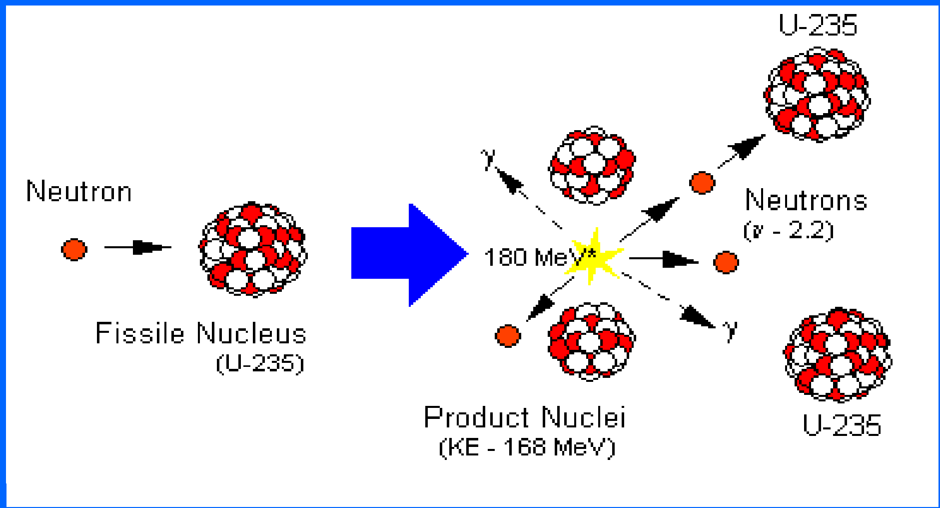
Thorium som energiressurs

Fordeler og ulemper

Sverre Hval

Institutt for energiteknikk

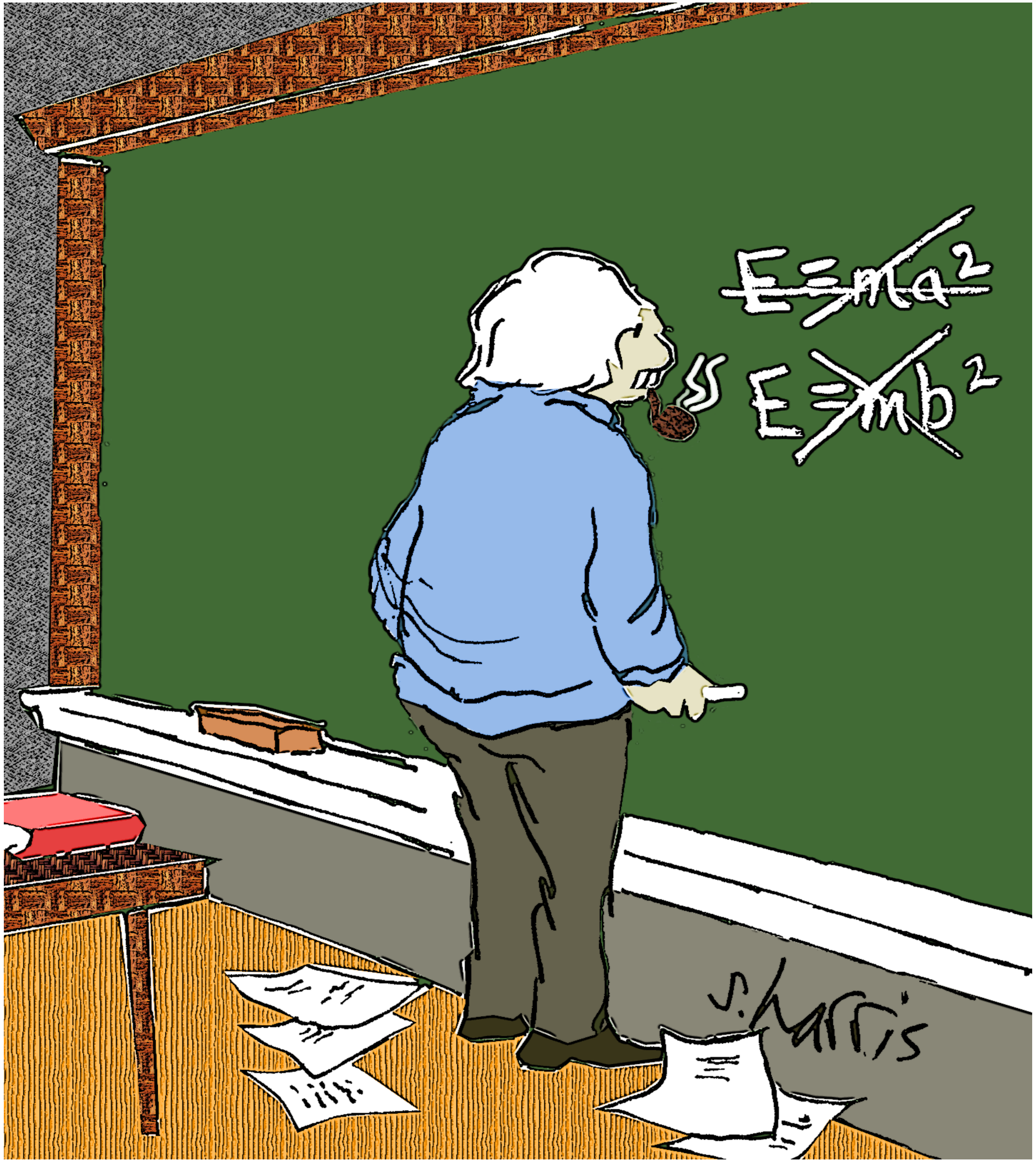
F I S J O N



$$E = mc^2$$

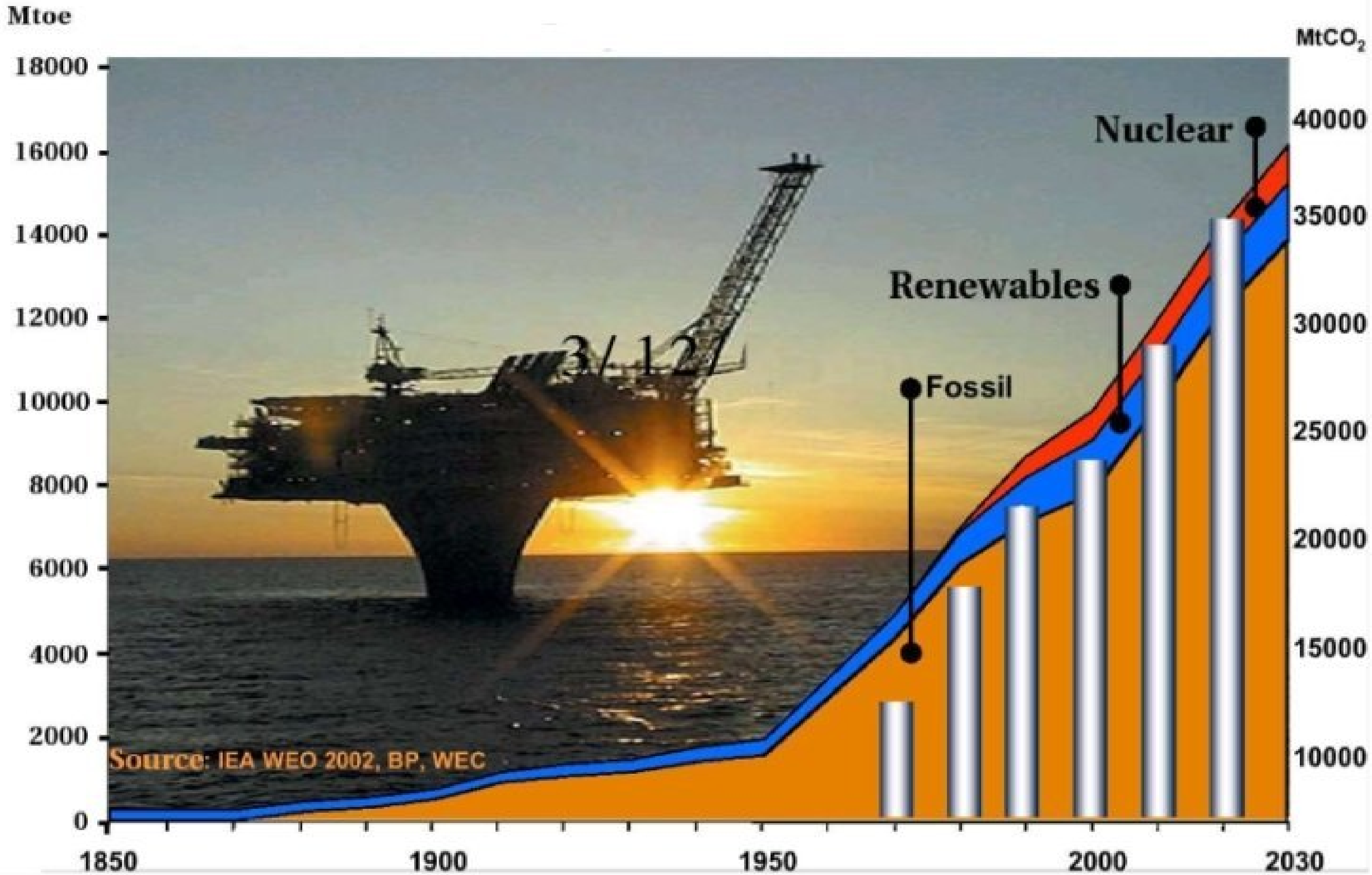
Massen avtar 1 promille, og omdannes til 200 MeV energi.

Stråling: γ: 0 - 7 MeV; nøytroner 0 - 10 MeV


E=ma²
E=mb²
S. Harris

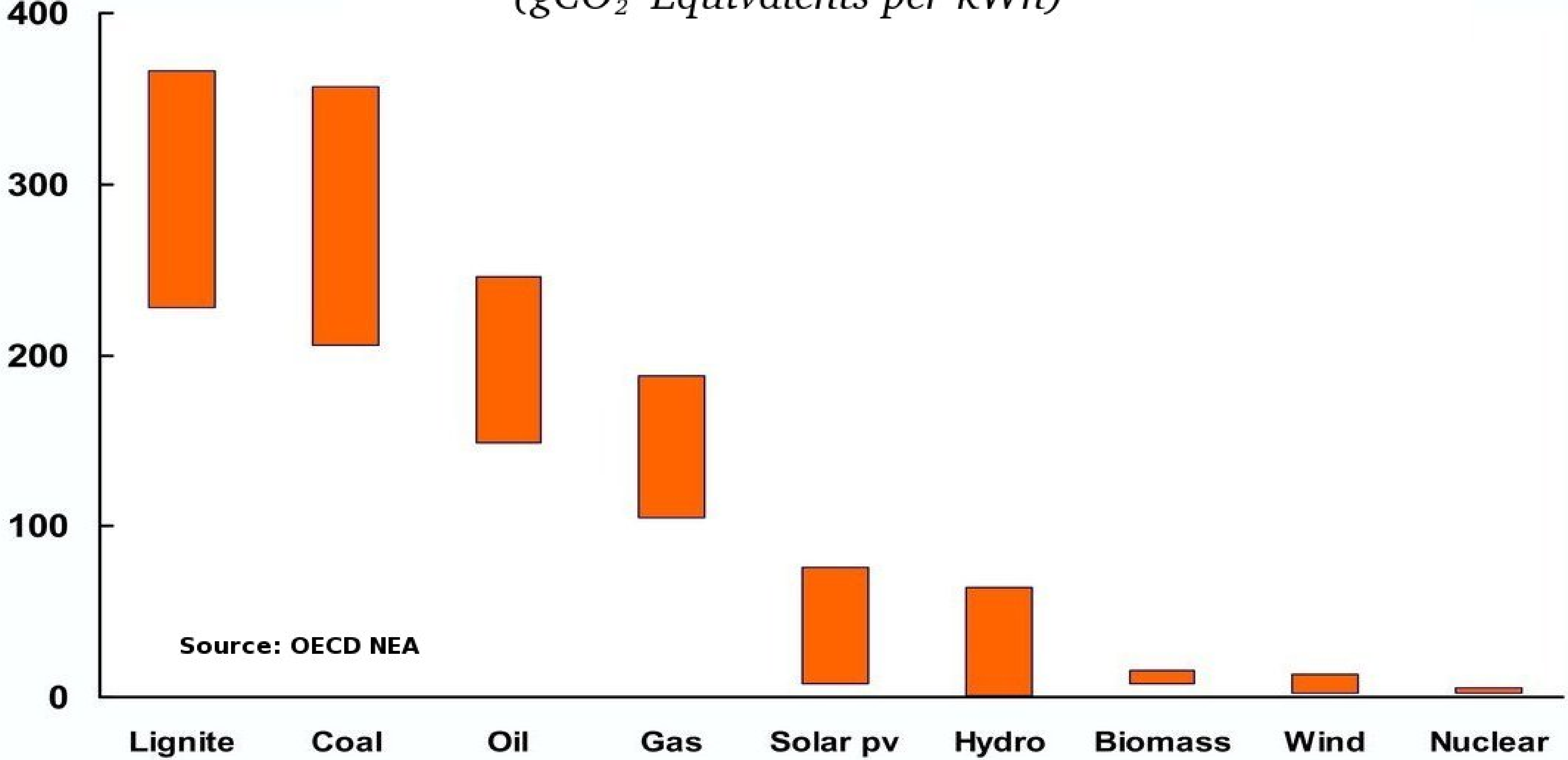
A Challenge for Mankind

Global Energy Consumption 1850 - 2030



Greenhouse Gas Emission from Electricity Production

(gCO_2 Equivalents per kWh)



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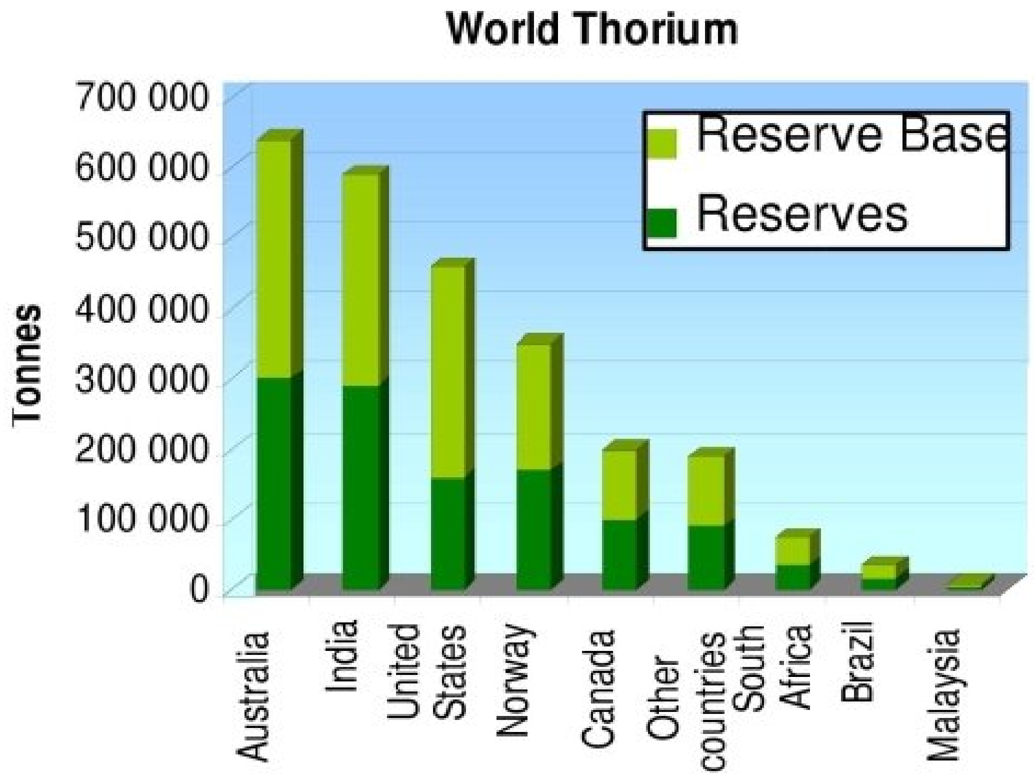
$$^{232}Th + n \quad \rightarrow \quad ^{233}Th \quad \underset{22\ \mathrm{min}}{\rightarrow} \quad ^{233}Pa \quad \underset{27\ \mathrm{d}}{\rightarrow} \quad ^{233}U$$

Thorium in Norway



US Geological Survey:

- Norway has one of the major thorium reserves in the world.

NGU:

- No systematic exploration for thorium has been performed
- Fensfeltet is the most promising
- Low concentration, 0.1-0.4 wt%
- The particles are too small for flotation
- Norway has a potential resource
- More exploration required

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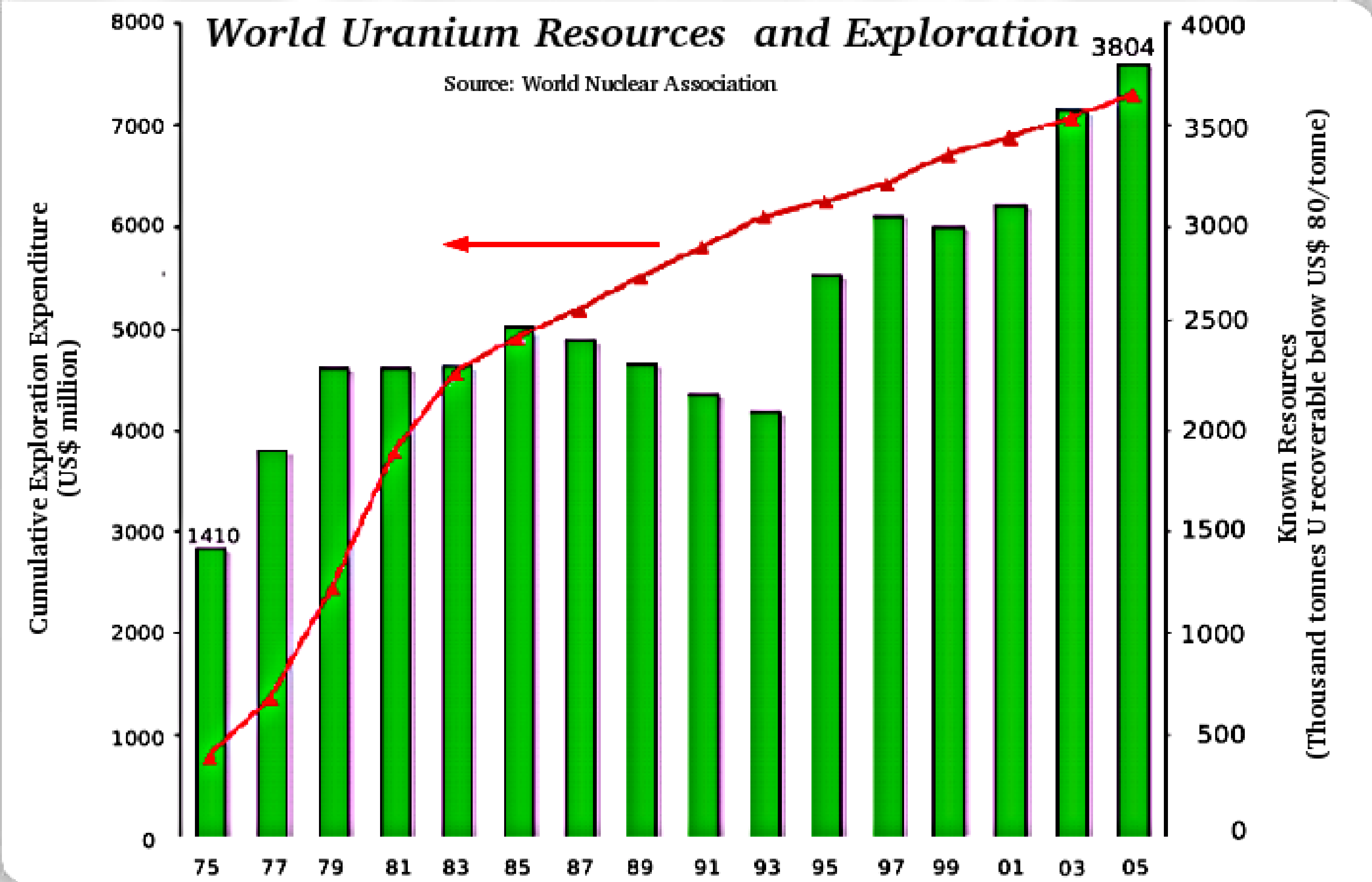
- Can "burn" radioactive waste (fission, transmutation)
- Less risk for misuse in nuclear weapons?


World Uranium Resources and Exploration
Source: World Nuclear Association
Cumulative Exploration Expenditure (US$ million)
Known Resources (Thousand tonnes U recoverable below US$ 80/tonne)
8000
7000
6000
5000
4000
3000
2000
1000
0
4000
3500
3000
2500
2000
1500
1000
500
0
1410
3804
75
77
79
81
83
85
87
89
91
93
95
97
99
01
03
05

Some Thorium Reactors

Country	Name	Type	Power	Operation
Germany	AVR	HTGR	15 MW_e	1967 - 1988
Germany	THTR	HTGR	300 MW_e	1985 - 1989
UK, OECD- EURATOM + Norway, Sweden and Switzerland	Dragon	HTGR	20 MW_{th}	1966 - 1973
USA	Fort St Vrain	HTGR	330 MW_e	1976 – 1989
USA, ORNL	MSRE	MSBR	7.5 MW_{th}	1964 – 1969
USA	Shippingport & Indian Point	LWBR PWR	100 MW_e 285 MW_e	1977 – 1982 1962 – 1980
India	KAMINI, CIRUS & DHRUVA	MTR	30 kW_{th} 40 MW_{th} 100 MW_{th}	Operating

Thorium as Nuclear Fuel

- **Fuel production:**
  More complex and expensive than U
- **Fuel behaviour:**
  Behaves remarkably well in LWR and HTR fuel. Tecnically well established as nuclear fuel
- **Reprocessing:**
  Requires a substantial amount of development
- **Waste management:**
  Follows known methods
- **Radiation protection:**
  Somewhat simpler than for uranium
- **Thorium-plutonium MOX-fuel:**
  Technically, the best way to dispose of a plutonium stockpile

Thorite

Most of the thorium projects terminated by 1990

Main reasons:

- The thorium fuel cycle could not compete economically with the well-established uranium cycle
- Lack of political support for the development of nuclear technology after the Chernobyl accident in 1986
- Increased worldwide concern about proliferation risks associated with reprocessing of spent fuel

The exception is India, which will utilize thorium for its long term energy security. Plans for 200 000 MW_e by 2050

Reactor types for thorium

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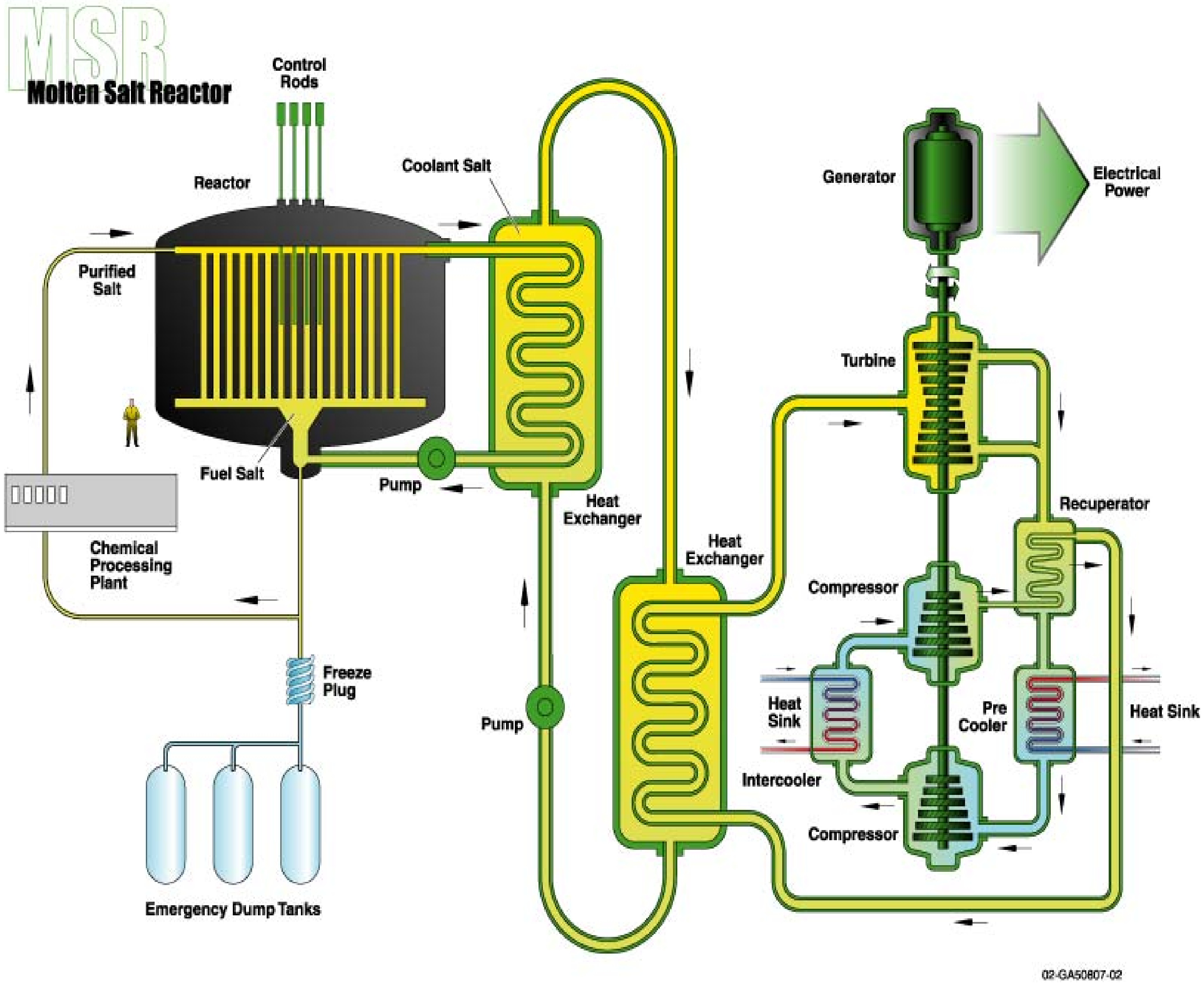
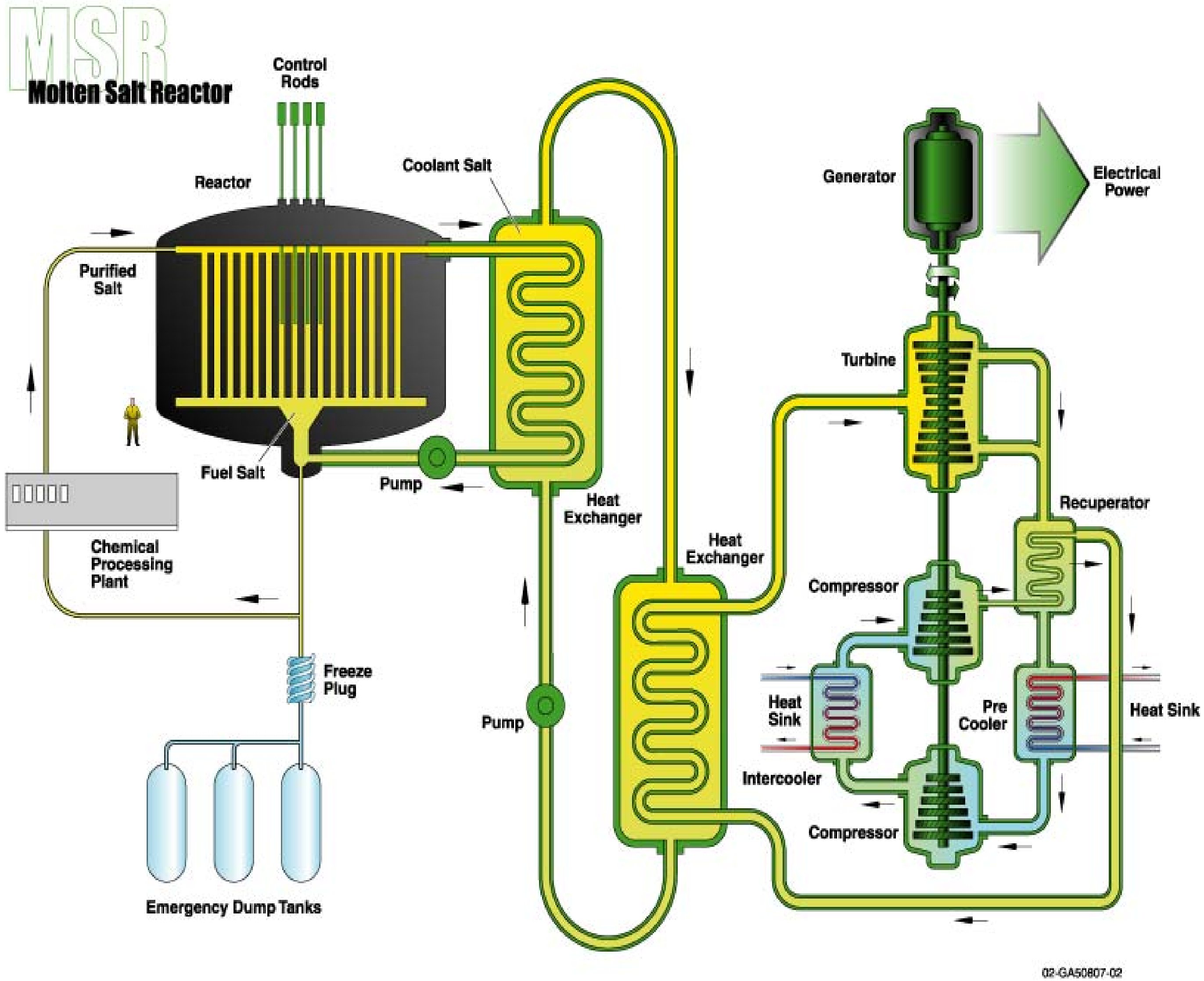
Molten Salt Reactor

Molten U/Th fluorides



Molten Salt Reactor

Molten U/Th fluorides
Simple fuel production



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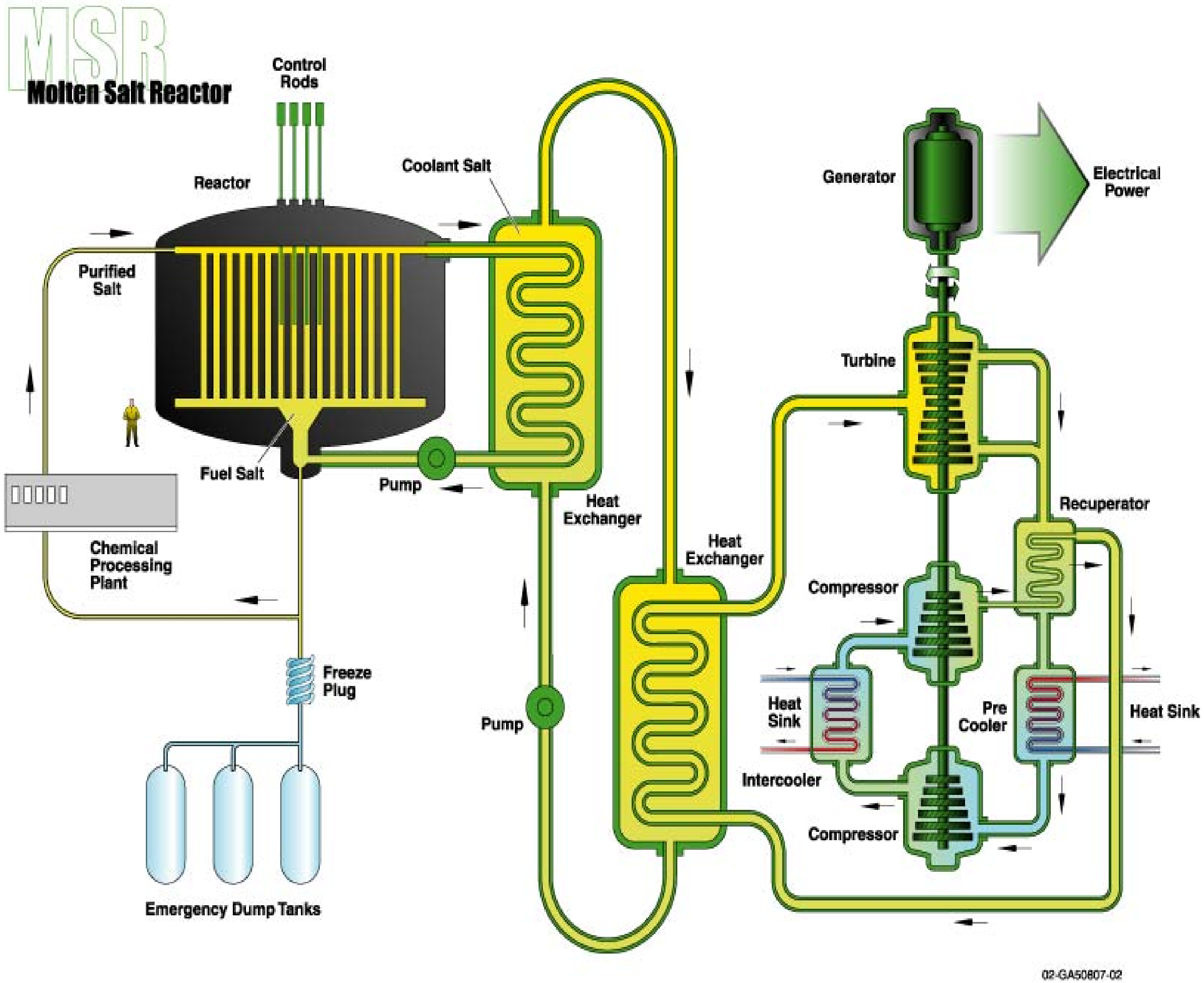
Molten U/Th fluorides
Simple fuel production
1000 MWe



Molten Salt Reactor

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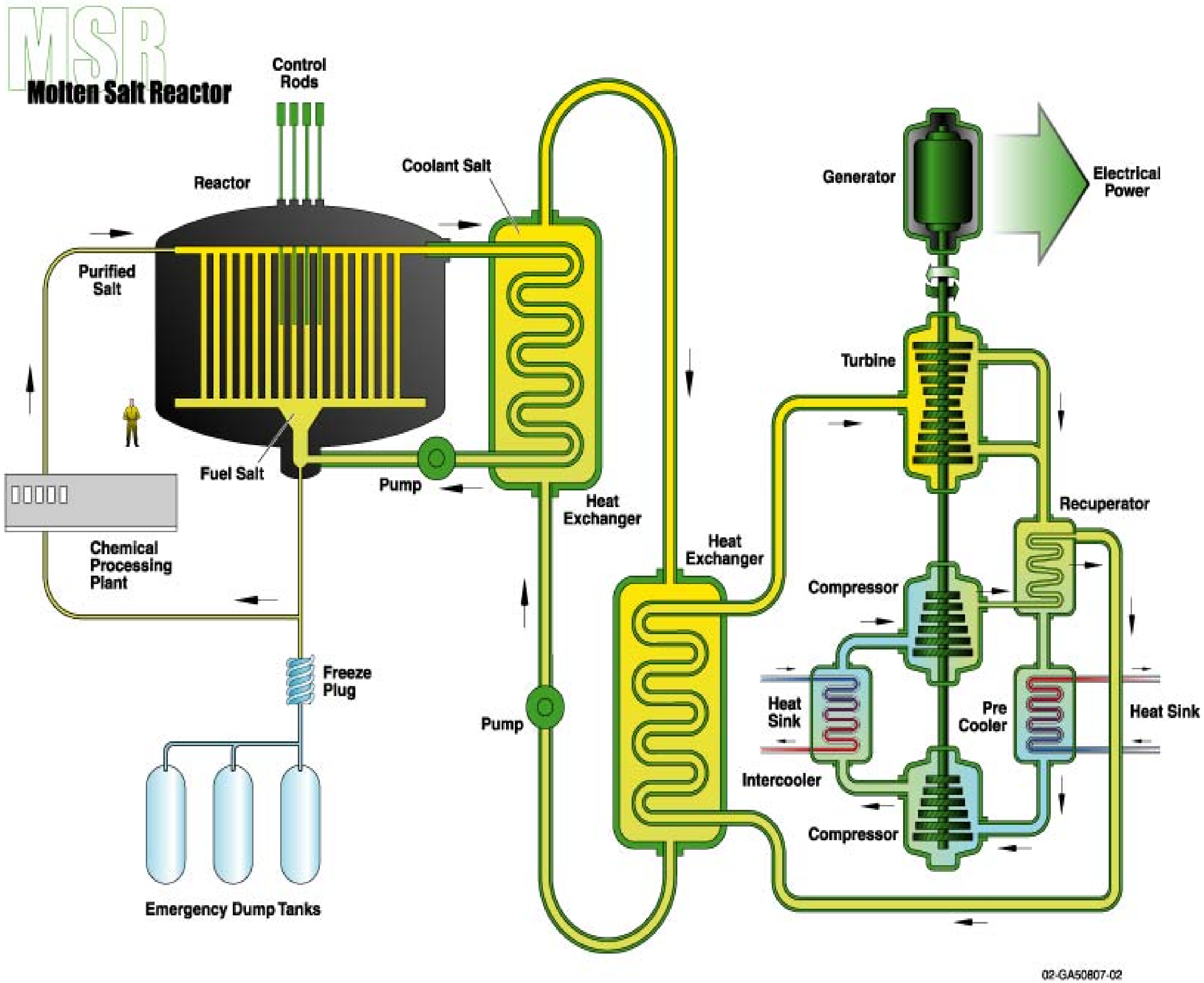
Simple fuel production

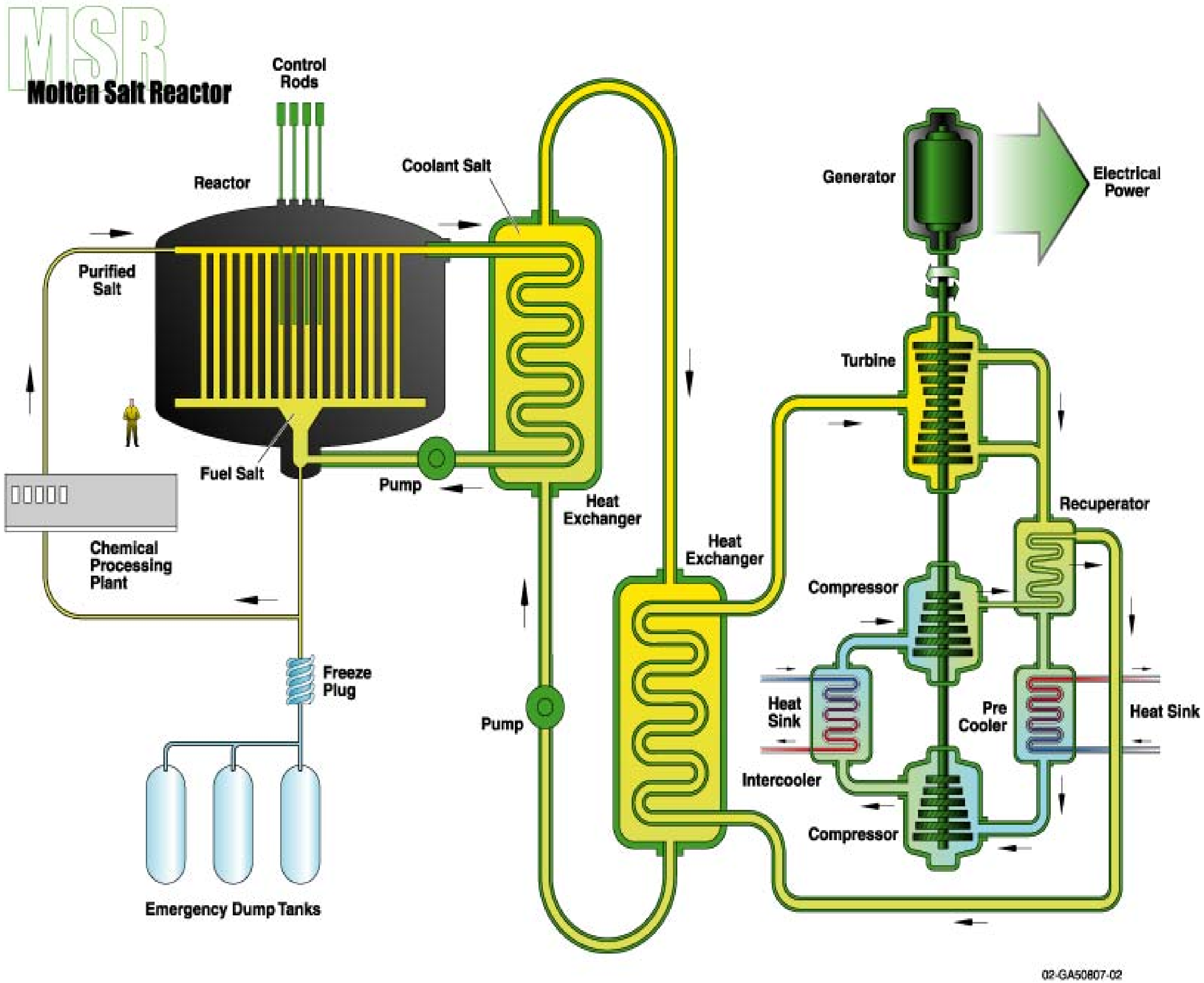
1000 MWe

700 - 800 °C



Molten Salt Reactor

Molten U/Th fluorides
Simple fuel production
1000 MWe
700 - 800 °C
Low pressure



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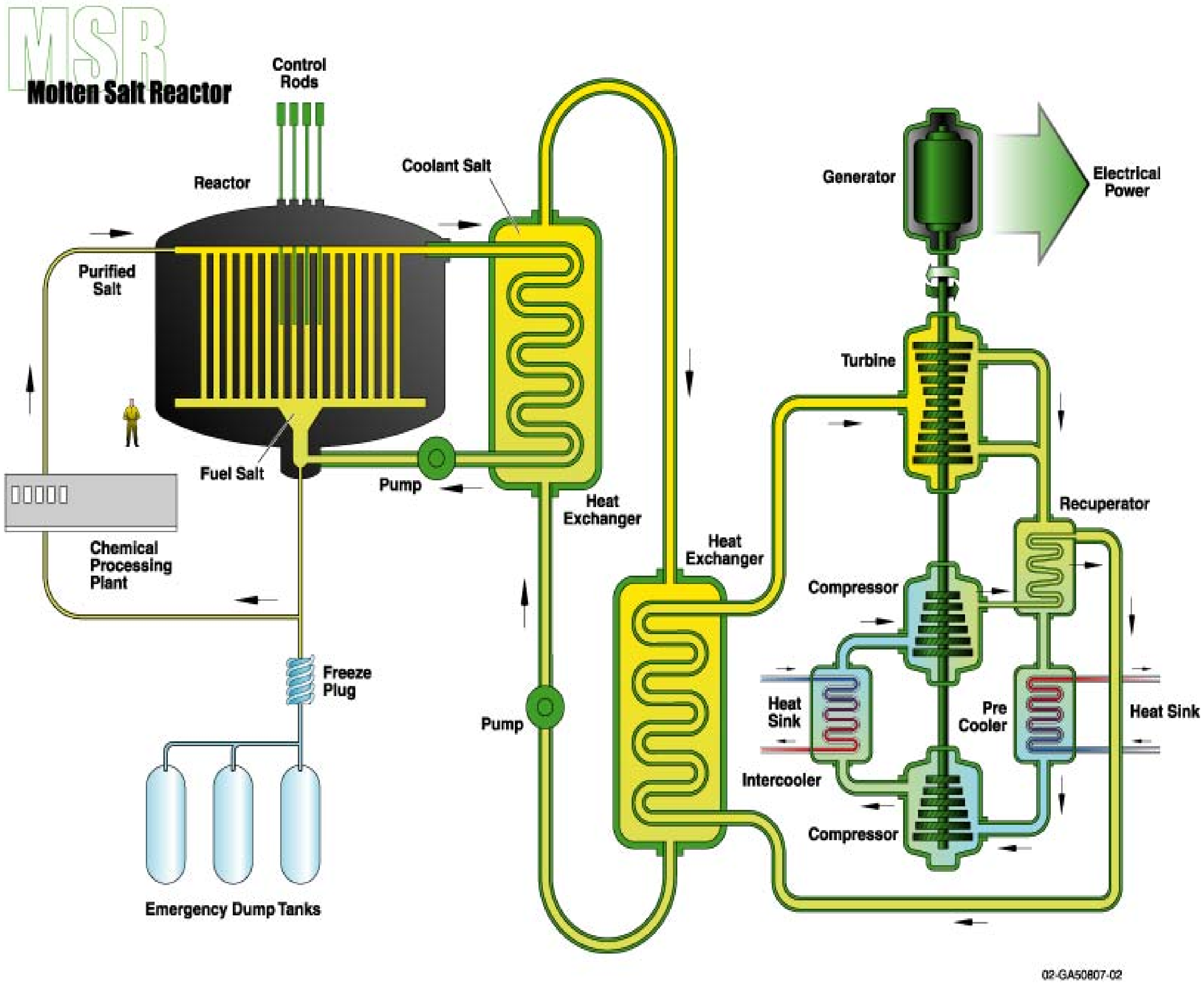
Low pressure
Actinide burning



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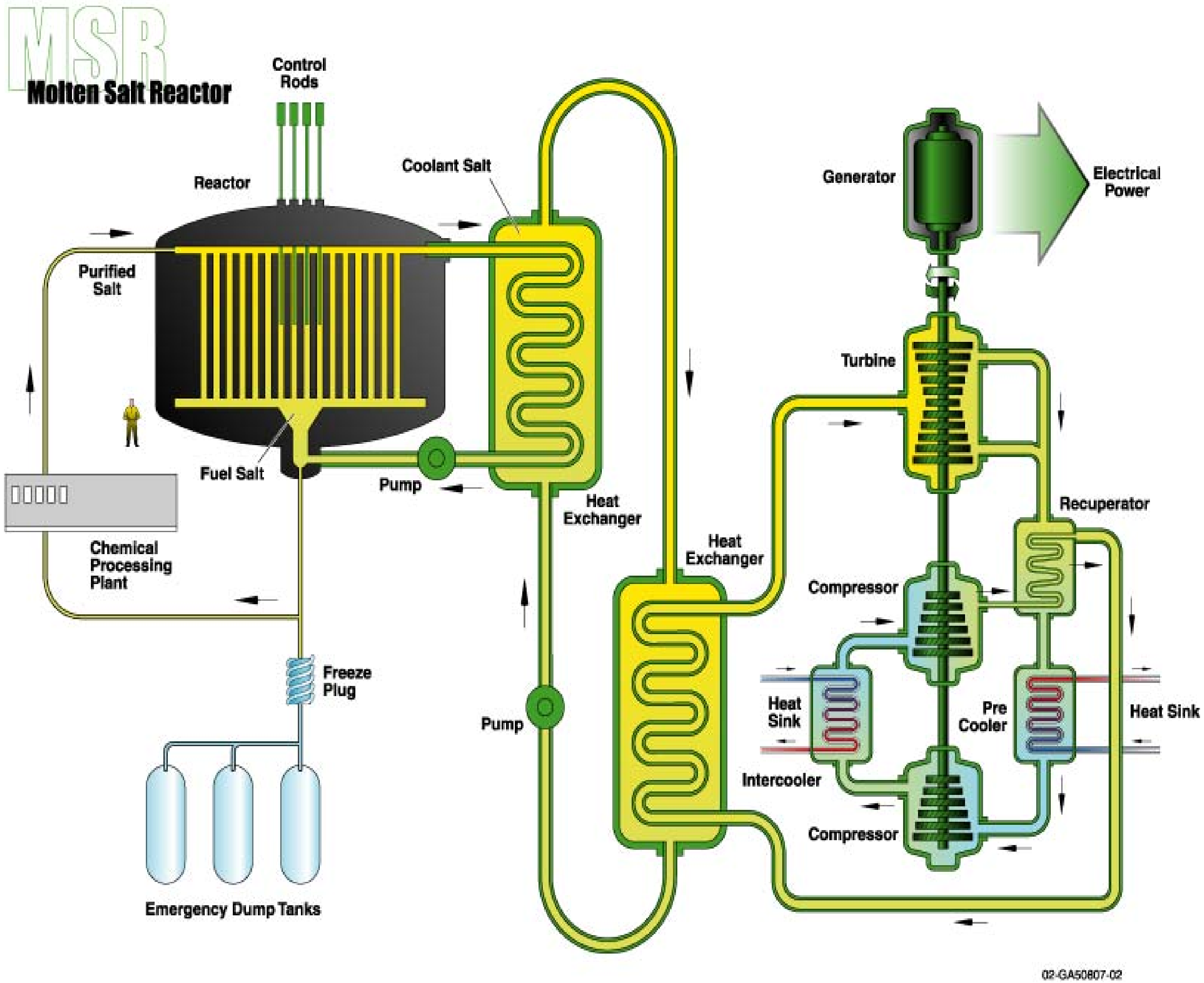
Low pressure
Actinide burning
Little longlived waste



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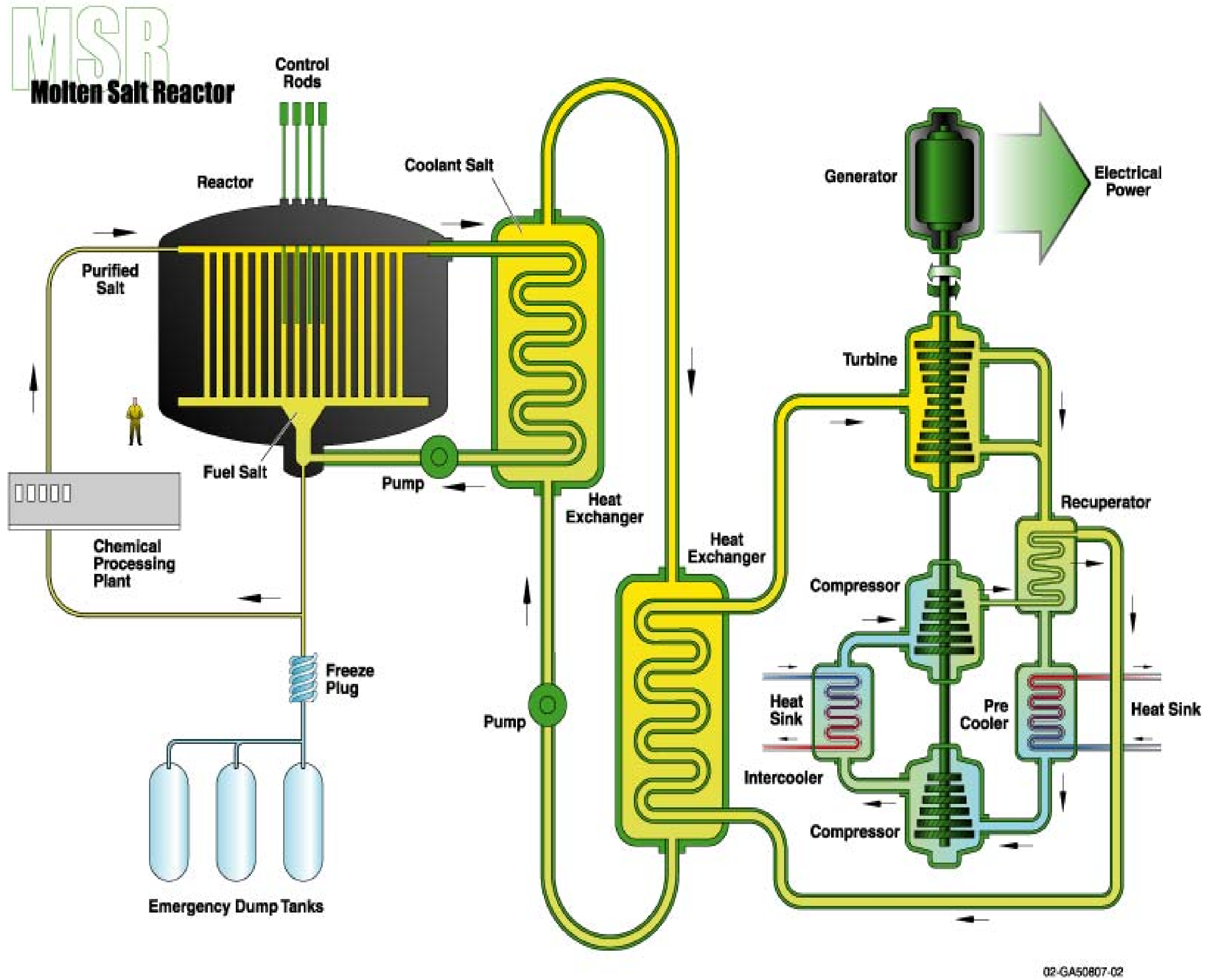
Actinide burning
Little longlived waste
Closed cycle



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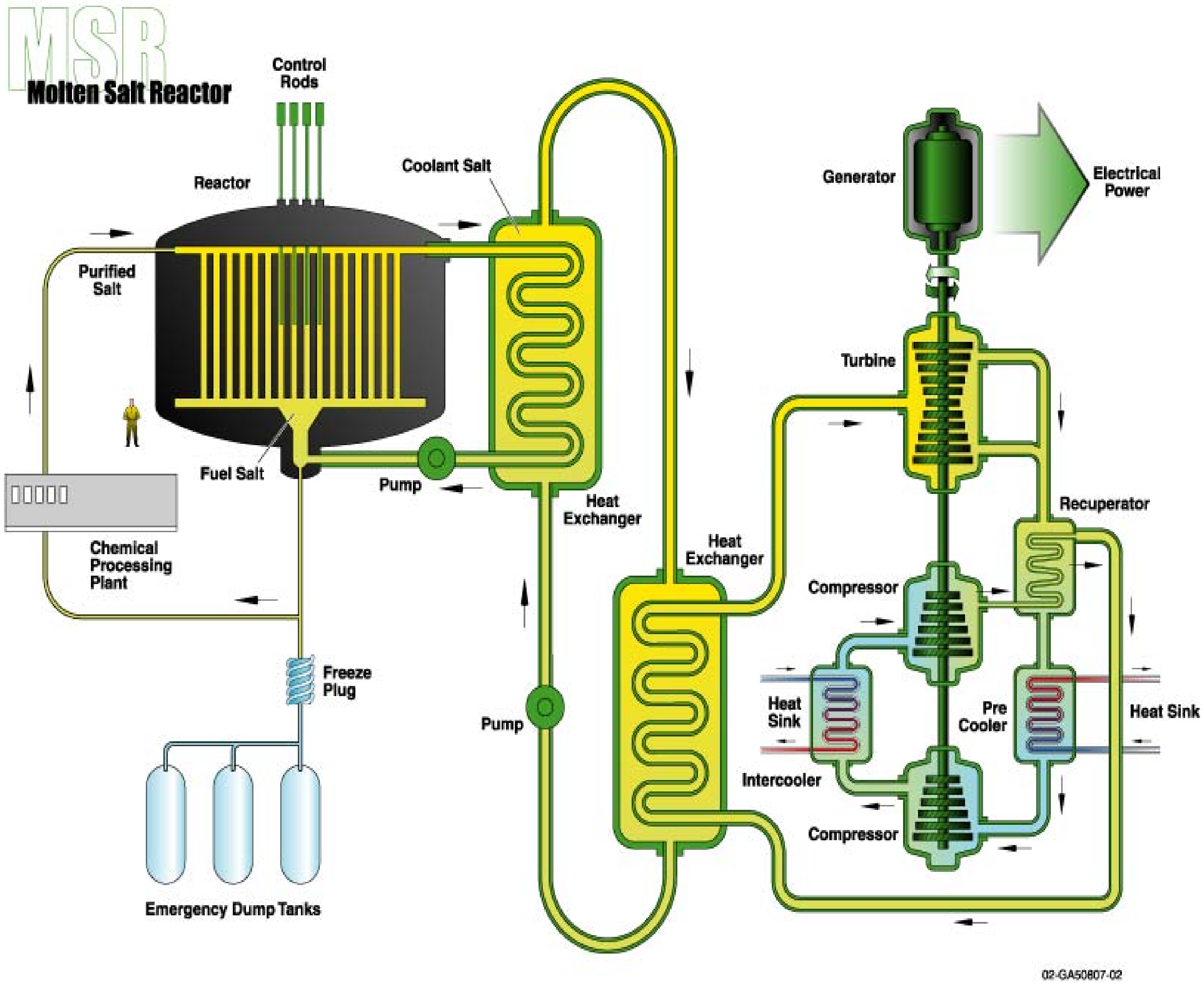
Cannot melt!



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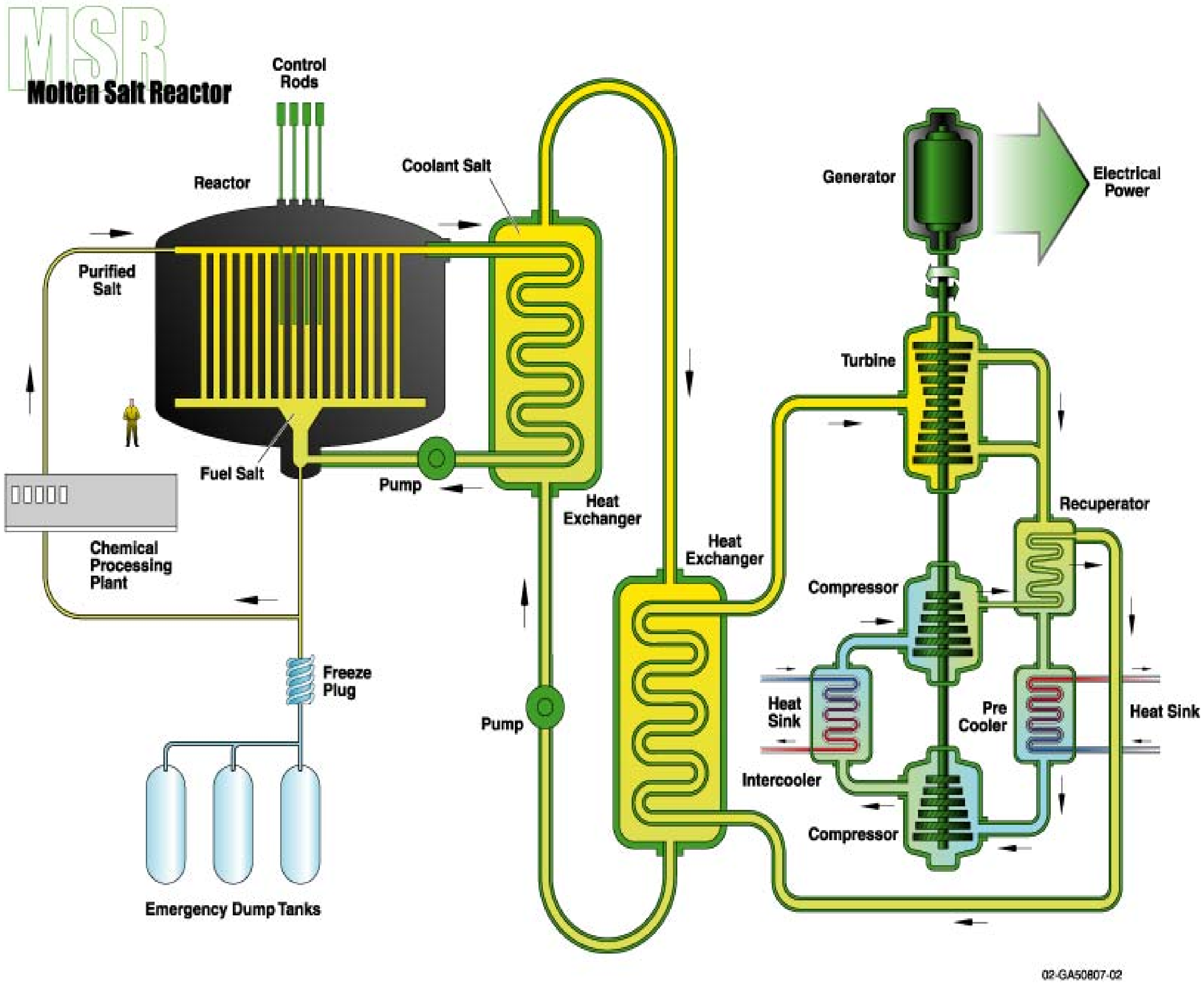
Chemical removal of fission products during operation



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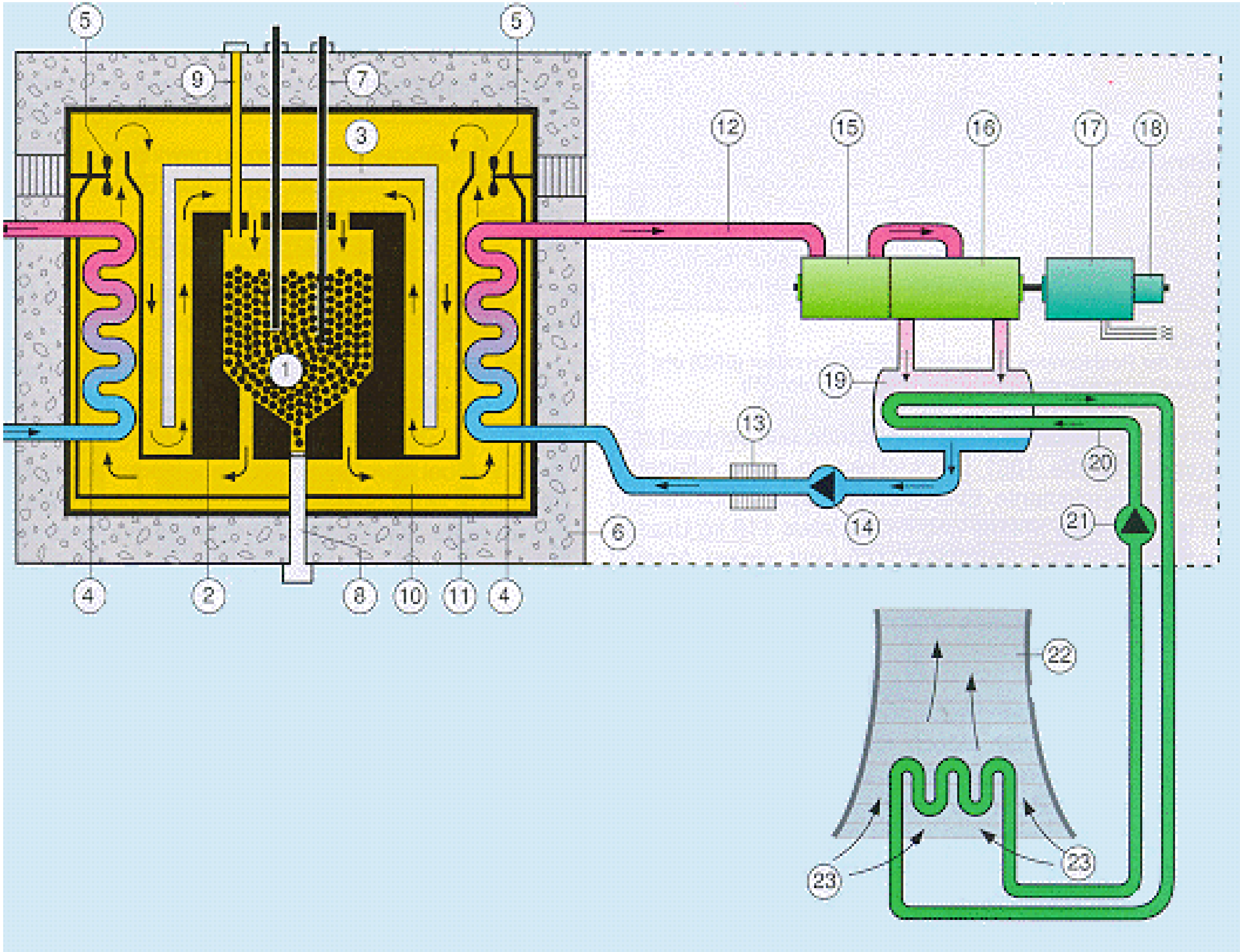
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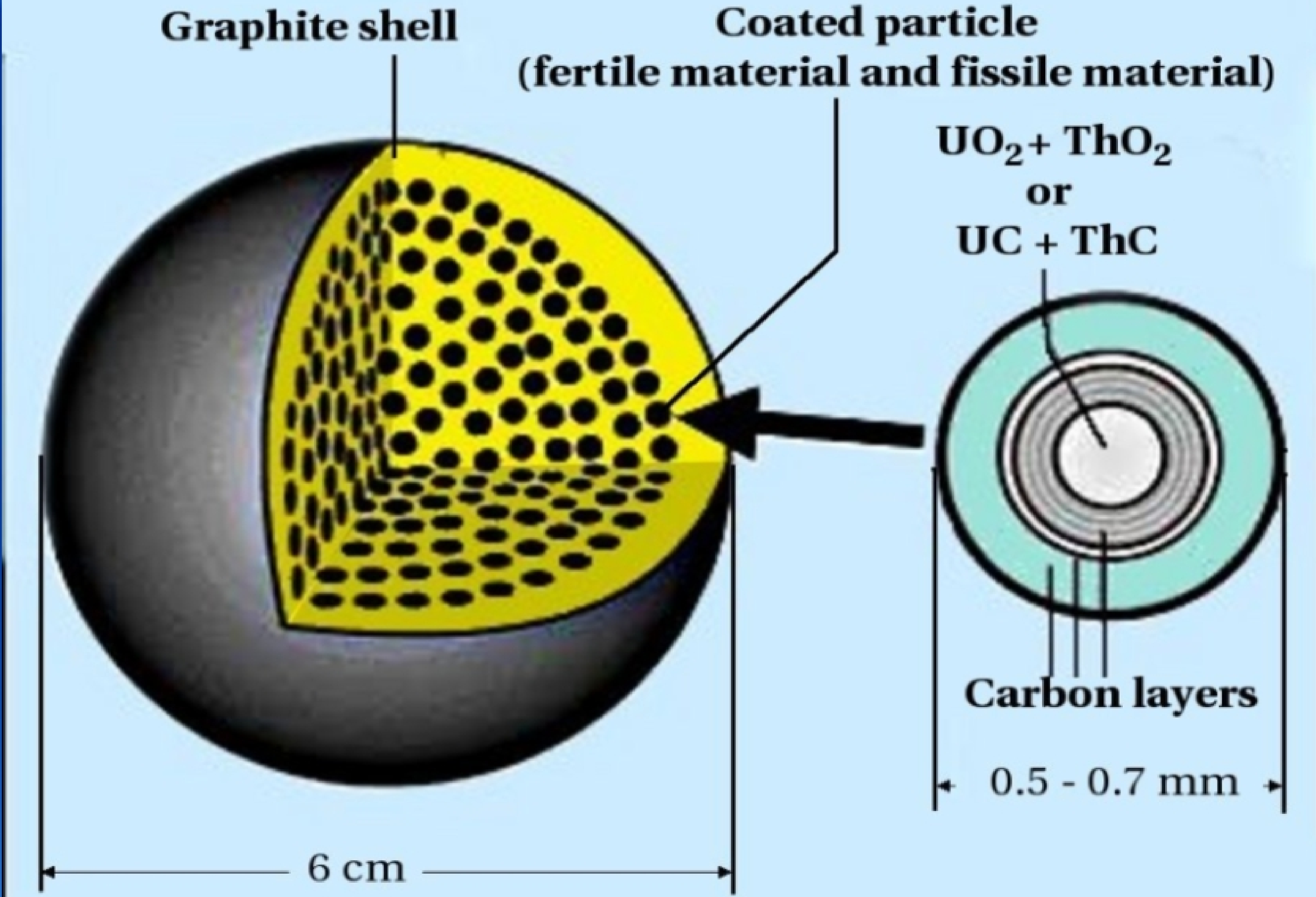

Graphite shell
Coated particle
(fertile material and fissile material)
$UO_2 + ThO_2$
or
UC + ThC
Carbon layers
0.5 - 0.7 mm
6 cm

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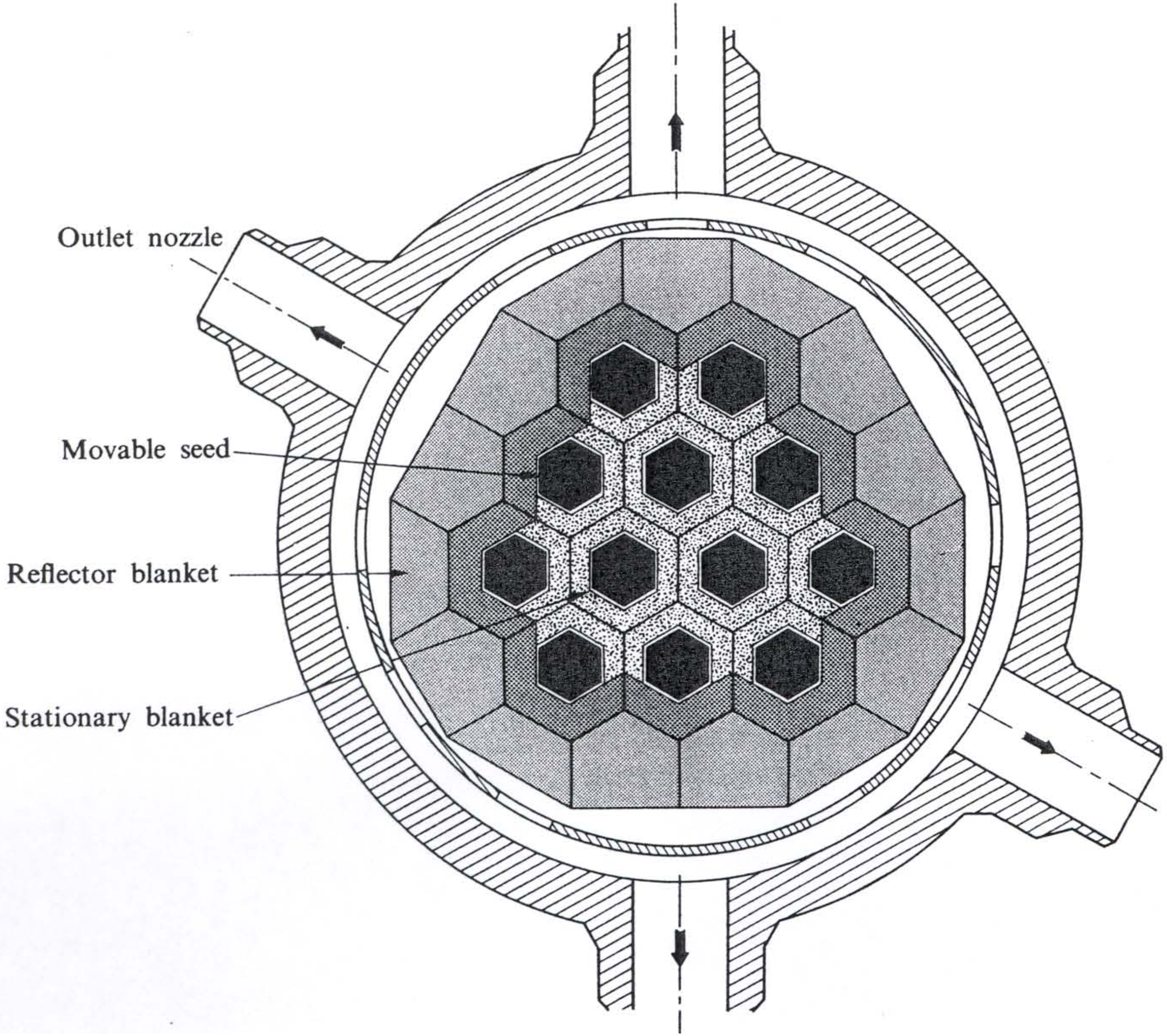
Outlet nozzle
Movable seed
Reflector blanket
Stationary blanket

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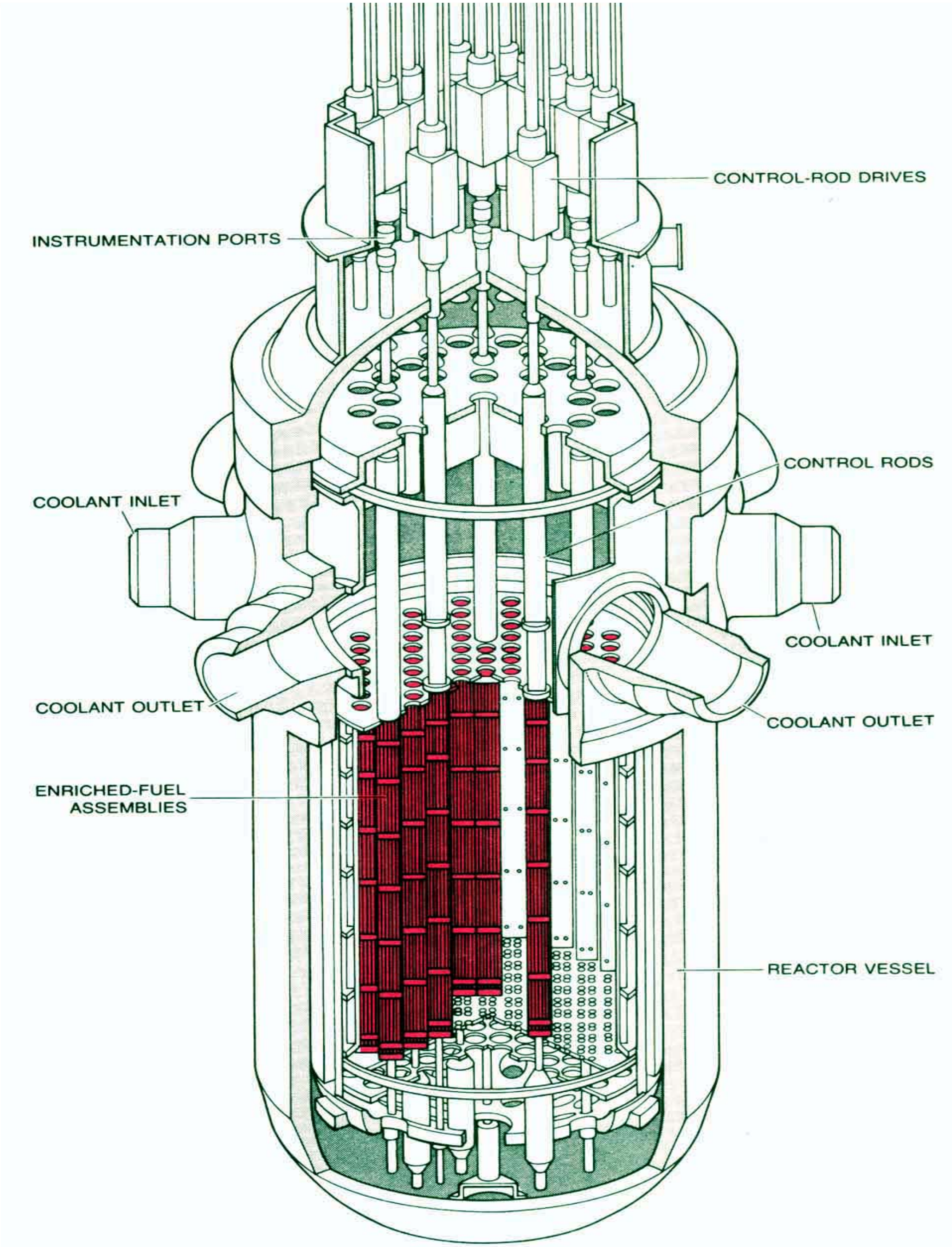

CONTROL-ROD DRIVES
INSTRUMENTATION PORTS
CONTROL RODS
COOLANT INLET
COOLANT INLET
COOLANT OUTLET
COOLANT OUTLET
ENRICHED-FUEL ASSEMBLIES
REACTOR VESSEL

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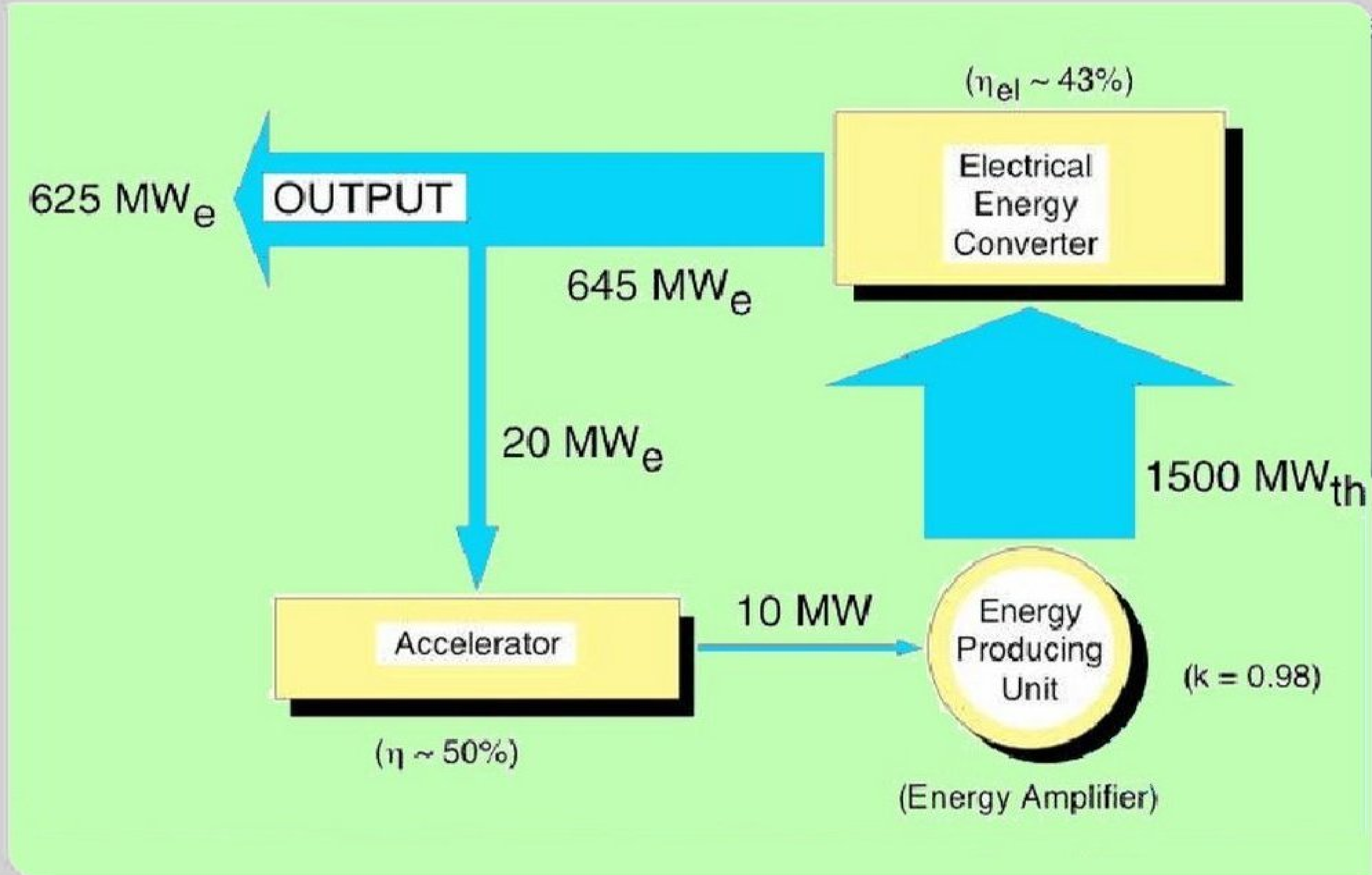
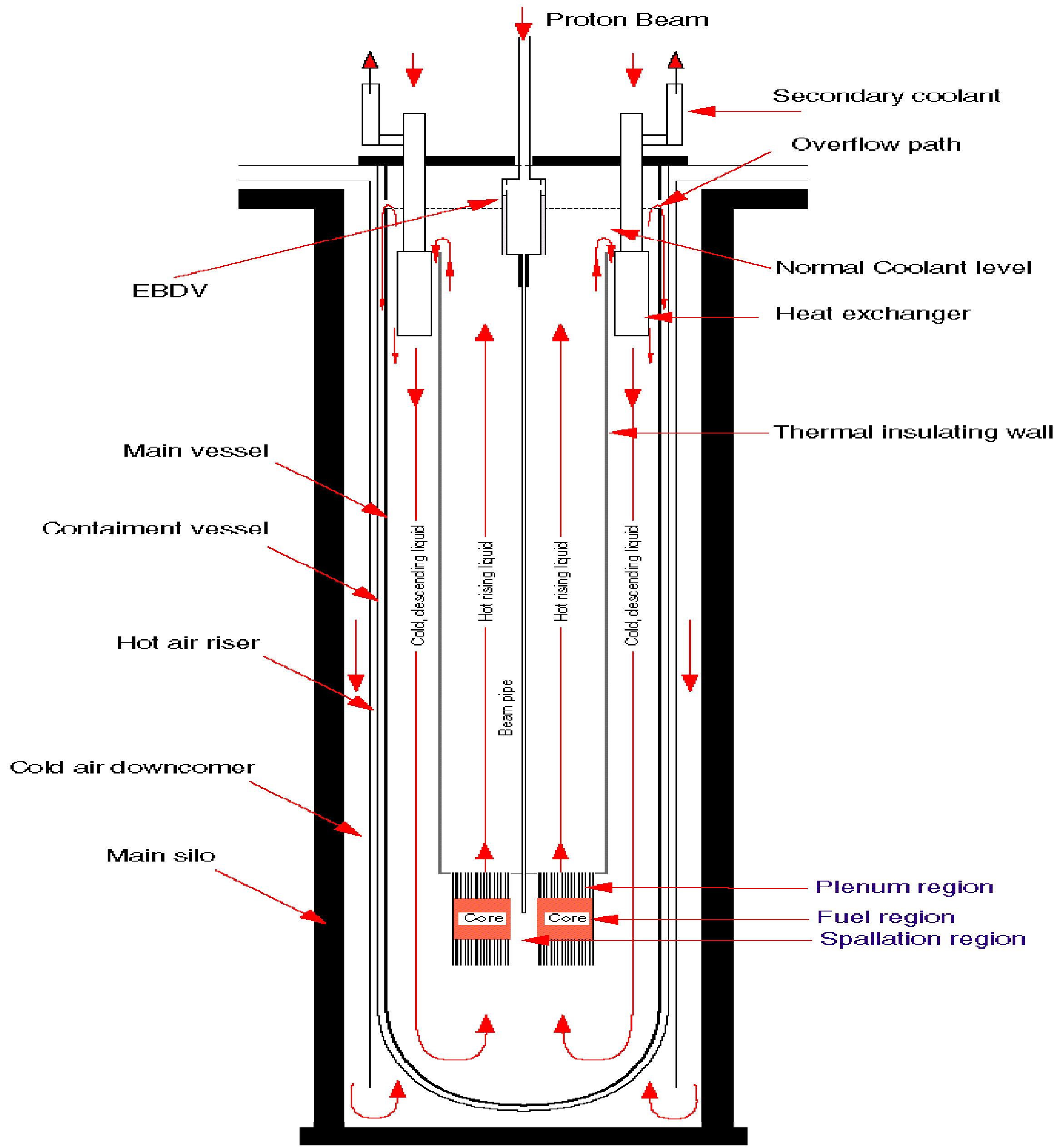
Accelerator Driven System

Sub-critical reactor - needs external neutron source

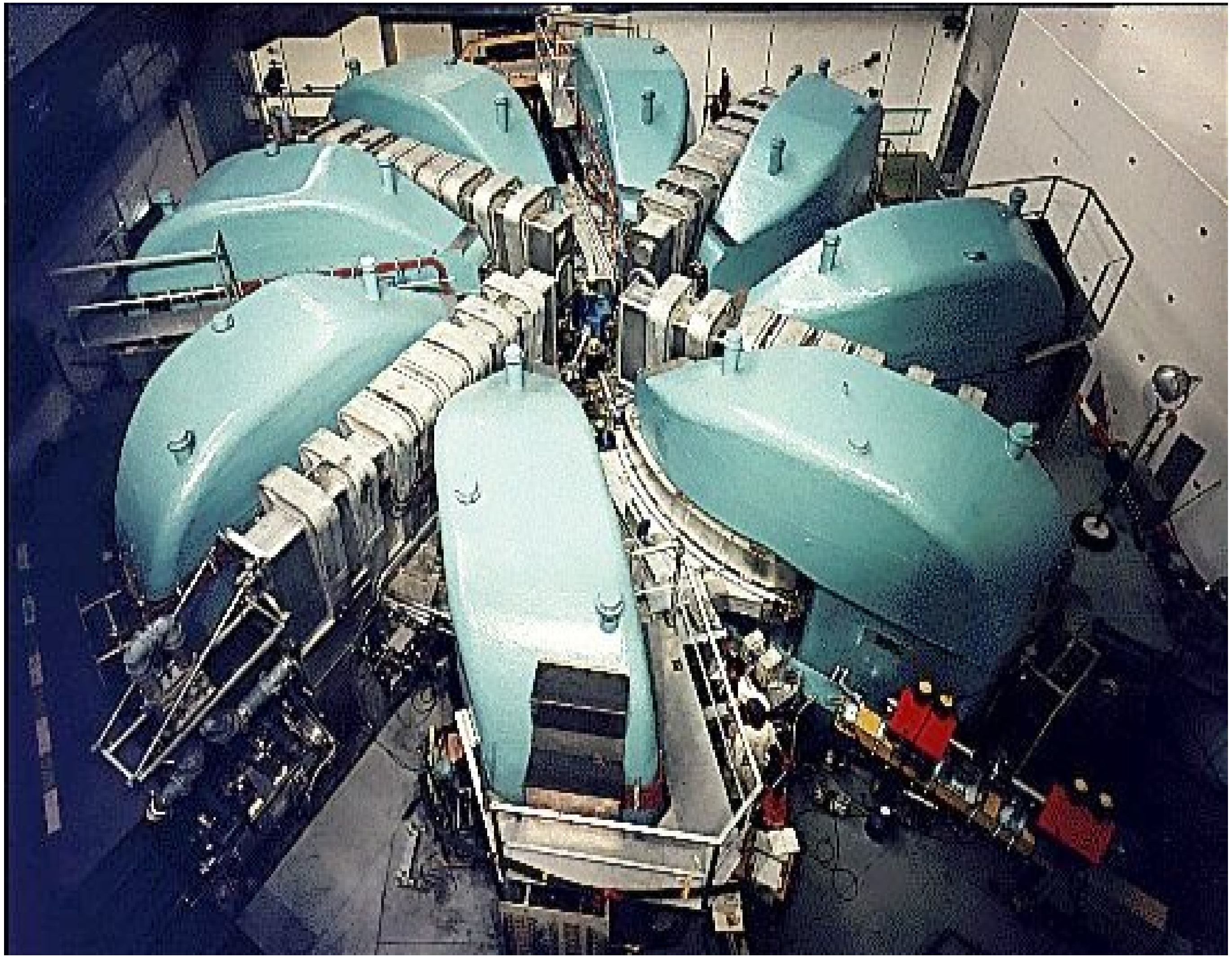
- First proposed by Nobel prize laureate E. O. Lawrence (1950's)
- Revived by Nobel prize laureate Carlo Rubbia (1993)
- Proton accelerator ➔ spallation source ➔ neutrons to the core
- Reactor core containing thorium and some uranium or transuranic waste
- No pilot scale ADS in operation yet
- MYRRHA project started in 1997 in Belgium. Plutonium, 60 MW_{th}. Expected to be in operation 2016 - 2018



(η_{el} ~ 43%)
Electrical Energy Converter
625 MW_e
OUTPUT
645 MW_e
20 MW_e
1500 MW_{th}
Accelerator
10 MW
Energy Producing Unit
(k = 0.98)
(η ~ 50%)
(Energy Amplifier)


Proton Beam
Secondary coolant
Overflow path
EBDV
Normal Coolant level
Heat exchanger
Thermal insulating wall
Main vessel
Containment vessel
Hot air riser
Cold air downcomer
Main silo
Cold, descending liquid
Hot rising liquid
Hot rising liquid
Cold, descending liquid
Beam pipe
Core
Core
Plenum region
Fuel region
Spallation region

CYCLOTRON



“Burning” of waste

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  ^{99}Tc

  211 000 years

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  $^{99}Tc + n$

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$$^{99}Tc + n \quad \rightarrow \; ^{100}Tc$$

211 000 years 16 s

“Burning” of waste

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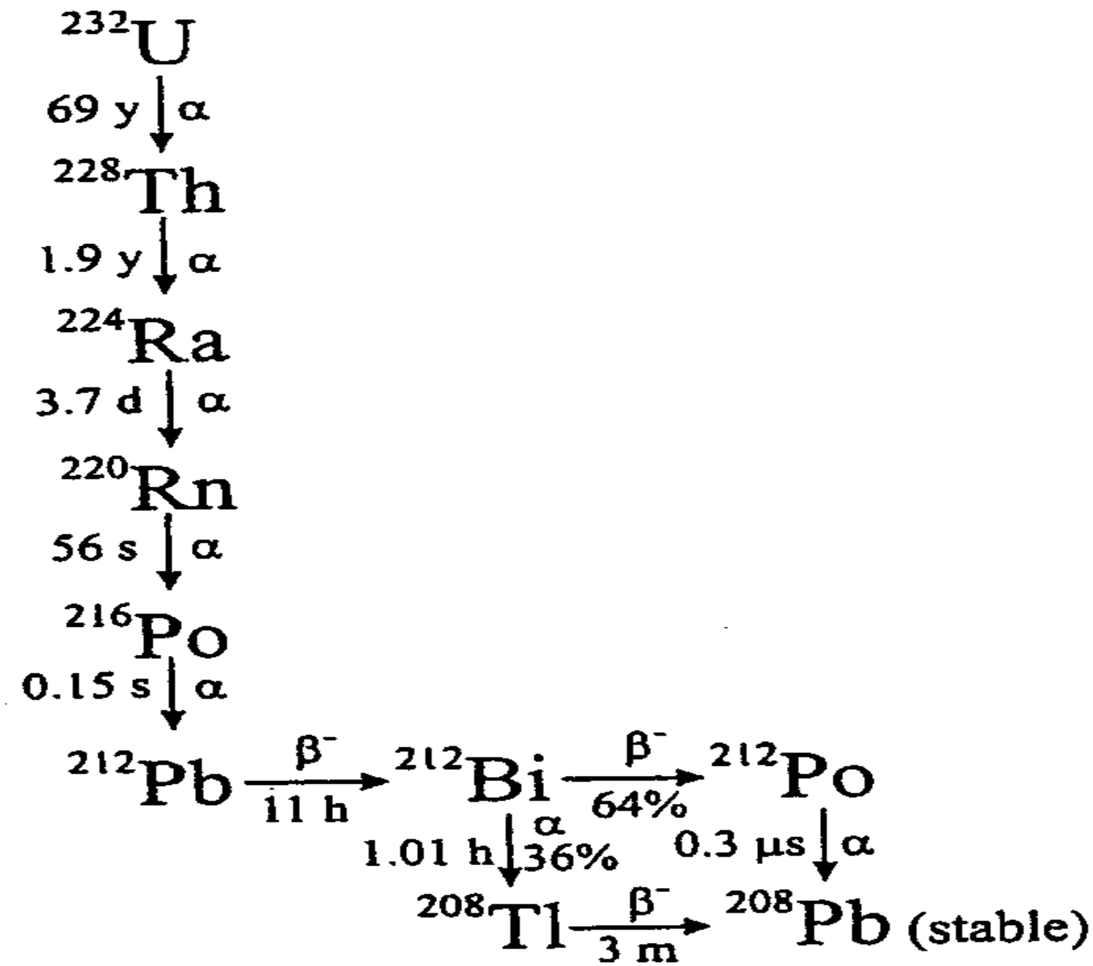
* Fission products: Transmutation

$$^{99}Tc + n \quad \rightarrow \; ^{100}Tc \quad \rightarrow \; ^{100}Ru$$

211 000 years   16 s   stable

Proliferation resistant?



Proliferation resistant?

Table 2: Unshielded working hours required to accumulate a 5 rem dose (5 kg sphere of metal at 0.5 m one year after separation)

Metal	Dose Rate (rem/hr)	Hours
Weapon-grade plutonium	0.0013	3800
Reactor-grade plutonium	0.0082	610
U-233 containing 1ppm U-232	0.013	380
U-233 containing 5ppm U-232	0.059	80
U-233 containing 100 ppm U-232	1.27	4
U-233 containing 1 percent U-232	127	0.04

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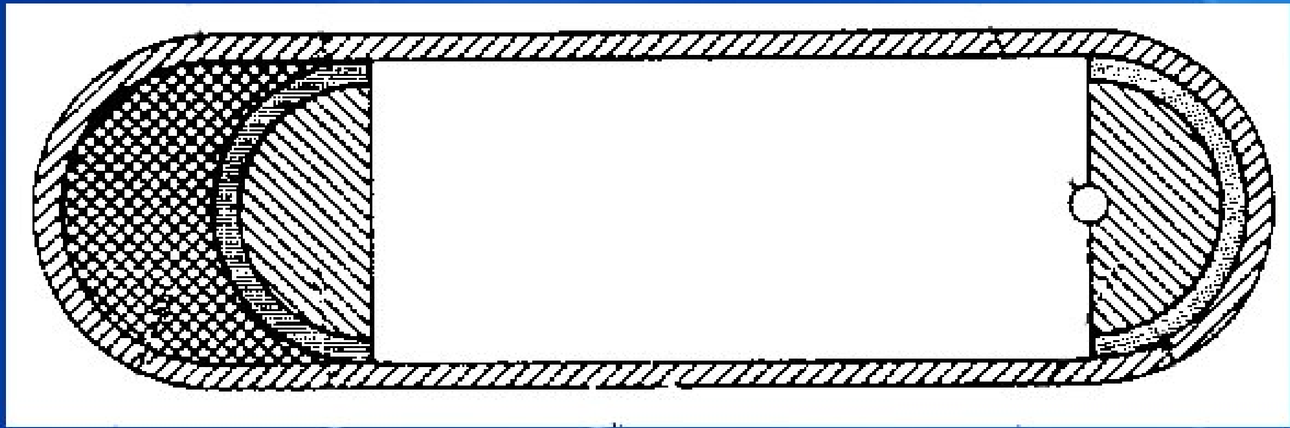
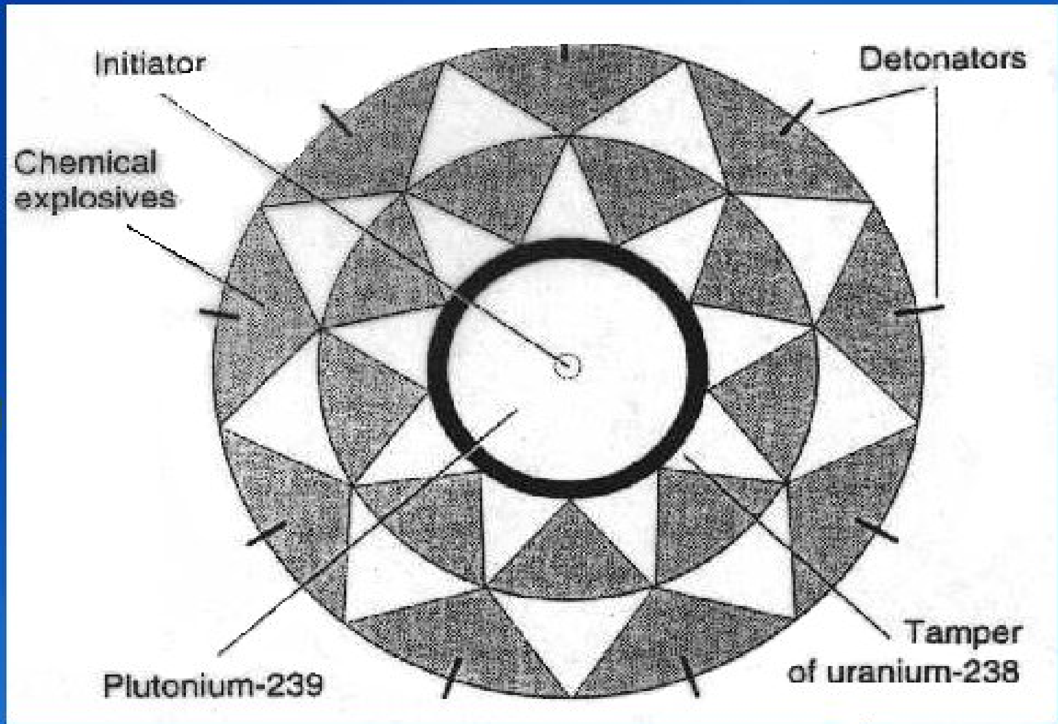
* Possible to make "Gun-type" bomb
Operation Teapot, Nevada 1955

Bombetyper

Uran



Plutonium



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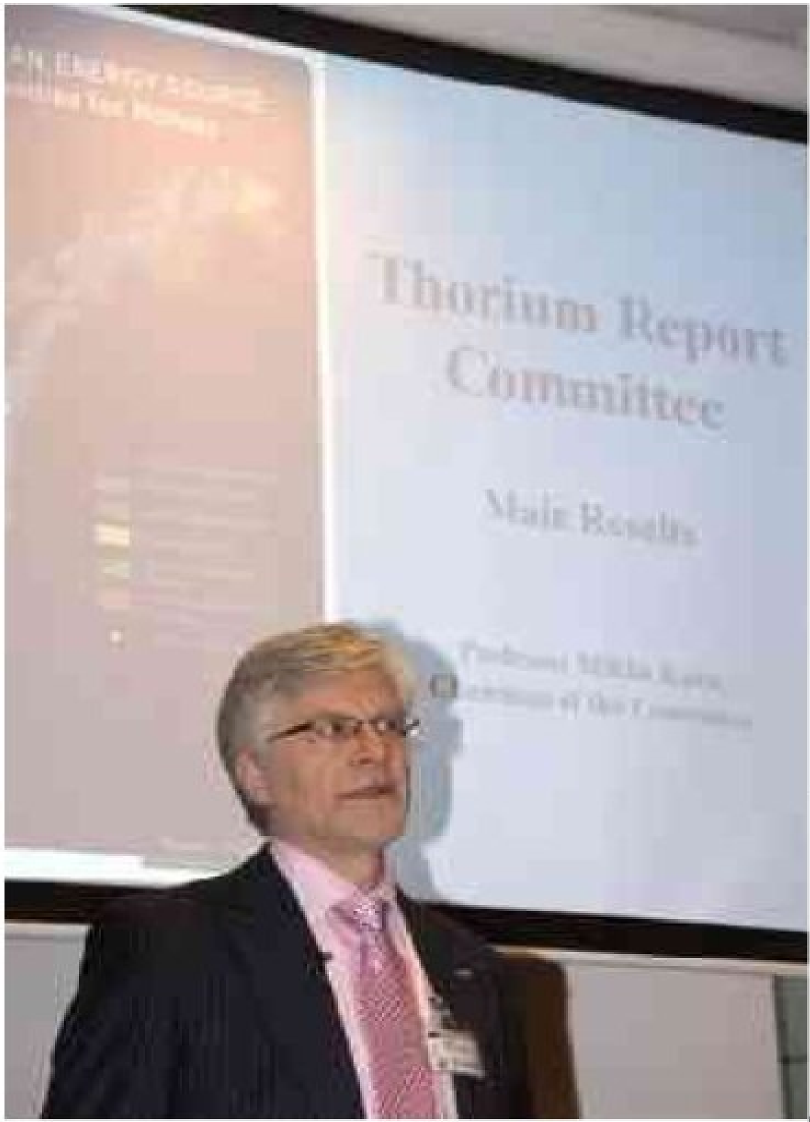
- Material technology: High temperature, corrosion

Summary from the Thorium Commitee



Professor Mikko Kara
(Finland)

- The current knowledge of thorium based energy generation and the geology is not solid enough to provide a final assesment regarding the potential value for Norway of a thorium based system for a long term energy production.

- The Committee recommends that the thorium option be kept open in so far it represents an interesting complement to the uranium option to strengthen the sustainability of nuclear energy.

Takk for oppmerksomheten!