東京都市大学/早稲田大学 大学院共同原子力専攻主催
第10回未来エネルギーシンポジウム
– 次世代原子炉の安全性はどこまで高められるのか？
2014年10月31日（金）: 渋谷エクセルホテル東急（プラネッツルーム）

小型炉、革新的原子炉の安全性

関本 博

都市大客員教授

東工大名誉教授

福島第一原子炉事故

廃炉

対応

軽水炉運転再開

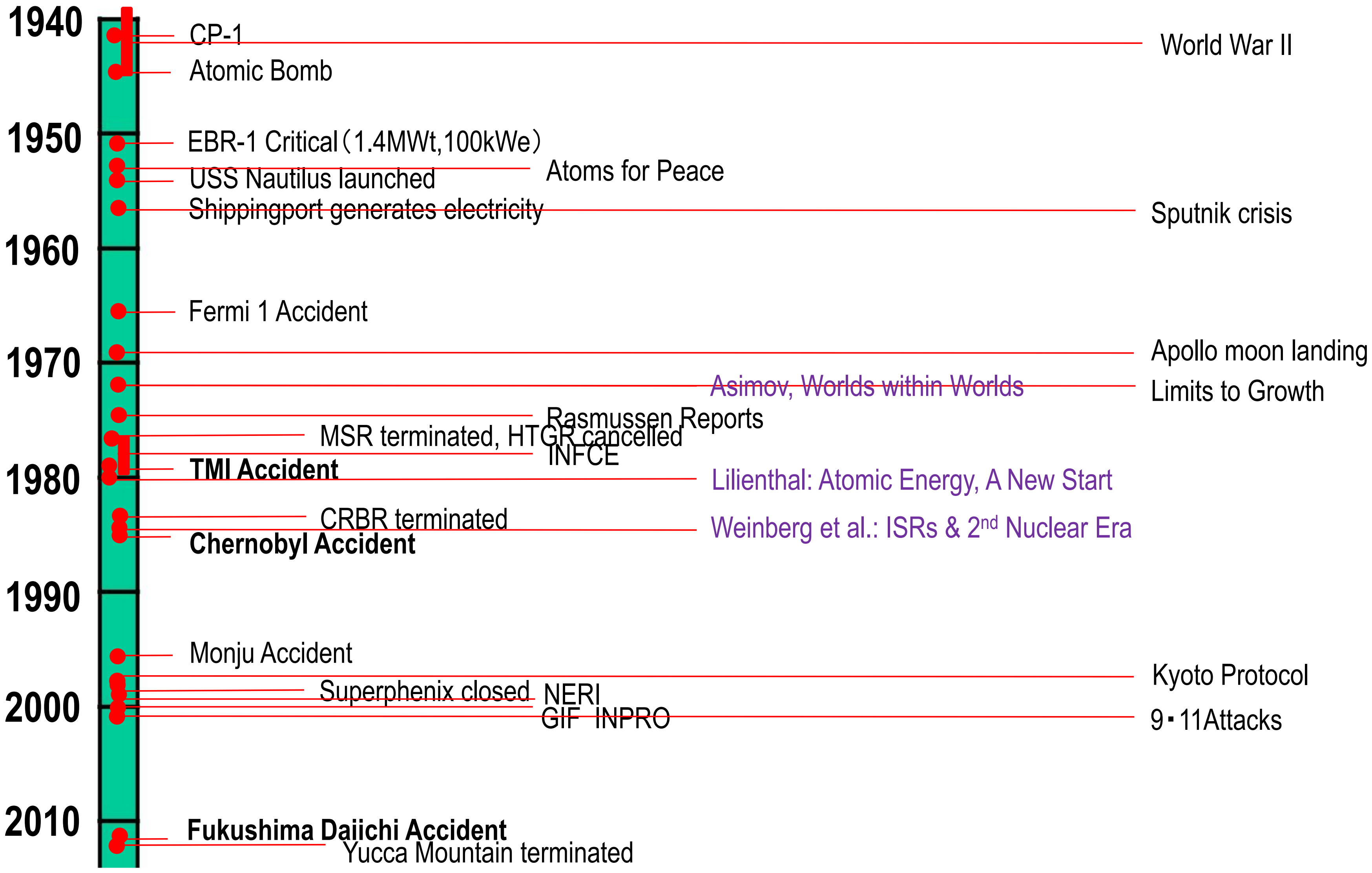
安全性を高める

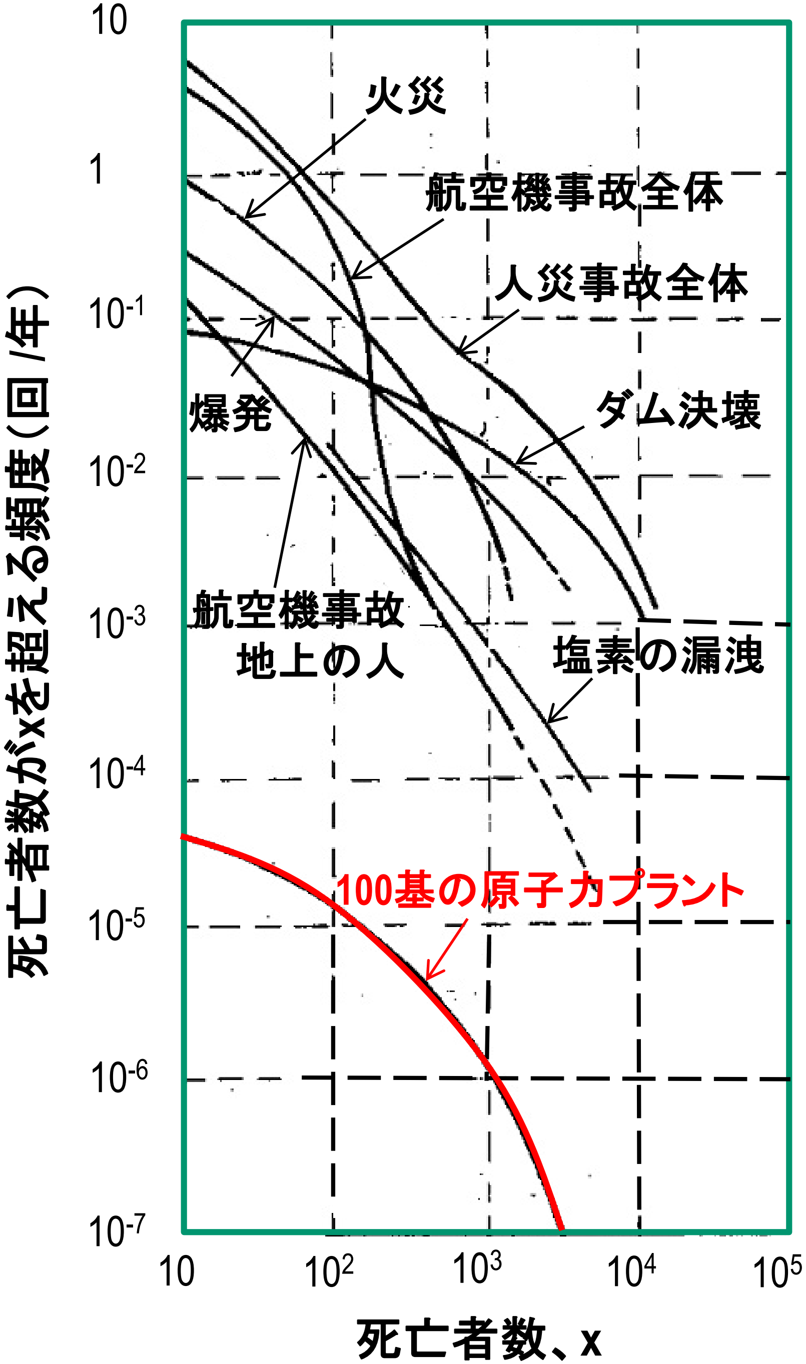
ストレステスト

安全設備、設計変更

システム改善

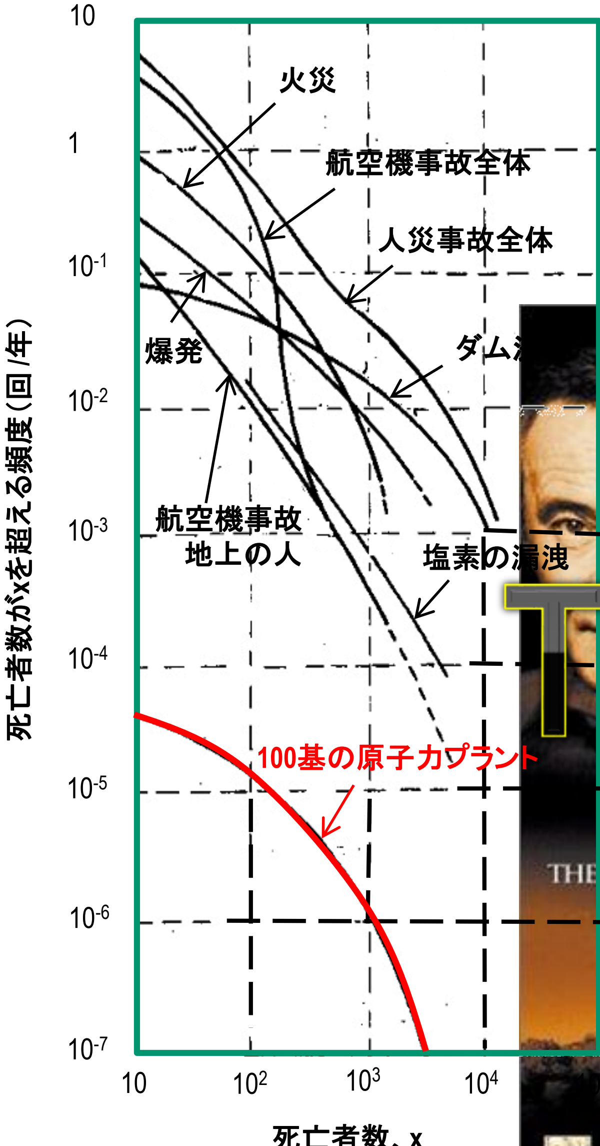
革新的原子炉に関連した簡単な歴史

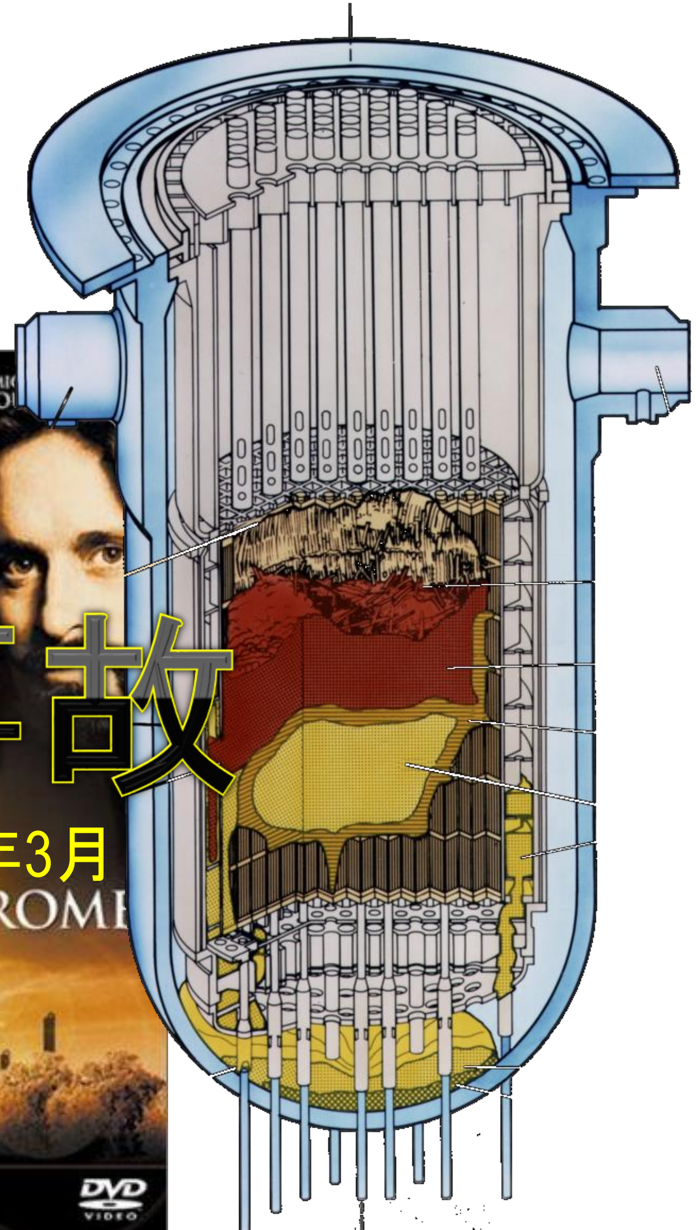




人災事故のリスクの比較

1974年WASH1400
ラスムッセン報告

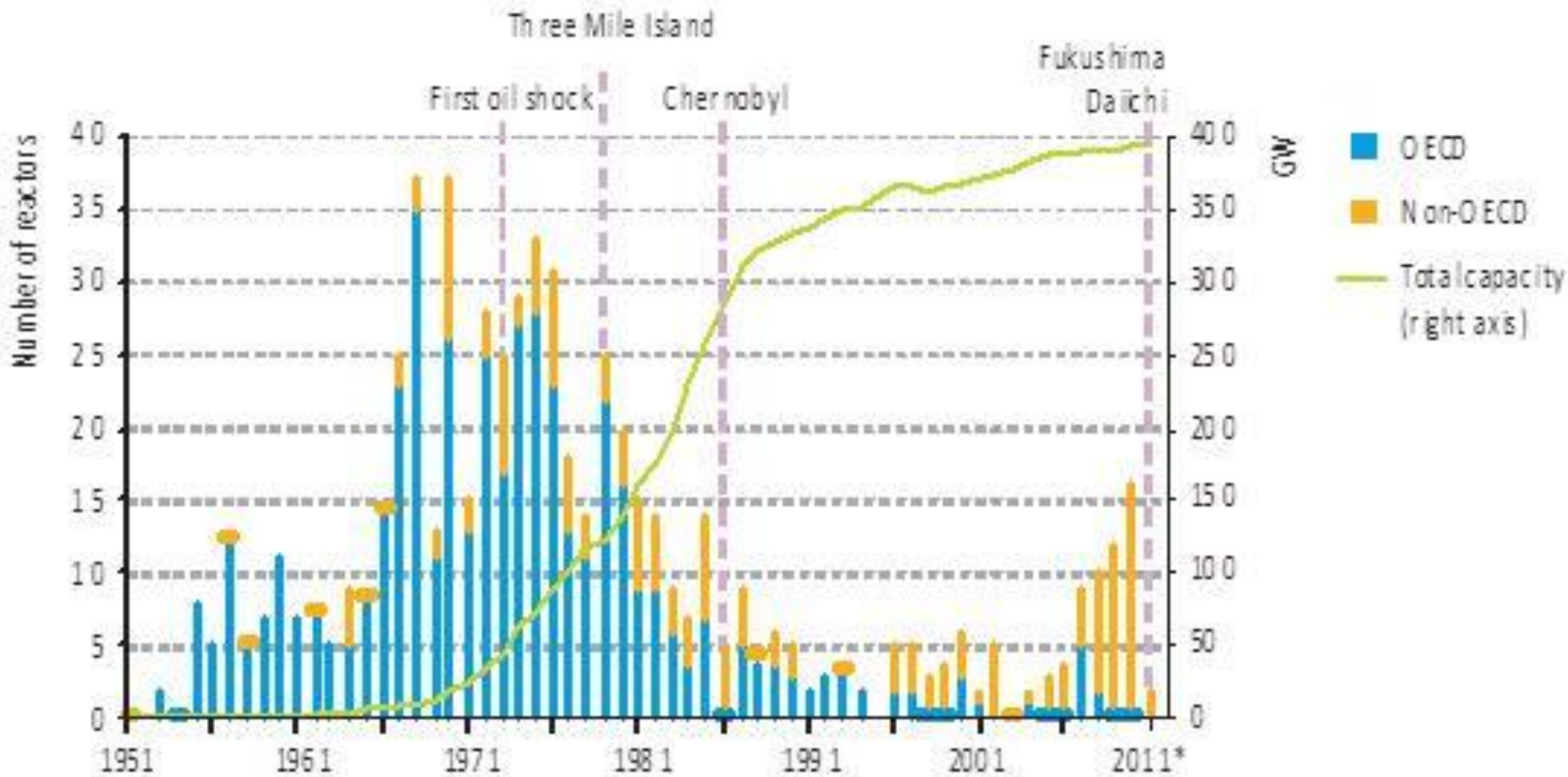




TMI事故

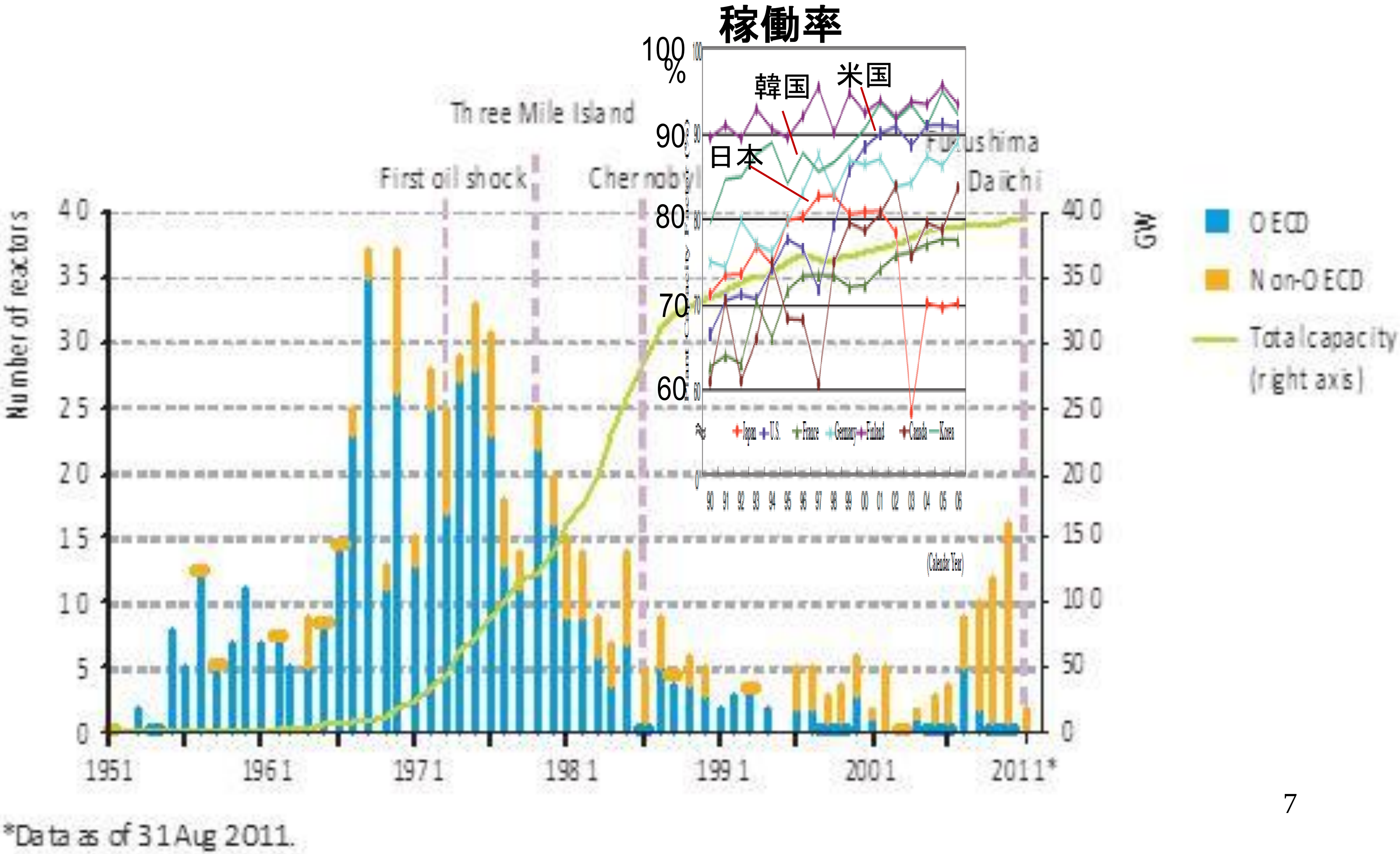
1979年3月

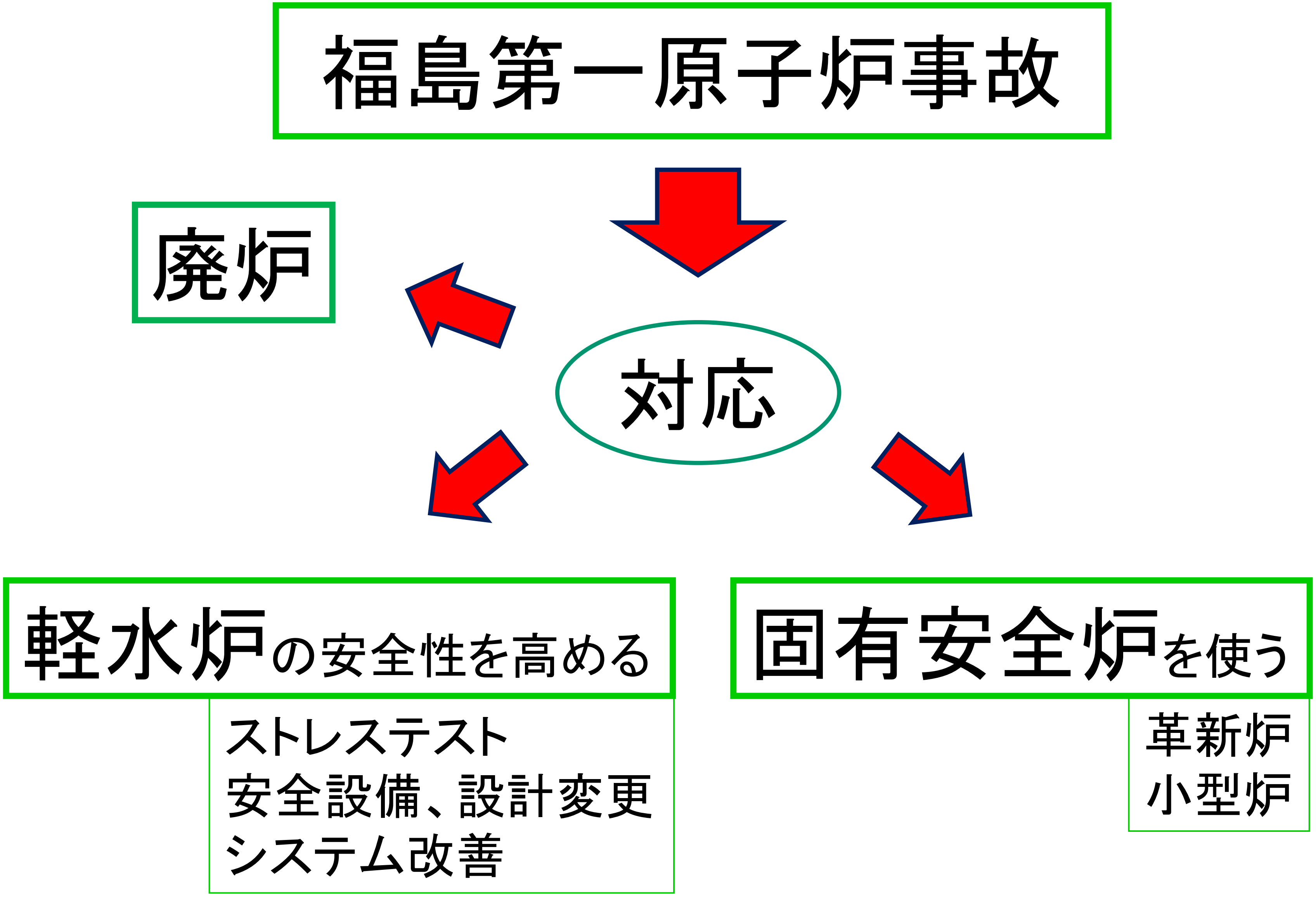
完成原子炉数と全出力



*Data as of 31 Aug 2011.

完成原子炉数と全出力


稼働率
100%
90
80
70
60
韓国
米国
日本
Three Mile Island
First oil shock
Chernobyl
Fukushima Daiichi
Number of reactors
GW
OECD
Non-OECD
Total capacity (right axis)
1951
1961
1971
1981
1991
2001
2011*
*Data as of 31 Aug 2011.


福島第一原子炉事故
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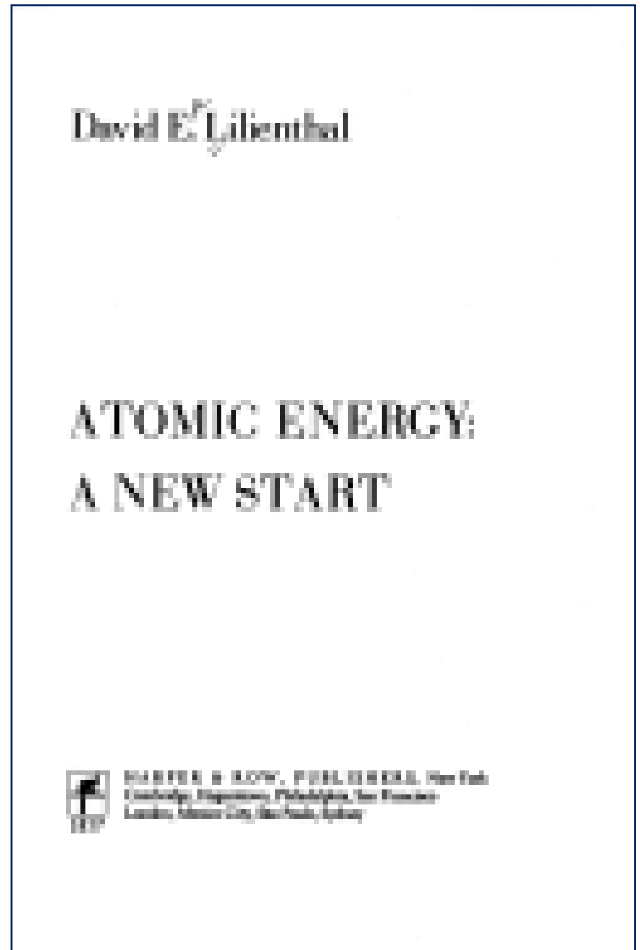
ストレステスト
安全設備、設計変更
システム改善
固有安全炉を使う
革新炉
小型炉

David E. Lilienthal

1st Chair of the AEC (1946 – 1950)



David E. Lilienthal

ATOMIC ENERGY:
A NEW START

HARPER & ROW, PUBLISHERS, New York

1980

固有安全炉

固有安全炉とは全ての安全機能が
人間の操作や動的な機器に頼らず、
物理的法則によっている原子炉である。
受動的安全炉とも呼ばれる。

安全機能:	止める（未臨界にする）	能動的→受動的
	冷やす（崩壊熱）	能動的→受動的
	閉じ込める（放射性物質）	より確実に

特長：EPZが原子炉敷地内に？

SCIENCE, Vol. 224: 29 June 1984

Inherently Safe Reactors and a Second Nuclear Era

Alvin M. Weinberg and Irving Spiewak

David Lilienthal, in his book *Atomic Energy, A New Start* (1), was among the first to call upon nuclear technologists to design a reactor that was inherently safe. He saw such a device as being necessary for a new start in atomic energy. Without such a forgiving reactor, Lilienthal doubted t
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Island in
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Nevertheless, in May of 1980, the Institute for Energy Analysis under the

P. Cohen of Westinghouse, J. Dietrich of Combustion Engineering, M. Edlund of Babcock and Wilcox, P. Fortescue of General Atomic, K. Davis, then of Bechtel and later deputy secretary of energy, H. Kendrick of Department of Energy, U. Gat of Oak Ridge National Laboratory, and H. G. MacPherson, J. A. Lane, E. P. Epler, M. W. Firebaugh, and the authors, associated with the Institute itself.

We concluded that a serious study of more forgiving, or perhaps even inherently safe, reactors was a good idea, but the study would have to begin by assessing the safety of existing light-water reactors and of incremental improvements to light-water reactors (3). Most of the participants in the workshop believed that such a reexamination would confirm the widely held view that light-water
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is director of the Institute for
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formerly section head in the
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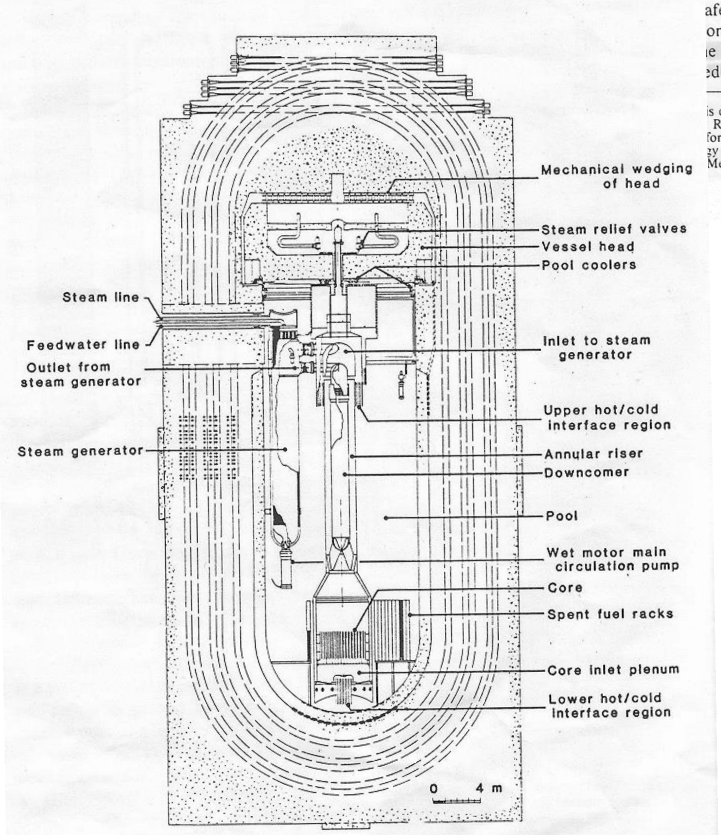
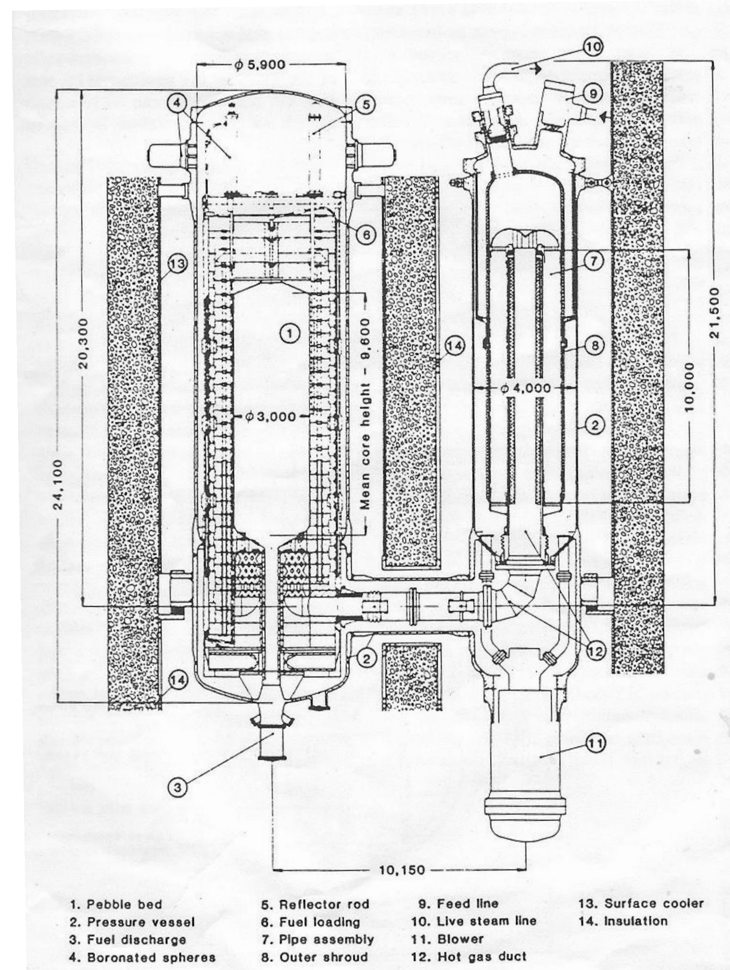
Mellon Fellow at the Institute

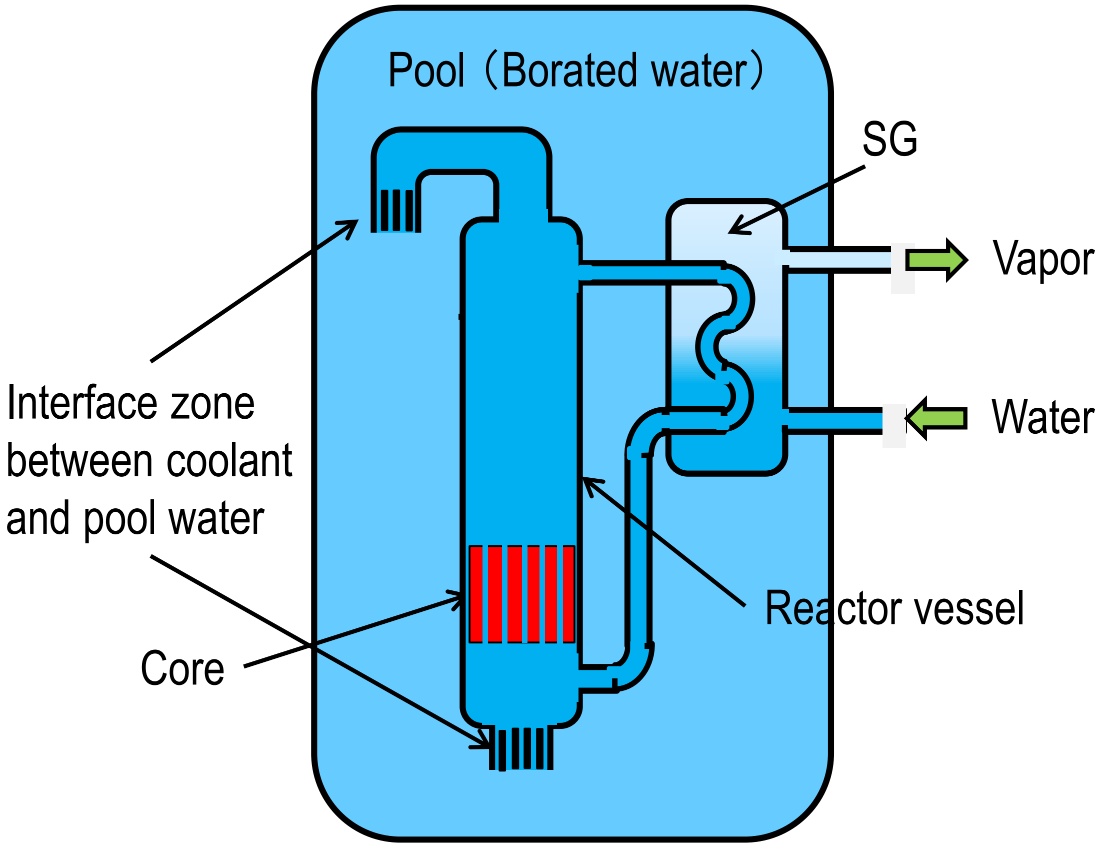


PIUS reactor

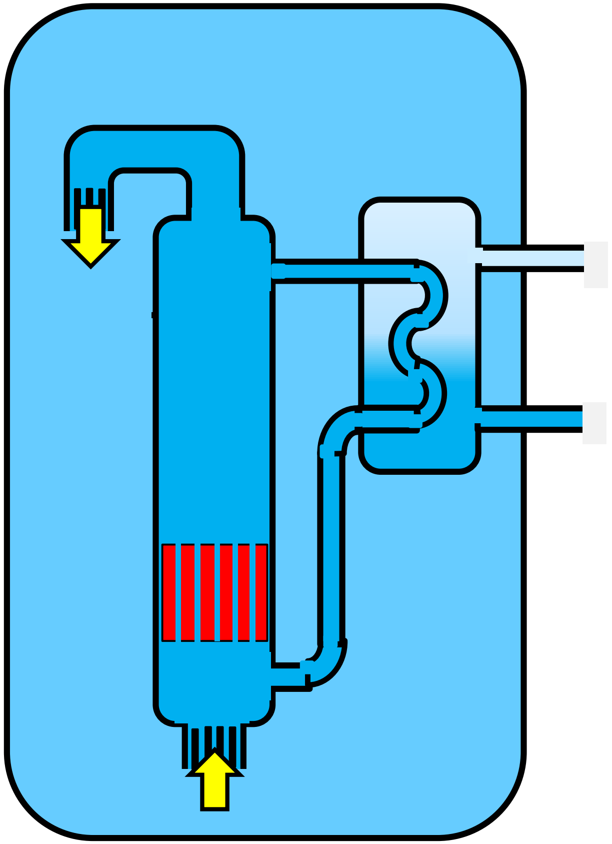


Modular HTR reactor

PIUS Reactor



normal operation



accident

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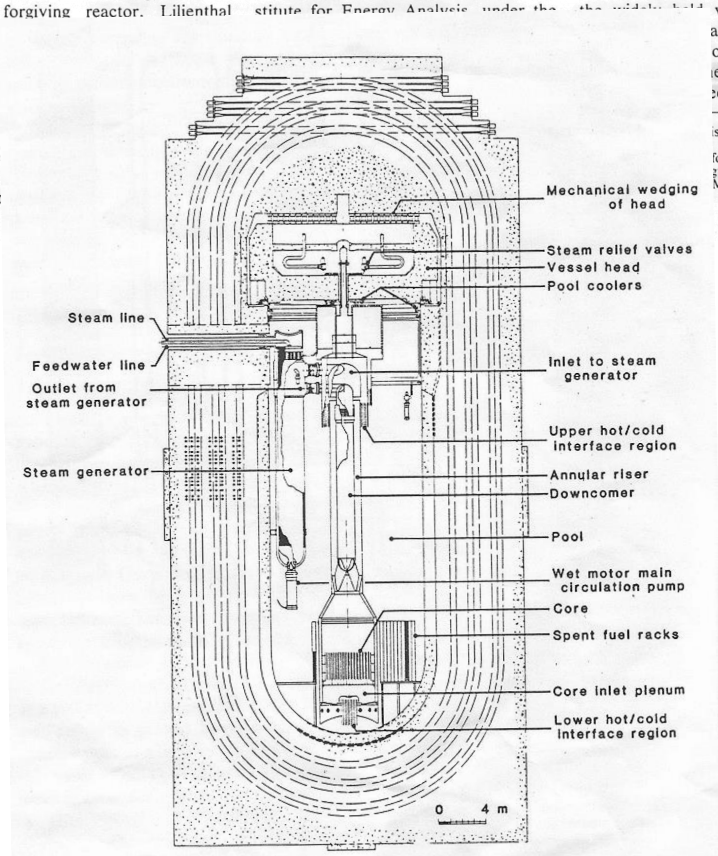
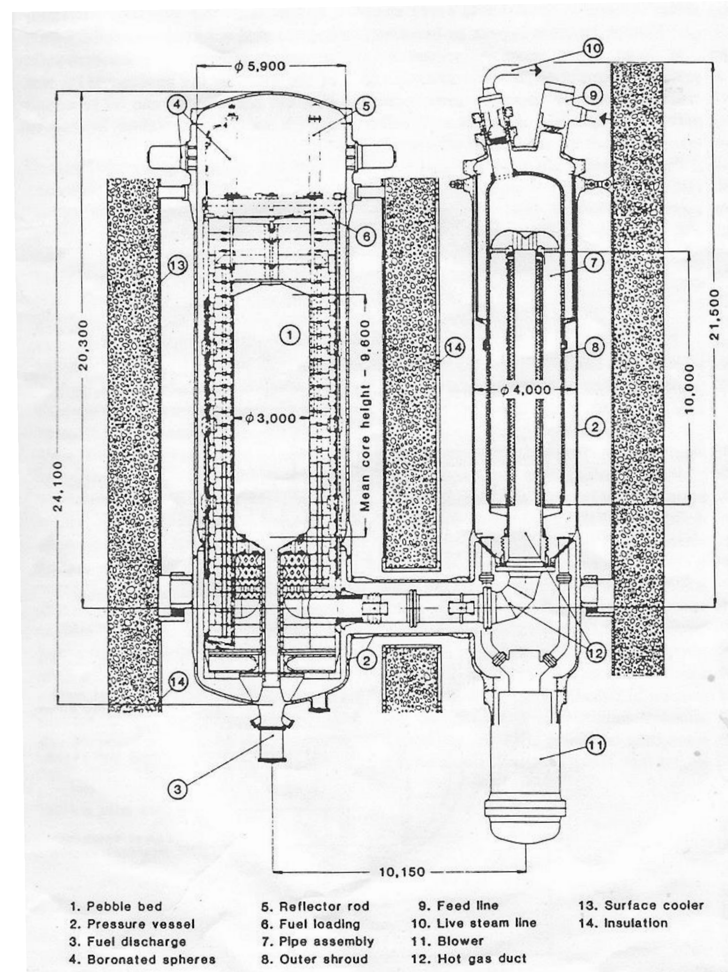
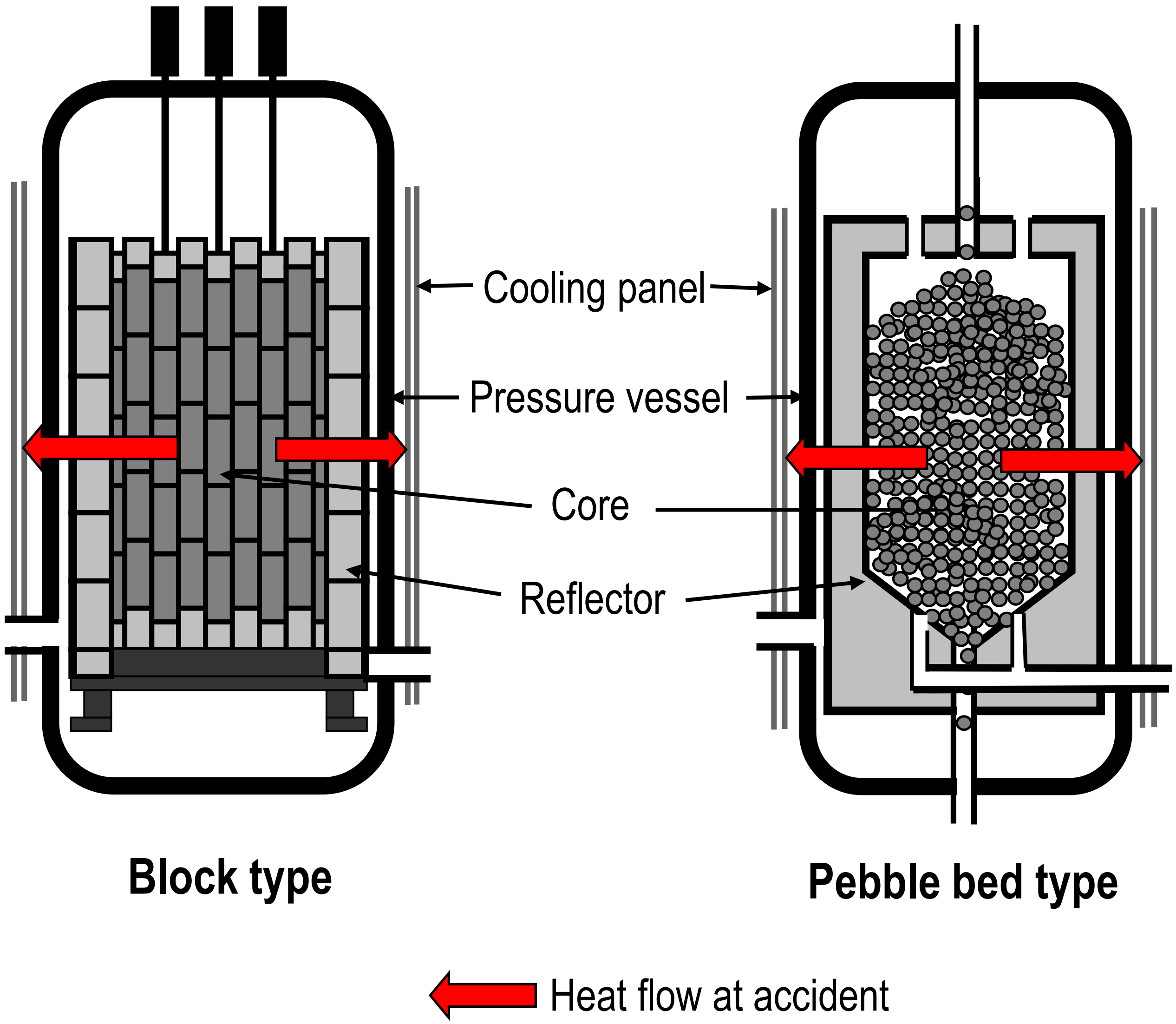


PIUS reactor

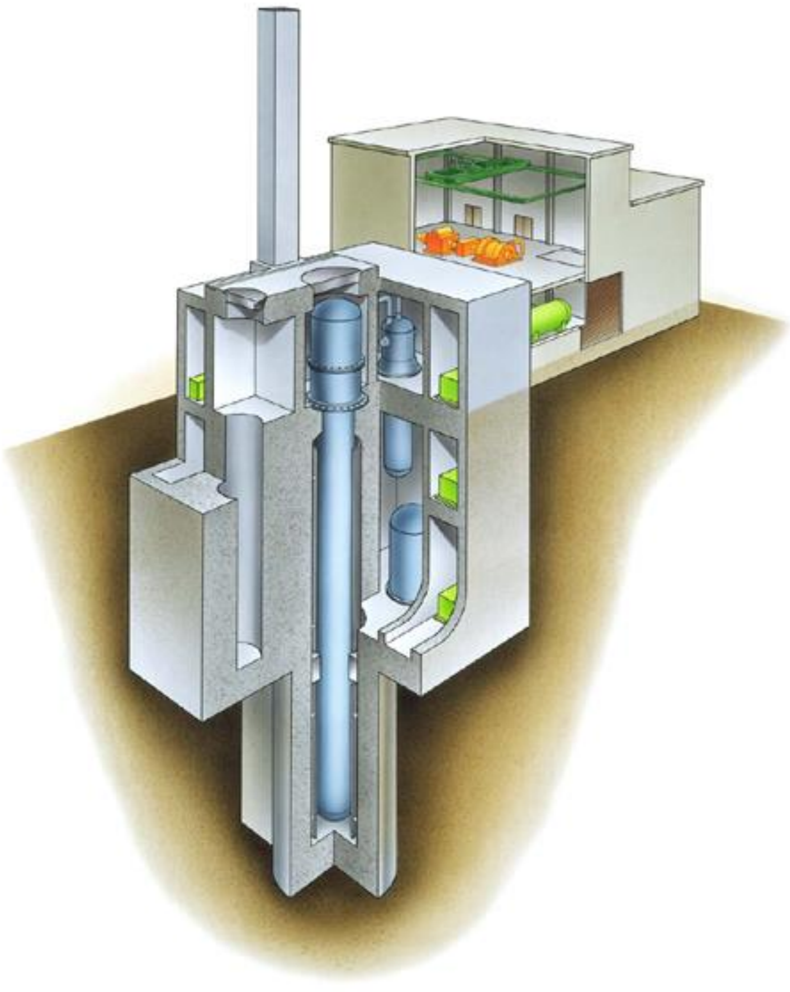


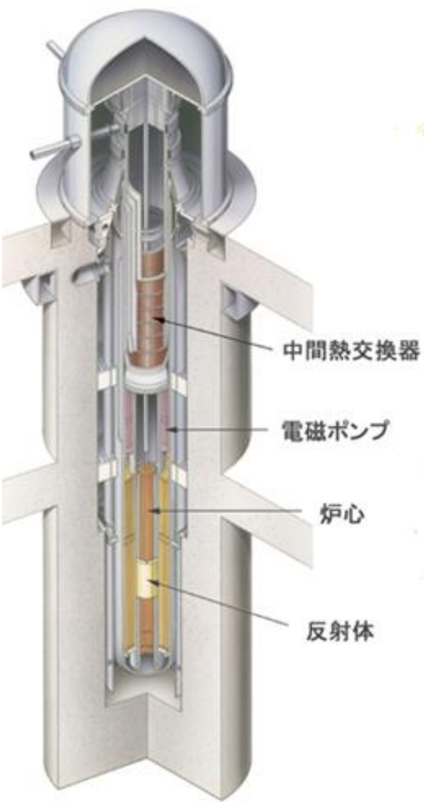
Modular HTR reactor

Modular HTR Reactor



4S (Super Safe, Small and Simple)

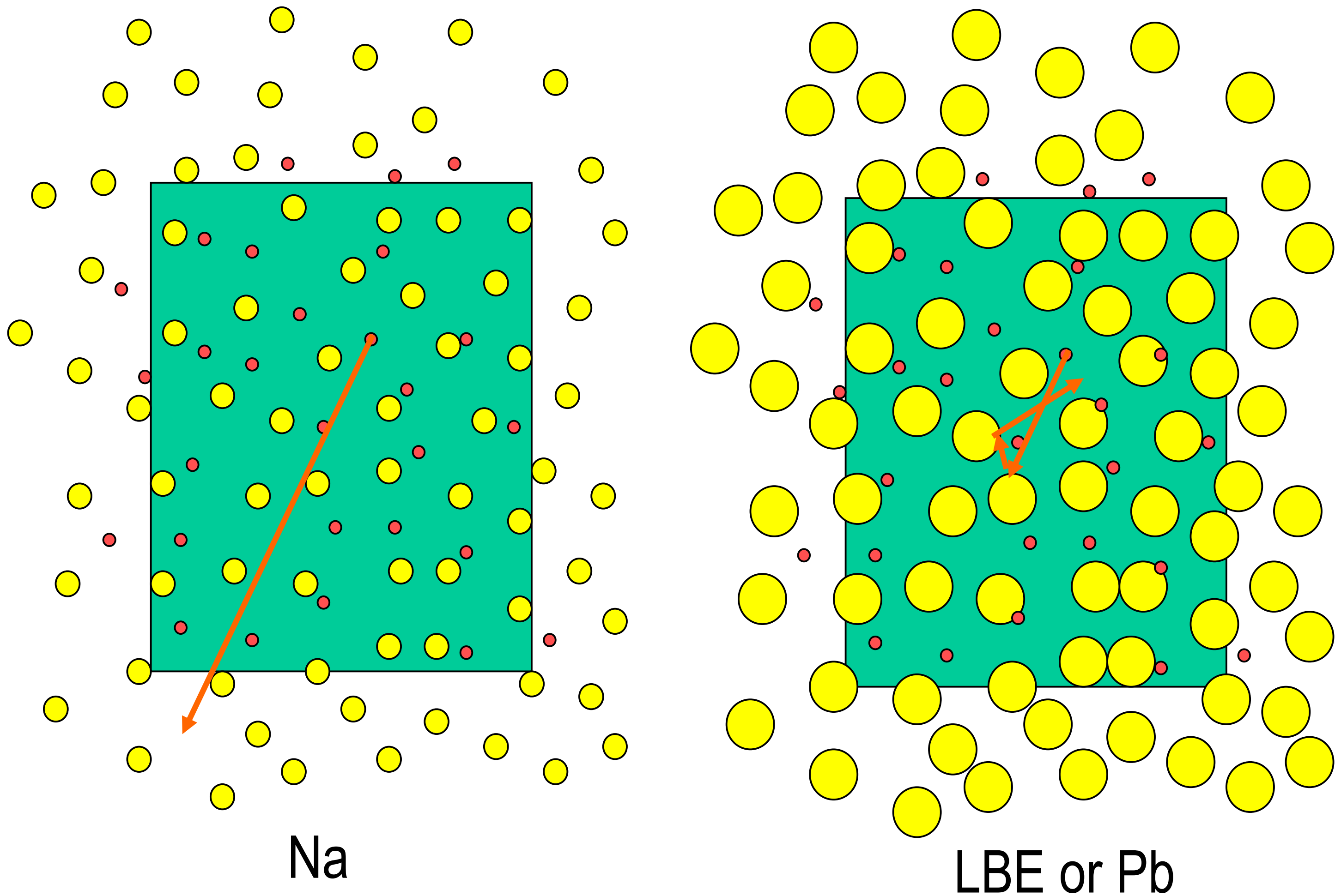




Main Design Parameters

Reactor Thermal Output	150	MWt
Reactor Electric Output	53	MWe
Reactor Outlet Temperature	510	℃
Reacot Inlet Temperature	360	℃
Reactor Vessel Diameter	5.2	m
Reacor Vessel Height	15.2	m
Core Barrel Diameter	3.4	m
Type of Steam Generator	Serpentine Tube	
No. of Steam Generators	2	unit
Type of Pump	Centrifuge Pump	
No. of Circulating Pump	2	unit
Total Pressure Drop	0.7	kg/cm2
Pb-Bi Coolant Flow Rate	12300	ton/hr
Pb-Bi Coolant Core Velocity	0.9	m/s
Feed Water Temperature	210	℃
Feed Water Flow Rate	294	ton/hr
SG Outlet Steam Temperatu	280	℃
SG Outlet Steam Pressure	6.47	MPa
Turbine Efficiency	35	%

中性子の漏えい



散乱断面積の大きいLBEやPbは中性子の閉じ込め性能が高い

1） 閉じ込め性能が高い冷却材は小型炉の設計が容易になる。

2） 閉じ込め性能が高い冷却材が無くなると、反応度が大きく下がり安全性が高まる。

小型炉の安全性

安全機能

止める（未臨界にする）

反応度係数がより負←中性子の漏れの効果が大

受動的原子炉停止が容易に

冷やす（崩壊熱）

炉心表面からの熱放出大←炉心半径小

受動的崩壊熱除去が容易に

閉じ込める（放射性物質）

放射能の閉じ込め量が小

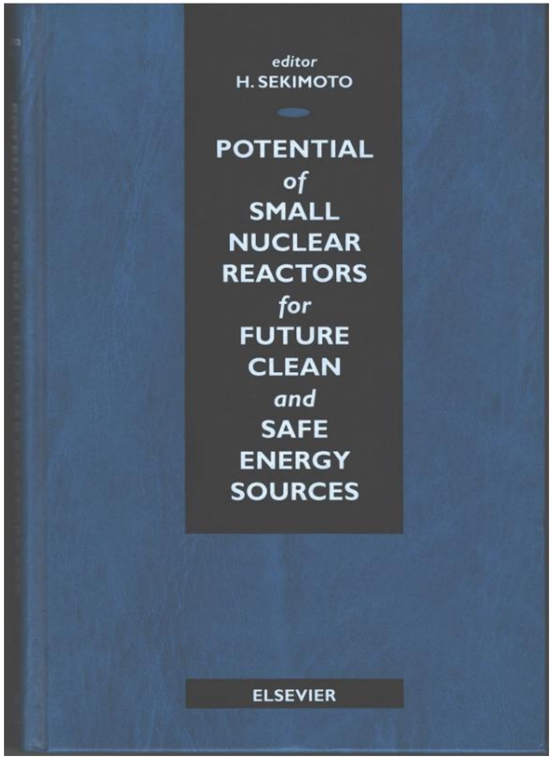
漏れの確率が小←表面積小

地下立地が容易

小型炉国際会議

SR/TIT

International Specialists' Meeting on
Potential of Small Nuclear Reactors for
Future Clean and Safe Energy Sources
Tokyo, Japan, 23-25 October, 1991



Water Cooled Reactors

SPWR, TRIGA-PS, DHR, MRX, DRX

Gas Cooled Reactors

MHTGR, Peu-a-Peu, CNPS

Fast Reactors

IFR, 4S, LSPR

Other Reactors

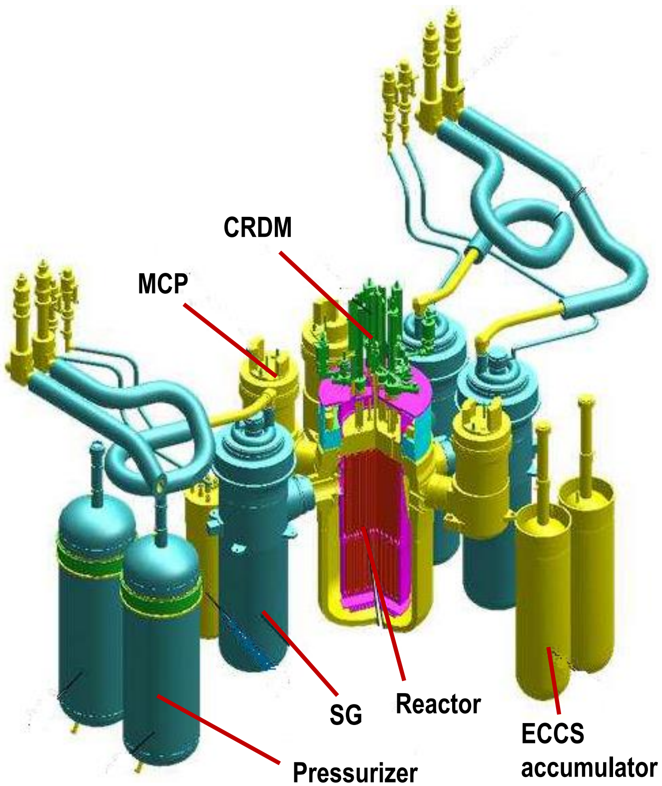
(mini)FUJI, Fluidized-Bed

小型炉リスト

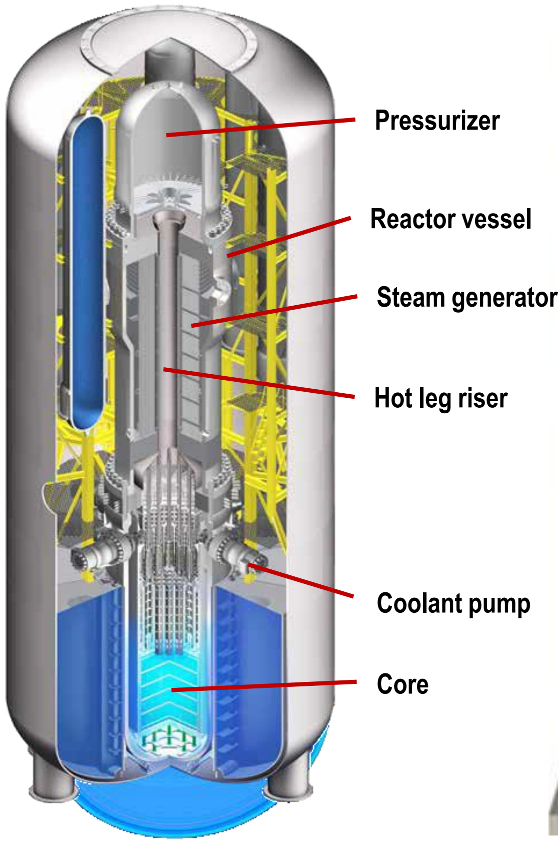
Name	Capacity	Type*	Developer
CAREM	27-100 MWe	PWR	CNEA + INVAP, Argentina
MRX	30-100 MWe	PWR	JAERI, Japan
KLT-40S	35 MWe	PWR	OKBM, Russia
NuScale	45 MWe	PWR	NuScale Power + Fluor, USA
Flexblue	50-250 MWe	PWR	Areva TA, France
SMART	100 MWe	PWR	KAERI, South Korea
ACP100	100 MWe	PWR	CNNC + Guodian, China
NP-300	100-300 MWe	PWR	Areva TA, France
IRIS	100-335 MWe	PWR	Westinghouse-led, international
mPower	150-180 MWe	PWR	B&W + Bechtel, USA
SMR-160	160 MWe	PWR	Holtec, USA
Westinghouse SMR	225 MWe	PWR	Westinghouse, USA
VK-300	300 MWe	BWR	Atomenergoproekt, Russia
PBMR	165 MWe	HTR	Escom, South Africa, et al.
HTR-PM	2x100 MWe	HTR	INET + HSNPC, China
SC-HTGR (Antares)	250 MWe	HTR	Areva, France
GT-MHR	285 MWe	HTR	GA + Minatom, USA-Russia
4S	10-50 MWe	FNR	Toshiba, Japan
SVBR	10-100 MWe	FNR	AKME (Rosatom), Russia
Hyperion Power Module	25 MWe	FNR	Hyperion Pwr Gen, USA
LSPR, PBWFR	50-150 MWe	FNR	TokyoTech, Japan
ALFRED	120-600 MWe	FNR	Ansaldo, Italy
EM^2	240 MWe	FNR	GA, USA
BREST	300 MWe	FNR	RDIPE, Russia
S-PRISM	311 MWe	FNR	GE-Hitachi, USA
PB-AHTR	410 MWe	FHR	MIT + UCB + UWM, USA
FUJI, miniFUJI	10, 100-200 MWe	MSR	IThEMS, Japan-Russia-USA
IMSR	45 MWe	MSR	Terrestrial Energy, USA

* PWR: pressurized water reactor
BWR: boiling water reactor
HTR: high-temperature reactor
FNR: fast neutron reactor
FHR: Flibe cooled HTR
MSR: molten salt reactor

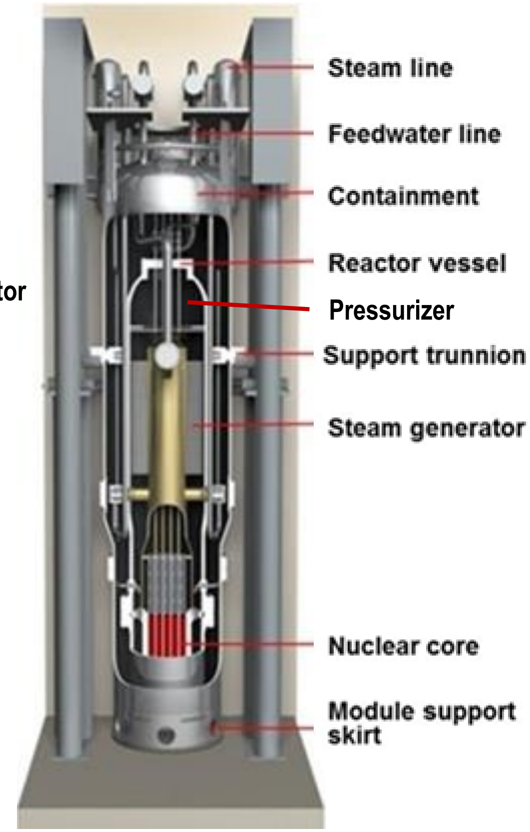
Some of the Present Small LWRs



KLT-40S



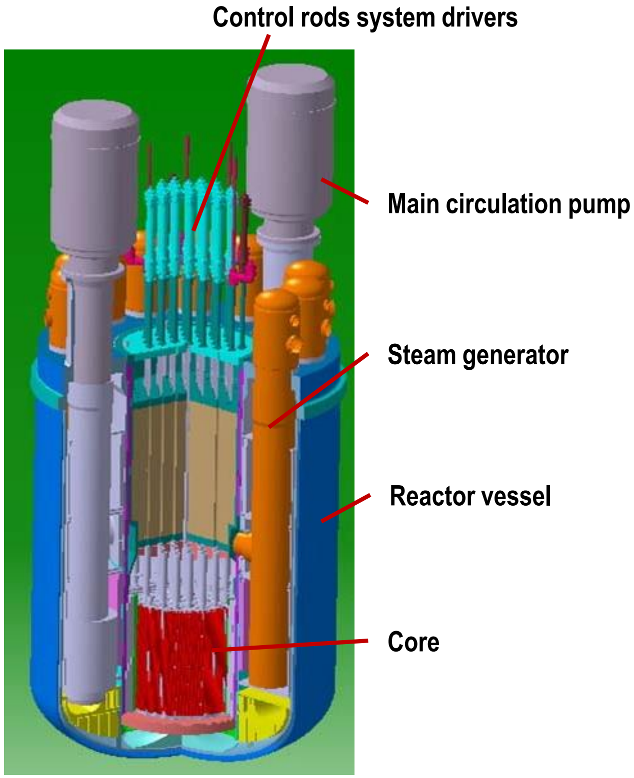
Westinghouse SMR



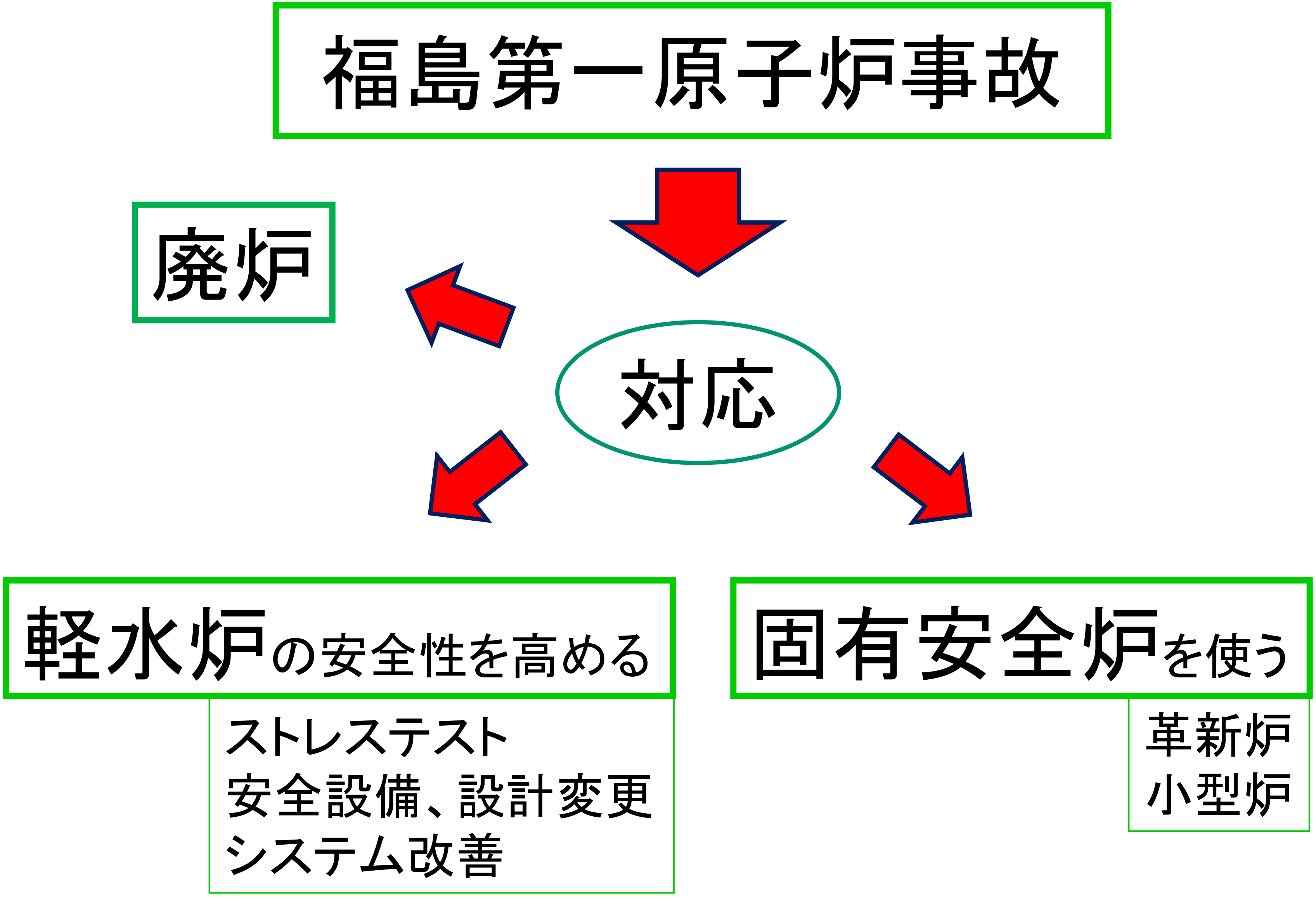
NuScale

Some of the Present Small FR

EM²



SVBR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革新炉
小型炉

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ありがとうございました