Molten Salt Reactors

Resource Requirements and Proliferation-Risk Attributes of Single-Fluid and Two-Fluid Designs

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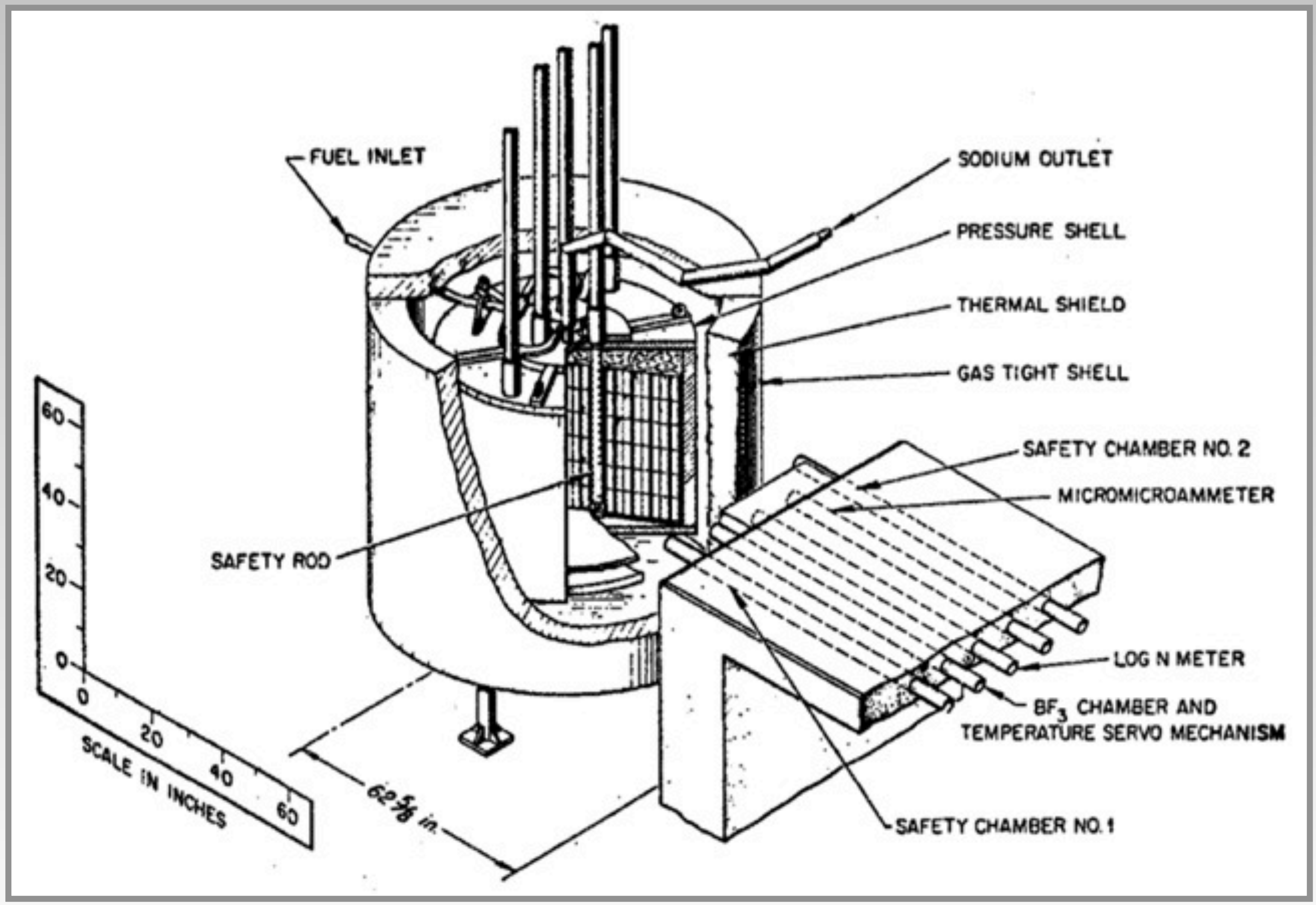
54th Annual INMM Meeting, July 2013

Revision 4

Aircraft Reactor Experiment

(Oak Ridge National Laboratory, 2 MW thermal, 1953–1954)



E. S. Bettis et al., "The Aircraft Reactor Experiment: Design and Construction," *Nuclear Science and Engineering*, 2, 1957

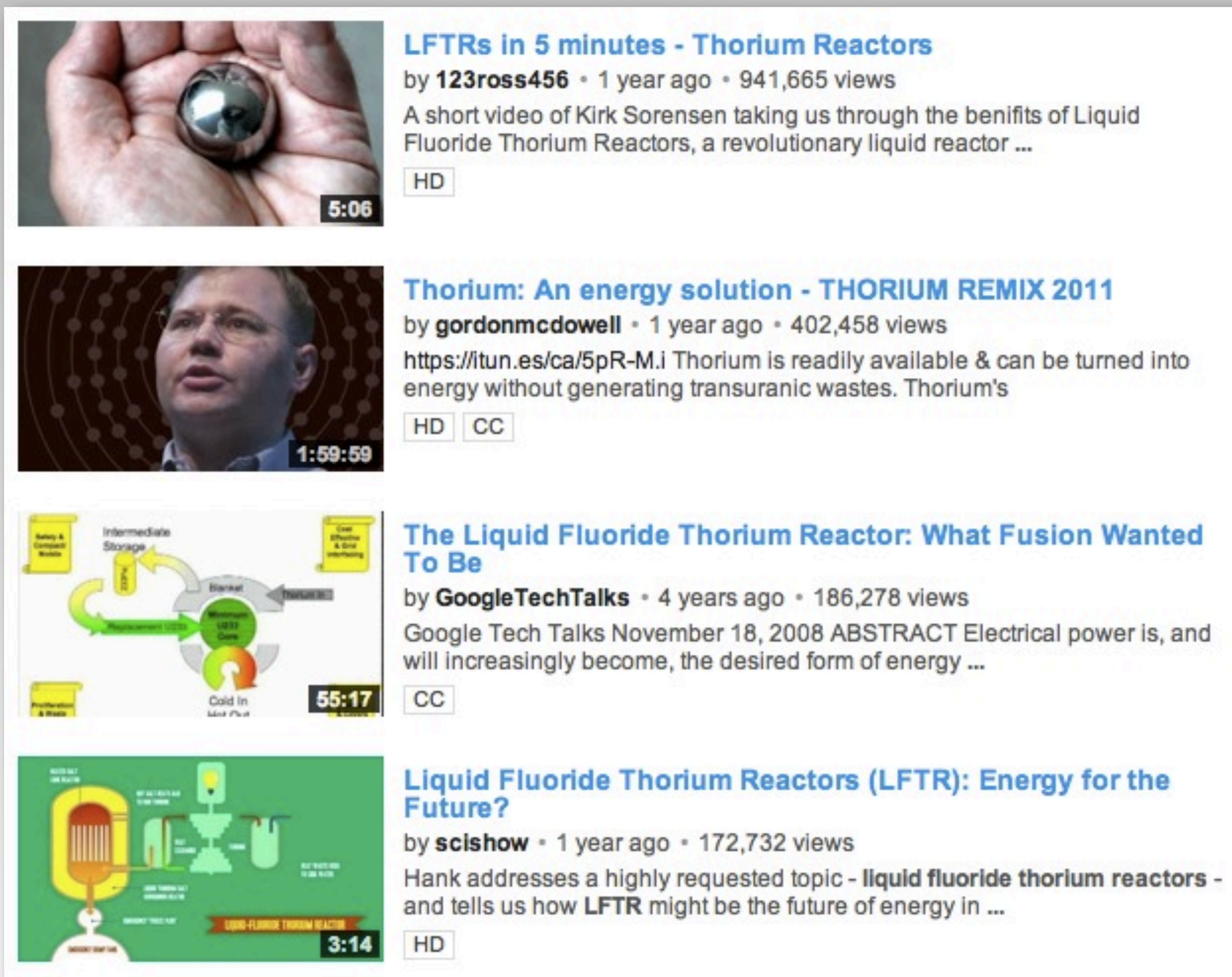
Molten Salt Reactor Experiment

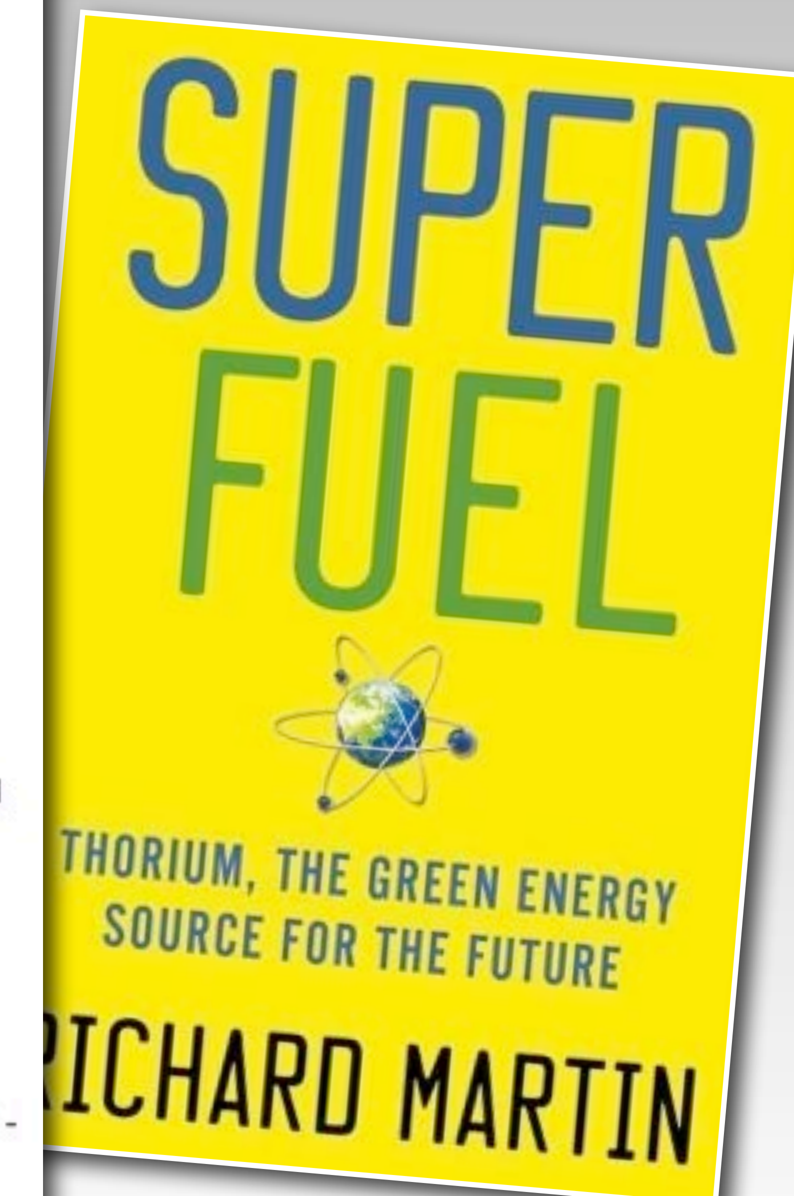
(Oak Ridge National Laboratory, 8 MW thermal, 1965–1969)

Alvin Weinberg and Paul Haubenreich, 1967

Too Good To Be True?

Molten Salt Reactors and Thorium on the Web and in the Media





Design Principles and Options for Molten Salt Reactors

Design Options and Choices

for Molten Salt Reactors

Typically (but not necessarily) thermal systems

Proposed carrier salt often FLIBE (Fluorine-Lithium-Beryllium, LiF-BeF_2)

Fissile and fertile material added as UF_4 and ThF_4

Liquid fuel: flexible geometry and online fuel processing

Single-fluid vs Two-fluid designs

Single-fluid design: salt contains both fissile and fertile materials (U/Th)

Two-fluid design: fissile and fertile components separated in different salts

Uranium-233 continuously separated from “blanket salt” and transferred to fuel salt

Denatured Designs

Early prototype design concepts sought to maximize fuel economy

1000-MWe Molten Salt Breeder Reactor (MSBR)

Highly enriched fuel and extensive fuel processing

Later designs also examined more proliferation-resistant options

Denatured Molten Salt Reactor (DMSR)

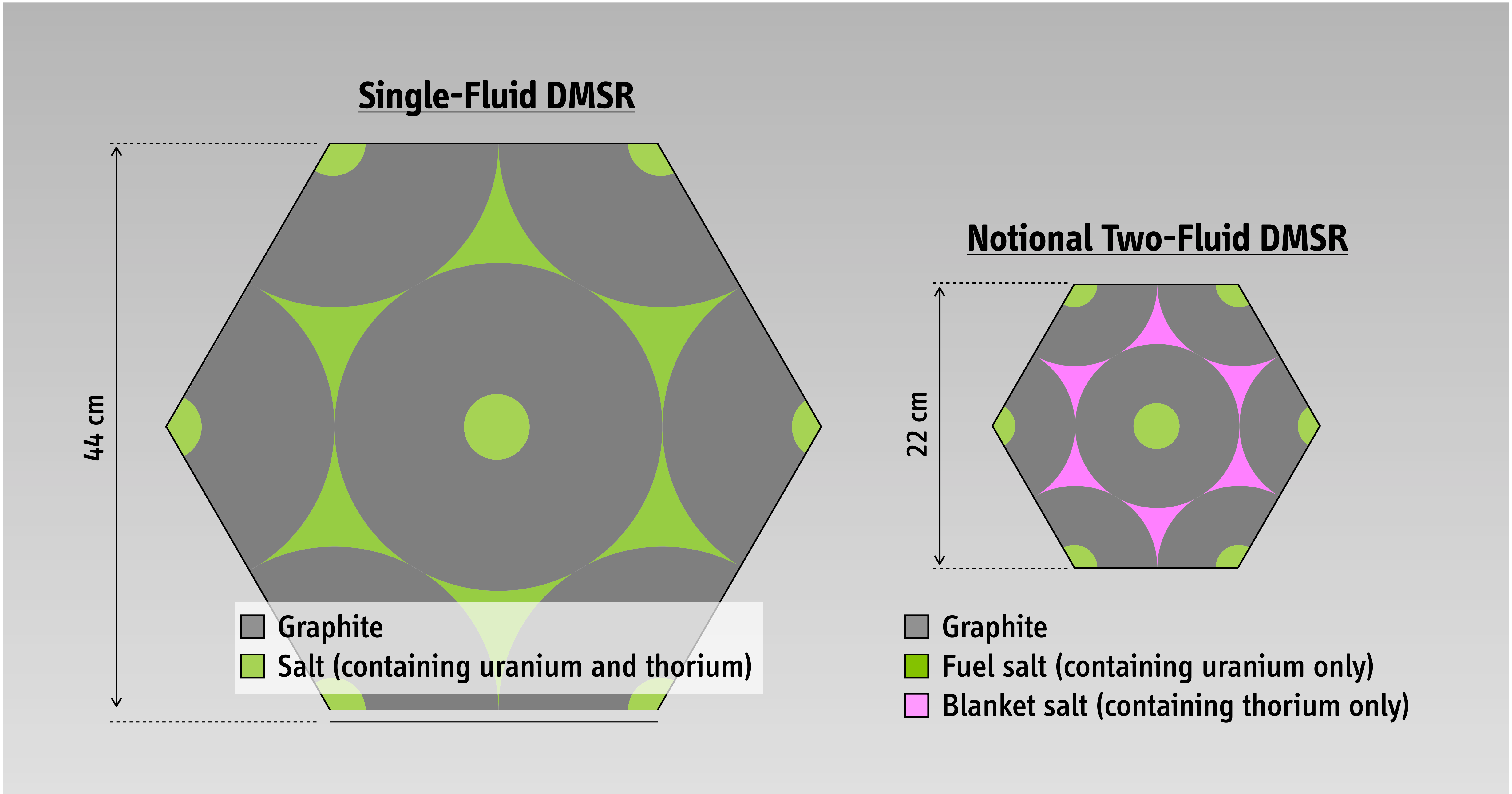
Defining Low-Enrichment

$$N_{238} > 7 \times N_{233} + 4 \times N_{235}$$

(12.5% U-233 or 20% U-235 in binary mixture with U-238)

MSR Reference Models and Results

Unit Cells of Notional DMSR Designs



Single-fluid design adapted from: J. R. Engel et al., *Conceptual Design Characteristics of a Denatured Molten-Salt Reactor with Once-Through Fueling*, ORNL/TM-7207, Oak Ridge National Laboratory, July 1980

Characteristics of Notional DMSR Designs

Single-fluid design

3 mol% UF_4 and 10 mol% ThF_4

(70 mol% LiF and 17 mol% BeF_2)

Power density in salt: 37.5 kW/l

Two-fluid design

Fuel salt: 4.5 mol% UF_4 • Blanket salt: 15 mol% ThF_4

(75.5 mol% LiF and 20 mol% BeF_2 in fuel salt)

Power density in fuel salt: 74.0 kW/l

Both designs

500 MW thermal (equivalent to 200 MW electric)

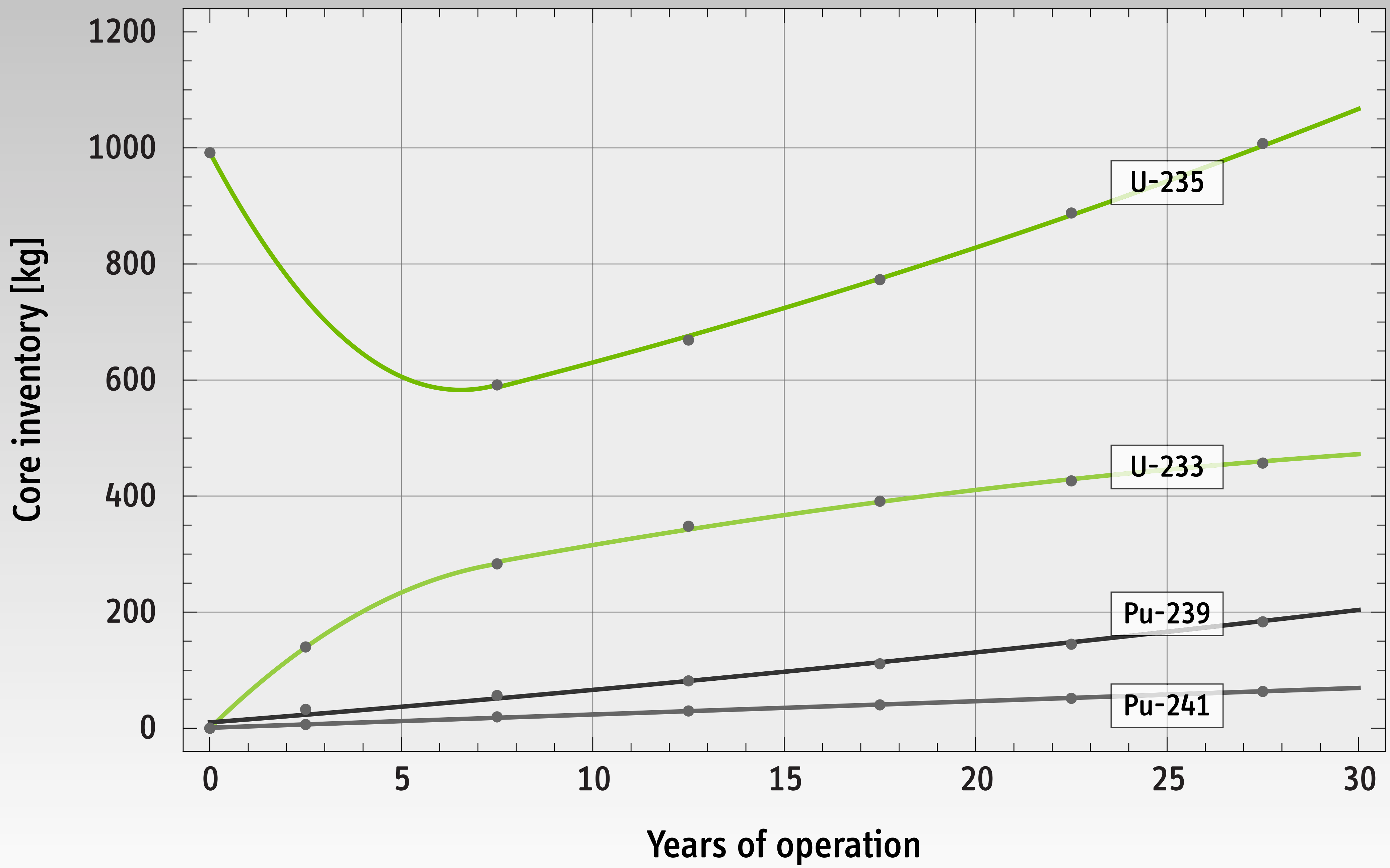
Initial core inventory: 5,000 kg uranium containing 1,000 kg U-235

MCODE Simulation Results

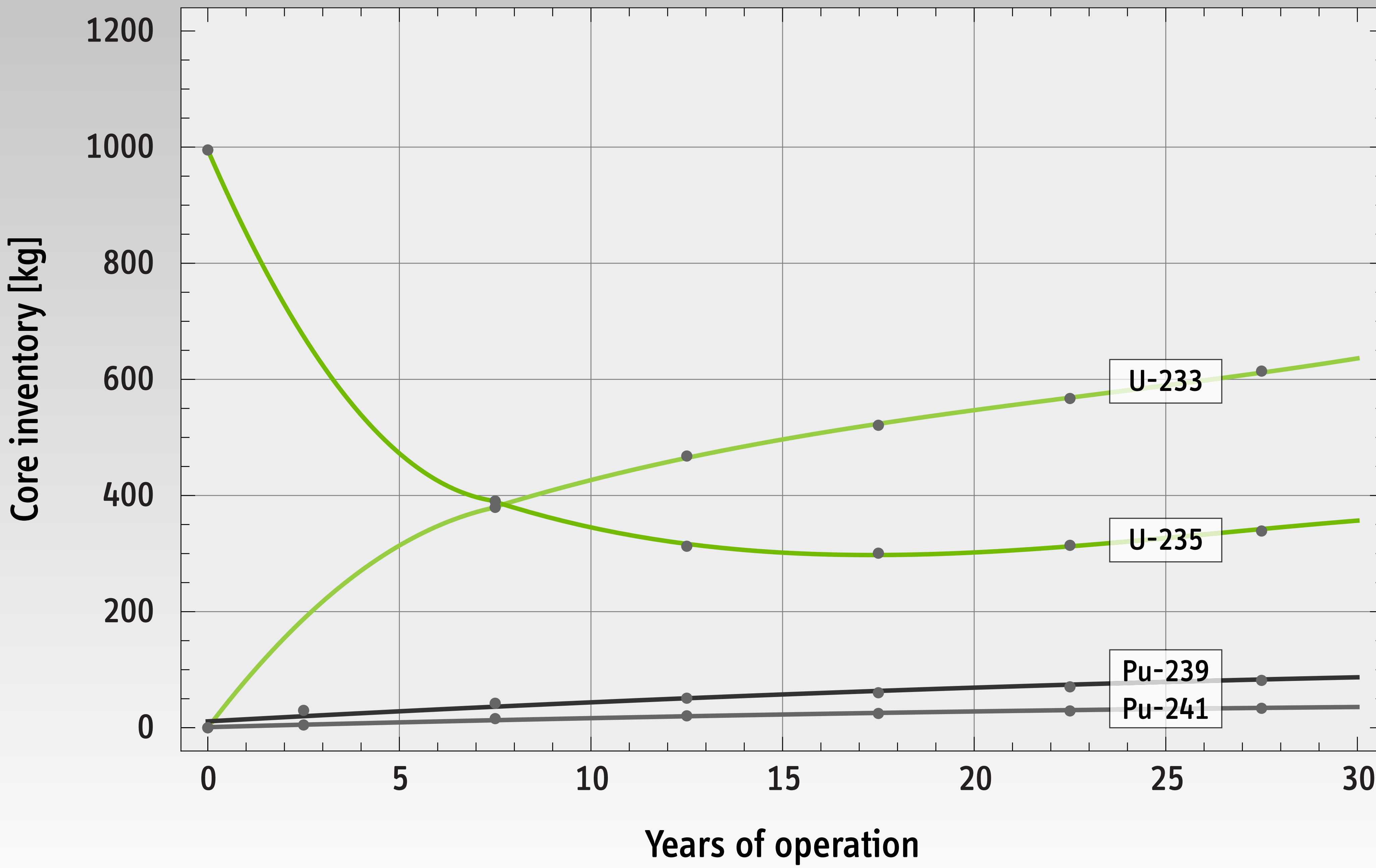
(based on ORIGEN2 and MCNP5 calculations)

Fissile Material Inventory

of the Single-Fluid Denatured Molten Salt Reactor



Fissile Material Inventory
of the Two-Fluid Denatured Molten Salt Reactor



Resource Requirements and Proliferation-Risk Attributes

Resource and Fuel-cycle Requirements

200-MWe reactor, 30 years of operation

	iPWR	Single-Fluid DMSR	Two-fluid DMSR
Initial Core			
Natural uranium	200,000 kg	235,500 kg	235,500 kg
Enrichment level	5%	20%	20%
Separative work	128,000 SWU	190,000 SWU	190,000 SWU
Enriched uranium	18,000 kg	5,000 kg	5,000 kg
Annual requirements for services and materials			
Natural uranium	67,000 kg	23,500 kg	9,400 kg
Enrichment level	5%	20%	20%
Separative work	42,500 SWU	19,000 SWU	7,600 SWU
Enriched uranium	6,000 kg	500 kg	200 kg
Lifetime requirements			
Natural uranium	2,000 tons	940 tons	520 tons
Separative work	1,280,000 SWU	760,000 SWU	420,000 SWU

Fissile Material Production
in Denatured Molten Salt Reactors

No separated fissile material present under routine operation

but protactinium-233 could be separated for out-of-core decay to U-233

Two-fluid designs cannot be effectively denatured

Protracted uranium-233 diversion (during transfer to fuel) difficult to detect

“Poison Pill”

Instantaneous injection of depleted uranium to denature salts in case of breakout

Does not address proliferation concerns as host could disable such a mechanism

Graphics: gfxpremium.com

In Lieu Of Conclusions

In Lieu Of Conclusions

Resource Requirements

Single-fluid designs are significantly less fuel-efficient than two-fluid designs

Both designs superior to conventional thermal (light-water) reactors
(2–4 times more fuel efficient than LWRs)

Proliferation-Risk Attributes

Fully denatured single-fluid designs
(with minimum fuel processing and using low-enriched make-up fuel)
appear as the most promising candidate MSR technology

Detailed assessments needed for particular designs
(Largely unavailable for most proposed concepts)