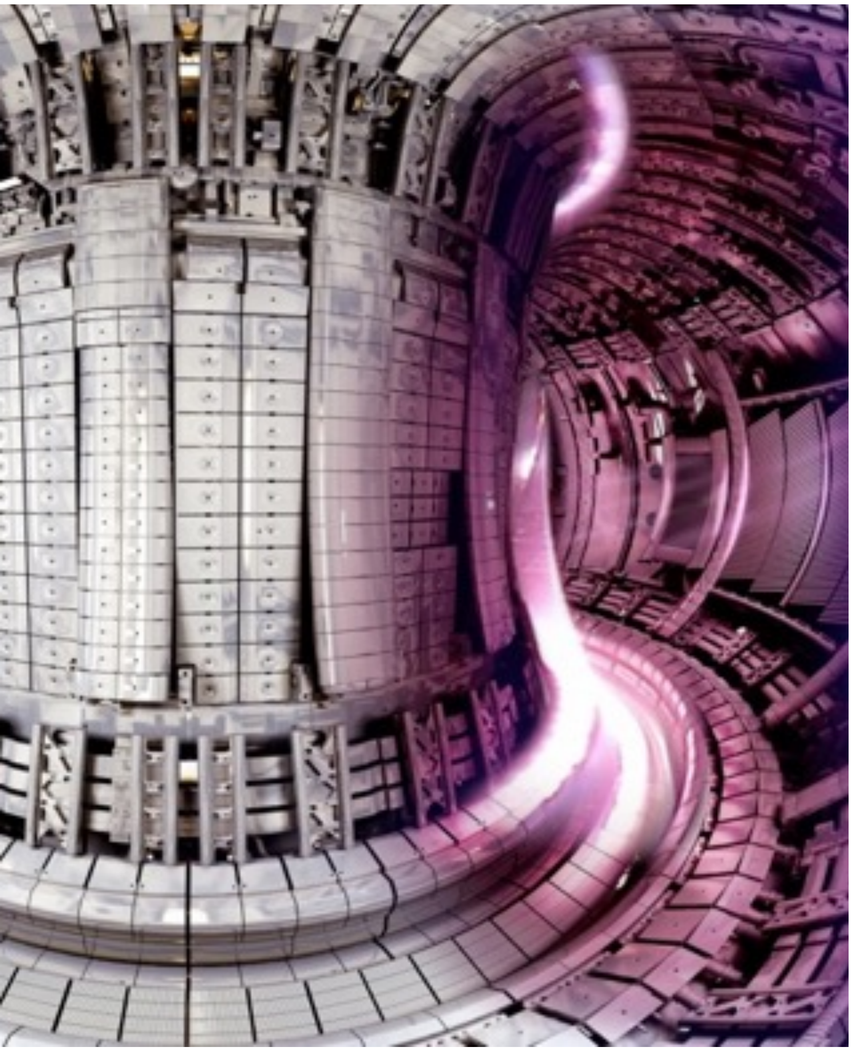

Proliferation Risks of Magnetic Fusion Energy

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*based on work with Robert J. Goldston

Background

Gigawatt-scale nuclear fusion reactor: 10^{20}–10^{21} neutrons per second

(so the possibility of fissile material production comes as no surprise)

Three Proliferation Scenarios

Clandestine Production

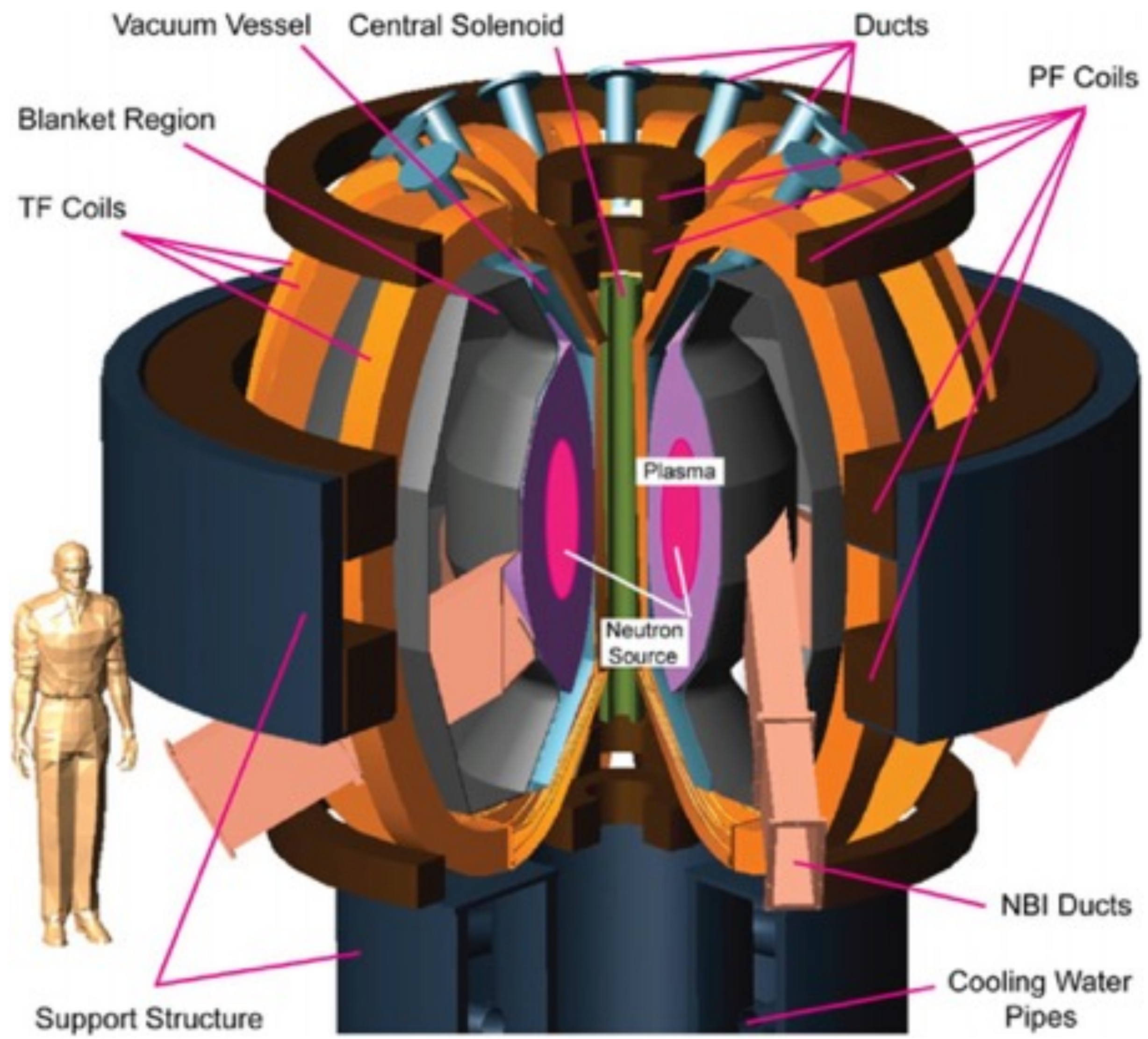
Covert Production (in a declared facility)

Breakout

Discussion based on: A. Glaser and R. J. Goldston, “Proliferation Risks of Magnetic Fusion Energy,” *Nuclear Fusion*, 52, 2012

Also relevant, but not included in this overview: Access to tritium

Clandestine Production (in an Undeclared Facility) is Not a Very Credible Proliferation Concern



40 MW of line power to produce
1.8 MW of fusion power

<u>Hypothetical fissile material production capability</u>

3.5 kg of plutonium per year

A. Glaser and R. J. Goldston, "Proliferation Risks of Magnetic Fusion Energy," *Nuclear Fusion*, 52, 2012

Weapons Material Production in a Lead–Lithium Blanket

(of a Gigawatt-scale Nuclear Fusion Reactor)

Notional Blanket Design

Dual-coolant (liquid) lead-lithium blanket (DCLL)
of a representative DEMO reactor

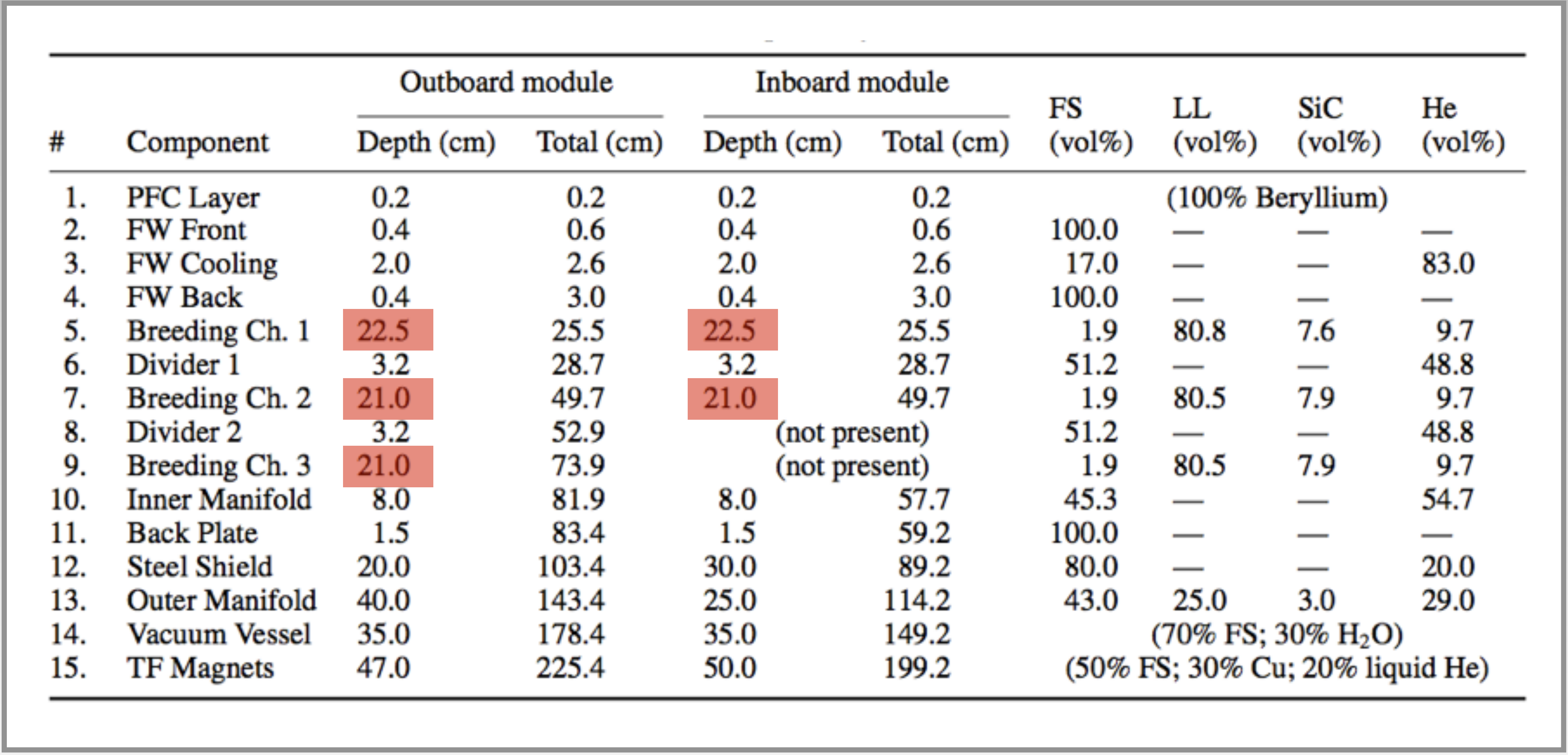
Lead–lithium eutectic (Pb–17Li) with lithium-6 enriched to 90%

Slightly different inboard and outboard designs
(22% and 78% of the neutrons go to the inboard and outboard, respectively)

M. Z. Youssef, N. B. Morley, and M. Dagher, “Impact of the SiC FCI in the DCLL Blanket Module on the Nuclear Environment Inside a Demo Reactor Configuration,” *23rd Symposium on Fusion Engineering*, May 31–June 5, 2009, San Diego

Notional Blanket Design for Calculations

Global Tritium Breeding Ratio (TBR) of system: 1.125



#	Component	Outboard module		Inboard module		FS	LL	SiC	He
		Depth (cm)	Total (cm)	Depth (cm)	Total (cm)	(vol%)	(vol%)	(vol%)	(vol%)
1.	PFC Layer	0.2	0.2	0.2	0.2	(100% Beryllium)			
2.	FW Front	0.4	0.6	0.4	0.6	100.0	—	—	—
3.	FW Cooling	2.0	2.6	2.0	2.6	17.0	—	—	83.0
4.	FW Back	0.4	3.0	0.4	3.0	100.0	—	—	—
5.	Breeding Ch. 1	22.5	25.5	22.5	25.5	1.9	80.8	7.6	9.7
6.	Divider 1	3.2	28.7	3.2	28.7	51.2	—	—	48.8
7.	Breeding Ch. 2	21.0	49.7	21.0	49.7	1.9	80.5	7.9	9.7
8.	Divider 2	3.2	52.9	(not present)		51.2	—	—	48.8
9.	Breeding Ch. 3	21.0	73.9	(not present)		1.9	80.5	7.9	9.7
10.	Inner Manifold	8.0	81.9	8.0	57.7	45.3	—	—	54.7
11.	Back Plate	1.5	83.4	1.5	59.2	100.0	—	—	—
12.	Steel Shield	20.0	103.4	30.0	89.2	80.0	—	—	20.0
13.	Outer Manifold	40.0	143.4	25.0	114.2	43.0	25.0	3.0	29.0
14.	Vacuum Vessel	35.0	178.4	35.0	149.2	(70% FS; 30% H_2O)			
15.	TF Magnets	47.0	225.4	50.0	199.2	(50% FS; 30% Cu; 20% liquid He)			

M. Z. Youssef, N. B. Morley, and M. Dagher, "Impact of the SiC FCI in the DCLL Blanket Module on the Nuclear Environment Inside a Demo Reactor Configuration," *23rd Symposium on Fusion Engineering*, May 31–June 5, 2009, San Diego

Scenario Assumptions

One-dimensional MCNP5 model with homogenized radial zones

2500 MW thermal power (2660 MW plasma power)
Incident neutron rate: 9.42 x 10^{20} n/s

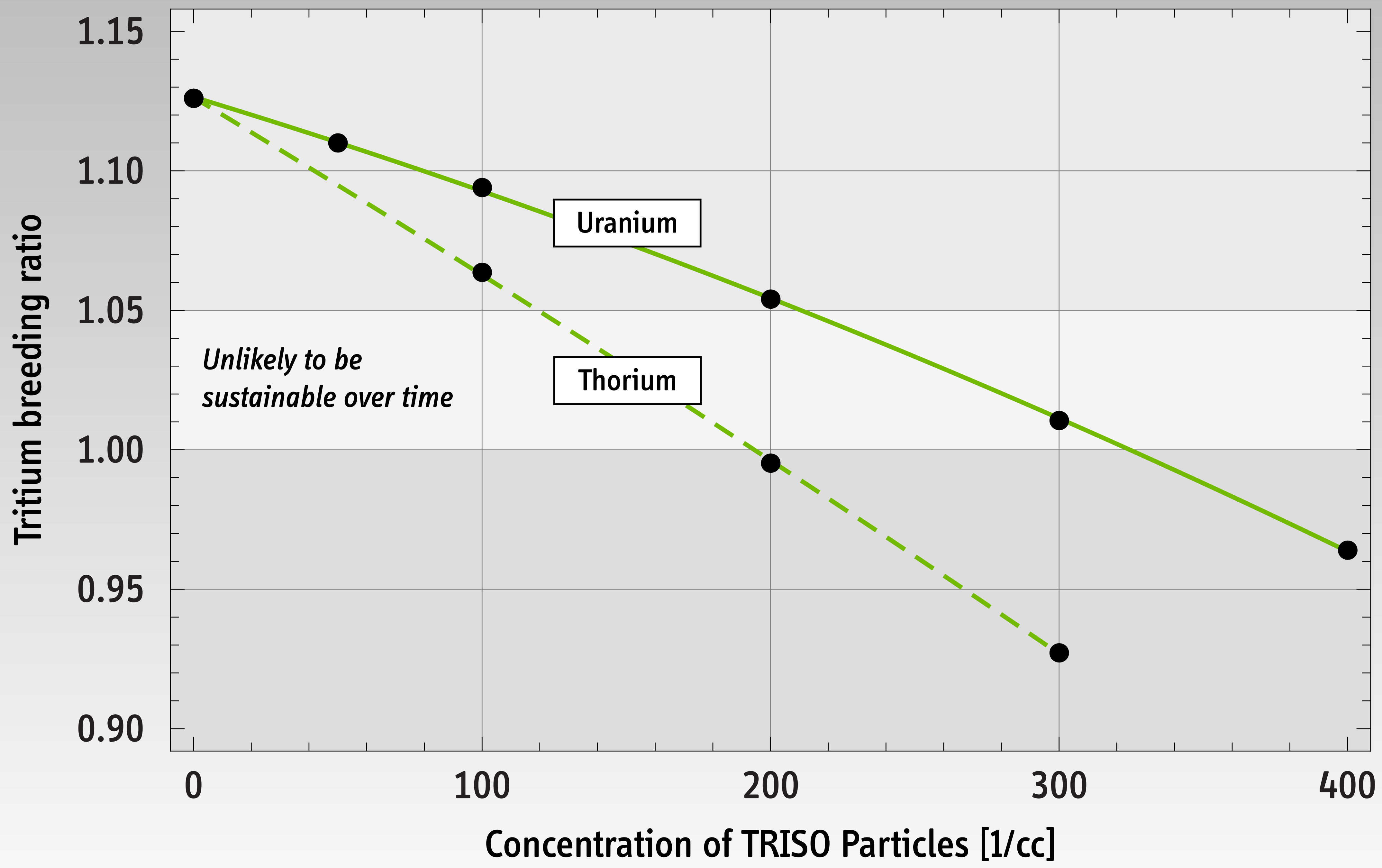
TRISO/BISO particles suspended (not dissolved) in liquid blanket
(offering “mechanical” extraction with dedicated filtration system)

10,000 metric tons of liquid lead-lithium
(For typical scenarios: several hundred tons of fertile material in the system)

MCNP5 Simulation Results

Tritium Breeding Ratio

(Drops with loading of fertile material in the blanket; constrains thorium scenario)



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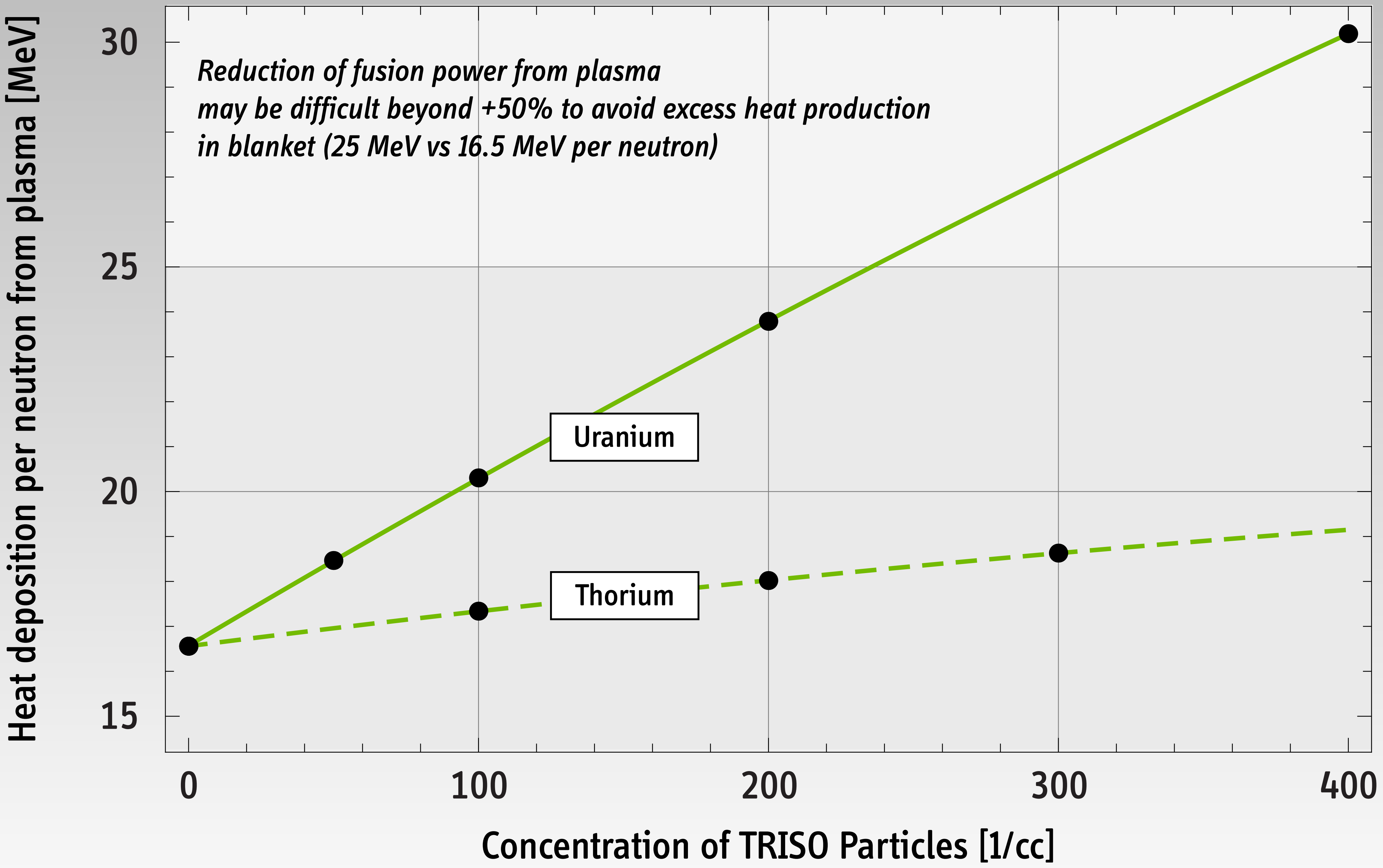
Heat Deposition

(Much larger for uranium than for thorium; constrains uranium scenario)



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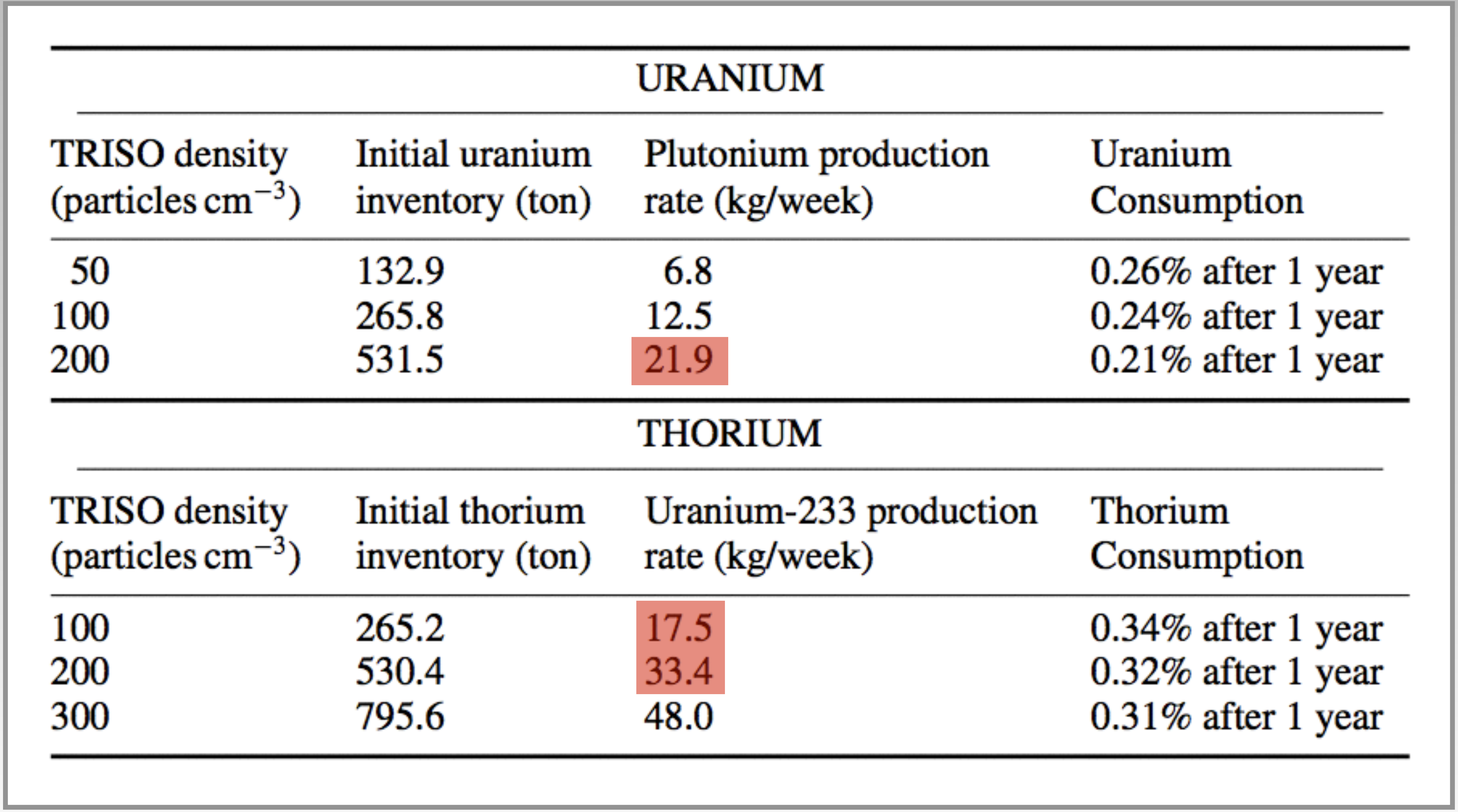
Production Rates of Fissile Material



URANIUM			
TRISO density (particles cm^{-3})	Initial uranium inventory (ton)	Plutonium production rate (kg/week)	Uranium Consumption
50	132.9	6.8	0.26% after 1 year
100	265.8	12.5	0.24% after 1 year
200	531.5	21.9	0.21% after 1 year

THORIUM			
TRISO density (particles cm^{-3})	Initial thorium inventory (ton)	Uranium-233 production rate (kg/week)	Thorium Consumption
100	265.2	17.5	0.34% after 1 year
200	530.4	33.4	0.32% after 1 year
300	795.6	48.0	0.31% after 1 year

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Simulation Results

Summary

Uranium: Fertile load limited by additional heat load in blanket

Thorium: Fertile load limited by loss of breeding ratio

Maximum Production Rates of a Gigawatt-scale Fusion Reactor

Both strategies could yield on the order of 1000 kg of fissile material per year

Thorium possibly more (c. 1500 kg/yr) if operated in non-sustainable mode

(while consuming tritium inventory available onsite)

Covert Production of Fissile Material

Scenario Assumptions

Objective

Produce one significant quantity (8 kg) of plutonium or uranium-233 per year

Based on calculations/results from above, this would correspond to:

- About one TRISO/BISO particle per cubic centimeter
- 2–3 tons of fertile inventory in the system

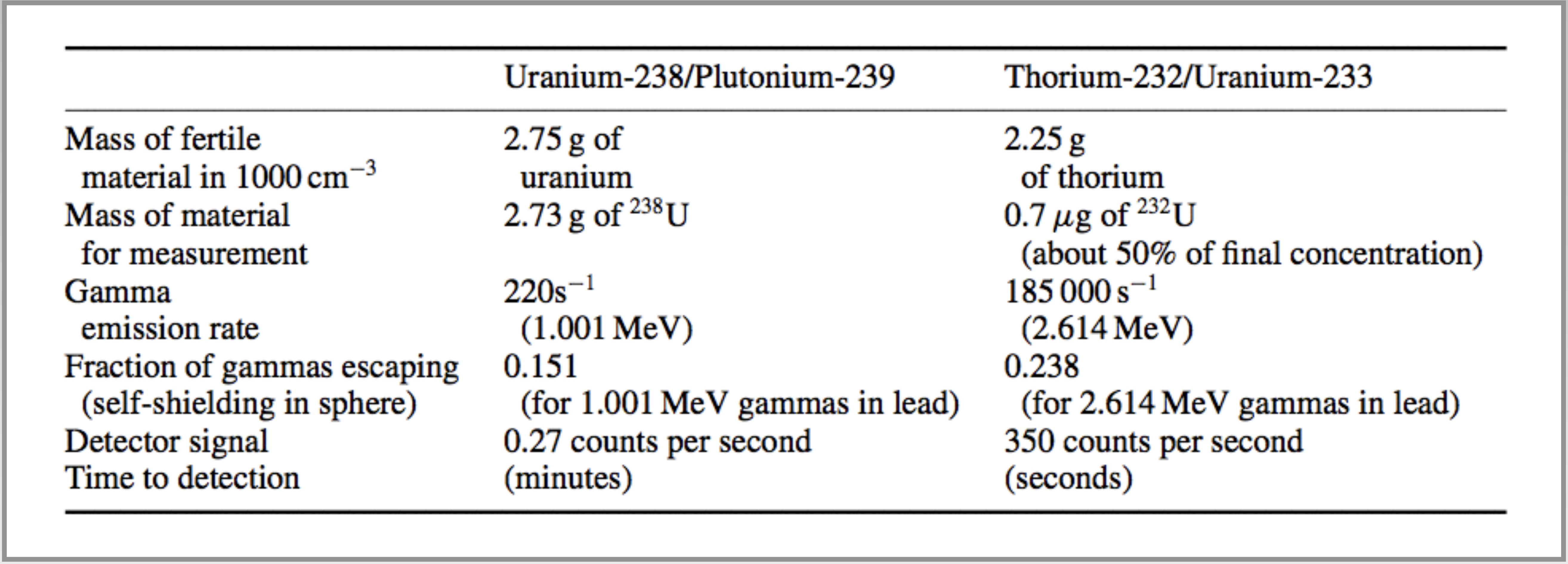
Detecting the presence of fertile/fissile material at a fusion reactor?

One (promising) approach could be the detection of gamma emissions from the fertile or (after irradiation) the fissile material

Detecting Covert Production of Fissile Material

should be feasible for reasonably small sampling volumes

(here: 1 liter containing 9.4 kg of lead)



	Uranium-238/Plutonium-239	Thorium-232/Uranium-233
Mass of fertile material in 1000 cm^{-3}	2.75 g of uranium	2.25 g of thorium
Mass of material for measurement	2.73 g of ^{238}U	0.7 μg of ^{232}U (about 50% of final concentration)
Gamma emission rate	220s^{-1} (1.001 MeV)	185 000 s^{-1} (2.614 MeV)
Fraction of gammas escaping (self-shielding in sphere)	0.151 (for 1.001 MeV gammas in lead)	0.238 (for 2.614 MeV gammas in lead)
Detector signal	0.27 counts per second	350 counts per second
Time to detection	(minutes)	(seconds)

Fixed ceramic breeders would need to be checked for uranium and thorium before installation or for fissile material after use

A. Glaser and R. J. Goldston, "Proliferation Risks of Magnetic Fusion Energy," *Nuclear Fusion*, 52, 2012

Breakout

Scenario Assumptions

Objective

Produce one significant quantity (8 kg) of plutonium or uranium-233 as quickly as possible and without making efforts to conceal it

Based on calculations/results from above, this could be accomplished in a matter of days (based on maximum production rates alone)

BUT we estimate that the time required to reconfigure and restart the plant could be on the order of 1–2 months

Note that, in contrast to fission systems, no fissile material is available at the time of breakout

In Lieu Of Conclusions

There Are Many Open Research Questions

Could ITER serve as a test bed to resolve some of these?

- Measurements of radiation spectra near cooling pipes, comparison with projected spectra of fertile and fissile materials
- Development of optimal methods to assure that blanket modules do not contain fertile materials or (after irradiation) fissile materials
- Examination of the feasibility of transporting significant quantities of TRISO particles in realistic flow geometries; Examination of techniques to make this more difficult
- Practical experience with the length of time required to replace a test blanket module and restart a fusion device in a breakout scenario