Improvement of Long-term Proliferation Resistance

Joonhong Ahn
Professor and Vice Chair
Department of Nuclear Engineering
University of California, Berkeley

December 4, 2013
Panel discussion 2: Roles of safeguards and technical measures for ensuring nuclear non-proliferation for nuclear fuel cycle options

2013 International Forum on Peaceful Use of Nuclear Energy, Nuclear Non-Proliferation and Nuclear Security, December 3-4, 2013
Jiji Press Hall, Tokyo

Japan's Used Fuel Balance (02/2013)

Stored at JNFL (Rokkasho)	3,350 MT
Stored at NPPs	14,170 MT
Overseas reprocessing	7,100 MT
Tokai reprocessing	1,020 MT
TOTAL	25,640 MT

Vitrified HLW
Pu
RepU

- 1 Metric Ton (MT) of LWR Used Fuel
  - Has generated 0.05 GWyr(e)
  - Contains 10 kg of Np/Am/Pu
    - 9 kg of Plutonium, including 5 kg of Pu-239
    - 1 kg of Neptunium and Americium
  - Generates 1 canister of vitrified HLW

Diameter ~ 0.4 m,
Height ~ 1.0 m
Volume = 150 liter

Materials waiting for disposal

- HLW (including TRU wastes from reprocessing)
  - IAEA Safeguard inspection likely to be terminated due to low Pu content
- Used fuel (UO2 or MOX):
  - Subject to IAEA Safeguard inspection
- Pu stockpile
- Reprocessed U
  - Subject to IAEA Safeguard inspection
- Depleted uranium (DU)
  - Approximately 7 times more mass than fuels
  - Subject to IAEA Safeguard inspection
- Mill Tailings

Pu stockpile → MOX → Disposal

- Costly, but feasible
- Subject to IAEA Safeguard inspection for geological disposal
- Radiological safety of geological disposal
  - Higher TRU contents
    - Greater hear emission
    - Greater radiotoxicity
    - Higher heterogeneity in fuel

Advanced options for Pu inventory management

- Thermal neutron systems
  - High-Temperature Gas-Cooled Reactor (HTGR)
- Fast neutron systems
  - Fission reactors (SFR, IFR, …)
  - Accelerator-driven system
  - Fusion
- Deep bore-hole disposal

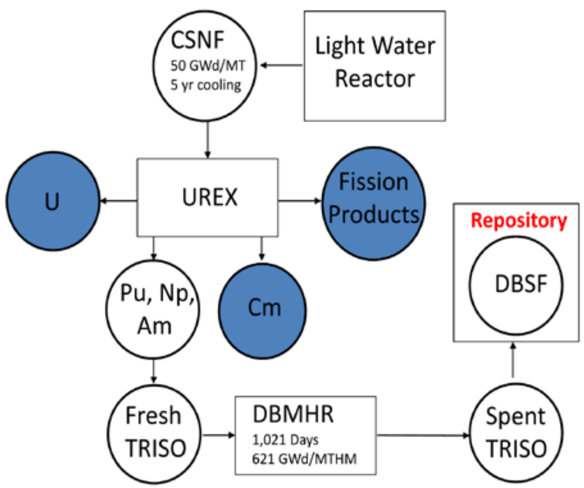
HTGR as Pu Burner

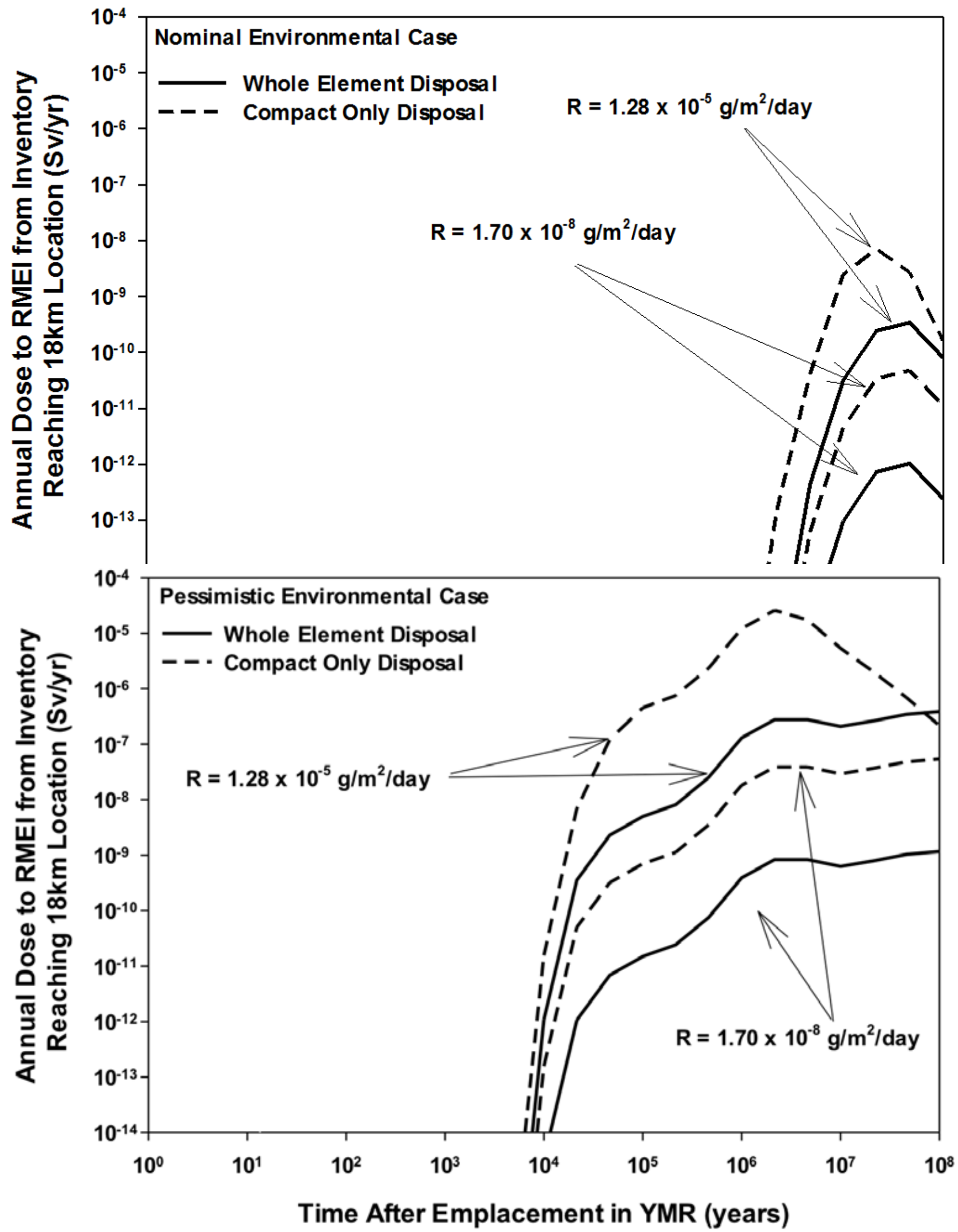
- thermal efficiency > 40%
- 90 ~ 120 GWday/MT
- Reactor with Inherent safety
  - Negative reactivity coefficient with temperature (stops chain reactions)
  - Low power density and robust fuel forms (cools reactor core naturally)
    - No melt down
    - No significant radiation release in accident
  - Demonstrate with actual test of reactor
- Deep burn of Pu-239
  - > 90% of Pu-239 is burnt by once-through
  - Possibility for termination of IAEA safeguard inspection for geological disposal
- High durability of graphite-TRISO fuel in virtually any geological conditions
  - Relaxation of temperature constraints for engineered barriers in a geological repository (higher density, i.e. smaller footprint; simpler repository design)

Reduction of fissile Pu by TRISO-HTGR

	Inventroy Per 1000kg LWR-CSNF							
	LWR TRU		Fresh TRISO		Once Through		Twice Through	
Nuclide	w/o	kg	w/o	kg	w/o	kg	w/o	kg
237Np	4.68	0.468	5.2	0.468	7.7	0.231	4.4	0.044
238Pu	1.35	0.135	1.5	0.135	6	0.18	10.3	0.103
239Pu	51.3	5.13	57	5.13	3.2	0.096	0.1	0.001
240Pu	20.7	2.07	23	2.07	27.8	0.834	7	0.07
241Pu	7.47	0.747	8.3	0.747	21	0.63	5	0.05
242Pu	4.5	0.45	5	0.45	26.5	0.795	35	0.35
241Am	8.18	0.818	0	0	1	0.03	3.3	0.033
242mAm	0.03	0.003	0	0	0.1	0.003	0.5	0.005
243Am	1.48	0.148	0	0	5.3	0.159	16.7	0.167
244Cm	0.29	0.029	0	0	1.3	0.039	16	0.16
245Cm	0.02	0.002	0	0	0.1	0.003	1.7	0.017
Total	100	10	100	9	100	3	100	1
Energy Produced MWyr(e)	35.61				5.92		2.63	
Cumulative Energy MWyr(e)	35.61				41.53		44.16	

TRISO SF Disposal in YMR





HTGR Deployment

- In an HTGR core, 1.27 MT-(PuAmNp), or 1.13 MT-Pu
  - 5 regions shuffled with a cycle of 300 days
  - 0.2 MT-Pu/year/reactor is consumed.
    - 1GWyr LWR generates 20 MT used fuel, containing 0.2 MT-Pu
- Construction cost ~ $2,000/kW(e)
  - For a 600MW(th) plant with 50% efficiency (300MW(e)), $ 600 Million
  - 20 reactors → $12 Billion (1.2兆円）
- Power generation cost ~ 4 cent/kWh(e)

SFR as U burner (or Pu breeder)

- RepU and DU in the blanket → Pu.
- It increases short-term proliferation concern.
  - Creating Stockpile
  - Increasing interest in Pu breeding in emerging countries (technology proliferation)

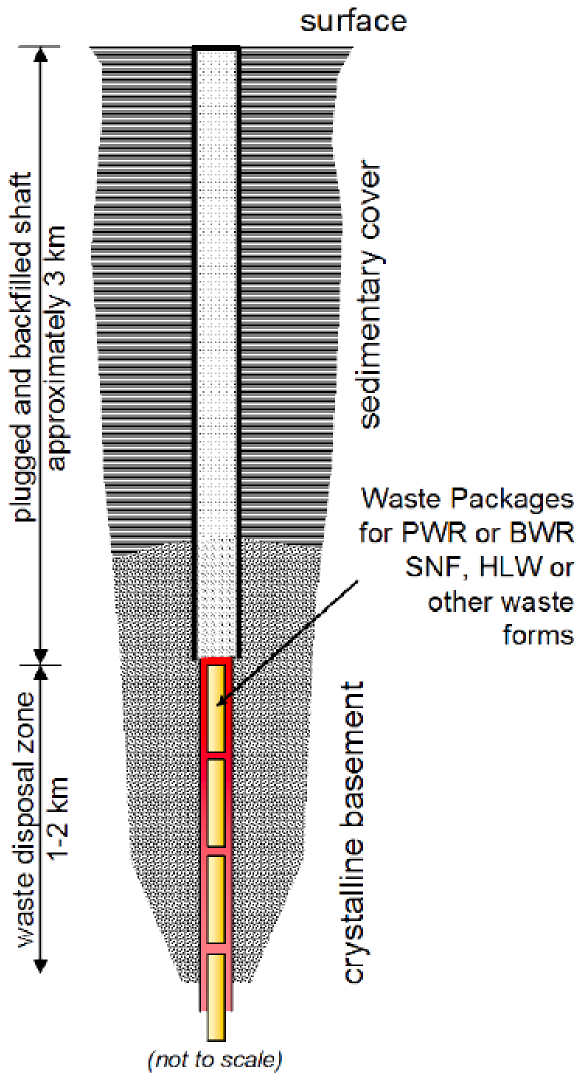
HTGR vs. SFR

- Both the HTGR (utilizing thermal neutrons) and the SFR (utilizing fast neutrons) can destroy Pu, Np and Am. However, the quality of destruction is different.
- The HTGR can burn:
  - rapidly due to high cross sections with thermal neutrons,
  - deeply due to very high fuel burnup thanks to high material durability, but
  - somewhat incompletely due to unfavorable fission-to-capture ratios.
- The SFR can burn:
  - slowly due to small cross sections with fast neutrons,
  - lightly due to relatively low burnup particularly with metal fuel, but
  - completely due to favorable fission-to-capture ratios.
- Thus, it will be ideal to construct a system that integrates both types of reactors.

Accelerator-driven system

- Suitable for small mass flow (minor actinides)
  - E.g. ATW for Pu+MA after UREX (60 cores for 60 years)
- Double strata fuel cycle
  - Pu cycle as the primary
  - MA cycle as the secondary. ADS is applied for this.
    - 1 ADS for 6 ~ 10 GW
    - MA stockpile issue
  - Thus, not available for all countries
- International fuel cycle is inevitable.

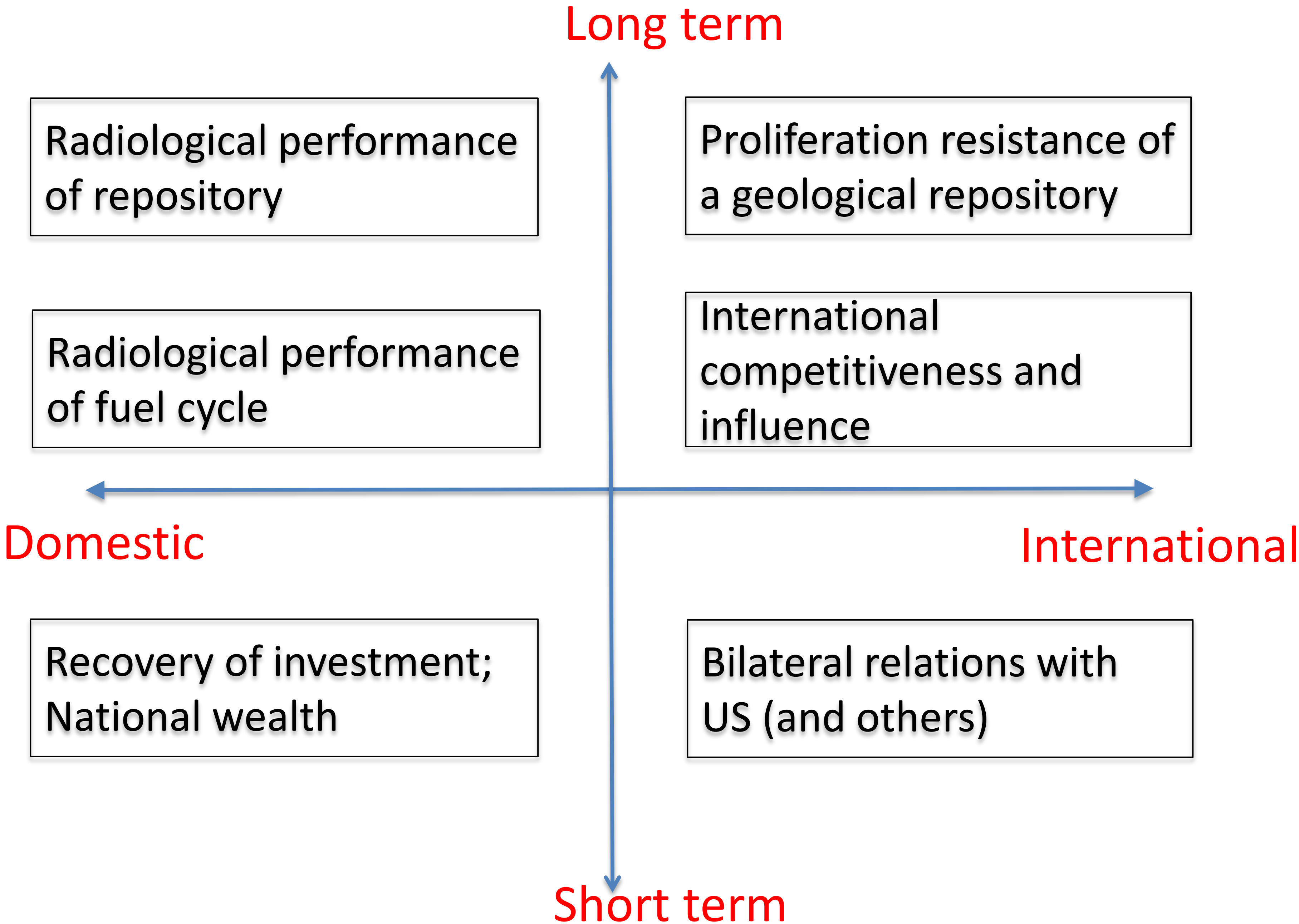
Deep bore-hole disposal



- No retrievability
  - High proliferation resistance
- Epistemic uncertainty
  - Criticality safety
  - Radiological safety
- Suitable for disposal of long-lived FP and U, but not of TRU.

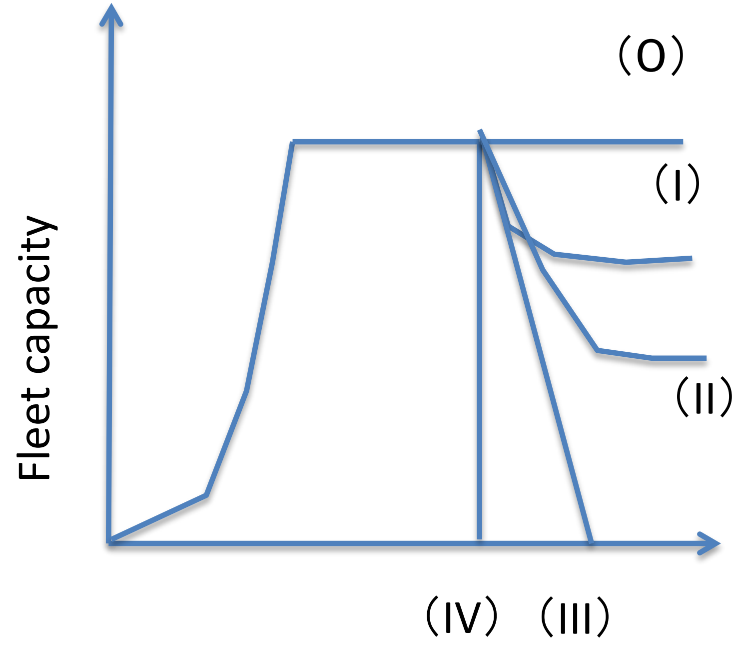
Couplings observed in spent fuel management

- Short term (fuel cycle) vs. Long term (disposal)
  - Short term ➔ Long term
    - Overall long-term *performance* is dependent on short-term options.
  - Long term ➔ Short term
    - Without a plan for repository siting, implementation of short-term options is difficult due to lack of public trust and confidence.
- Domestic vs. International
  - Domestic ➔ International
    - Failure in consuming recovered fissile materials may cause international skepticism.
  - International ➔ Domestic
    - International and bilateral treaties define framework for fuel-cycle options.
      - E.g., US-Japan 123 agreement negotiation by 2018

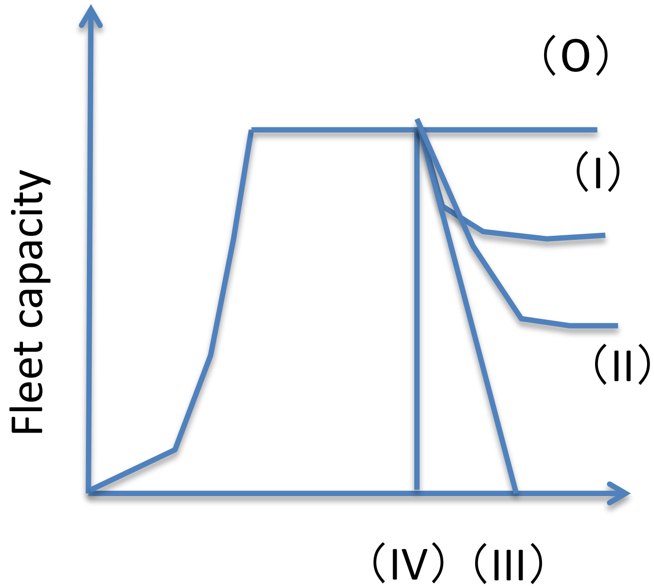

Long term
Radiological performance of repository
Proliferation resistance of a geological repository
Radiological performance of fuel cycle
International competitiveness and influence
Domestic
International
Recovery of investment; National wealth
Bilateral relations with US (and others)
Short term

Options

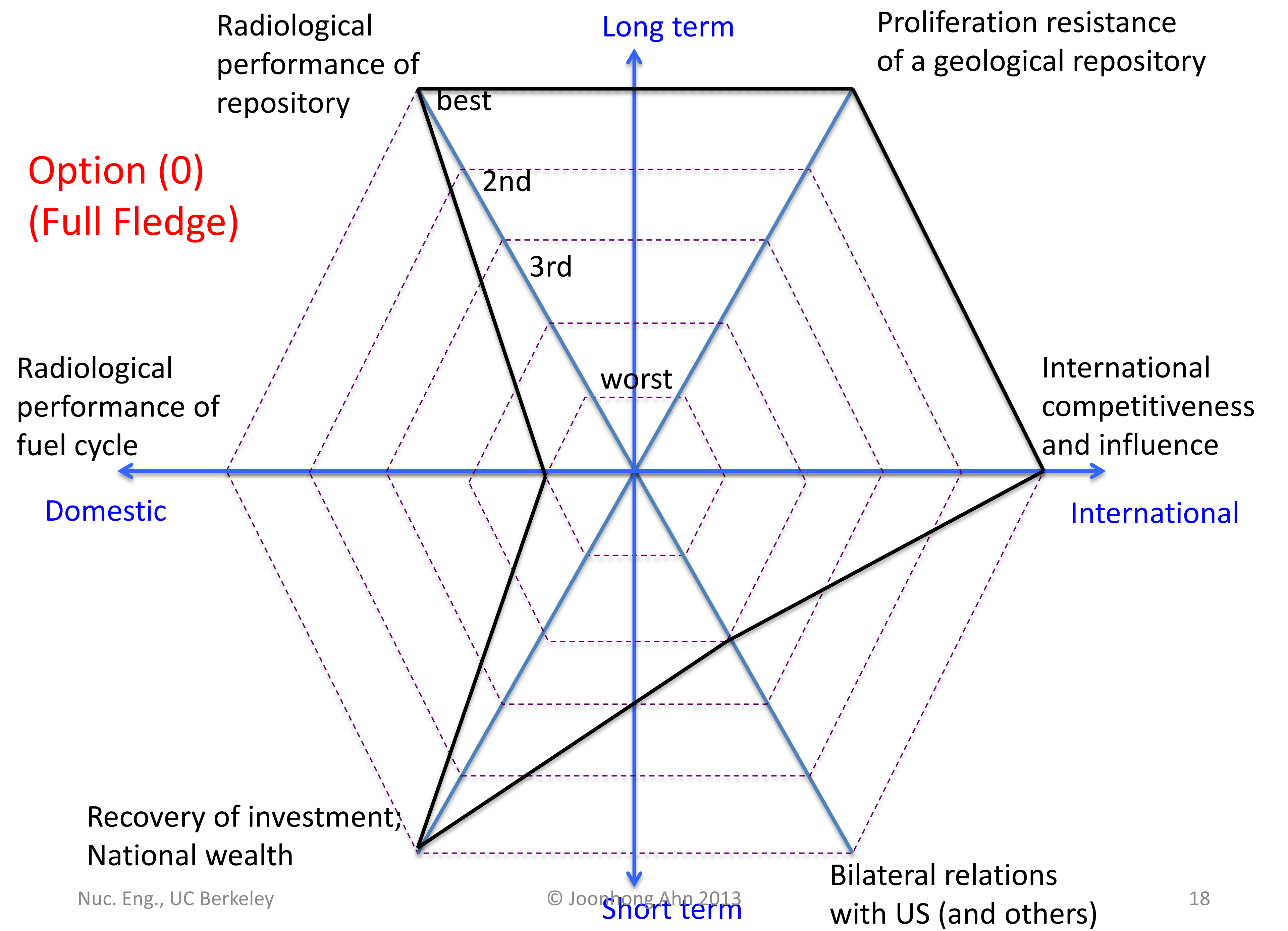
- Option（0）：Full-fledged fuel cycle
  - Maintain the same fleet capacity (e.g., 50 LWRs equivalent; includes FBRs)
  - PUREX (U, Pu recovered)
  - Recovery of TRU for transmutation
  - Disposal: HLW vitrified waste（legacy + future）
- Option（IV）：Phase out immediately
  - Disposal：HLW vitrified waste（legacy）, Pu stockpile, Spent fuel including MOX, Recovered U



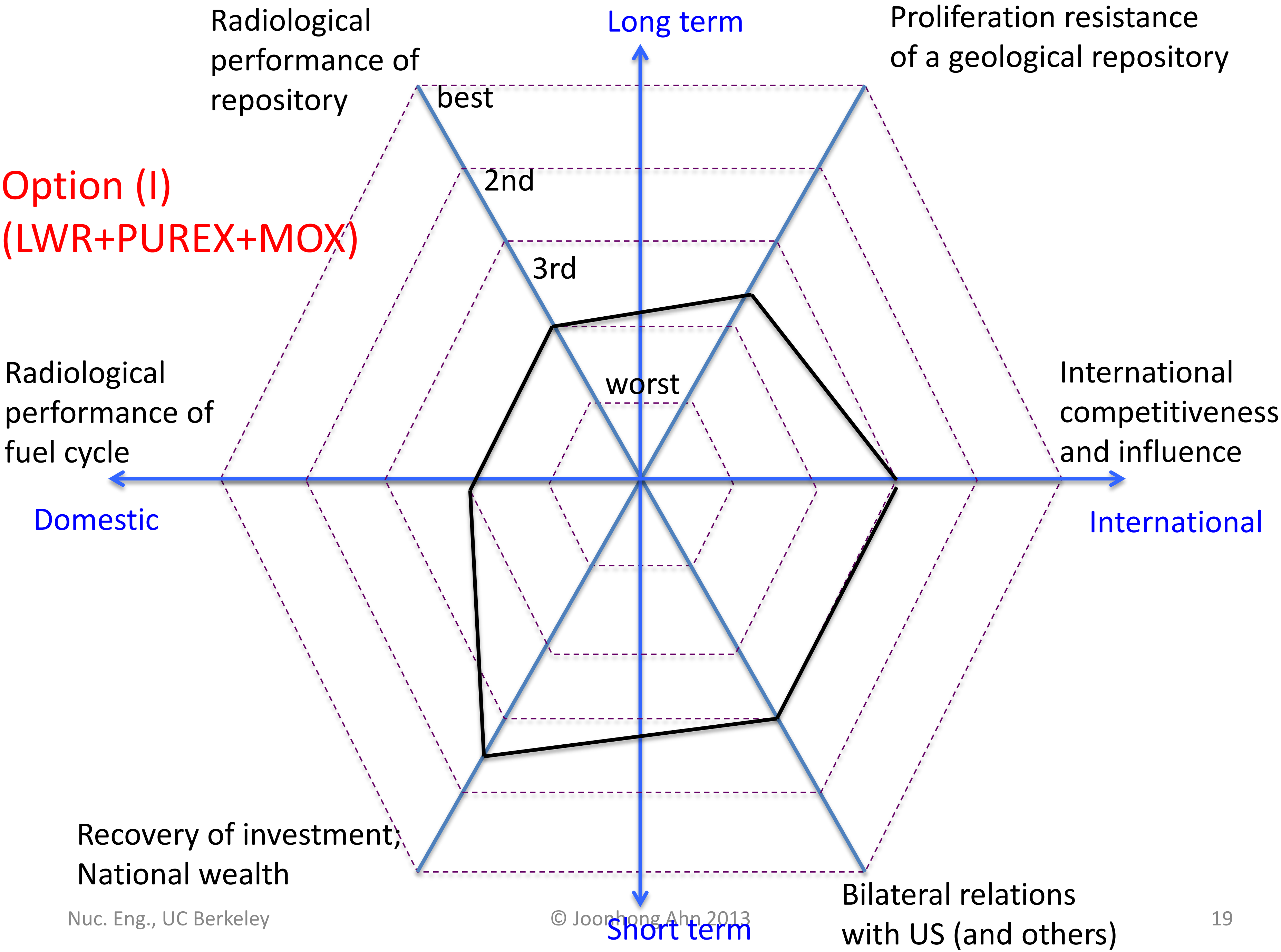
Options



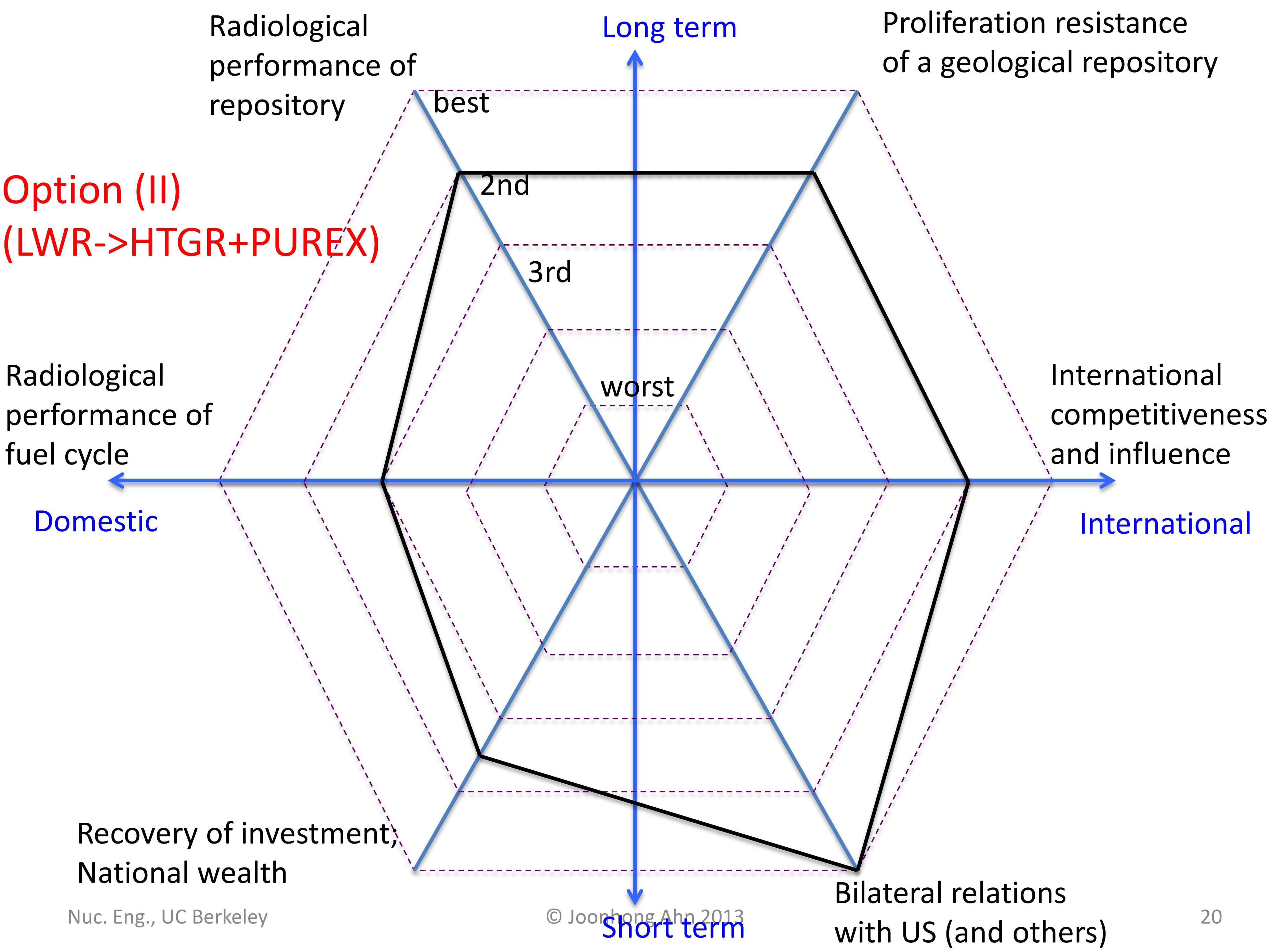
- Option (I)
  - Fleet capacity that can be accommodated by Rokkasho capacity
  - Old reactors replaced as needed
  - PUREX (U, Pu recovered)
  - MOX
  - Disposal : HLW vitrified waste (legacy + future), MOX SF, Recovered U
- Option (II)
  - Fleet capacity that can be accommodated by Rokkasho capacity
  - No LWR replacement; HTGR
  - PUREX (U, Pu recovered)
  - TRISO
  - Disposal : HLW vitrified waste (legacy), TRISO, Recovered U
- Option (III)
  - No replacement of reactors
  - No reprocessing
  - Legacy Pu is made into MOX and used in remaining LWRs
  - Disposal : HLW vitrified waste (legacy), MOX SF, Spent fuel, Recovered U


Option (0)
(Full Fledge)
Radiological performance of repository
Long term
Proliferation resistance of a geological repository
best
2nd
3rd
worst
Radiological performance of fuel cycle
Domestic
International competitiveness and influence
International
Recovery of investment; National wealth
Short term
Bilateral relations with US (and others)

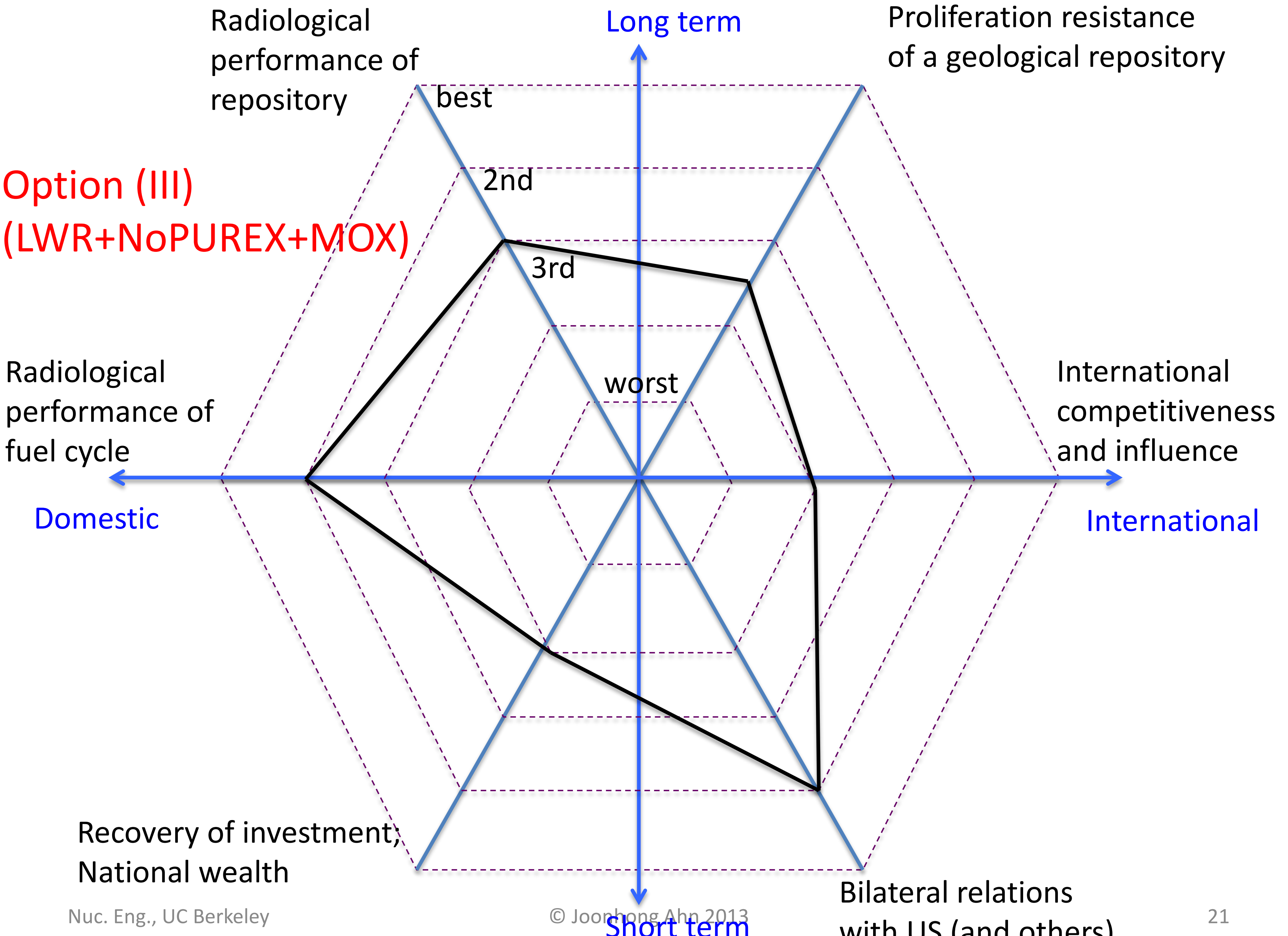
Option (I)
(LWR+PUREX+MOX)



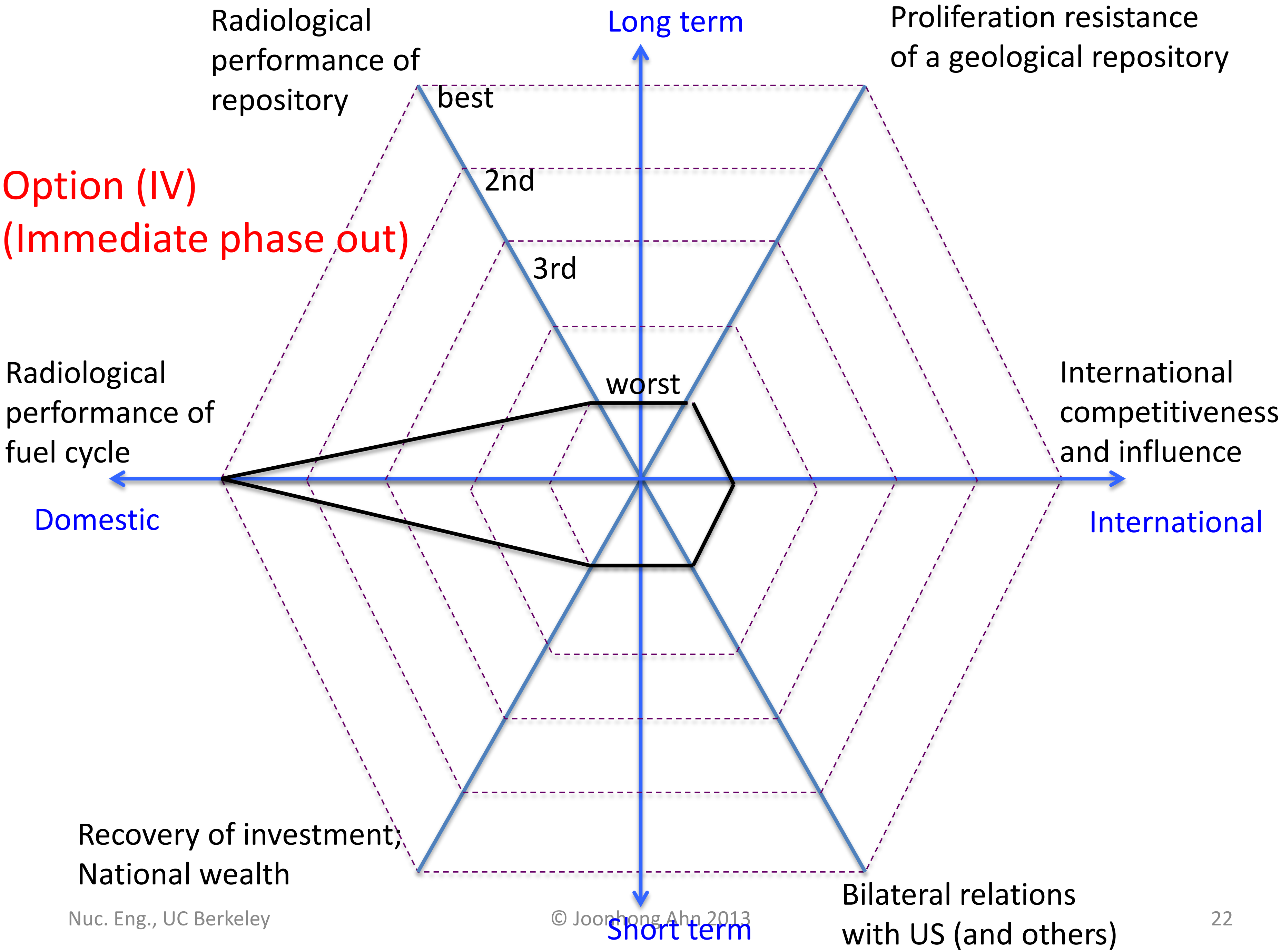
Option (II) (LWR->HTGR+PUREX)



Option (III)
(LWR+NoPUREX+MOX)



Option (IV)
(Immediate phase out)



Closing remarks

- Coupling between long-term and short-term proliferation risk is observed.
- Choose options flexibly, as the international and domestic environment evolves.
- International fuel cycle system is inevitable to reduce long-term proliferation risks.