Making Highly Enriched Uranium

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Revision 4


200 meters
Fuel Enrichment Plant
(FEP)
(FEP)
Sep 2002
Natanz Site, Iran, 2007

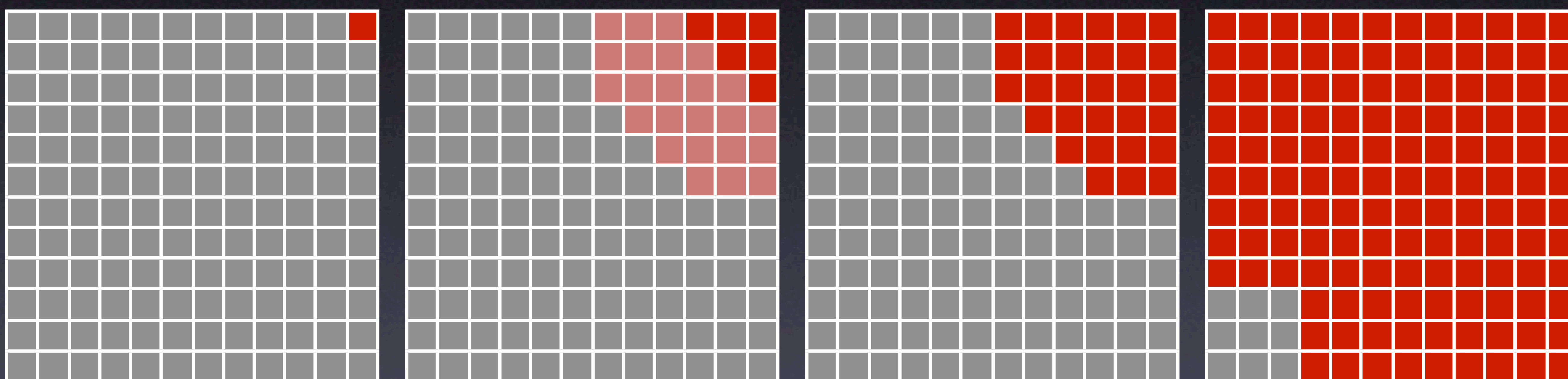
What is HEU ?

Highly Enriched Uranium

(visually)

HEU

(weapon-usable)



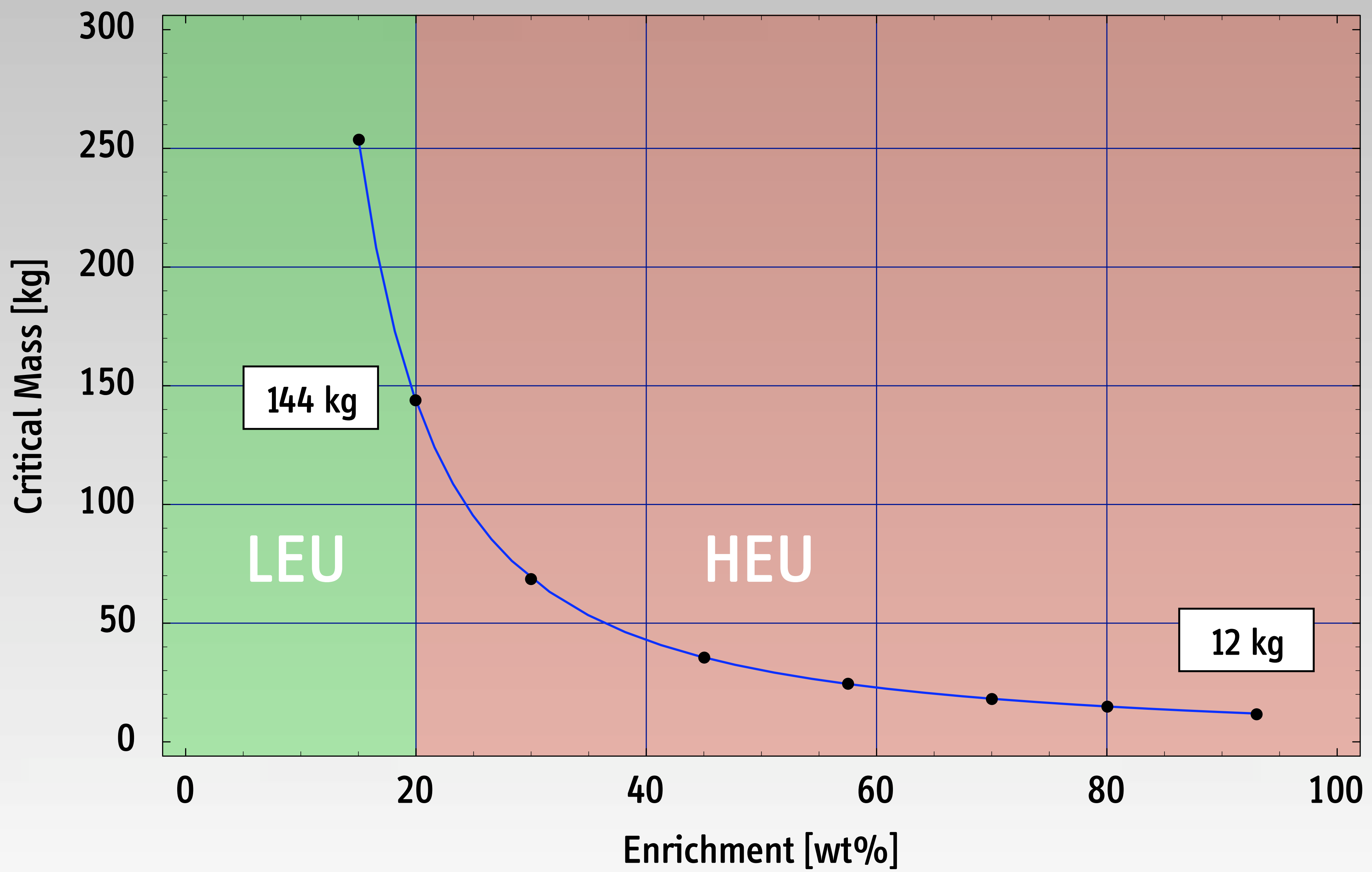
Natural uranium	Low-enriched uranium	Highly enriched uranium	Weapon-grade uranium
0.7% U-235	typically 3-5%, but less than 20% U-235	20% U-235 and above	more than 90% U-235

Uranium

- U-235
- U-238

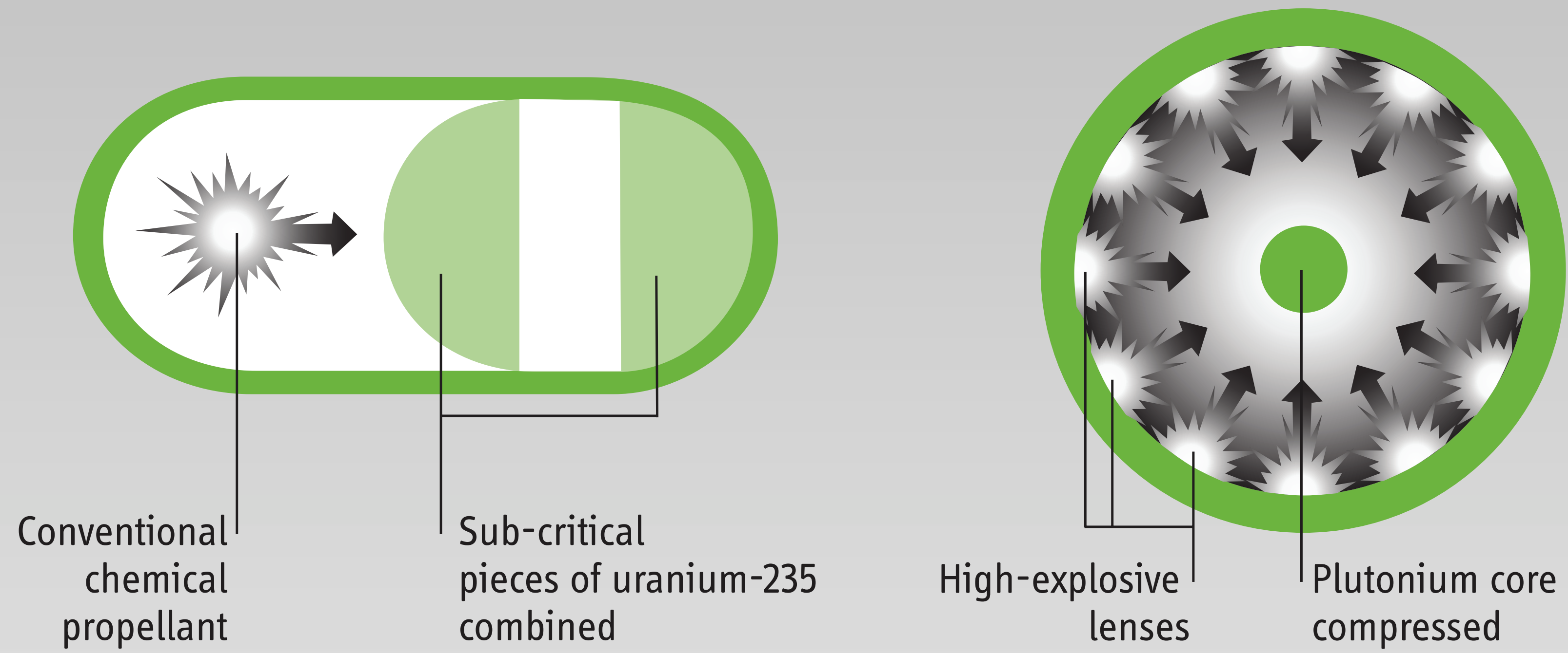
Critical Mass of Uranium

(for a beryllium-reflected metallic sphere)



Characteristics of Highly Enriched Uranium

Easy to handle
Easy to use in nuclear weapon or nuclear explosive device
Difficult/Impossible to detect



Difficult to produce

Why Make HEU Anyway?

(if there is so much of it around)

Global HEU Inventory 2007

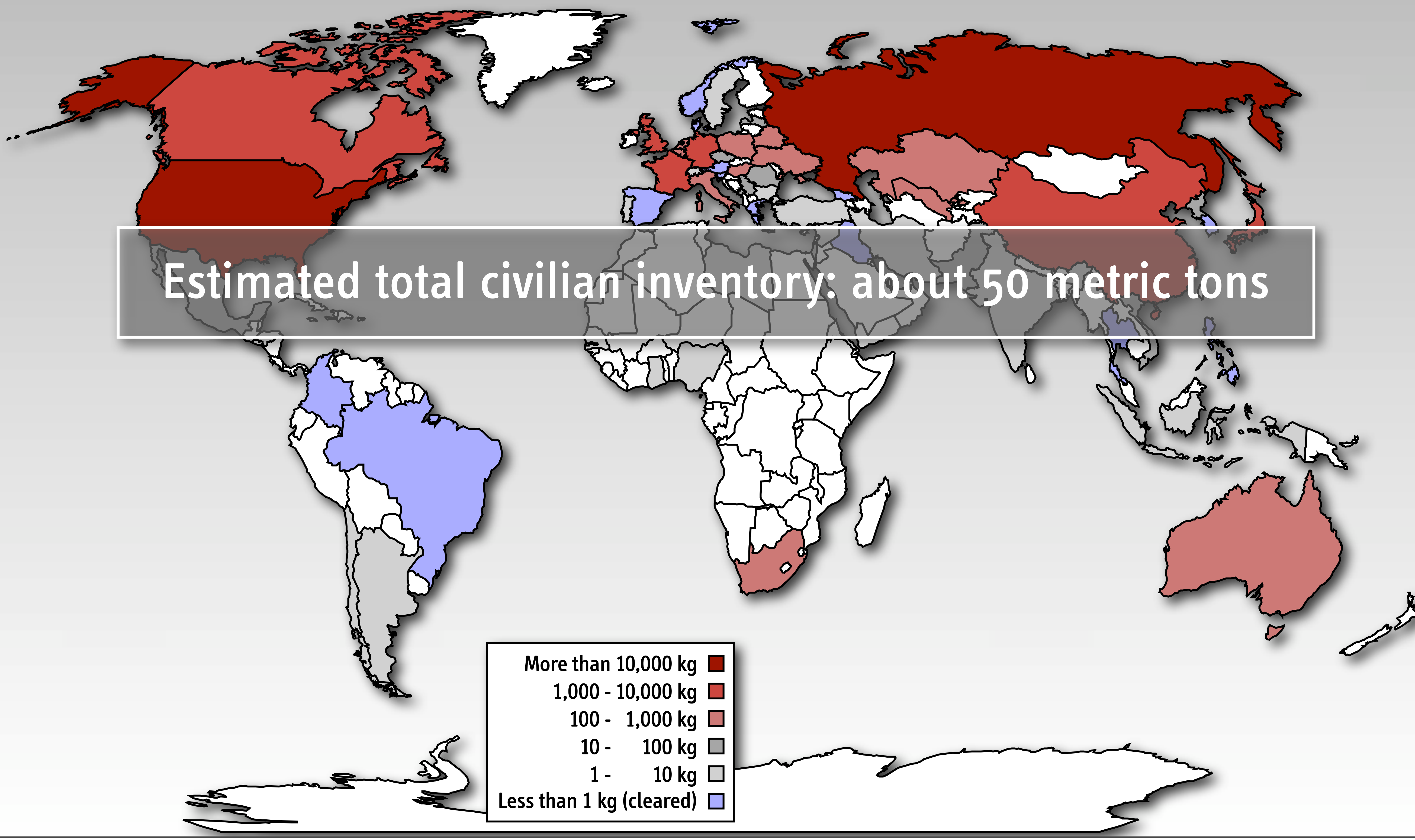
(civilian and military combined)

Country	National Stockpile (estimate)	
China	22 MT	± 25%
France	33 MT	± 20%
India	0.2 MT	± 50%
Pakistan	1.4 MT	± 15%
Russia	770 MT	± 300 MT
United Kingdom	24 MT	declared
United States	467 MT	declared
Non-nuclear states	10 MT	
TOTAL (rounded)	1325 MT	± 310 MT

(total world-inventory of HEU is enough for 50,000-100,000 nuclear weapons)

Estimates from IPFM Global Fissile Material Report 2006, updated partially based on D. Albright (ISIS)

Global Distribution of Civilian HEU



Production of Enriched Uranium

(Uranium Enrichment)

Global Enrichment Picture 2007

Country	Name/Location	Type	Status	Process	Capacity [tSWU/yr]
Brazil	Resende	Commercial	Under construction	GC	120
China	Lanhou 2	Commercial	Under construction	GC	500
	Shaanxi	Commercial	In operation	GC	500
France	George Besse	Commercial	In operation	GD	10800
	George Besse II	Commercial	Planned	GC	7500
Germany	Urenco Deutschland	Commercial	In operation	GC	1800 (+2700)
India	Rattehalli	Military	In operation	GC	4-10
Iran	Natanz	Commercial	Under construction	GC	100-250
Japan	Rokkasho	Commercial	In operation	GC	1050
Netherlands	Urenco Nederland	Commercial	In operation	GC	2500 (+1000)
Pakistan	Kahuta	Military	In operation	GC	15-20
Russia	Angarsk	Commercial	In operation	GC	2350
	Novouralsk	Commercial	In operation	GC	12160
	Zelenogorsk	Commercial	In operation	GC	7210
	Seversk	Commercial	In operation	GC	3550
U.K.	Capenhurst	Commercial	In operation	GC	4000
USA	Paducah	Commercial	In operation	GD	11300
	Piketon (USEC/DOE)	Commercial	Planned	GC	3500
	Eunice (LES)	Commercial	Planned	GC	3000

Comparison of Enrichment Capacities

Values for a reference facility with a capacity of 130 tSWU/yr

Material and separative work required to fuel a 1000 MWe light-water reactor

Feed		Product		Time
150,000 kg	U(nat) at 0.71%	20,000 kg	LEU at 4% (Tails at 0.20%)	1 year

Material and separative work required to produce enough HEU for several bombs per year

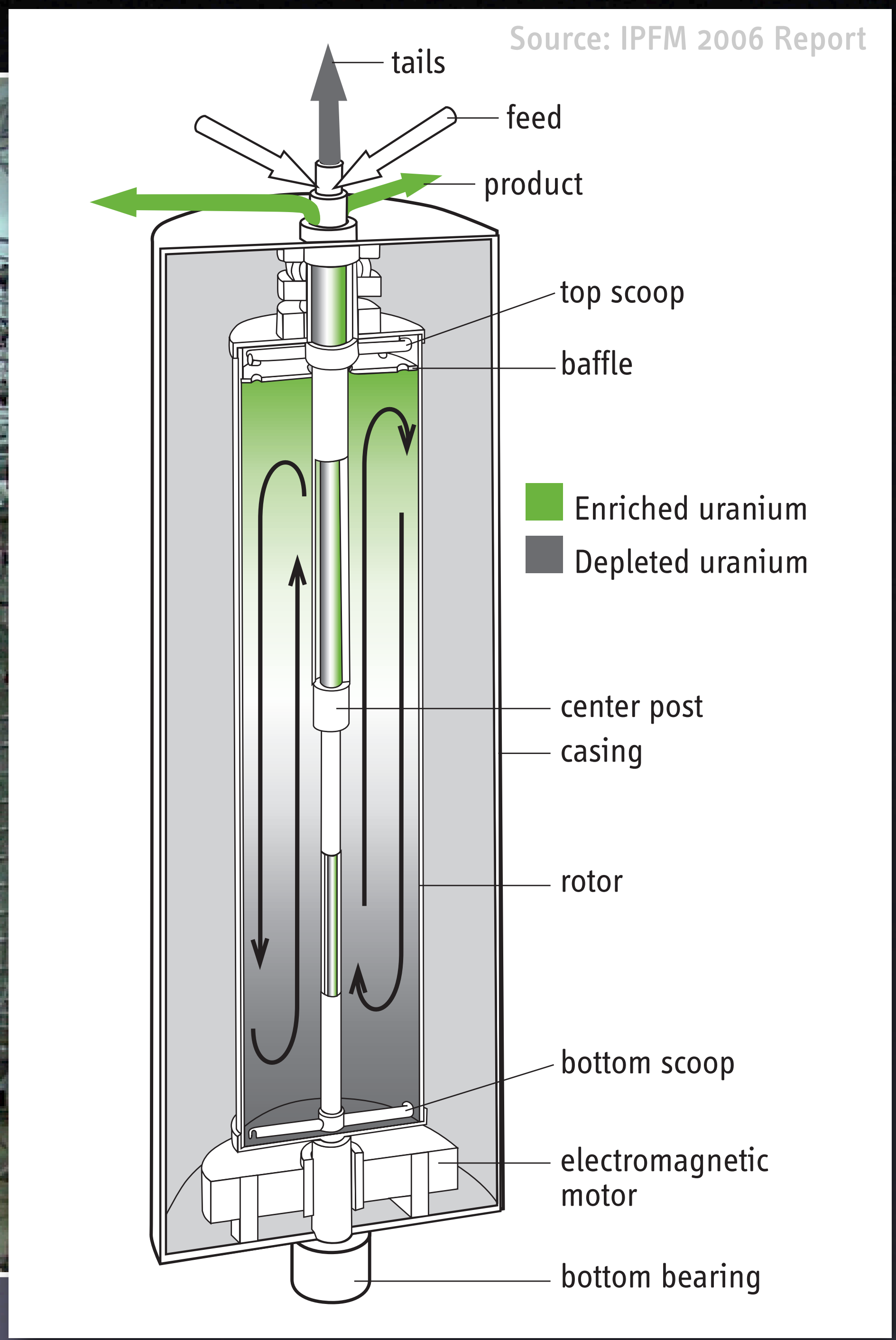
Feed		Product		Time
150,000 kg	U(nat) at 0.71%	654 kg (25-50 bombs)	HEU at 93% (Tails at 0.30%)	1 year
150,000 kg	U(nat) at 0.71%	100 kg (4-8 bombs)	HEU at 93% (Tails at 0.65%)	40 days
20,000 kg	LEU at 4%	100 kg (4-8 bombs)	HEU at 93% (Tails at 3.55%)	8 days

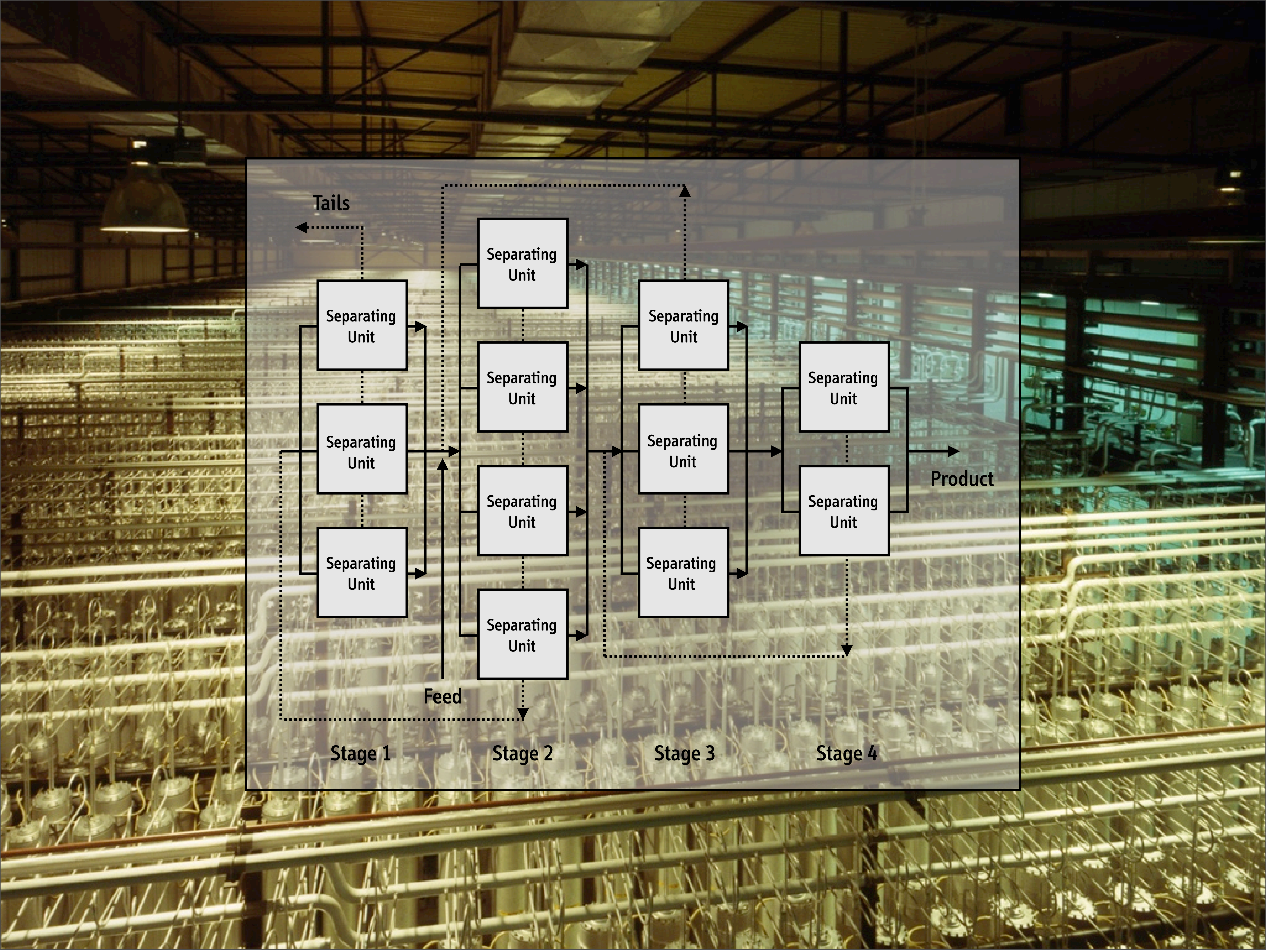
Additional time is needed before HEU can be produced in a facility that previously produced LEU because the “old” uranium gas has to be “flushed out” from the equipment and the facility may have to be reconfigured

The Case of the Gas Centrifuge

Centrifuges for Uranium Enrichment

Source: Presentation by Mohammad Saeidi (AEOI)




Tails
Separating Unit
Separating Unit
Separating Unit
Separating Unit
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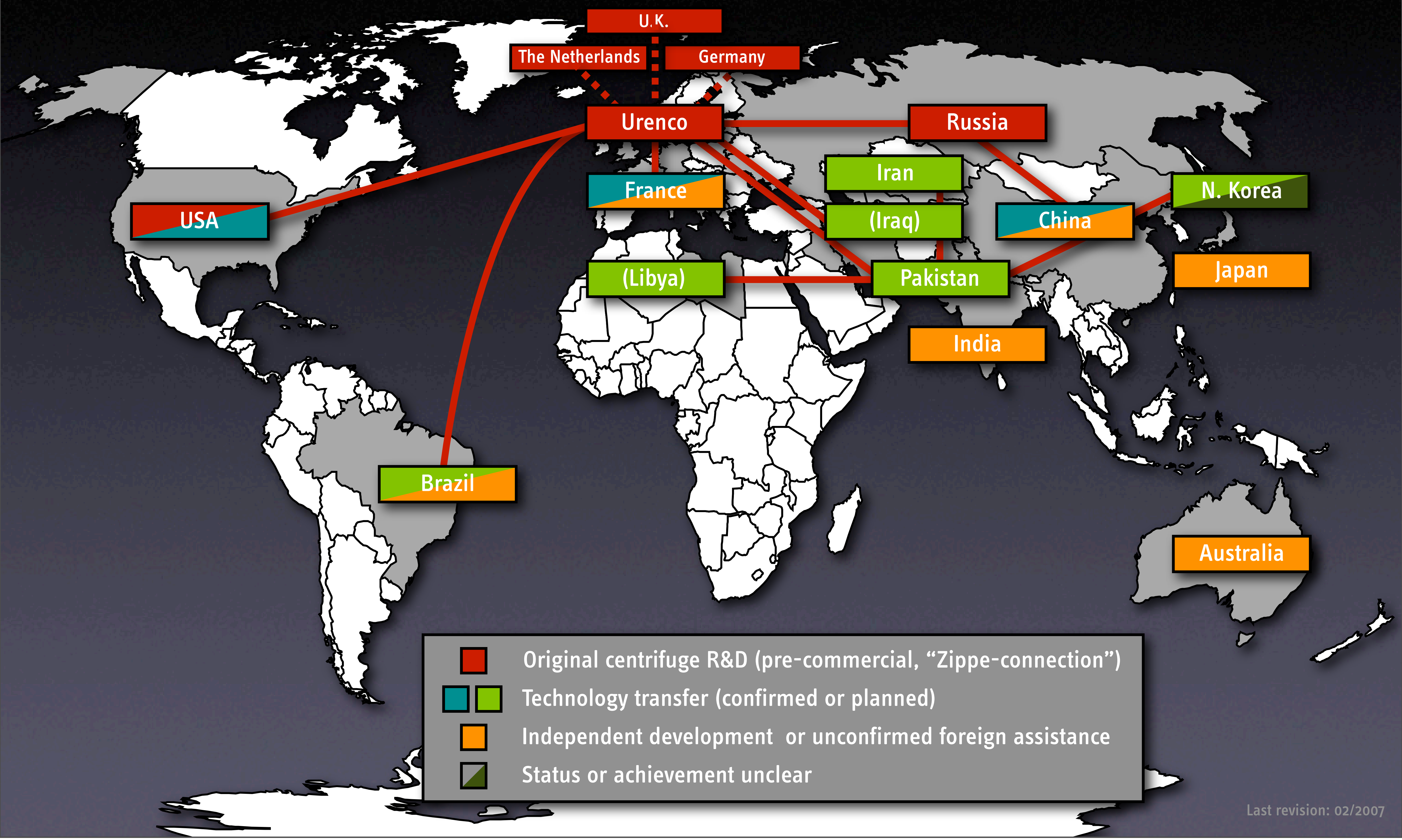
Separating Unit
Product
Feed
Stage 1
Stage 2
Stage 3
Stage 4

Genealogy of the Gas Centrifuge

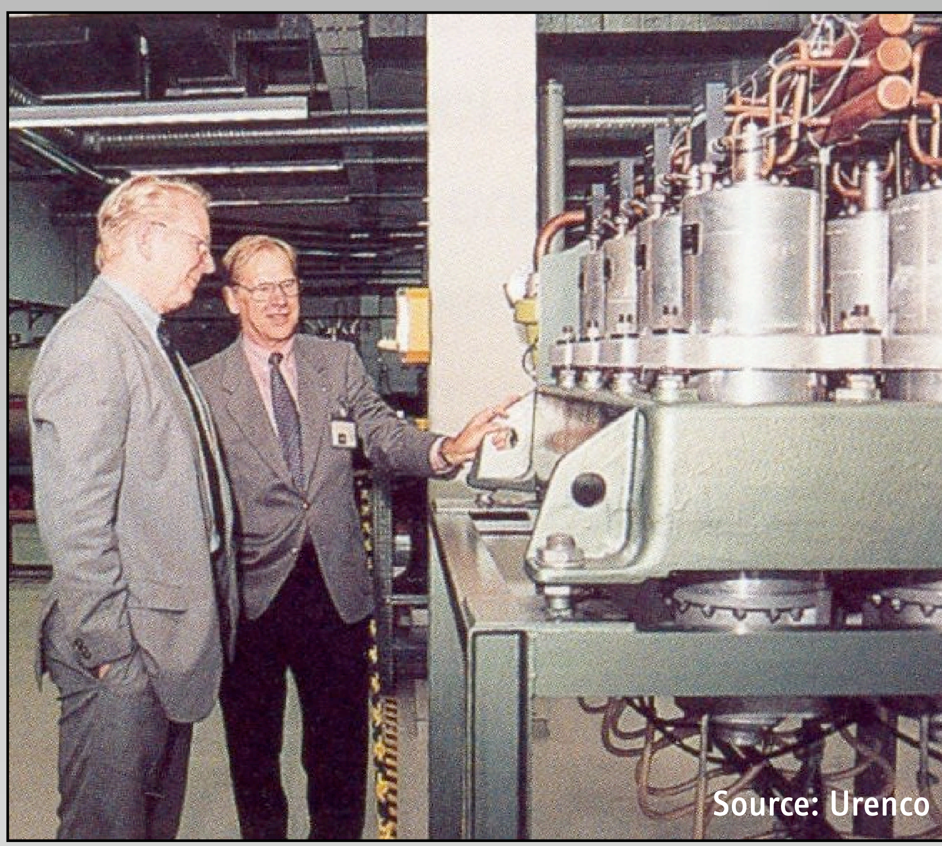


Last revision: 02/2007

Why Are Centrifuges Different?

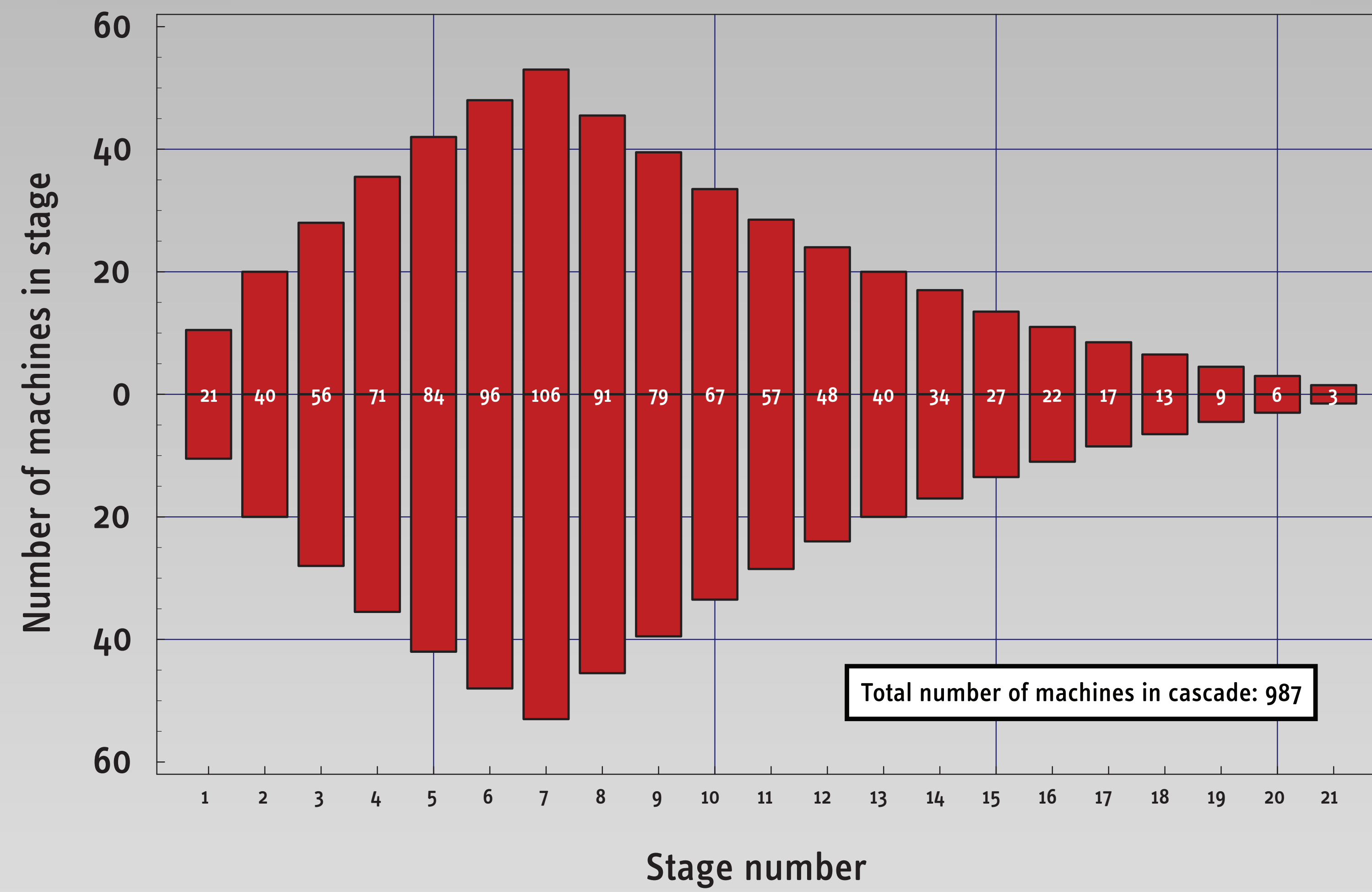
Crude Breakout Scenario

(using an early-generation machine)



Assumed characteristics of P-2-type machine

peripheral velocity = 485 m/s
rotor diameter = 15 cm
rotor height = 100 cm
separative power = 5 SWU/yr

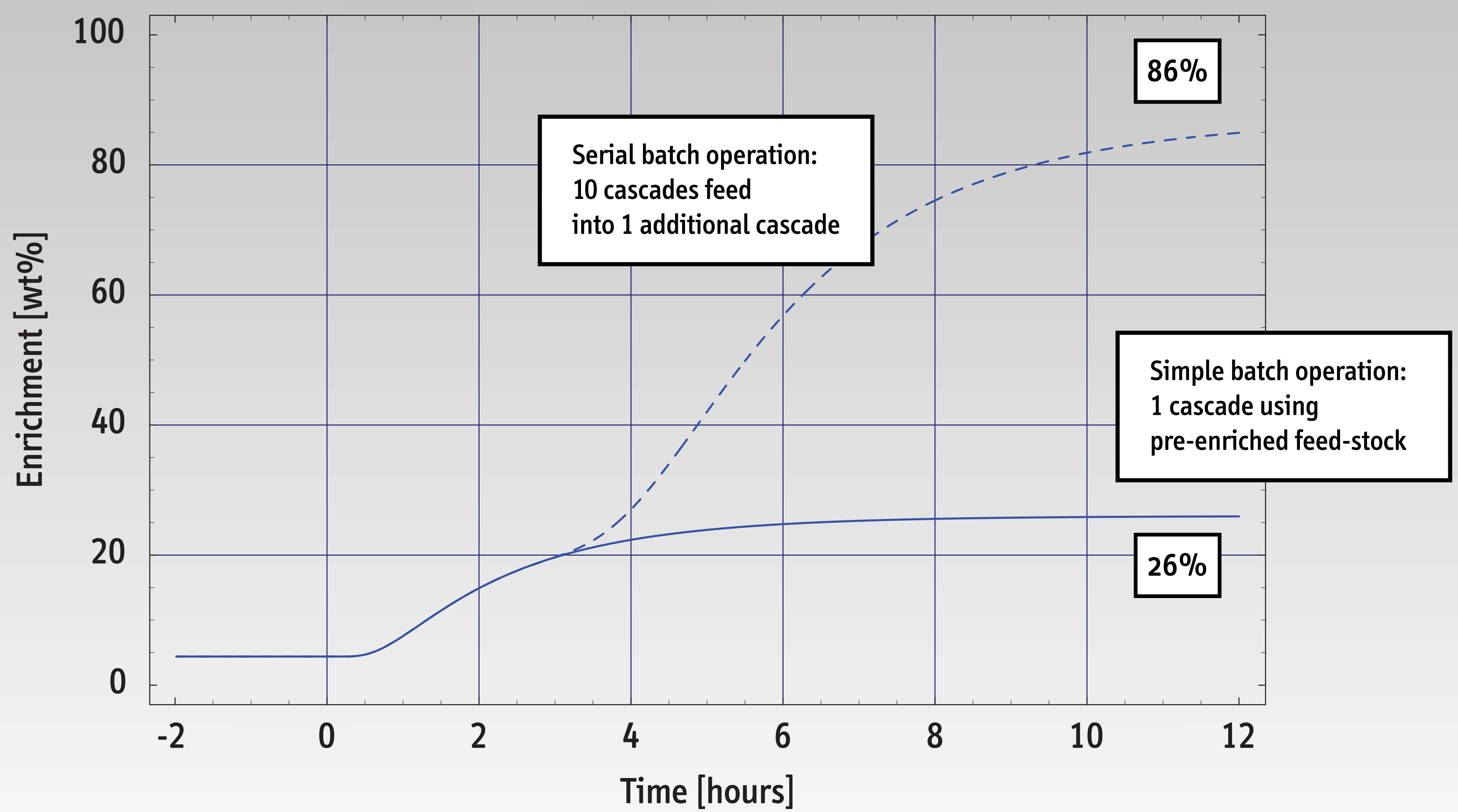


Performance of reference LEU-cascade

Feed = 32.4 kg/d of UF_6 w/ natural uranium
Product = 3.3 kg/d of UF_6 w/ 4.4%-enriched uranium

Simple Breakout Scenario

(using an early-generation machine)



(compare to equilibrium time for gaseous diffusion process, which is on the order of months)

Detection of Undeclared Facilities

GRONAU centrifuge enrichment facility, Germany
Current capacity: 1,800,000 SWU/a (to be expanded to 4,500,000 SWU/yr)
Footprint of facility: 200 meters x 240 meters

Specific capacity of facility: 37.5 SWU/yr per square meter

Minimum capacity of facility to produce 25 kg of HEU annually: about 6,000 SWU/yr
Hypothetical footprint: 160 square meters (42 ft x 42 ft)

Detectability of Undeclared Facilities

		Detectability (Selected Criteria)		
		Identifiable Structure	Thermal Signature	Effluents
Plutonium Production	Reactor	Yes	Yes	No
	Reprocessing	No	No	(Yes)
Uranium Enrichment	Calutron/EMIS	No	Yes	Yes
	Gaseous diffusion	Yes	Yes	Yes
	Centrifuge	No	No	No

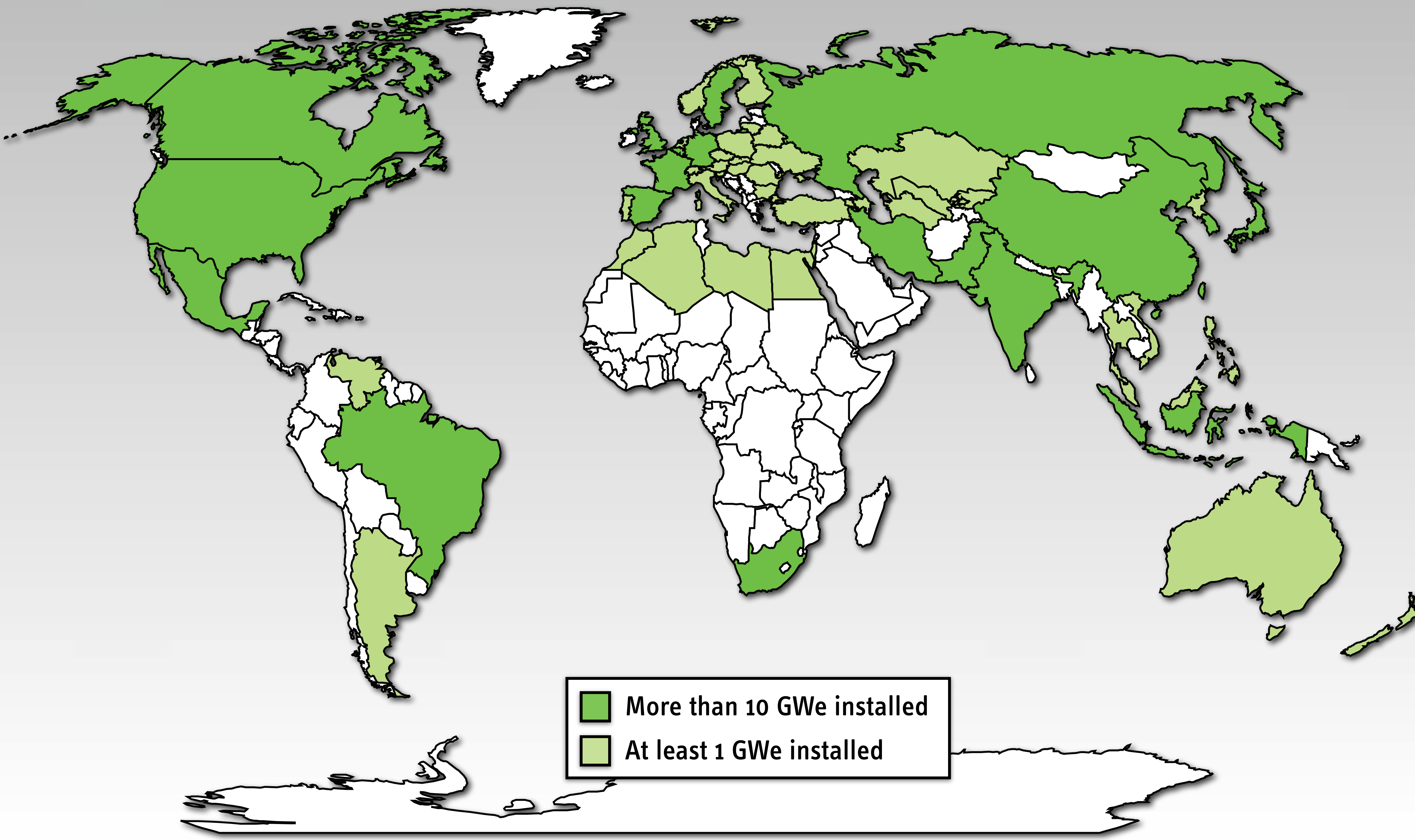
What Are Our Options?

Possible Strategies to Limit the Front-End Proliferation Risks of the Nuclear Fuel Cycle

STRATEGY	TARGET / OBJECTIVE
• Increase the effectiveness of (and the confidence in) safeguards	Preclude covert misuse
• Increase the ability to detect undeclared facilities	Deter clandestine activities
• Contain technology to existing or selected producers	Know-how held by “trusted users”
• Focus on the demand side (i.e. “devalue” nuclear weapons)	Motivation

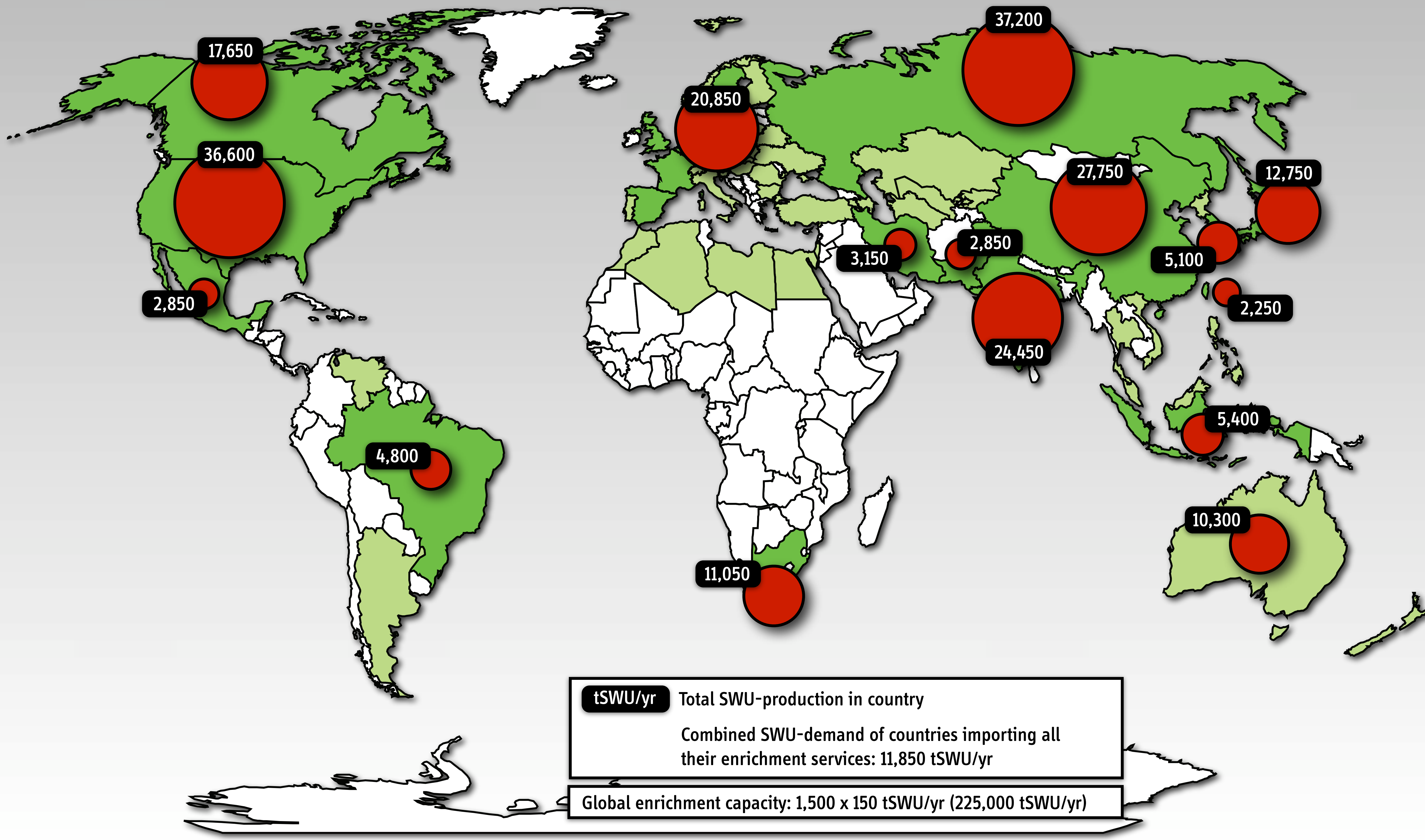
Global Nuclear Expansion Scenario

(1500 GWe in 58 countries, based on 2003 MIT study)



Enrichment Demand and Distribution

(for 1500 GWe Global Nuclear Expansion Scenario)



tSWU/yr Total SWU-production in country

Combined SWU-demand of countries importing all their enrichment services: 11,850 tSWU/yr

Global enrichment capacity: 1,500 x 150 tSWU/yr (225,000 tSWU/yr)

Containment Strategies

Have and have-not approaches

Bush Proposal (2004) or other “criteria-based” proposals

Black Box approaches

with or without “Poison Pills” and combined with multinational operation of facilities

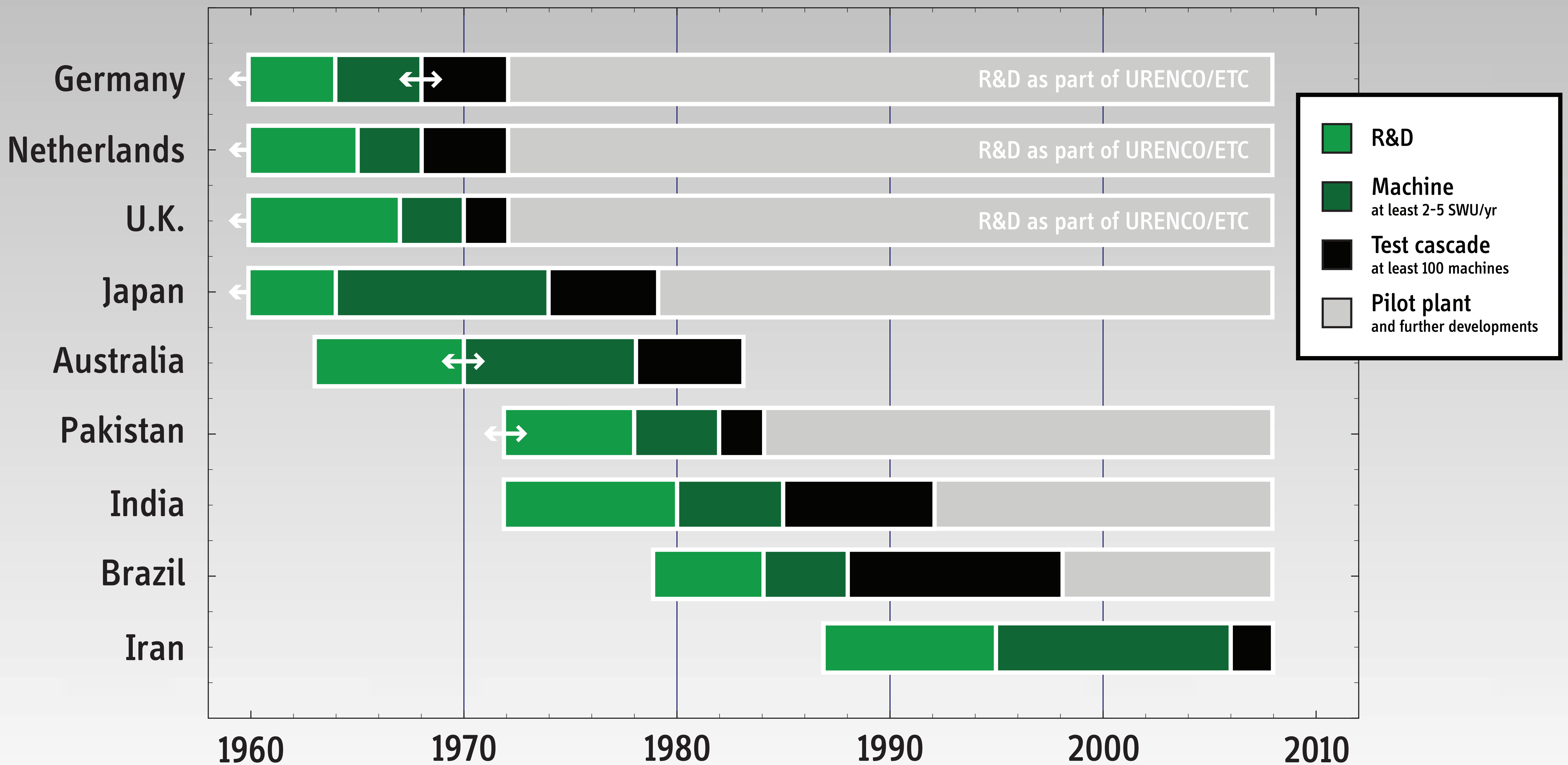
Export Controls

Deter, delay, detect procurement efforts

But to what extent are they durable?

Underlying assumption that indigenous R&D efforts are irrelevant/insufficient

Timeline of Centrifuge Programs



DRAFT version, August 2006 - by Alexander Glaser, Princeton University

(arrows indicate uncertain dates of respective events or milestones)

Possible Strategies to Limit the Front-End Proliferation Risks of the Nuclear Fuel Cycle

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