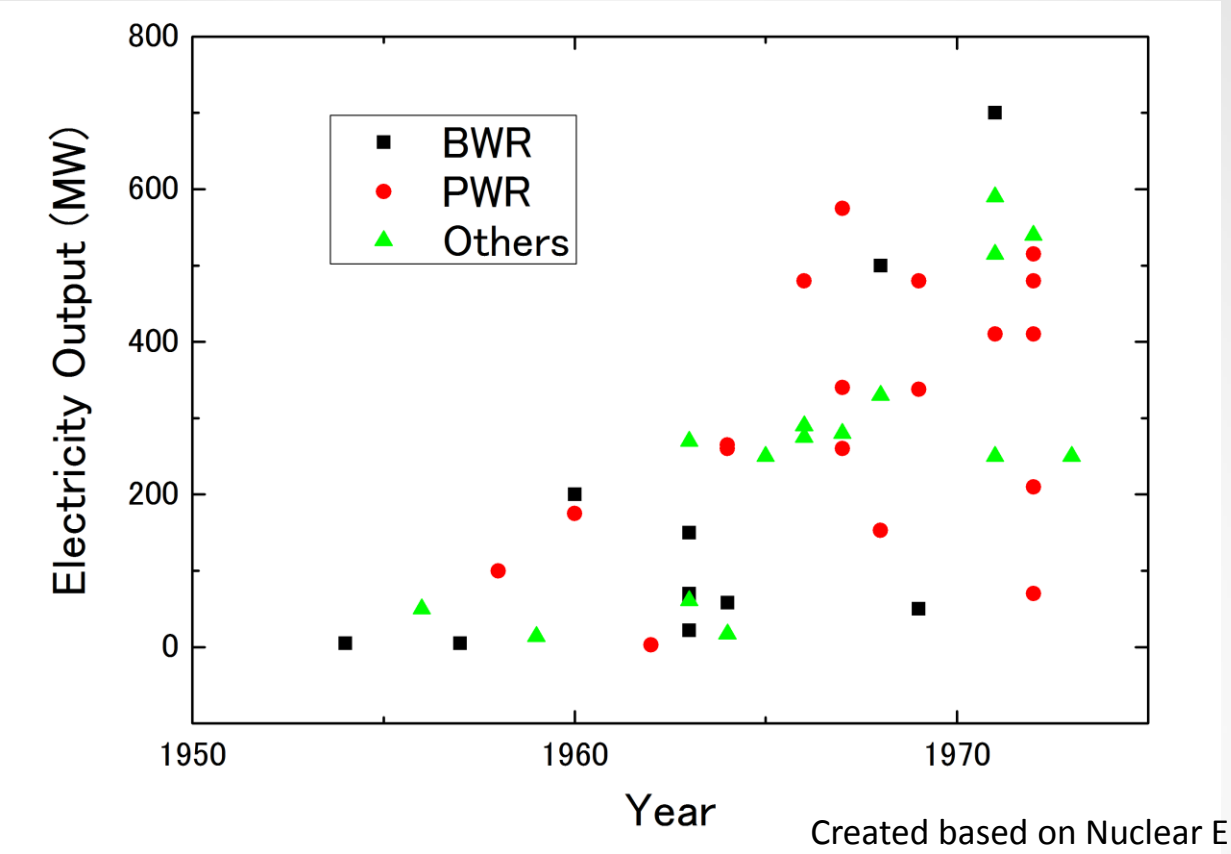
Least Innovative technoloGy based High CoE Tokamak

FAST-TRACK: SMALL FUSION POWER

Large ←	P_{fus} ←	Small
Large	Neutron Load/Heat flux	Small
Much	Nuclear Waste	Less
High	Maintenance frequency	Low
Large	Impacts on Grid/Power bill	Small
High	Economic feasibility	Low

As Low As Reasonably Acceptable

DEVELOPMENTS OF FISSION PP



Created based on Nuclear Energy Encyclopedia

Several small power reactors were build for fission developments.
(Of course, most of them had political motivations.)

Is 42 Yen/kWh Reasonable?
Feed-in Tariff in Japan

Solar Power FIT @Kansai-area

< 10 kW, f_{av} ~ 0.1
(market: 42 Yen/kWh)

~ 1500 GWh/year

Fusion Reactor

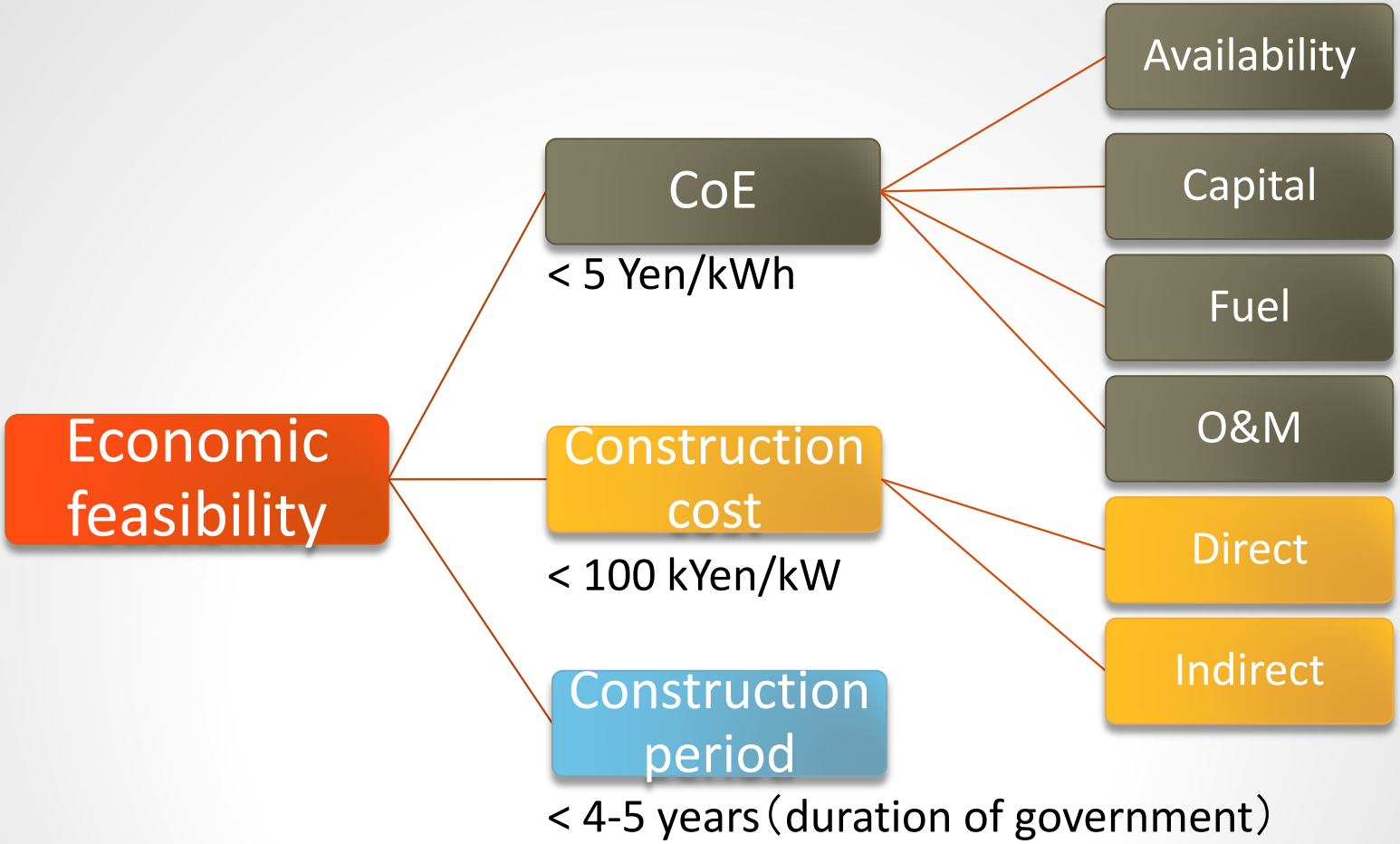
200 MW_e, f_{av} ~0.8
(CoE: 42 Yen/kWh)

~ 1400 GWh/year

Total electricity production per year was estimated from their 180k cases of agreements.
http://www.kepco.co.jp/s-ryoukin/document/document12-5.pdf

"Affordable"

ECONOMICS ON POWER PLANTS



COST OF ELECTRICITY

$$CoE = \left\{ \frac{C_{\mathrm{ac}} + C_{\mathrm{om}} + C_{\mathrm{scr}} + C_{\mathrm{fuel}}}{8760 \times P_{\mathrm{e}} \times f_{\mathrm{av}}} + C_{\mathrm{dec}} \right\} \times F$$

(1.0)

(.15 Yen/kWh)

C_{ac}: accounting capital

C_{om}: maintaining

C_{scr}: periodic replace

C_{fuel}: fuel fee(D)

C_{dec}: Waste & shut down

P_e: Electricity output [MW]

f_{av}: utilization rate

F: 10th of a kind factor

$$\text{utilization rate} = \frac{\text{electricity output}}{\text{rated output} \times \text{time}} \times 100\ (\%)$$

STUDIES ON REPLACEMENT OF BLANKET

$$f_{\text{availability}} = 1 - \underbrace{\frac{t_{\text{replacement}}}{Y}}_{\text{planned}} - \underbrace{\text{Test\&Maintenance}}_{\text{unplanned}}$$

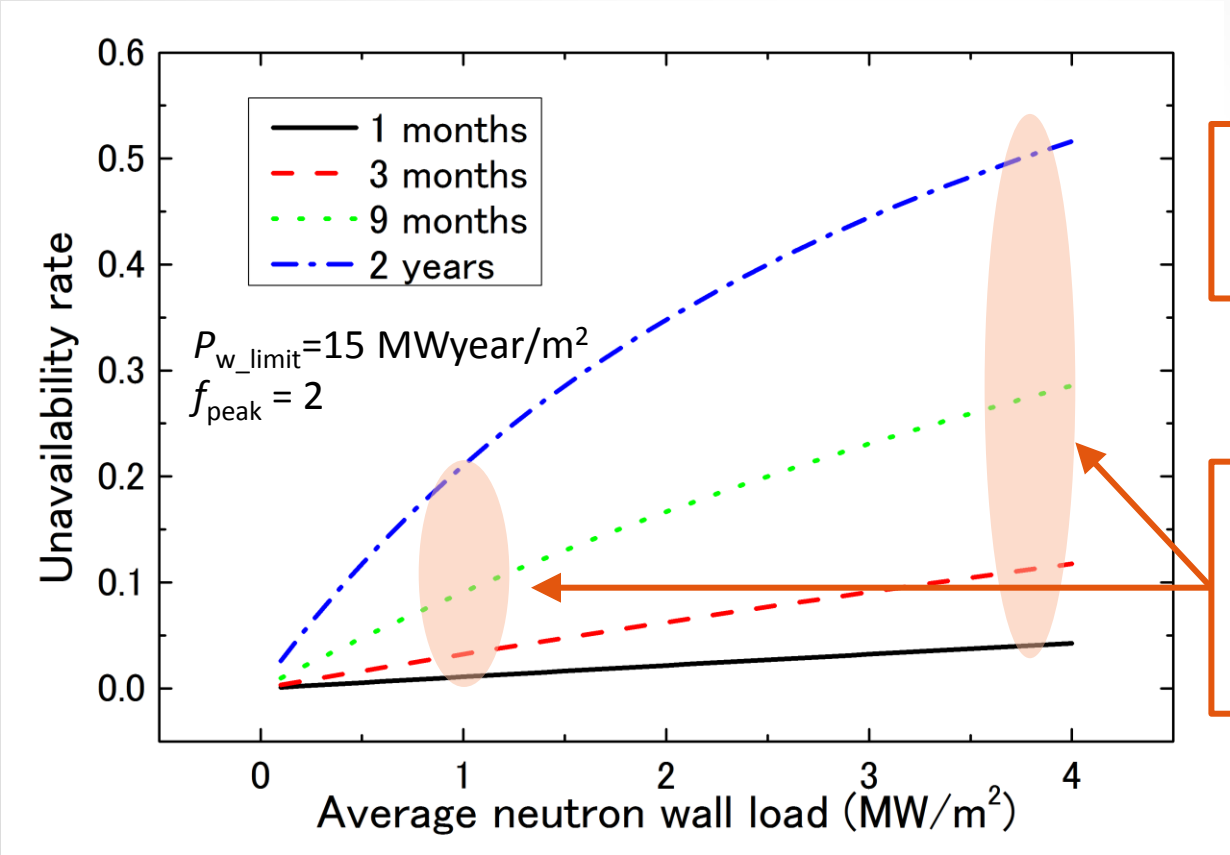
device	scheme	Unit time (Days)	Total time (months)	# of units	ref
ITER	Module	56	24	440 modules	ITER DRG2, ch.8.1 (2001)
Slim-CS	Sector	1	1~2	12 sectors	Slim-CS report (2010)
ARIES-AT	Sector	1.45	1	16 sectors	L. Waganer, FED, **80**, 161 (2006)
European DEMO	Module	1.8	9	448 modules	D.V. Sherwood, FED, 31, 29 (1996)
PPCS	Multi- Module Segment	?	1~9	52 MMSs	T. Ihli, IAEA,FT/P5-11 (2006)

N.P. Taylor, FED, 51-52, **363** (2000)
L.M. Waganer, Nuclear Energy Encyclopedia, Ch.39 (2012)

UNAVAILABILITY BY PERIODIC REPLACEMENT

$$\begin{cases} Y = \dfrac{P\mathrm{w}_{\mathrm{limit}}}{f_{\mathrm{avilability}}(Y) f_{\mathrm{peak}} P\mathrm{w}_{\mathrm{avg}}} \\ f_{\mathrm{availability}} = 1 - \dfrac{t_{\mathrm{replacement}}}{Y} - \mathrm{Test\&Maintenance} \end{cases}$$

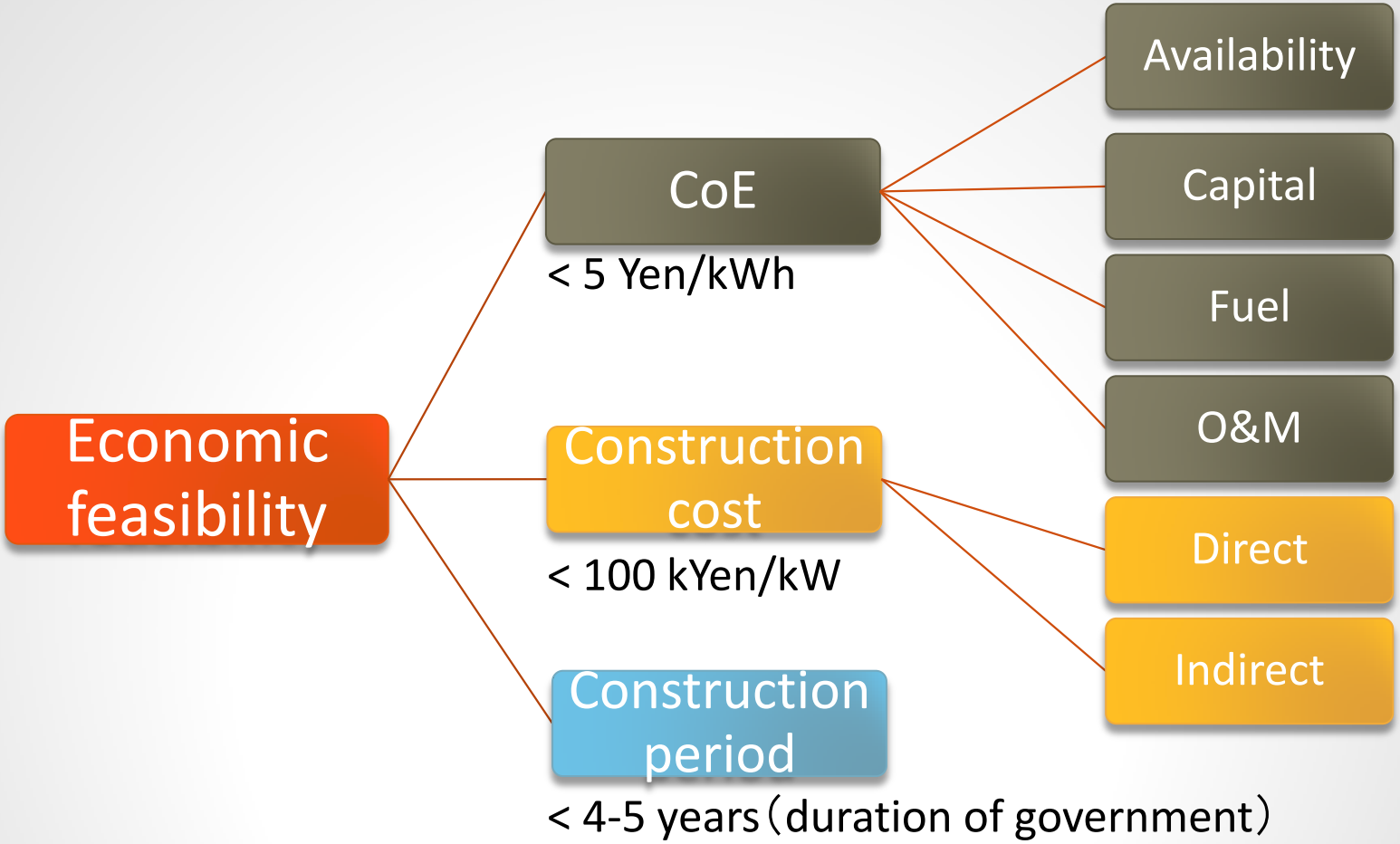
$$f_{\mathrm{availability}} = \frac{1 - \mathrm{Test\&Maintenance}}{1 + \dfrac{t_{\mathrm{replacement}} f_{\mathrm{peak}} P\mathrm{w}_{\mathrm{avg}}}{P\mathrm{w}_{\mathrm{limit}}}}$$



Low n flux means Less replacements

Replacement time is less significant for low flux devices.

ECONOMICS ON POWER PLANTS



CONSTRUCTION COST ESTIMATION: ITER

Table 9.1-2 Summary ITER Direct Capital Cost

	Direct Capital Cost (kIUA)	Percentage of Total	Deferred Investment (kIUA)
Magnet Systems	762.1	28%	40.2
Vacuum Vessel	230.0	8%	0.0
Blanket System	165.2	6%	8.6
Divertor	76.0	3%	6.9
Machine Assembly	92.7	3%	0.0
Cryostat	75.8	3%	0.0
Thermal Shields	28.8	1%	0.0
Vacuum Pumping & Fueling System	34.2	1%	6.8
Machine Core, subtotal	**1464.8**	**53%**	**62.5**
R/H Equipment	61.1	2%	52.3
Cooling Water Systems	131.5	5%	16.8
Tritium Plant	36.6	1%	45.2
Cryoplant & Distribution	88.9	3%	7.9
Power Supplies & Distribution	214.7	8%	3.5
Buildings	380.3	14%	12.0
Waste Treatment and Storage	2.1	0%	7.0
Radiological Protection	1.0	0%	3.2
Auxiliaries, subtotal	**916.2**	**33%**	**147.9**
IC H&CD	32.2	1%	2.0
EC H&CD	77.5	3%	3.0
NB H&CD	96.0	3%	0.2
Heating and CD, subtotal	**205.7**	**7%**	**5.2**
Diagnostics	118.0	4%	42.3
CODAC	50	2%	0.0
Grand Total	**2754.7**	100%	**257.9**

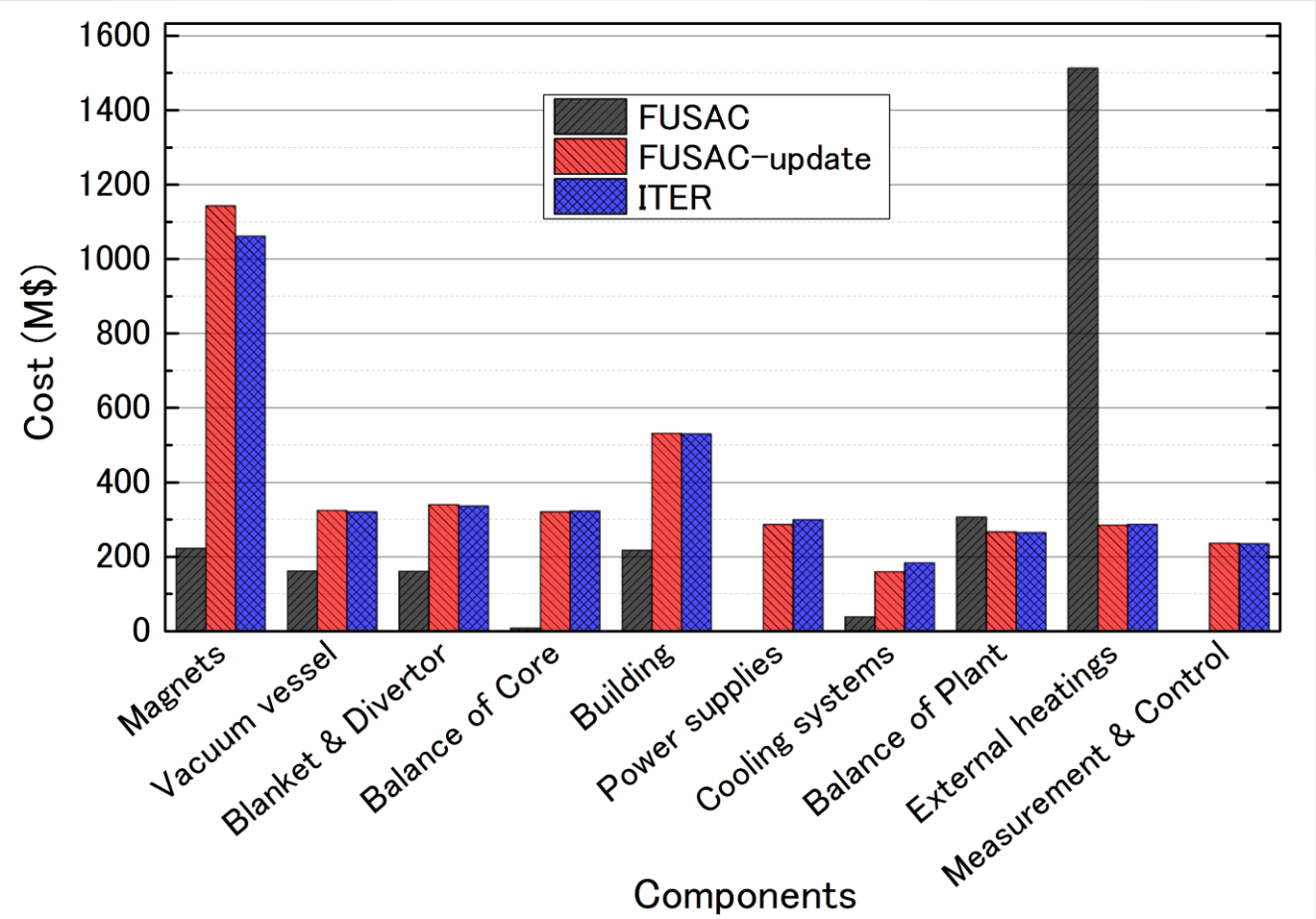
SUMMARY of the ITER FINAL DESIGN REPORT (2001)

FINAL REPORT of the ITER ENGINEERING DESIGN ACTIVITIES (2001)

FUSAC systems code

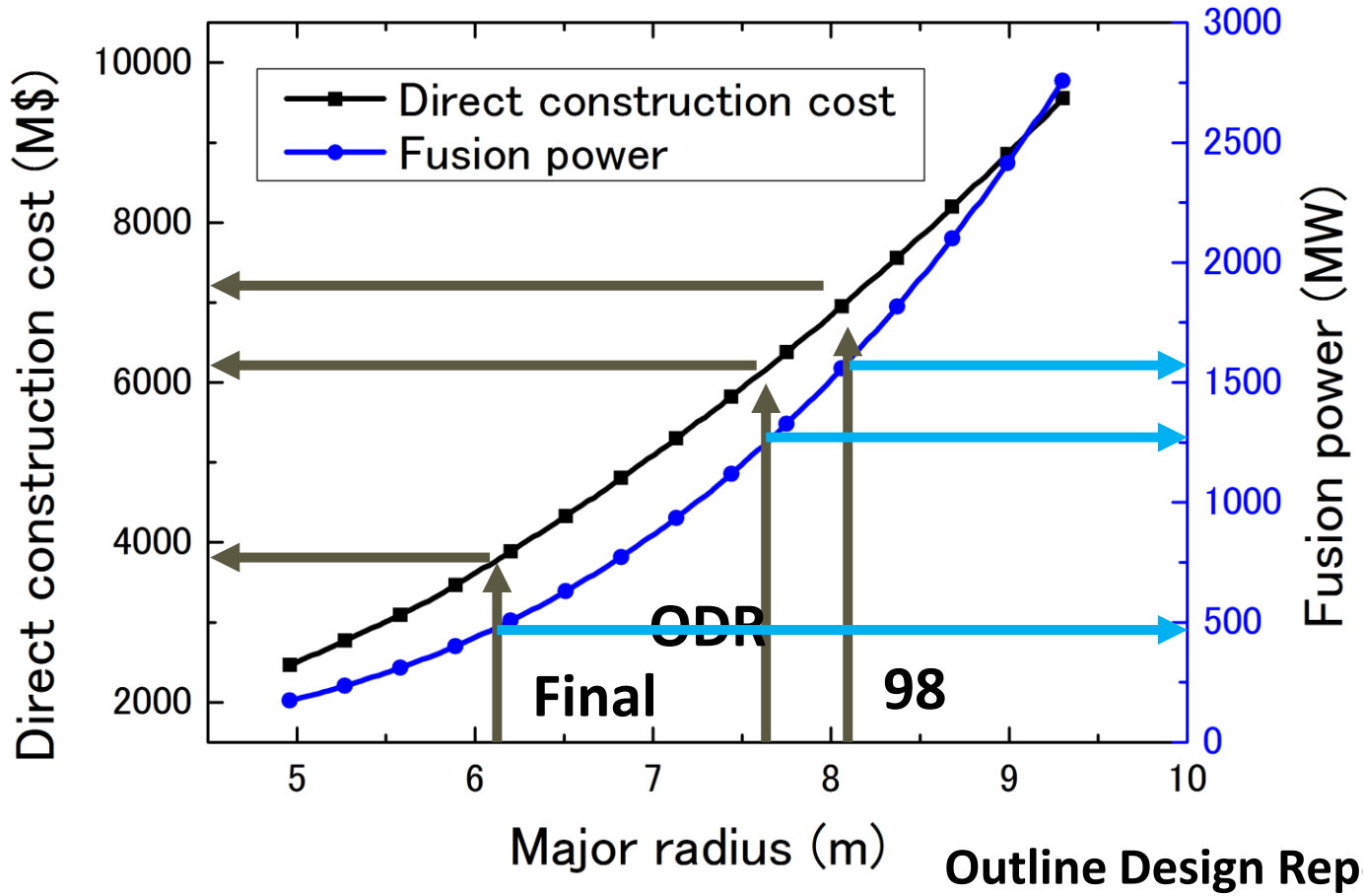
17 minor changes to simulate this ITER estimation.

CONSTRUCTION COST ESTIMATION



Updated code can reproduce the ITER estimate.

ITER DESIGNS SIMULATED BY FUSAC



Outline Design Report

Actual construction cost of ITER will be easily reflected.

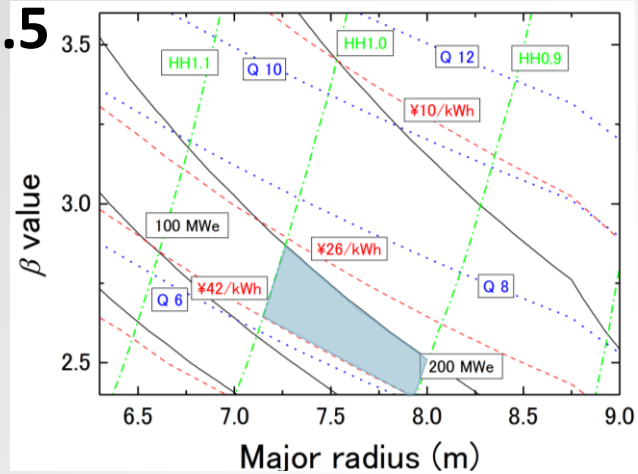
PRELIM ANALYSIS

Surveyed parameter range for LIGHT.

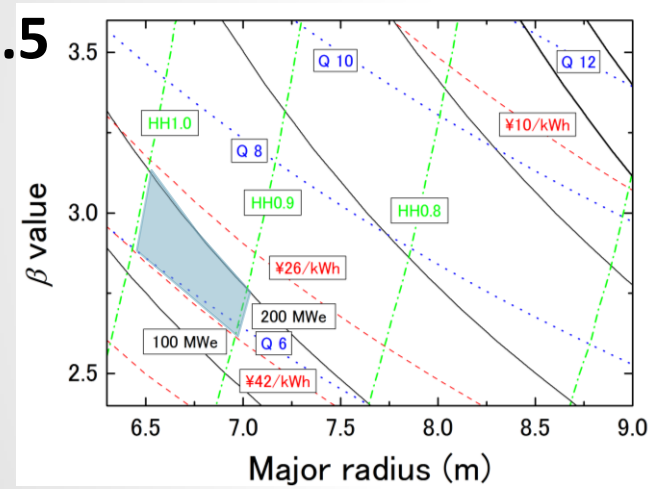
R_p = 4.8 – 9 m	κ = 1.85
A = 2.5 - 3.5	δ = 0.35
β_N = 1 - 4.1	q_{MHD} = 3.5
Te = 8 - 13 keV	B_{t_max} = 11 T

PRELIMINARY ANALYSIS

A=3.5

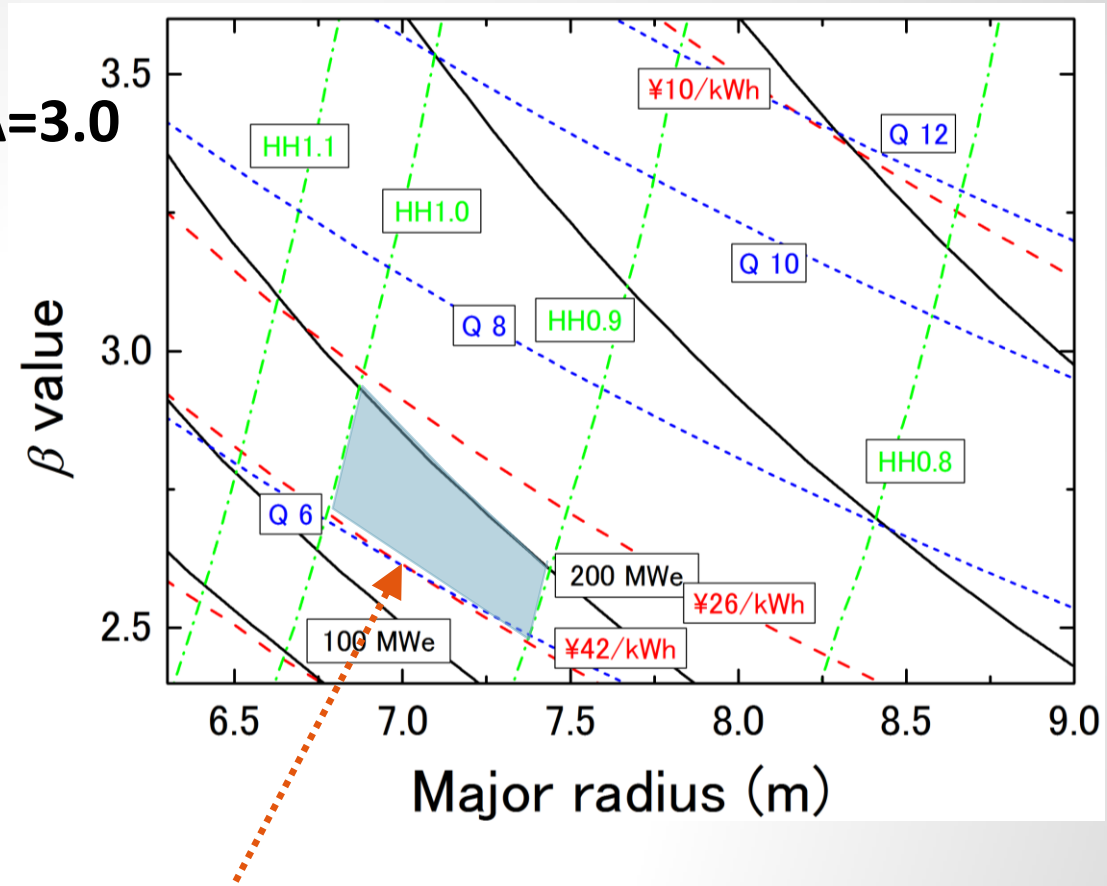


A=2.5



Te=13keV

A=3.0



P_{fus} ~ 1.0 GW, Q ~6 ➔ P_{SOL} ~ 380 MW

CANDIDATE PARAMETER

		ITER	DEMO-CREST	**LIGHT** (tentative)
Major radius	R_p	6.2 m	7.25 m	< 7.0 m
Aspect ratio	A	3.1	3.4	~3.0
Max field	B_{max}	11.8 T	16 T	11 T
Average temperature	$\langle T_e \rangle$	8.9 keV	17.9 keV	13 keV
Fusion power	P_{fus}	500 MW	1260 MW	~1000 MW
Heating	P_{CD}	73 MW	188 MW	~180 MW
Neutron wall load	P_n	0.57 MW/m^2	~ 0.8 MW/m^2	~ 0.7 MW/m^2

Quite similar with DEMO-CREST, but more conservative technologies.

POTENTIALS AND ISSUES

- High CoE as current FIT for solar powers. (42 Yen/kWh)
- Affordable scale as current FIT for solar powers. (1400 GWh/year)
- SLOW replacement scheme can be acceptable. (~ 1 year)

- Divertor flux concern because of low-*Q*.
- Analysis on construction period should be taken.

THANK YOU!