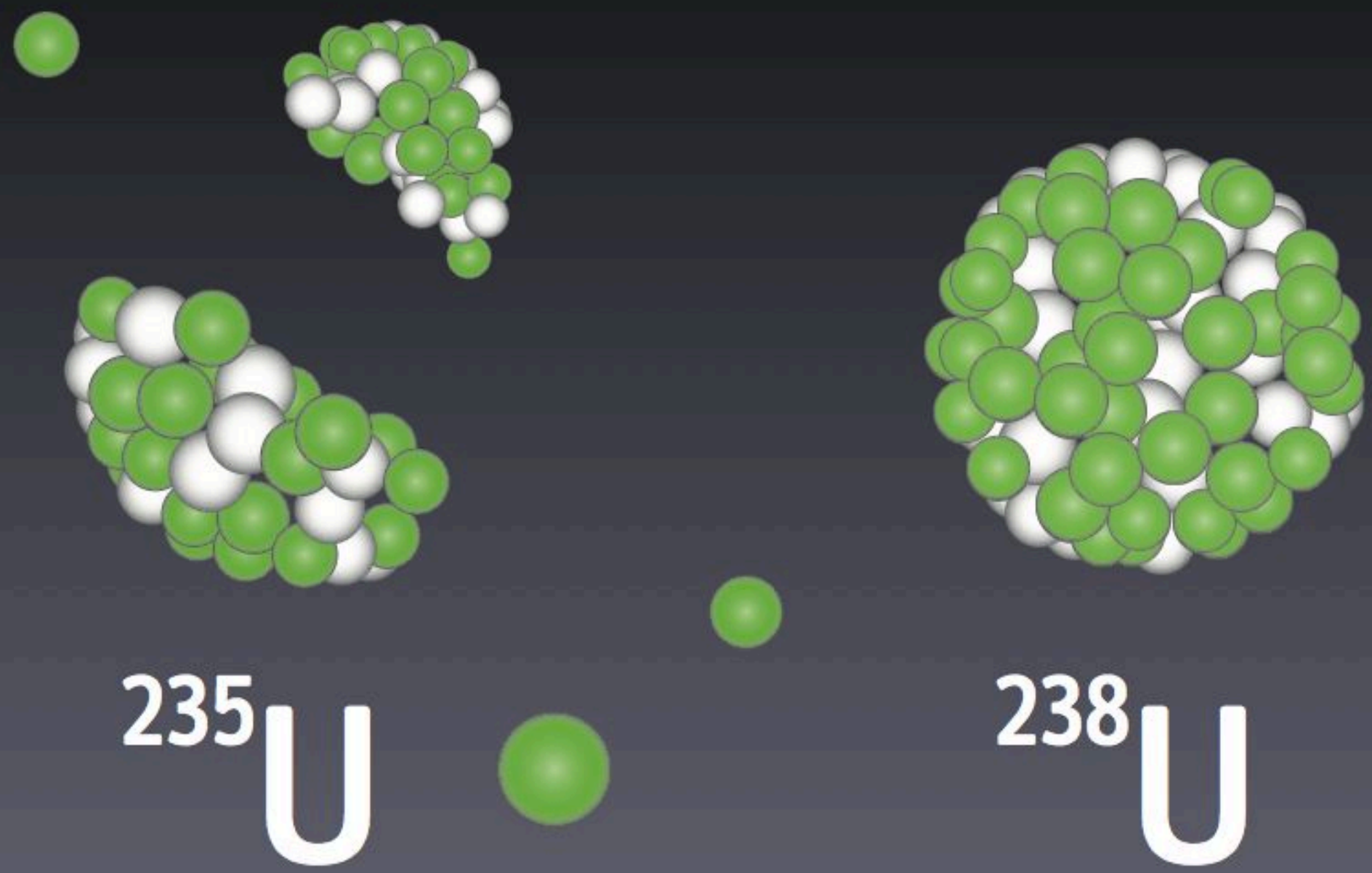
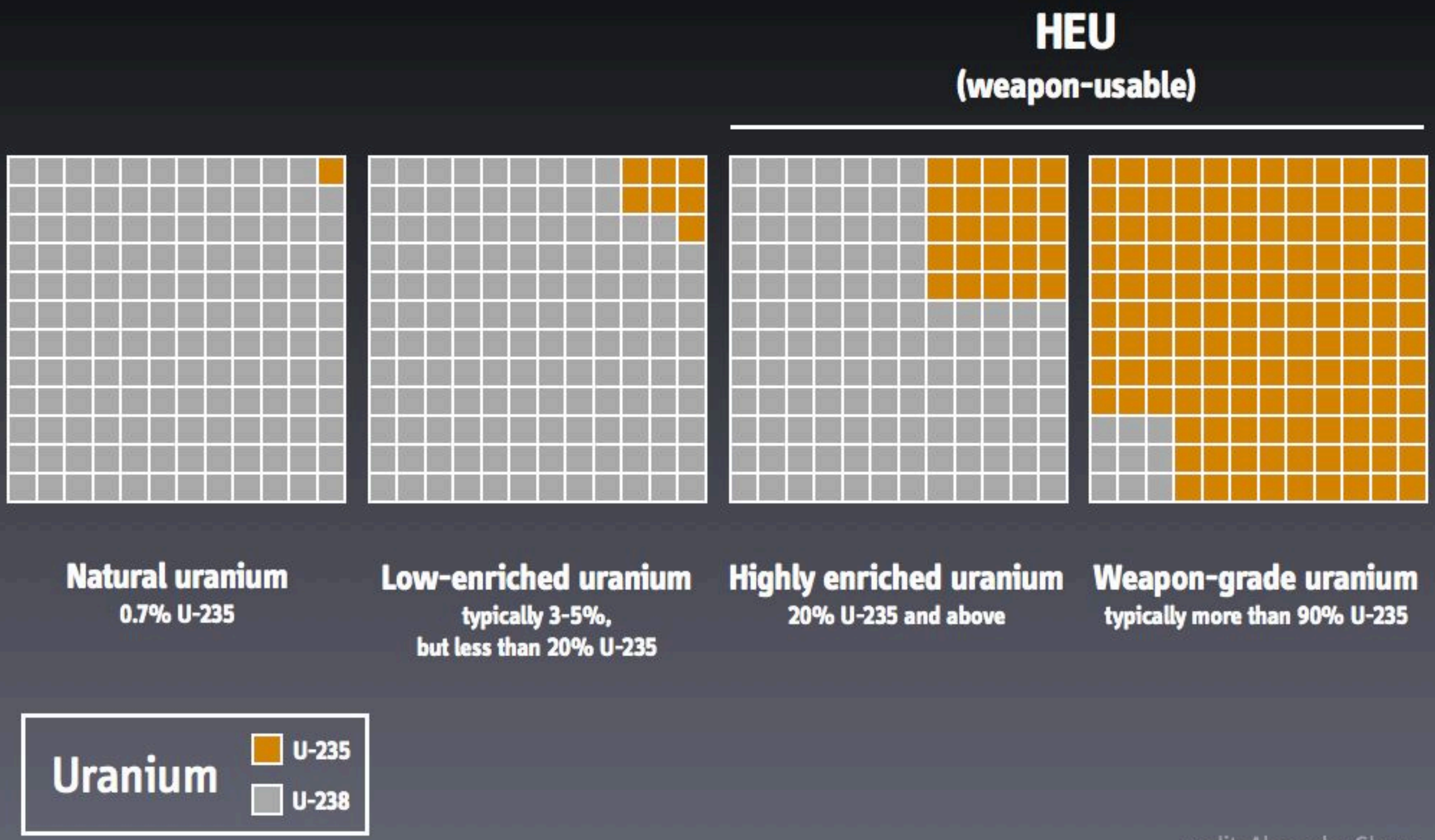
Uranium Enrichment

(for nuclear weapons!)

R. Scott Kemp
Program on Science and Global Security, Princeton University

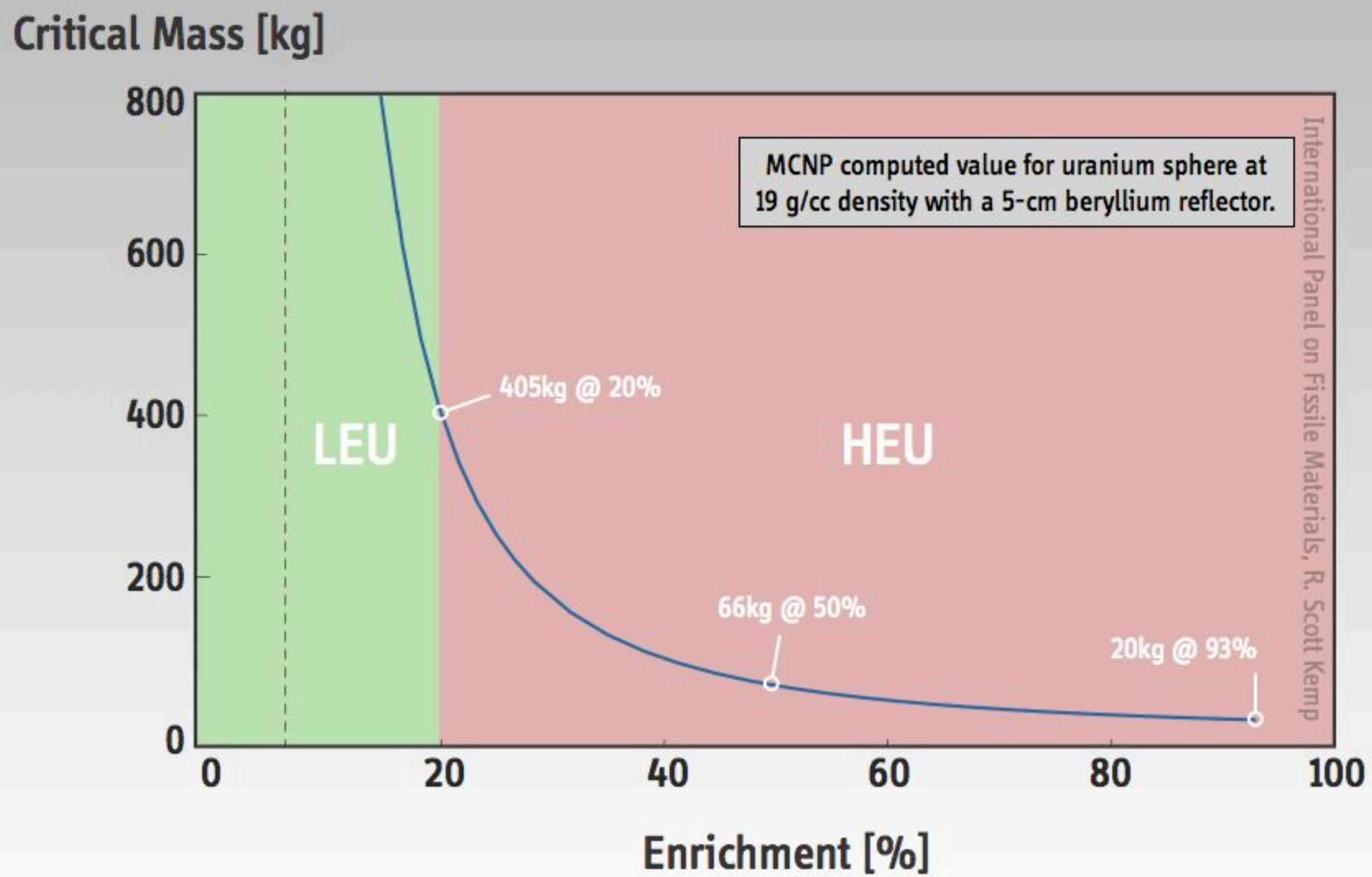


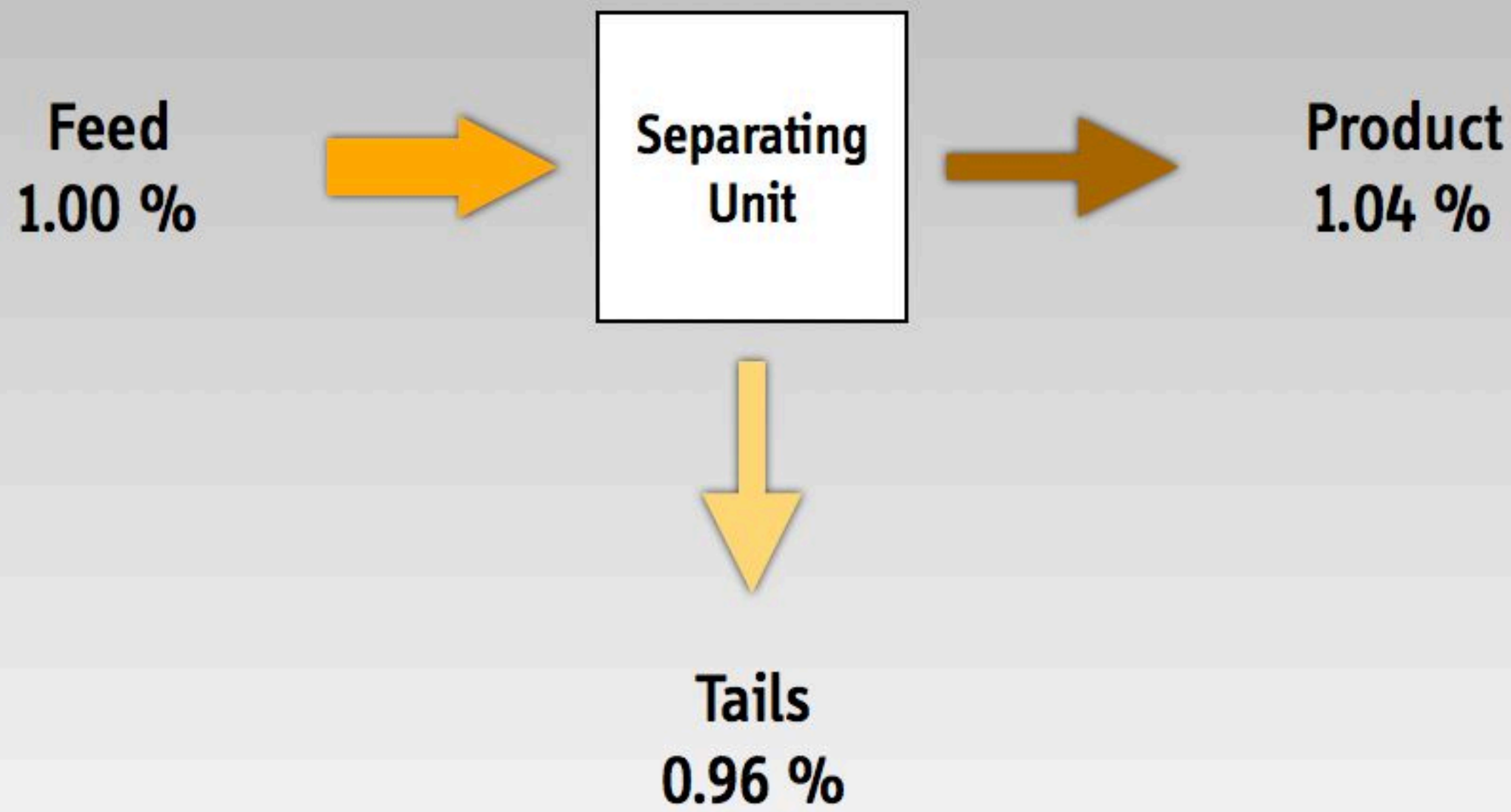
R. Scott Kemp



credit: Alexander Glaser

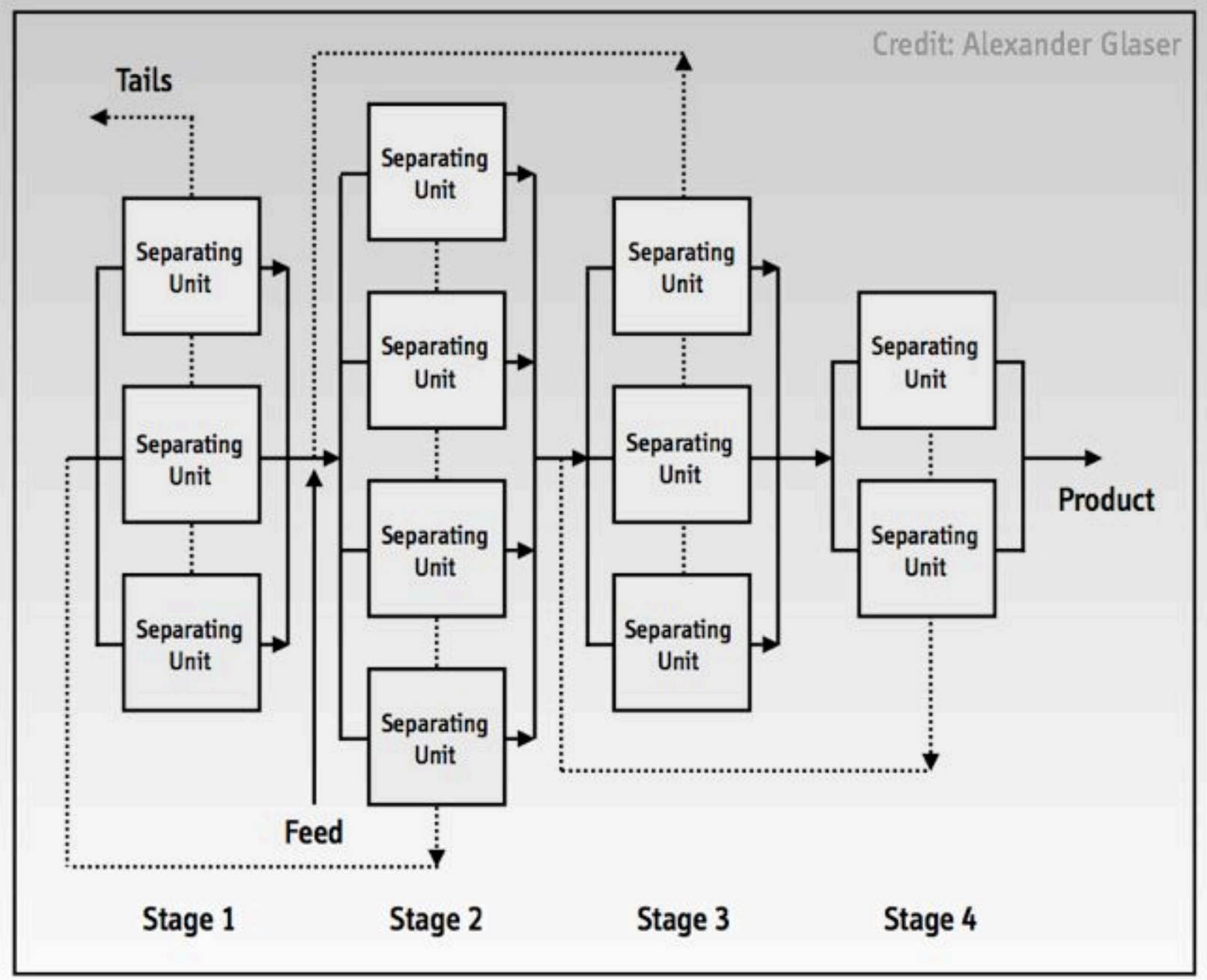
Critical Mass of Uranium



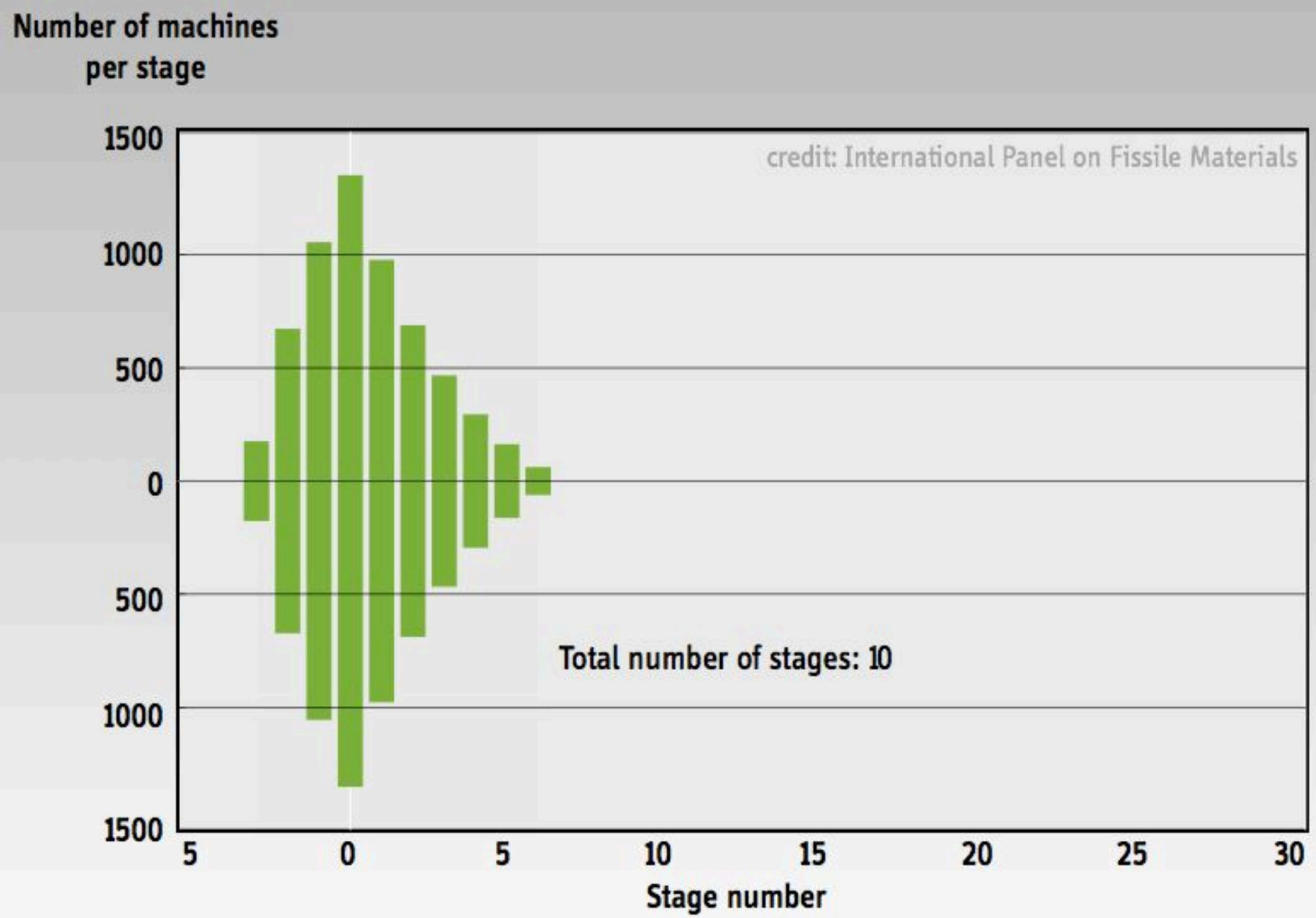

Feed
1.00 %
Separating
Unit
Product
1.04 %
Tails
0.96 %

Enrichment Cascade

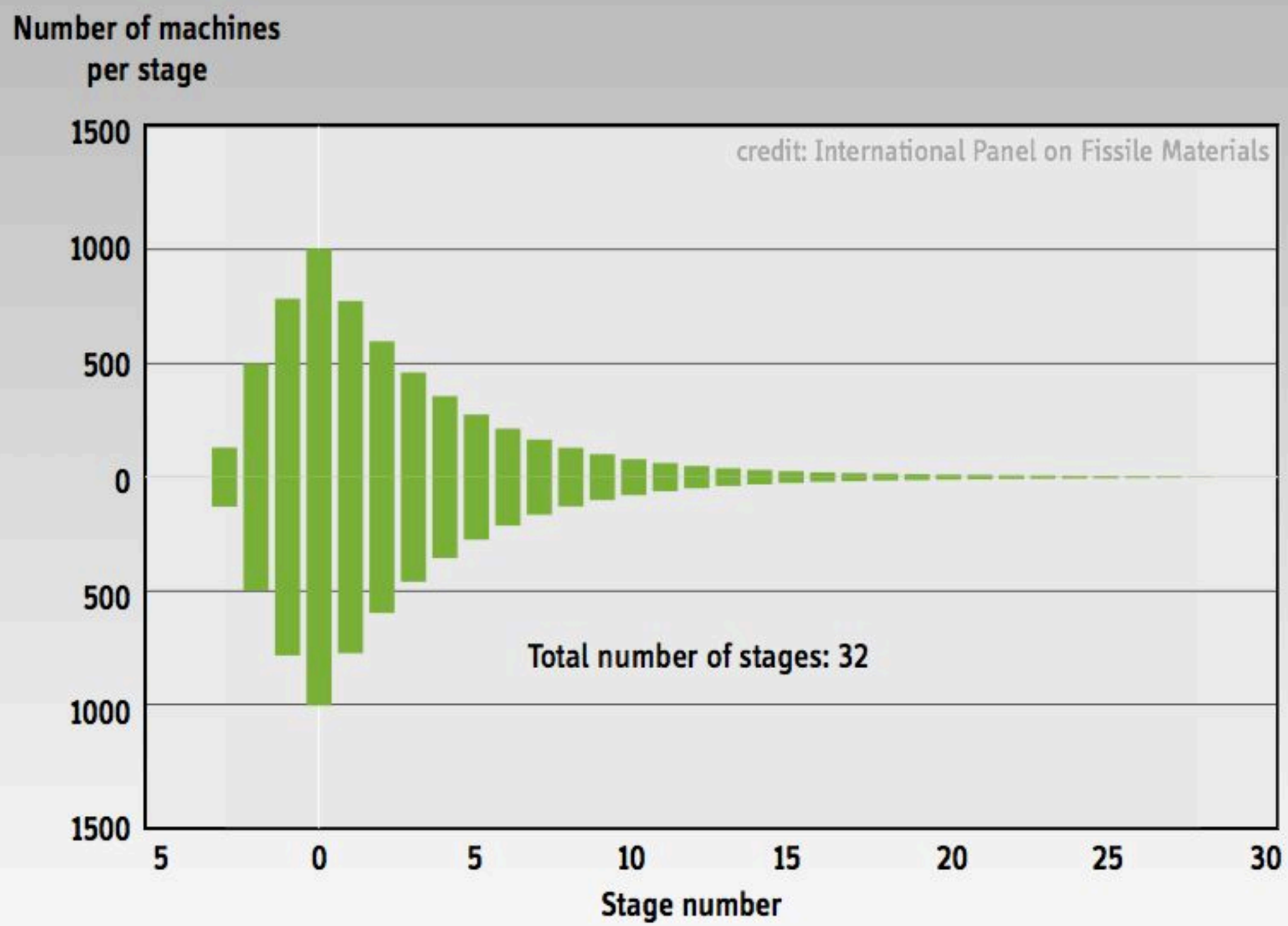
(schematic)



Example LEU Cascade

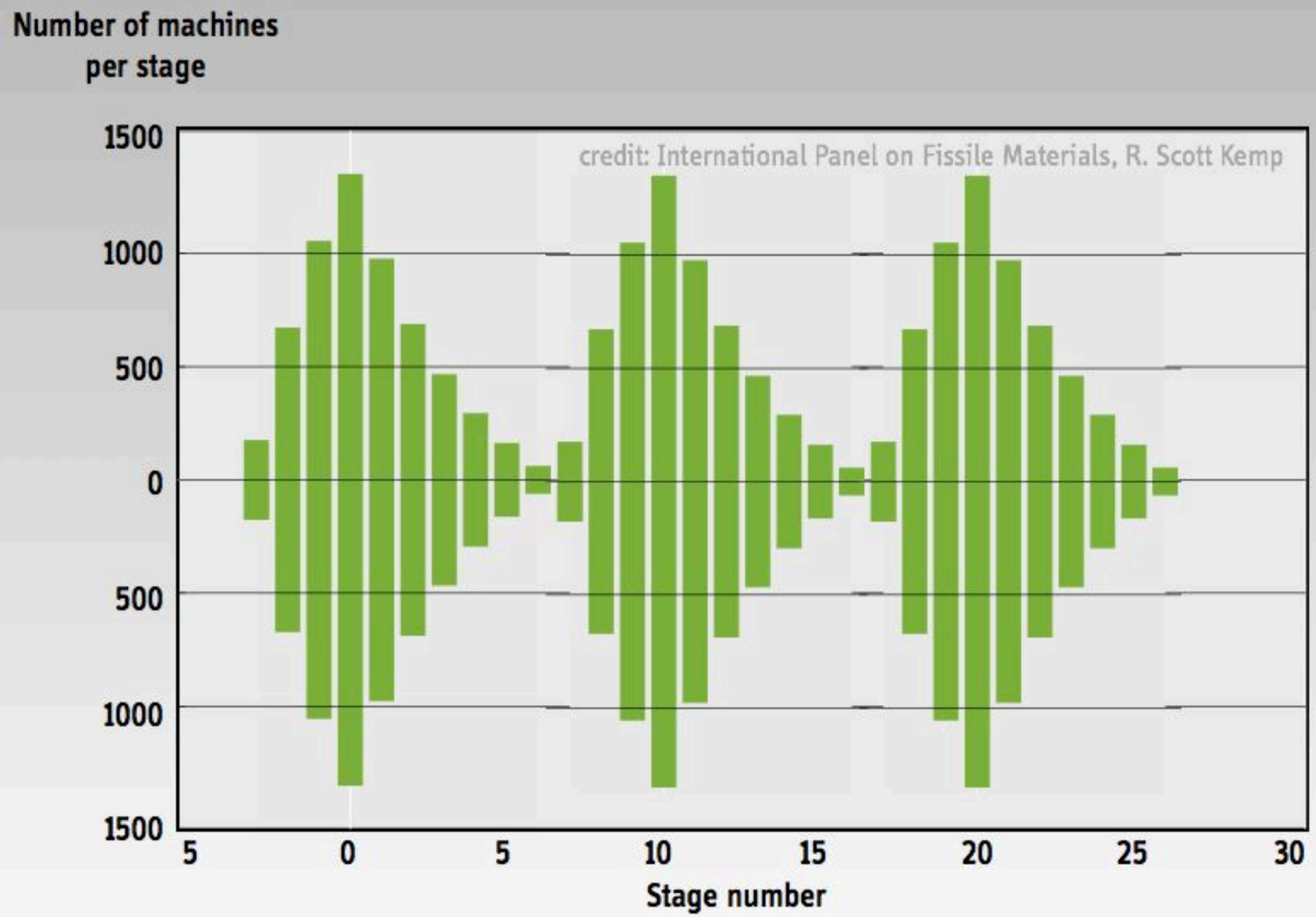


Example HEU Cascade



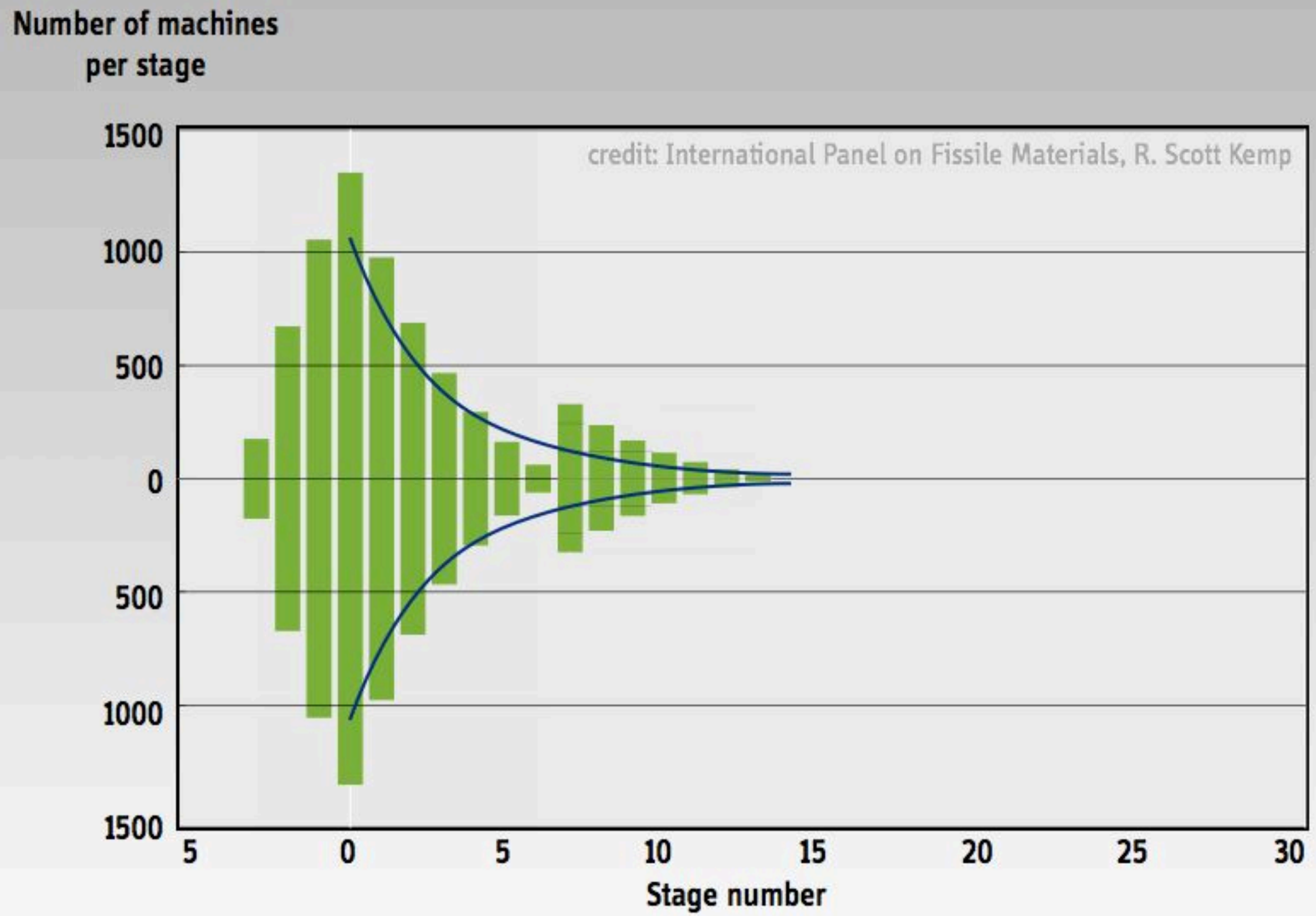
Batch-Recycle Imperfections

(overdramatized)



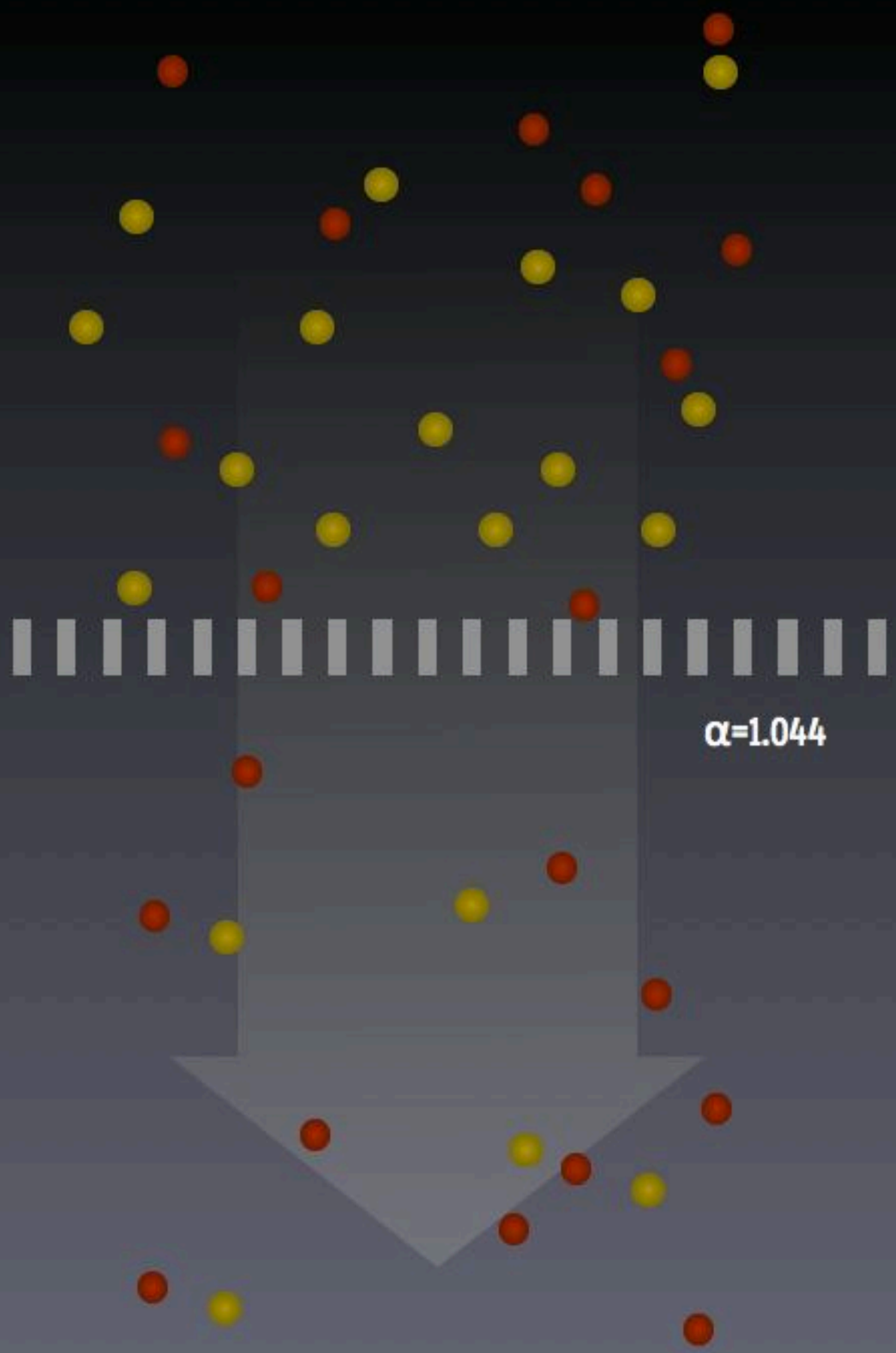
One way to make 20%

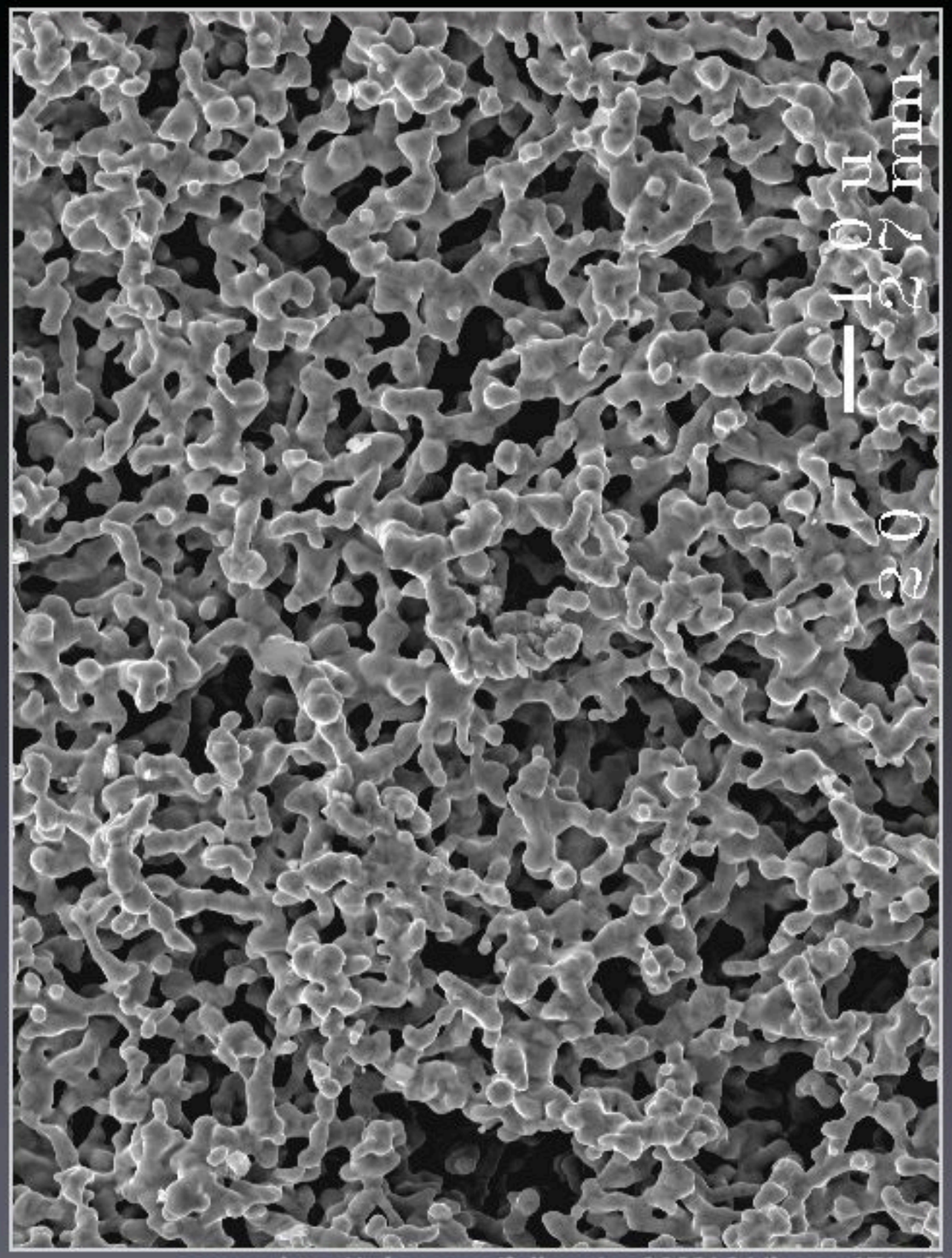
(schematically)



Types of Separating Elements

Electromagnetic (Calutron)
Thermal Diffusion
Gas Diffusion
Gas Centrifuge
Becker Nozzle
Vortex Stream (Helikon)
Chemical Ion Exchange (CHEMEX)
Atomic Laser (AVLIS)
Molecular Laser (MLIS/MOLIS)
Chemical Laser (CRISLA)
Condensation Laser (SILEX)





source: http://sti.srs.gov/fulltext/ms2002431/image174.gif

Gaseous Diffusion Plants can be BIG

The Gas Centrifuge

credit: R. Scott Kemp for the New York Times

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Advantages for weapon programs

- high separation factor ⟶ fewer stages
- low inventory ⟶ rapid conversion
- modular
- no emissions or effluents
- requires no special facilities
- low energy consumption
- impossible to detect

Some Famous Centrifuges

Name	Countries	Length [meters]	Speed [meters/second]	Performance [kg-SWU/year]
P-1, IR-1, L-1	Pakistan, Iran, Libya	2	335	0.6-1.0
G-1, Iraq-1	Germany, Iraq	0.5	450	1.8
G-2, P-2, NK-1?	Germany, Pakistan, North Korea?	1	485	5
TC-21	Urenco	6.5	770	90
AC-100	USA	12.5	900	330

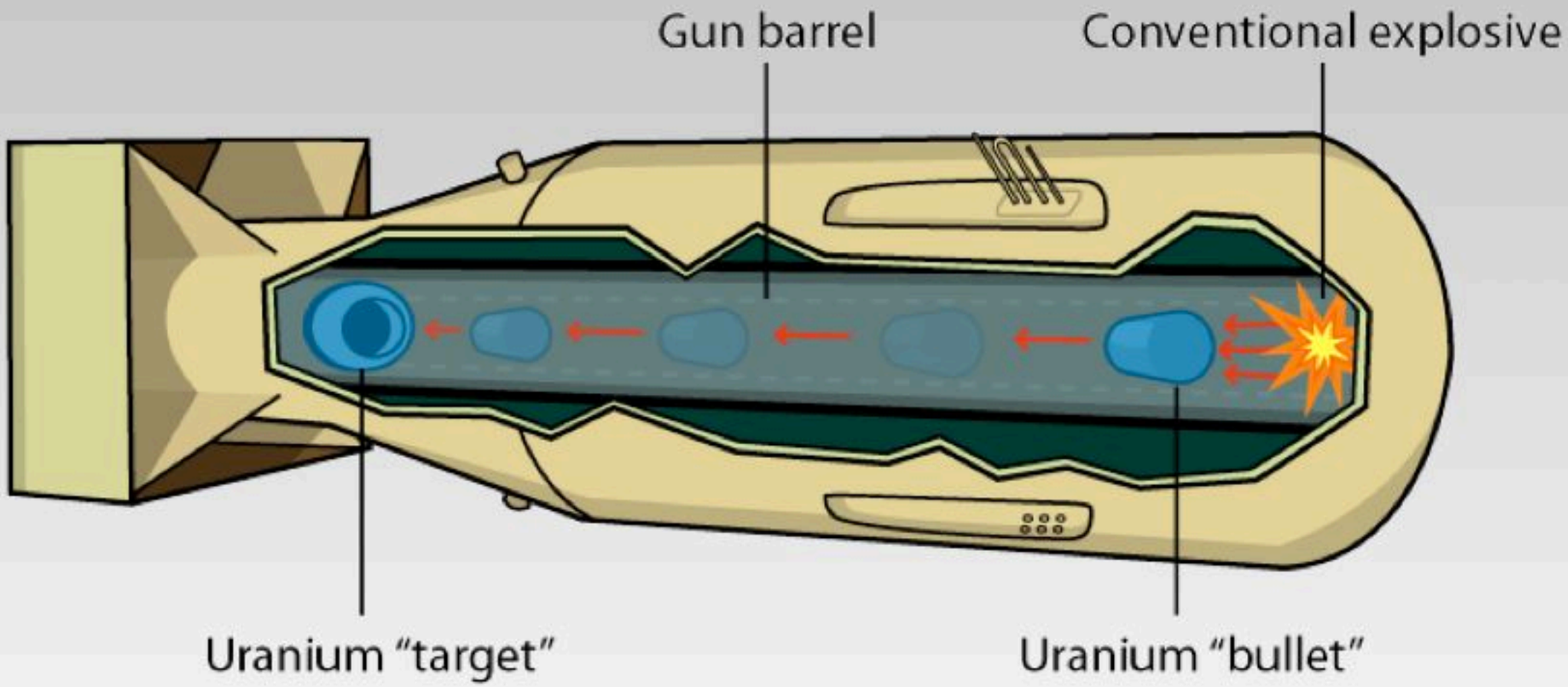
5,000 SWU / year = 1 bomb / year

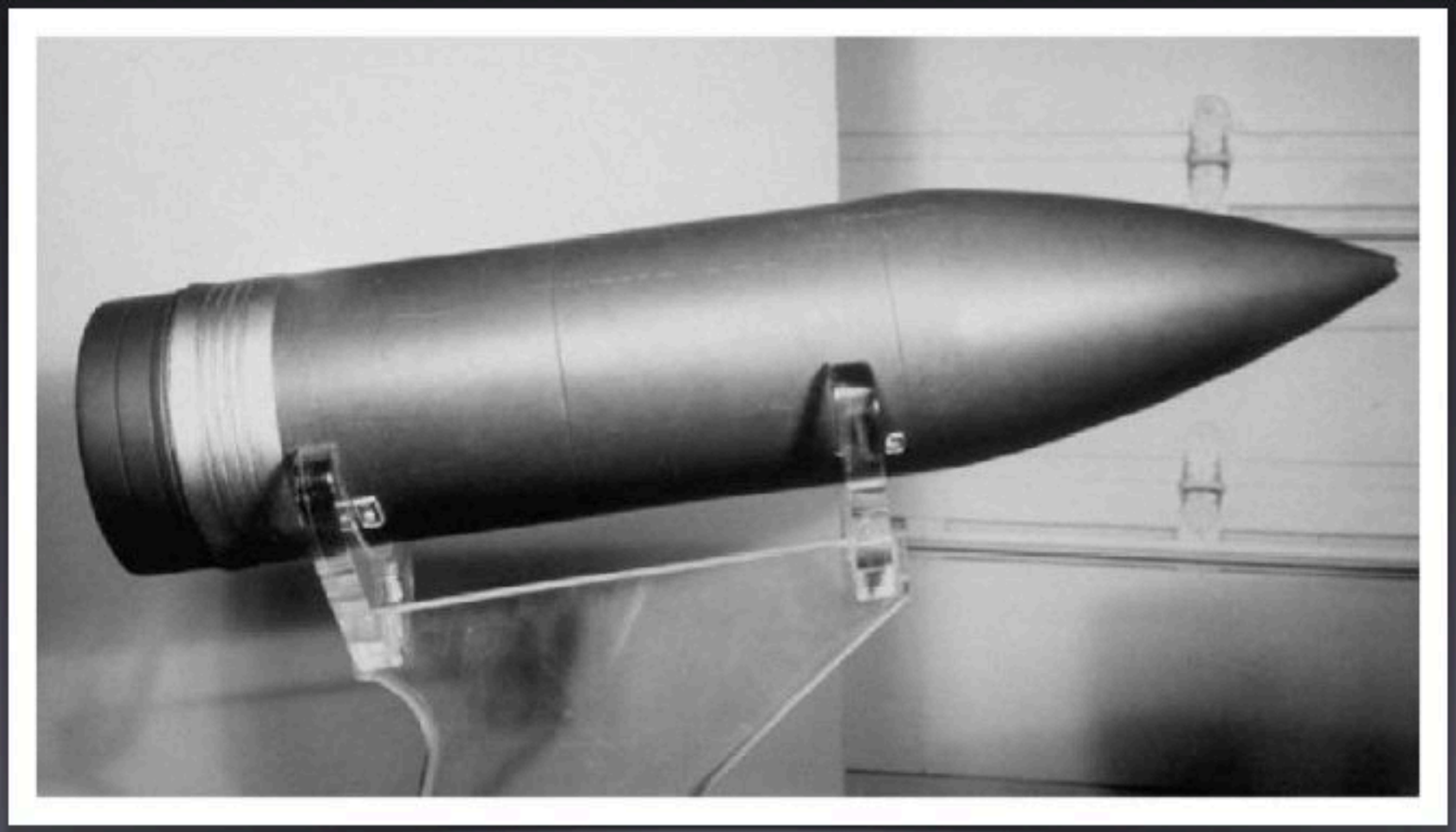
120,000 SWU / year = 1 GWe power reactor

Country	Facility	Technology	Declared Purpose	Capacity [1000-SWU/yr]
Argentina	Pilcaniyeu	Diffusion	Civilian	20-300
Brazil	Resende	Centrifuge	Civilian	120
China	Shaanxi	Diffusion	Civilian	500-1000
China	Lanzhou II	Centrifuge	Civilian	500
China	Lanzhou (new)	Centrifuge	Civilian	500
France	George Besse I	Diffusion	Civilian	10800
France	George Besse II	Centrifuge	Civilian	7500-11000
Germany	Gronau	Centrifuge	Civilian	2200-4500
India	Ratehalli	Centrifuge	Military	15-30
Iran	Natanz	Centrifuge	Civilian	5-6 presently
Iran	Qom	Centrifuge	Civilian	undetermined
Japan	Rokkasho	Centrifuge	Civilian	<1050
Netherlands	Almelo	Centrifuge	Civilian	3800
North Korea	Yongbyon	Centrifuge	Civilian	8-11 (est)
Pakistan	Kahuta	Centrifuge	Military	20-30
Pakistan	Dadwal	Centrifuge	Military	unknown
Russia	Angarsk	Centrifuge	Civilian	2200-5000
Russia	Novouralsk	Centrifuge	Civilian	13300
Russia	Zeleogorsk	Centrifuge	Civilian	7900
Russia	Seversk	Centrifuge	Civilian	3800
United Kingdom	Capenhurst	Centrifuge	Civilian	5000
United States	Paducah, KY	Diffusion	Civilian	11300
United States	Piketon, OH	Centrifuge	Civilian	3800 planned
United States	Eunice, NM	Centrifuge	Civilian	5900 planned
United States	Eagle Rock, ID	Centrifuge	Civilian	3300-6600 planned
United States	Wilmington, NC	Centrifuge	Civilian	3500-6000 planned

credit: The International Panel on Fissile Materials

Gun-Type Uranium Bomb



Wikimedia Commons Graphic

U.S. W33 Nuclear Weapon