

Fuel Cycles and Fissile Material Life After Physics

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OUTLINE

- Introduction
- Nuclear Fuel Cycle
- Nuclear Proliferation Risk Assessment
- Fissile Material Cutoff Treaty
- The Road Taken

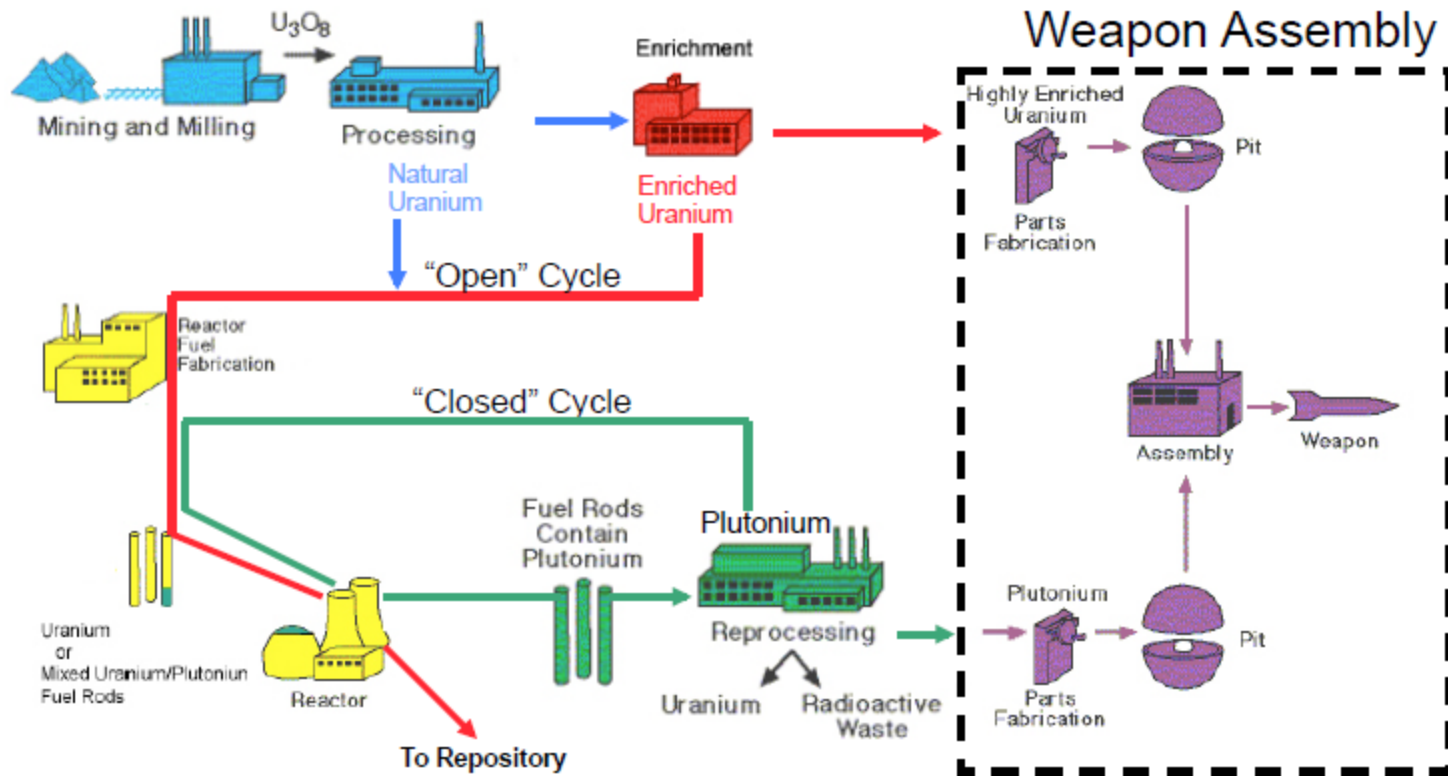
Introduction

- Ph.D. Princeton 1986
 - Dark Matter
 - String Theory
- Postdocs
 - Institute for Theoretical Physics UCSB
 - Rutgers
- 1990 took another path

My Career in Nuclear Nonproliferation

- Employers
 - Arms Control and Disarmament Agency 1995-99
 - Department of State 1999-2006 & 2009-present
 - Department of Energy 2006-2009
- Issues
 - Nuclear Export Control
 - Nuclear Nonproliferation Treaty
 - International Atomic Energy Agency
 - International Cooperation on Nuclear Energy
 - Proliferation Risks in Nuclear Fuel Cycle
 - Fissile Material Cutoff Treaty

Nuclear Fuel Cycle

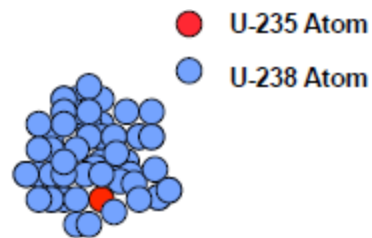


Civil and Military Nuclear Fuel Cycles

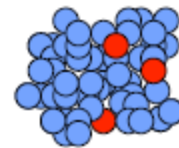
- Enrichment
 - 3,000,000 kw SWU/yr commercial plant
 - 120,000 kg SWU/GW/yr power plant
 - 5,000 kg SWU/SQ bomb
- Reprocessing
 - 8,000 kg/yr commercial plant
 - 250 kg/GW/yr power plant
 - 8 kg/SQ bomb

Uranium Enrichment

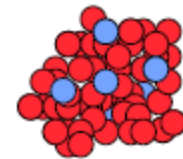
- U-238/U-235 mass difference ~ 1.25%
- Chemical properties essentially identical
- Physical separation
 - Thermodynamic
 - Spectroscopic



Natural Uranium

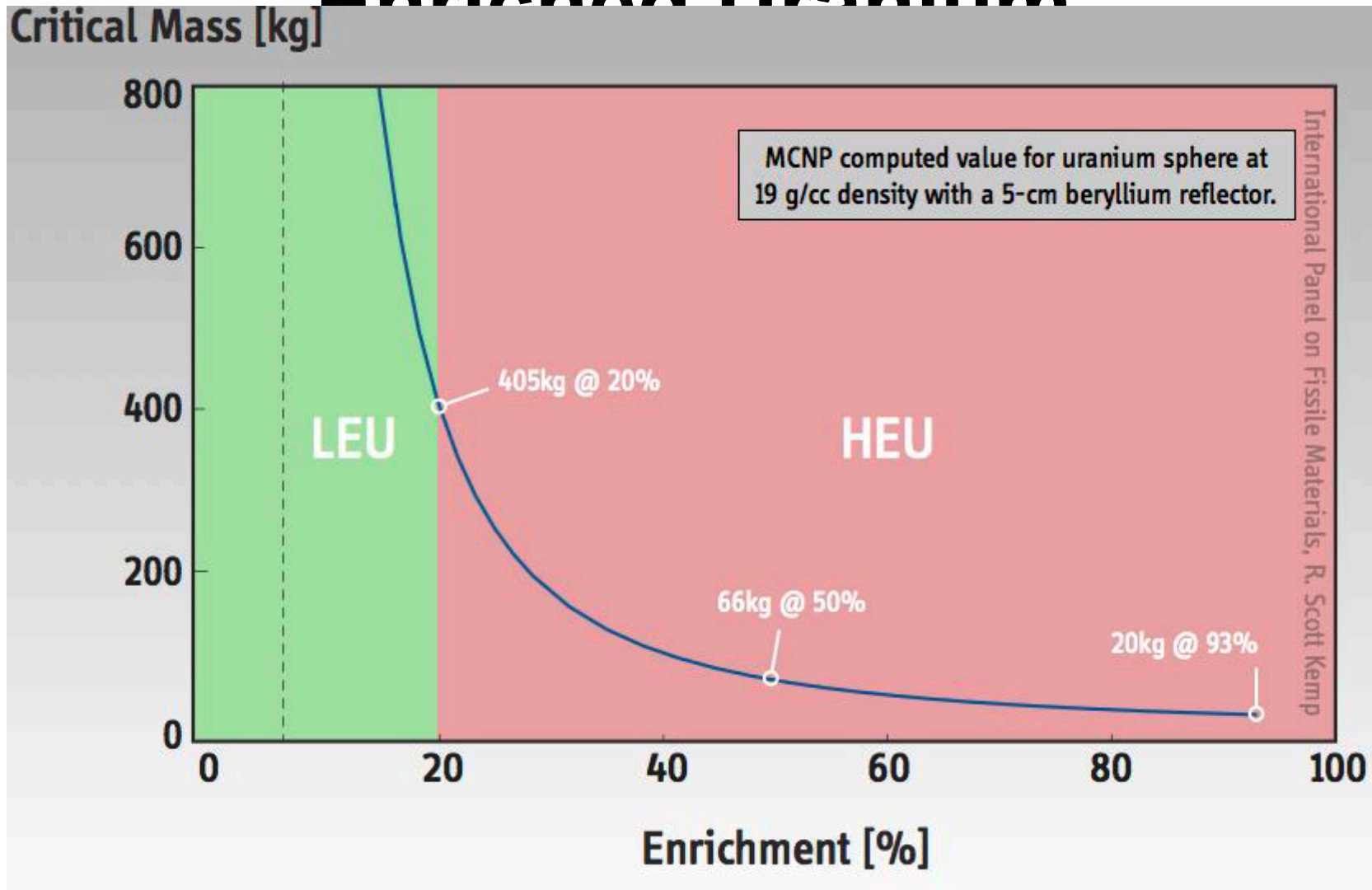


Low-Enriched Uranium (LEU)

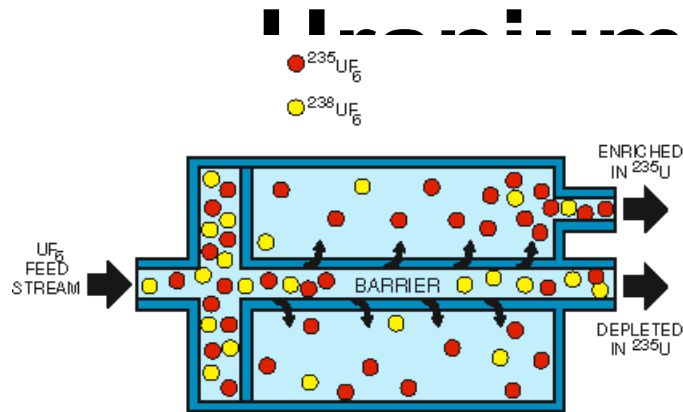


Highly Enriched Uranium (HEU)

Critical Mass of Enriched Uranium

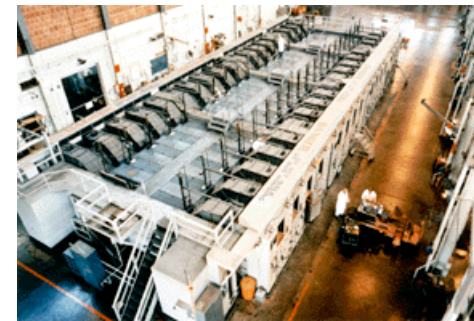


Enrichment

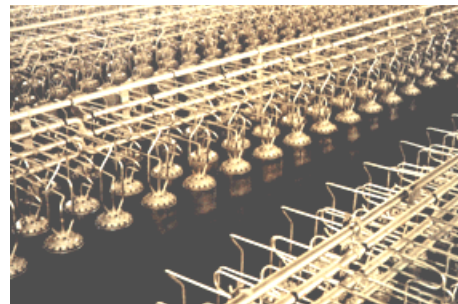


Gas Diffusion Unit

Calutron
Track

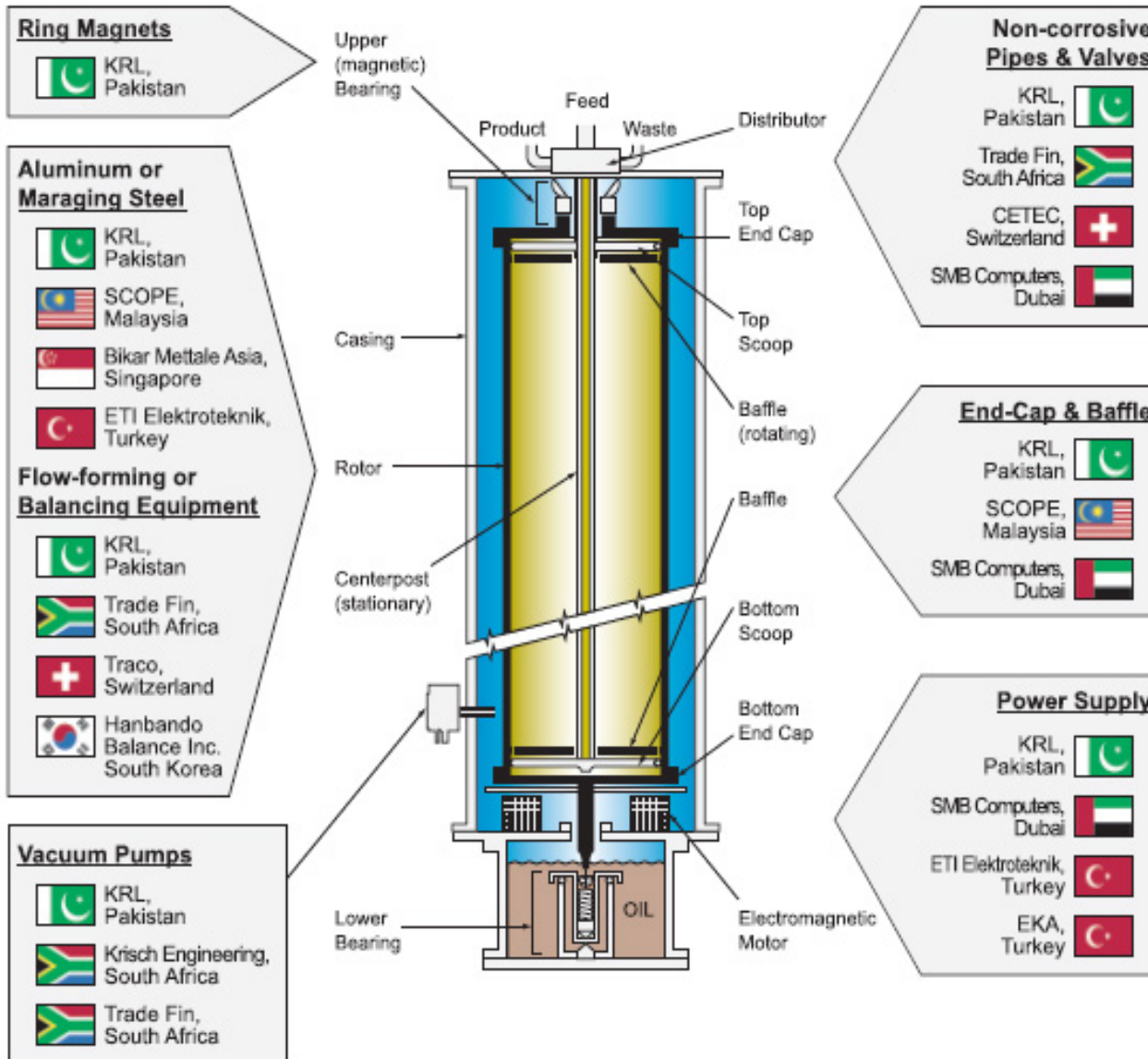


- Other methods:
 - Aerodynamic
 - Laser
 - Chemical

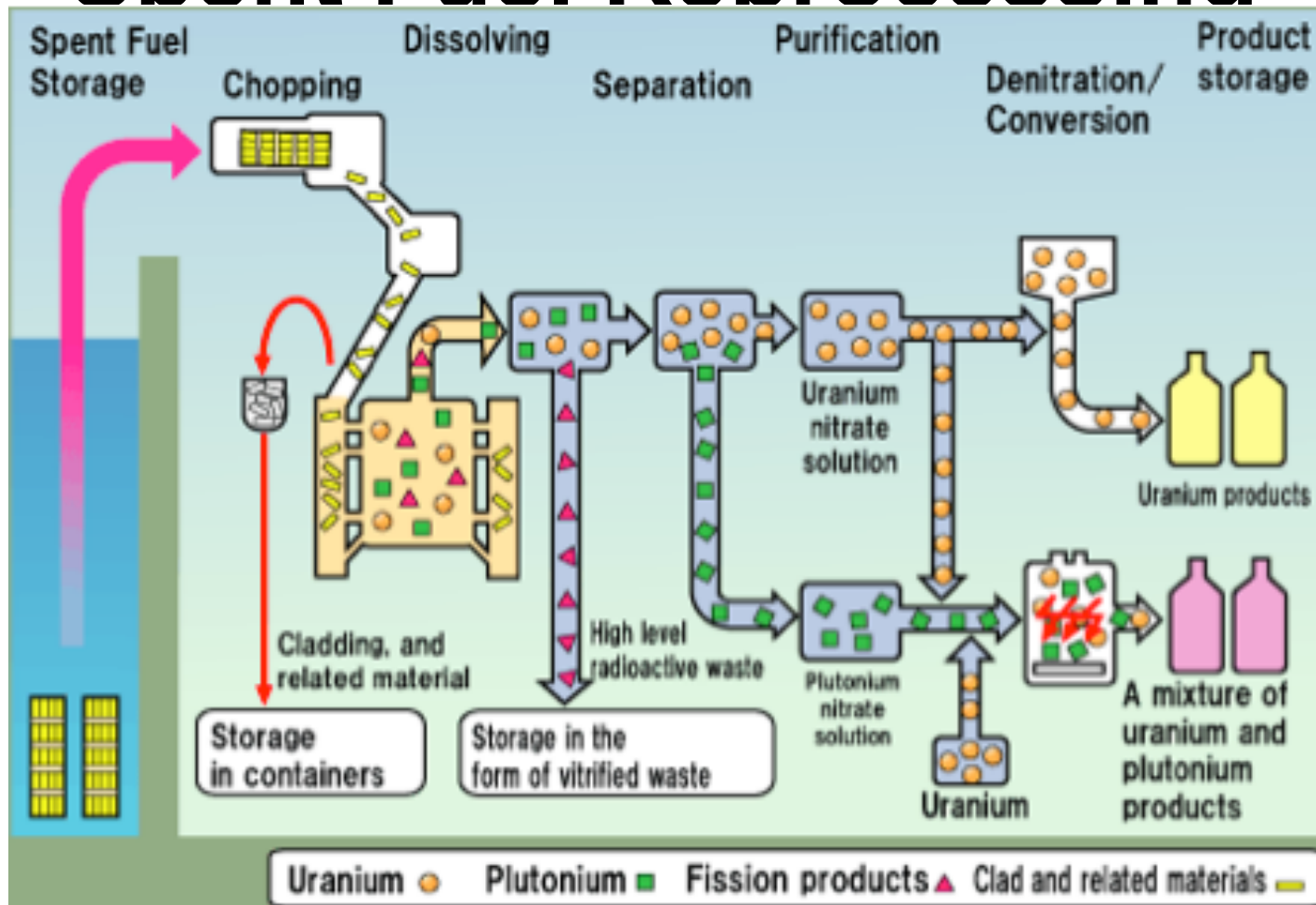


Gas
Centrifuge
Cascade

Uranium Enrichment



Spent Fuel Reprocessing



Proliferation Risk Assessment

- Global Nuclear Energy Partnership (GNEP)
- Atoms for Lease
 - Assured supply of enriched uranium fuel
 - Assured take-back of spent fuel
 - No need for enrichment or reprocessing
- But who will take back spent fuel?
 - Recycle and burn in fast reactors
 - Eliminate most long-lived radioactive waste

Proliferation Risk Assessment

- Nonproliferation Impact Assessment for GNEP
 - Assess proliferation impact of reasonable alternatives for spent fuel management
 - Analogous to Environmental Impact Statement
- Alternatives considered
 - Once through fuel cycles
 - Partial recycle in thermal reactors
 - Full actinide recycle in fast reactors

Proliferation Risk Assessment

- Policy Factors
 - Facilitate spent fuel take-back
 - Discourage spread of enrichment and reprocessing
 - Draw down plutonium stocks
- Technical Factors
 - Production of materials attractive for use in weapons
 - Potential misuse of technology

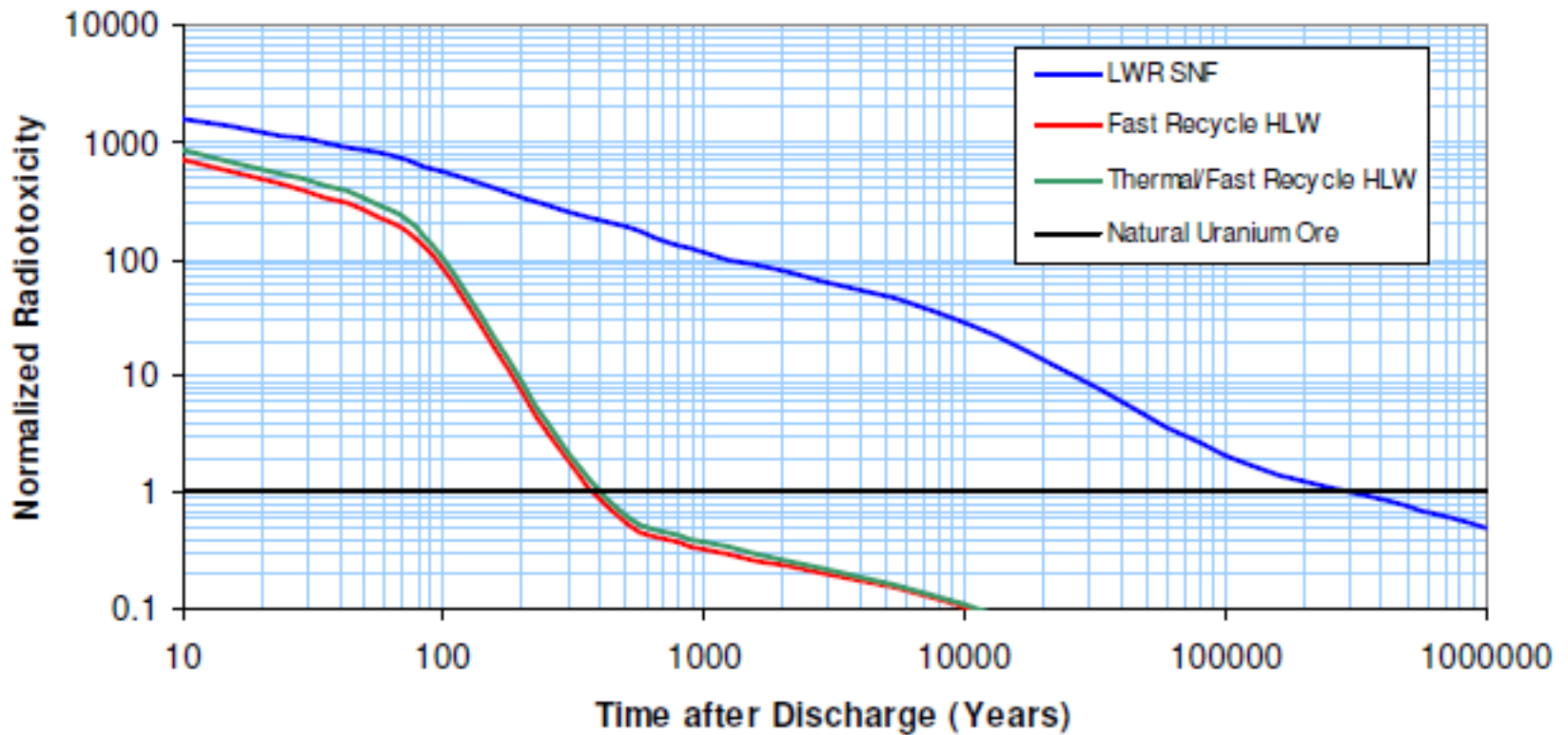
Proliferation Risk Assessment

A Technical Factor

Alternative	Maximum enrichment	Additional SWU required to produce 1 SQ	SWU requirement compared to natural uranium feed
Natural U	0.7%	4740	100%
HWR	2.1%	2520	53%
LWR	4.4%	1560	33%
HTGR	14.0%	660	14%
Thorium	19.9%	490	10%

TABLE 6.3 Separative Work Units Needed to Enrich One Significant Quantity (SQ) of 90% HEU⁹³

Proliferation Risk Assessment A Policy Factor



Overall Assessment

- Technical details of proliferation resistance have marginal significance
- Key distinguishing factor is international structure of fuel cycle:
 - Who has enrichment and/or reprocessing capabilities?
- Policy tradeoff:
 - We don't need to reprocess and neither do you
 - We will reprocess for you, so you don't need to

General Lessons

- **Compared to What?**
 - Policy decisions cannot be assessed in isolation but only in comparison among reasonable alternatives.
- **Look at the whole system**
 - Individual technical factors are rarely decisive.
 - Structural and context are key

Fissile Material Cutoff Treaty

- Ban future production of fissile material for weapons
 - Proposed in 1954 by Nehru
 - Endorsed by UN General Assembly in 1993
 - Currently blocked by Pakistan
- Would not ban other uses of fissile material
 - Plutonium used in civil fuel cycle
 - Highly enriched uranium used submarines and in some research reactors

FMCT Verification

- All newly produced fissile material must be accounted for and not diverted to weapons
 - Routine inspections of declared production and downstream facilities
- All enrichment and reprocessing facilities must be declared
 - Challenge inspections of suspect locations
- International Atomic Energy Agency has experience, capability, and mandate

FMCT Scope Issues

- Should existing stocks be covered?
- Should there be more comprehensive verification of civil nuclear activities?
- Should alternate nuclear materials be covered?

The Road Taken

Two roads diverged in a wood, and I,

I took the one less traveled by,
And that has made all the difference.

- Robert Frost

- How did I find this path?
 - Mentors
 - Fellowships
 - Institutions

Mentors

- While in graduate school I became interested in arms control
 - President Reagan's nuclear policies caused alarm and skepticism
 - Frank von Hippel was a leading skeptic
 - Former particle physicist
 - Wrote book on science advising in 1974
 - Trained/influenced many scientists in policy, including current White House Science Advisor John Holdren

Fellowships

- 1990-92 Social Science Research Council/
MacArthur Foundation Fellowship in
International Peace and Security
 - [Belfer] Center for Science and International
Affairs
- 1992-93 AIP Congressional Science Fellow
 - Senator Kent Conrad

Institutions

- Academic research centers
 - Center for Energy and Environmental Studies
 - Belfer Center for Science and International Affairs
- Office of Technology Assessment
- Arms Control and Disarmament Agency

