Centrifuge Enrichment

and the Breakout Problem

Alexander Glaser

Department of Mechanical and Aerospace Engineering
and Woodrow Wilson School of Public and International Affairs
Princeton University

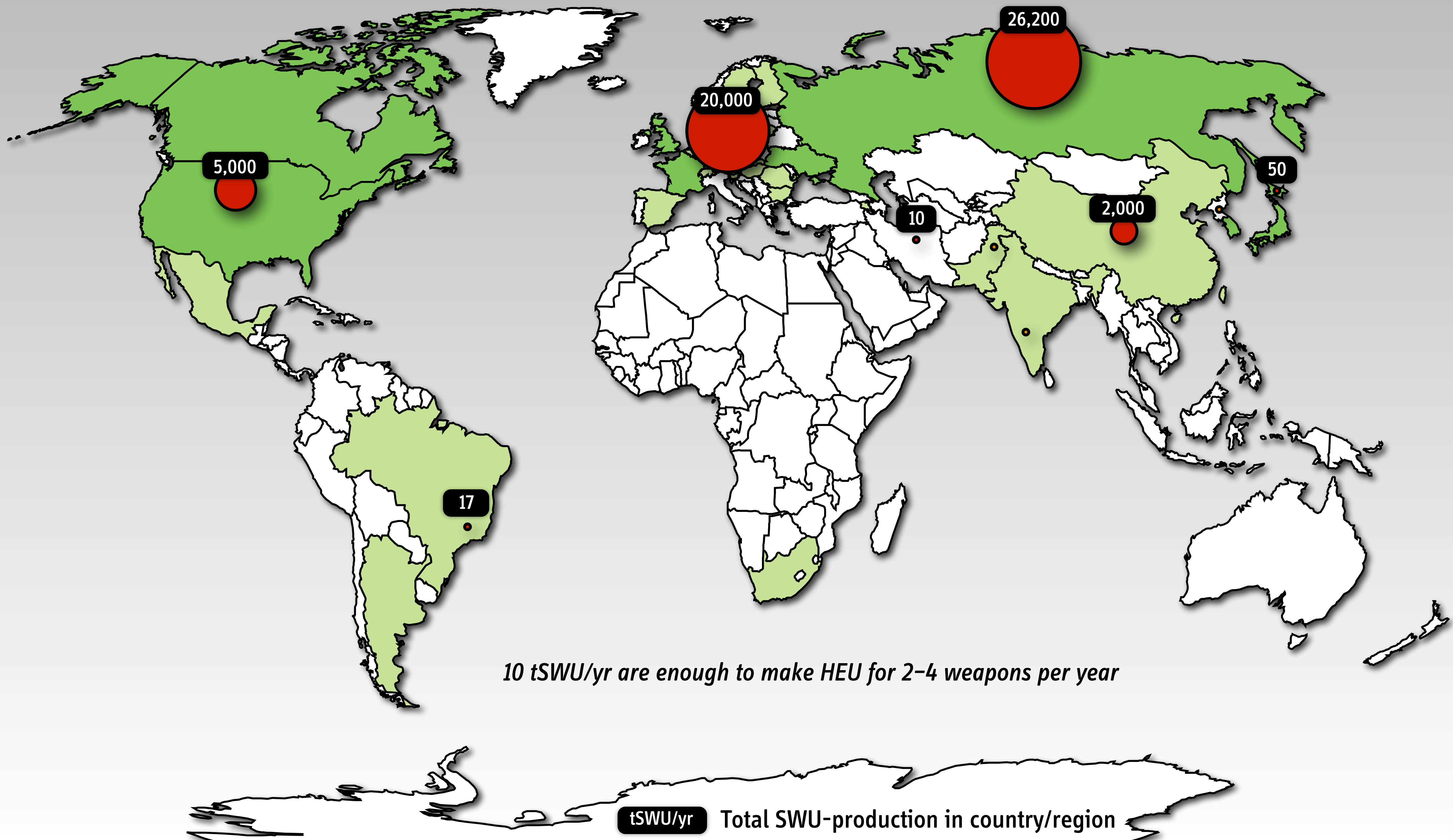
Spring 2014 Meeting of the International Panel on Fissile Materials
Rio de Janeiro, March 20, 2014

Revision 2

Background

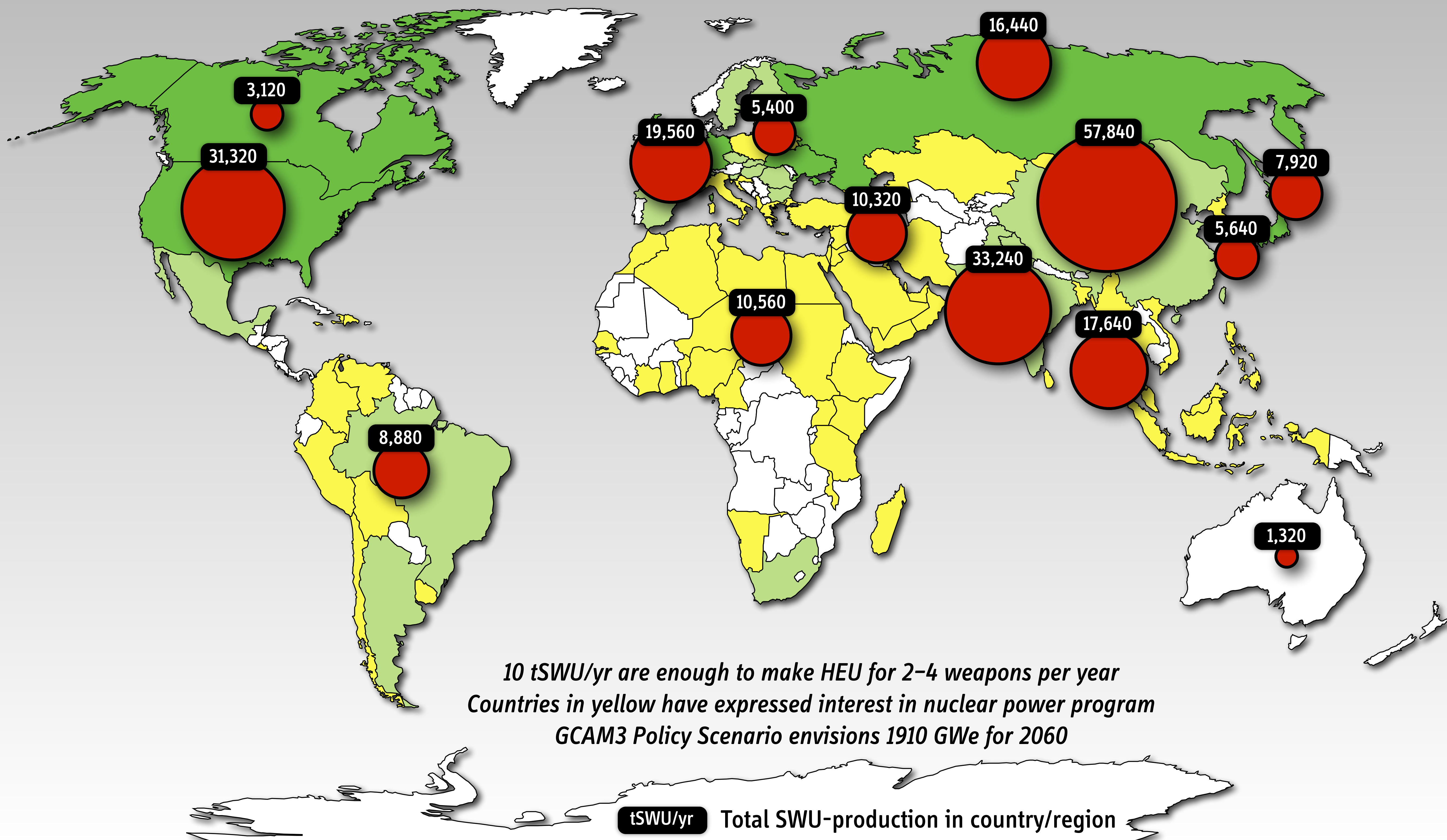
Global Enrichment Capacities, 2014

(16 operational plants in 10 countries, not including 2–4 military plants)



Global Enrichment Capacities, 2060

Based on the requirements for a (GCAM3) Policy Scenario in 14 World Regions

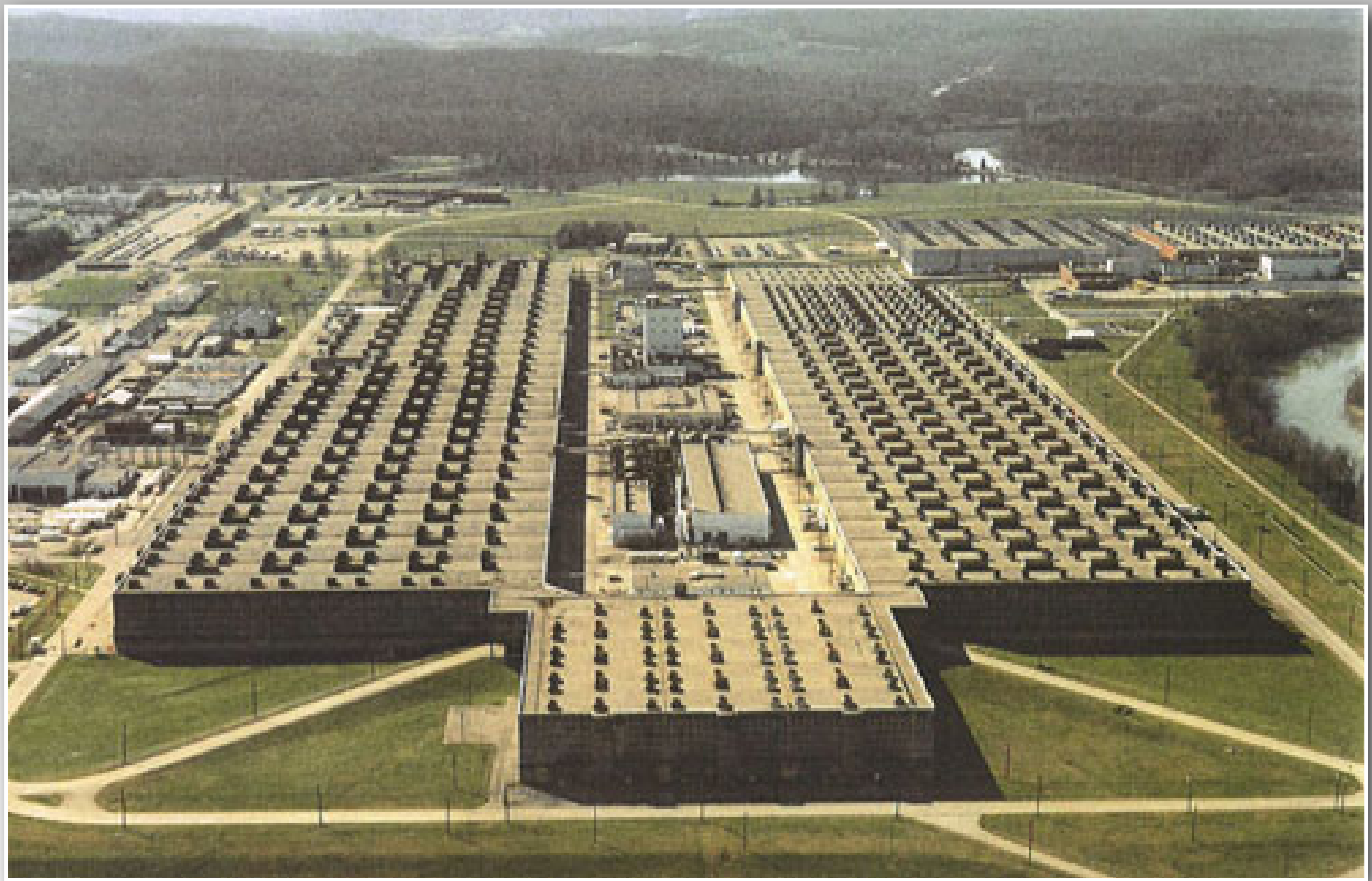


10 tSWU/yr are enough to make HEU for 2–4 weapons per year
Countries in yellow have expressed interest in nuclear power program
GCAM3 Policy Scenario envisions 1910 GWe for 2060

Uranium Enrichment
by Gas Centrifuge

Enrichment Plants Used to be Gigantic

(Gaseous Diffusion Plant K-25, Oak Ridge, TN, now demolished)



Why Centrifuges Are Different

Zippe Centrifuge, 1959

Characteristics of centrifuge technology relevant to nuclear proliferation

Clandestine Option and Rapid Breakout

Clandestine Option

Clandestine Option

Sensitivity and Detectability of Different Enrichment Technologies

	Proliferation Sensitivity	Detectability (Selected Criteria)		
		Size	Energy	Effluents
Calutron/EMIS	(High)	No	Yes	Yes
Gaseous diffusion	Low	Yes	Yes	Yes
Chemical exchange	Very low	(Yes)	(No)	(Yes)
Centrifuge	High	No	No	No
Laser	High	No	No	No

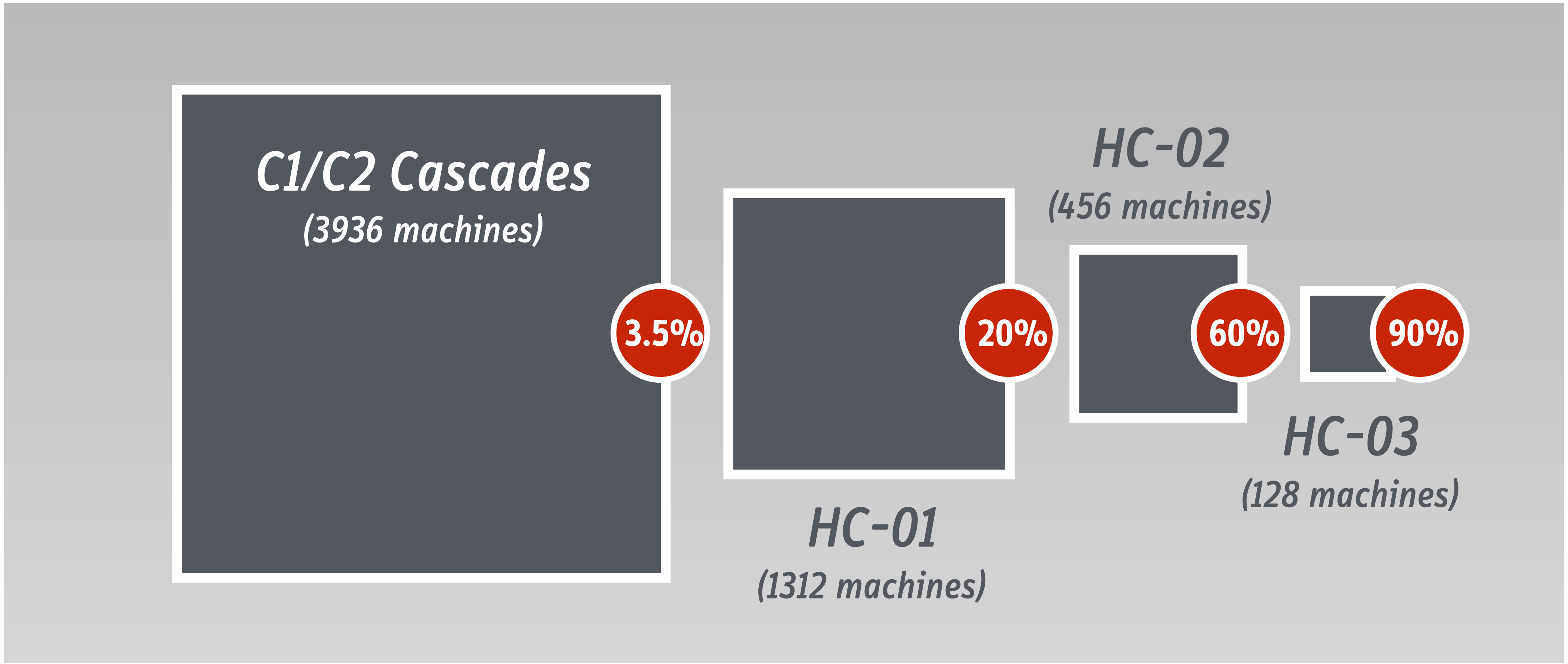

200 meters
Fuel Enrichment Plant
(FEP)
(FEP)
The Natanz Site in Iran (2007)


Google Earth, 34.885 N 50.995 E

Breakout Option

Minimal Breakout Times

A.Q. Khan Cascade Scheme



67.5% of total enrichment capacity is used to produce 3.5%-enriched product
90.0% of total enrichment capacity is used to produce 20.0%-enriched product

A. Glaser, Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation
Science & Global Security, 16 (1–2), 2008, pp. 1-25

Minimal Breakout Times

Time to first significant quantity (25 kg of U-235 in weapon-grade HEU)

Declared facility that produces 3.5% enriched uranium prior to breakout

18,000 1st-generation machines, 1 SWU/yr (18,000 SWU/yr), in about 100 cascades
using modified Khan scheme with valved down LEU cascades

Simulation Results

Without 3.5% LEU feedstock: about 6 months (vs 3 months)
With sufficient stock of 3.5% LEU feedstock: about 2 months (vs 1 month)

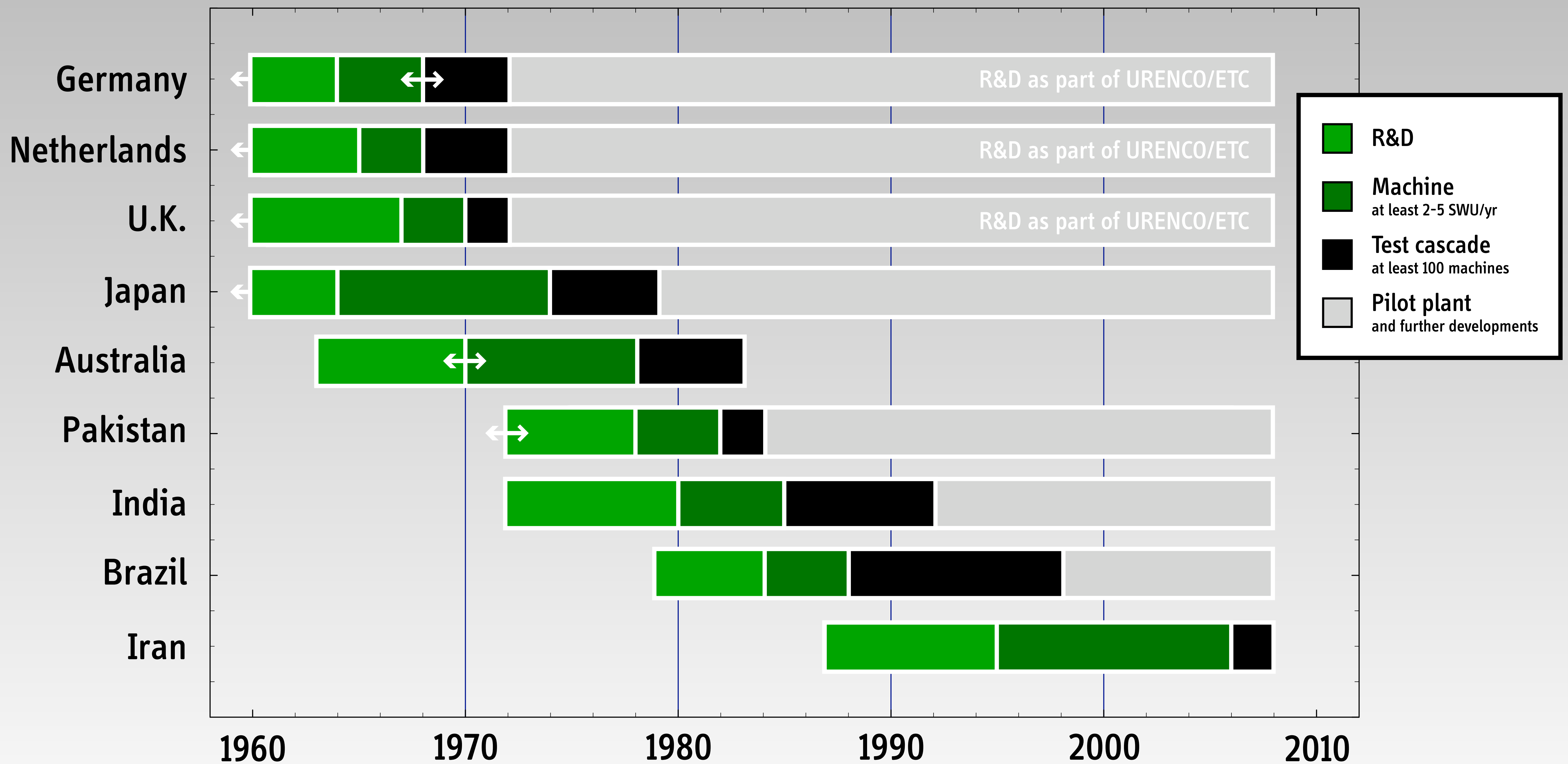
Assumes that no significant extra time is required to valve down machines
Numbers in red are based on simple SWU estimates

Numbers based on calculations by Patrick Migliorini (UVA) and Chuck Witt for Institute for Science and International Security, 2013

What Can Be Done About It?

Timeline of Centrifuge Programs

Many countries have successfully developed viable centrifuge enrichment technology



Preventing the Further Spread and Assuring Peaceful Use of Nuclear Technologies

Preventing Further Spread	• Tighten export controls (further)
	• Delegitimize enrichment in today's "non-enrichment" states
	• Increase the ability to detect undeclared facilities
	• Encourage multilateral approaches to the nuclear fuel cycle
Assuring Peaceful Use	• Increase the effectiveness of IAEA safeguards
	• Revisit alternative "proliferation-resistant" technologies
	• Devalue nuclear weapons

Multilateral Approaches to the Nuclear Fuel Cycle

Fuel Assurances

Joint Ownership of Enrichment Plants

Construction of new facilities exclusively under multilateral control
Conversion of existing facilities

Dilemmas of Joint Ownership

Proliferation

Can one share centrifuge technology without disseminating proliferation-sensitive information?

Risk of premature deployment of sensitive nuclear technologies where they are not needed

Market

Support of current technology holders needed (e.g. for new plants using "black-box" technology)

Current (and mid-term future) enrichment demand already covered

Territoriality

How effectively will the fact that a plant is multinationally owned reduce the risk of a "take over" by the host state?

Can Multilateral Approaches Strengthen Nonproliferation and Disarmament Efforts?

Development and Peaceful Use of Nuclear Energy

Sharing enrichment plant with partners in the region

Nuclear Nonproliferation

Avoiding additional small-scale deployment of centrifuge technology under national control

Possibility of implementing advanced safeguards approaches in new plants

Nuclear Disarmament

Application of IAEA safeguards in plants even if located in NPT weapon states