China's Policy of Plutonium Recycling: Considerations for policy makers

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China's nuclear energy development

--50s defense nuclear—1979 focus switched to civilian nuclear power; mid 80s decided to develop NPP.

--90s Qinshan 300MWe(92) and Daya bay 2X984MWe(94)

--since 2005, China's policy of nuclear development changed from " moderate development" to " energetic development" .

--by 2011, operating 14 reactors of 11. 88 GWe (<2% electricity) (12PWR+2 Candu).

--under construction 27 PWR: 29.89 Gwe, account for about 40% of the whole world's construction).

--2020: 40 GWe operation (4% electricity generating)+18 GWe under construction (The medium and long-term plan,2007)

--over 70 GWe by 2020 (prior to March 2011);

--about 200 GWe (--10%) by 2030; about 240-400 GWe (--15%) by 2050.

China's nuclear energy development

Fukushima effects:

--- the State Council announced17 March 2011:

China would suspend approval of all new nuclear power stations; conduct comprehensive safety checks on all existing plants; review all nuclear projects including those under construction.

---The new safety standards are expected to be released in early 2012.

---While the NPP development pace has been temporarily slowed down, many Chinese experts still expect China will install up to a 70 GWe capacity by 2020.

---China's long-term goal of the nuclear expansion will not be changed significantly.

Operating Reactor in China by 2011

Reactors	Capacity (MWe)	Type	Design	Operation
Qinshan I #1	300	PWR	China	1991.4
Daya Bay #1	984	PWR	Franatom	1994.2
Daya Bay #2	984	PWR	Franatom	1994.5
Qinshan II #1	650	PWR	China	2002.4
Qinshan II #2	650	PWR	China	2004.5
Lingao #1	990	PWR	Franatom	2002.5
Lingao #2	990	PWR	Franatom	2003.1
Qinshan III #1	700	Candu	Candu	2002.12
Qinshan III #2	700	Candu	Candu	2003.7
Tianwan #1	1060	VVER	Russia	2007.5
Tianwan #1	1060	VVER	Russia	2007.8
Lingao #3	1086	PWR	China	2010.9
Qinshan II #3	650	PWR	China	2010.10
Lingao #4	1086	PWR	China	2011.9

China's plans on reprocessing

Status

---In the mid 1980s, China selected a closed fuel cycle strategy to reprocess spent fuel and has recently speed up development of this strategy.

---A pilot reprocessing plant was built in the early 2000s.

---A larger commercial plant is under consideration.

Motivations

---Full use of uranium resources; Reducing cost of mining, milling and enrichment uranium

---Provide MOX fuel ; Development of FBR;

---Energy security concerns;

---Reduce the waste repository volume

---minimizing radioactive toxicity, disposal of radwast safely;

---Reducing the burden of spent fuel at reactor pools

A multi-purpose reprocessing pilot plant

Purpose:

R&D of future reprocessing technologies for LWR-MOX or FBR; reprocessing spent fuels from research reactors,….

Location: Gansu province

Capacity:50-100 tHM/a

Development:

project approved July 1986; construction commenced July 1997; first reception of spent fuel from Daya bay reactors in Sept. 2003 , water test conducted Oct.2004, successful hot test Dec 2010.

A commercial reprocessing plant

Proposed location: Gansu province

Capacity: up to 800 tHM/a

NSF storage capacity: 3000+3000 tHM

Development: preliminary work started (site selection, etc) ; Negotiating with France; Planned commission around 2025?

In addition: A pilot MOX fuel fabrication (0.5t/a) building.

A commercial MOX fuel fabrication plant planned in commission by 2025?

China's Fast Reactor Programs

--- Chinese nuclear experts believe: To install 240 GWe of nuclear power (15-20%) by 2050, China had to develop FBR, it is impossible to use only PWRs because of the limitation of uranium resources.

--- China's nuclear energy roadmap (three stages):

PWR---FBR---Fusion reactor

--FBR programs listed in National Hi-Tech "863 program" in 1986

---China Experimental Fast Reactor (CEFR) operating in 2010.

--Larger commercial FBRs to be commissioning 2030-2035.

China FBR Development Strategy (suggested by CIAE, Xu Mi, 2009)

Reactor	Power (MWe)	Design beginning	Commission
CEFR (I)	20	1990	2010
CDFR (II)	600-900	2007	2018-2020
CCFR (II)	Nx 800-900	2015	2030
CDFBR (III)	1000-1500	2018	2028
CCFBR (III)	1000-1500	2020	2030-2032

Status of China Experimental Fast Reactor

--Conceptual design: 1990-92

--CEFR project approved in 1995

--Preliminary design 1996-97

--detail design 1998-2003

--construction start: 2000.5

--reactor building completed 2002.8

--physics start-up & first criticality: 2010.7

--costs about 2 billions RMB

Location	**35km from Beijng**
Floor surface of building	**43731 m^2**
Main building size	**78m x 68m x 57m**
Water supply	**4500 ton/day**
Power supply	**3000 kw**
Thermal power	**65 MW**
Electric power	**20 MW**
Plant life	**30 yrs**

Management of Spent fuels

- **Spent fuel storage**

AR spent fuel pools of Qinshan1 and Daya bay was full around 2001-2 and 2003-4 respectively. Since Sept. 2003, SF transported to Jiuquan Spent Fuel Wet Storage Pool at the pilot reprocessing plant

Jiuquan wet storage pool

---Start construction in Nov.1994, started reception of SF in 2003.

---Capacity :550tHM, to be expanded to 1100tHM.

---planned storage at large commercial plant:3000+3000 tHM

---Required cooling time of spent fuel: 5 year.

Repository for HLW

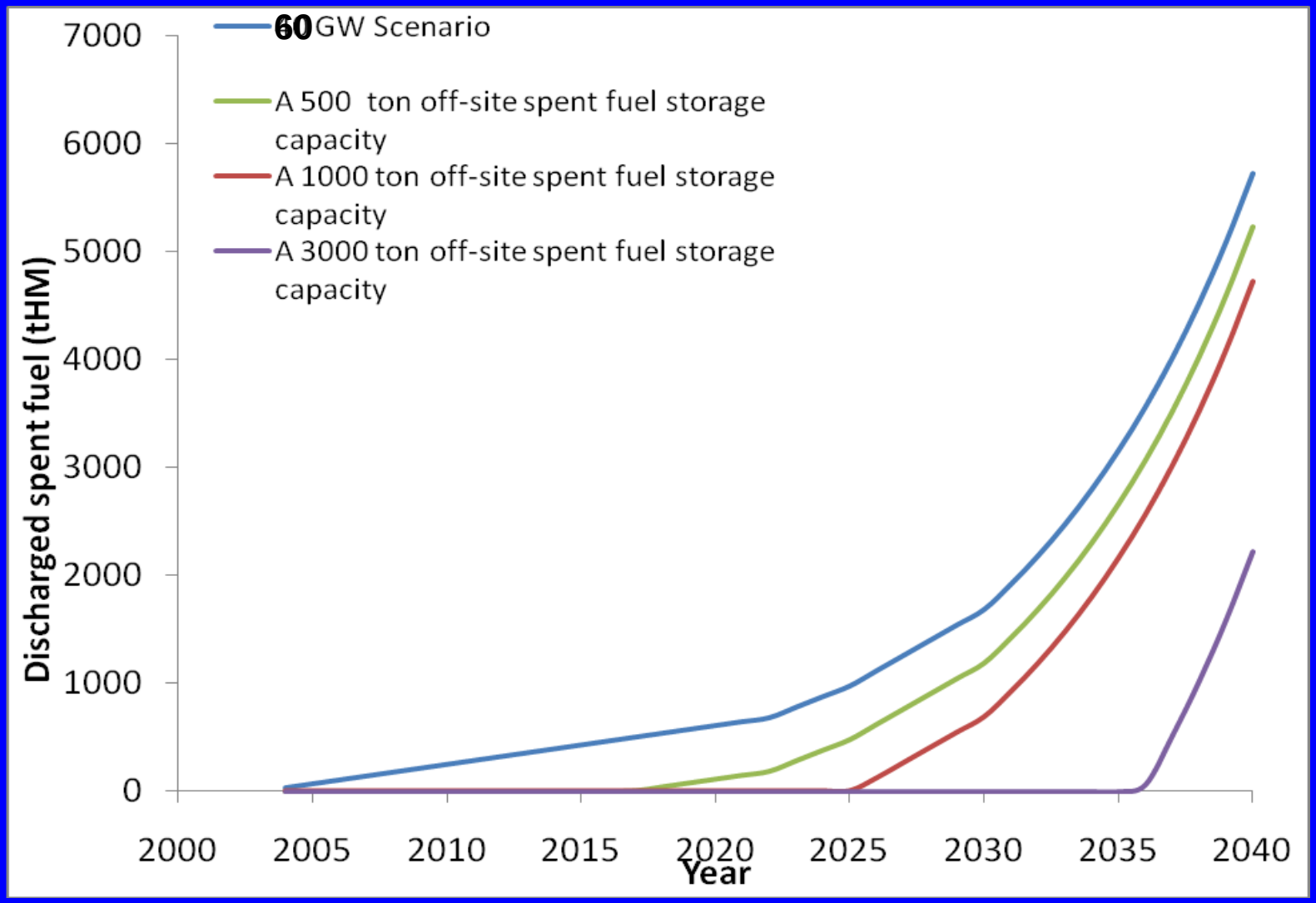
---Beishan area ,a desert area in Gansu is pre-selected for deep geological disposal of HWL from reprocessing. This huge area would be able to store all HLW from China's future nuclear power.

---an underground laboratory established by 2020

----to finish construction of the repository around 2030-2040

---VHLW disposal around 2060

Additional spent fuel storage demands



In Summary

---given the current capacity of Jiuquan AFR pool(550tHM) and planning for expanded 1300 tHM and potential larger pools,

---China will have little pressure to reduce the burden of NSF storage issue.

Offsite storage space (tons)	Estimate of when the storage will reach full capacity
500	2017
1000	2025
3000	2035

Discussion:

In practice, China could take measures to delay requirement for additional storage: e.g.

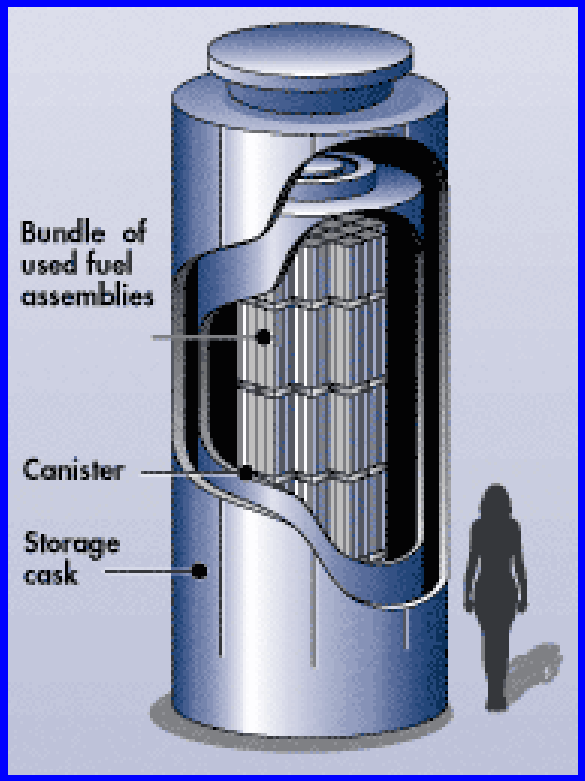
#re-racking spent fuel at already-built reactor's pool;

#building larger pools for new reactors;

#inter-ship spent fuels between pools at the same NPP site.

#on-site dry cask storage.

Dry cask storage



diverse technologies available
cheaper ($100-200/kgU)
safe storage for decades
for 75% of global nuclear capacity

See more: e.g.
Bunn, et al., Interim Storage of Spent Nuclear Fuel—A Safe, Flexible, and Cost-Effective Near-Term Approach to Spent Fuel Management (Harvard Univ.& Univ.of Tokyo,2001.)

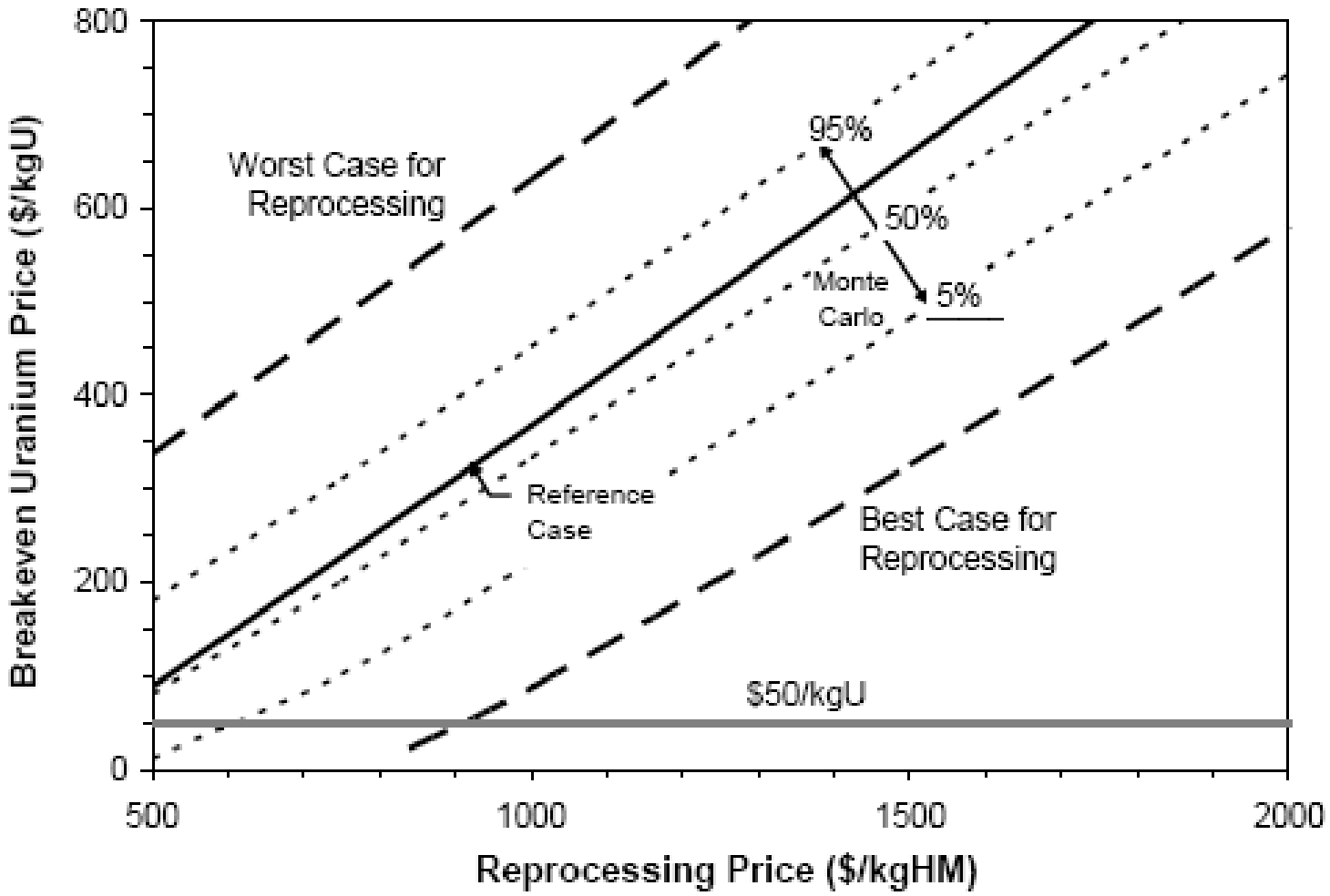
Economic aspects of nuclear reprocessing

--Many scientists show that "reprocessing" option is much more expensive that "direct disposal" option

--e.g Harvard group concluded :
"reprocessing and recycling plutonium in existing light-water reactors (LWRs) will be more expensive than direct disposal of spent fuel until the uranium price reaches over $360 per kilogram of uranium (kgU)…"

"Reprocessing and recycling plutonium in fast-neutron reactors (FRs) with an additional capital cost, …will not be economically competitive with a once-through cycle in LWRs until the price of uranium reaches some $340/kgU."

Figure 2.1. Breakeven uranium price as a function of the cost of reprocessing, for various sets of assumptions about the cost of other fuel-cycle services.



Bunn et al., Harvard 2003

Comparing the levelized cost of electricity (LCOE) for different fuel cycles (An MIT study: 2009)

Fuel cycle	LCOE (mill/kwh)	Increased
OTC	75.32	--
LWR MOX	76.99	2.2%
FR: burner	77.39	3%
FR: Breeder	78.51	4%

Note: e.g. 2-4% increase meaning :for 10 GWe installation, $1-2 billion /yr more than OTC.

A preliminary Harvard study on costs of Chinese reprocessing for different scenarios

Scenario I: No reprocessing Chinese reactors

Assuming: send all spent fuel that they cannot store onsite to off-site interim dry or wet storage.

Scenario II: recycling separated Pu as MOX fuel for LWRs

Assuming: 1) during 2010-2024, start reprocessing 50 tons/year; manufacturing MOX 0.5 tons/year; 2) During 2025-2034,Start reprocessing 800 tons/year in 2025; recycling separated Pu as MOX fuel for LWRs with a capability of 40 tons/year.

See details: Yun Zhou, China's spent fuel management: current practices and future strategies, Energy Policy,39(2011)4360-4369

---Based on the scenario studies, the reprocessing for MOX case is much more costly that of interim storage case.

---further studies on economics of Chinese reprocessing to be conducted.

Accumulative costs for spent fuel management scenarios (2008 US$M)

	0% discount rate	5% discount rate
Scenario I	319	124
Scenario II	20264	7274

---Other countries experience shows that plutonium recycle is much more costly than LWR once-through cycle. Chinese would have no significant change from others.

---In practice, China's pilot reprocessing plant reported costs over 2 billion Yuan (around 300 million US dollars) and take over 15 years from construction to a successful hot test. The 800 t commercial plant would be a few tens billions dollars (reported the deal with Areva about 30 billions US dollars . Even price cuts, could be around 20 billions), comparable to Japan's Rokkasho reprocessing.

---China should do its own assessment of the cost of Pu recycle.

Plutonium recycle in FBR?

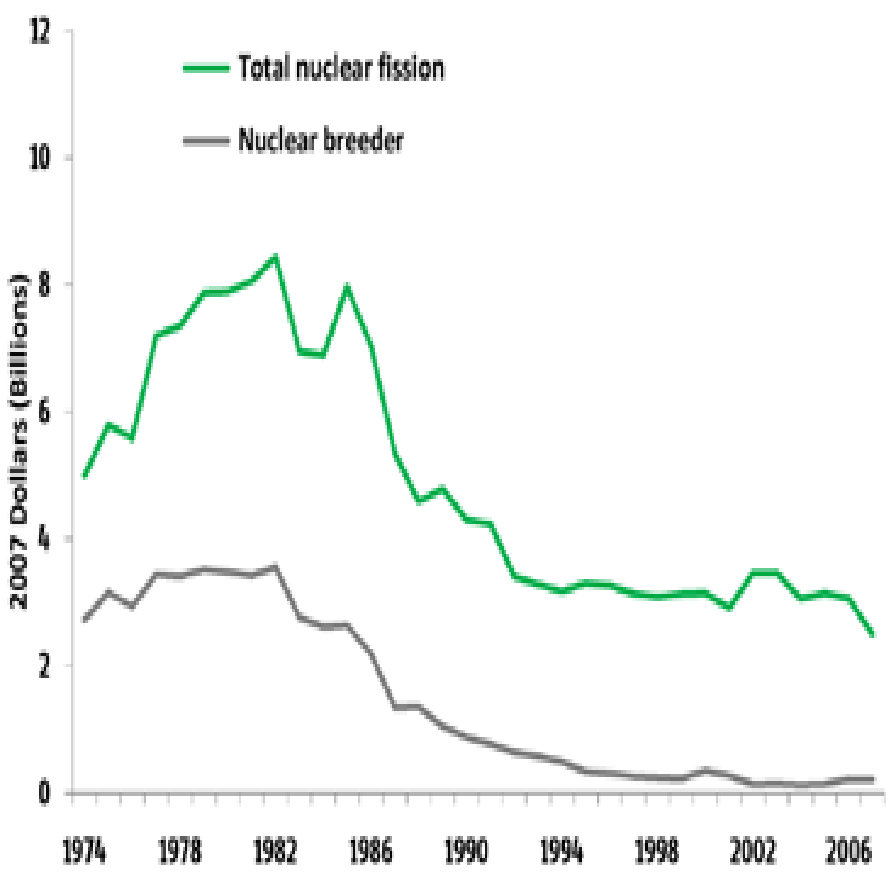
-- Only a few FBRs operating, less 1GWe

--Only commercialized FBR—Superphenix shutdown in 1998 and in decommissioning

---No commercialized FBR now

---R&D in OECD declined

---Many scientists doubt about those key assumptions of the rational for pursuing FBR



Total fission and breeder R&D and demonstration funding in the OECD (1974-2007)
Source: Fast Breeder Reactor Programs: History and Status, IPFM Feb.2010.

Major experimental, pilot and demonstration FBR

	MWe	MWt	operation		MWe	MWt	opeartion
China				**Russia**			
CDFR	20	65	**2010--**	BN-350(kazak)	350		1972-99
France				BN-600	600		**1980-**
Rapsodie		40	1977-83	BN-800	800		2014?
Phenix	250		1973-2009	**UK**			
Superphenix	1240		1985-98	DFR	15		1959-77
India				PFR	250		1974-94
FBTR		40	**1985-**	**USA**			
PFBR	500		2012?	EBR-I	0.2		1951-63
Japan				EBR-II	20		1963-94
Joyo		140	1977-	Fermi 1	66		1963-72
Monju	12		1994-95 2010?	Fast Flux Test facility		400	1980-93
				SEFOR		20	1969-72

Source: Fast Breeder Reactor Programs: History and Status

Energy security consideration

---one major motivation for Pu reprocessing and recycling is “saving uranium” to increase “independent” supply of uranium.

---the key for nuclear “Energy Security”—world uranium resource

If energy system depends much more on Nuclear and U resource soon used up---nuclear energy security would be important, UNFORTUNATLY, not such case.

China’s uranium resource

---CAEA 2007: 100,000 t of uranium resource (<$130kg/U)

---CNNC in 2008 : discovered China’s largest uranium ore in the northern Inner Mongolia region and China’s largest sandstone-hosted deposit at Yilin basin in the Xinjiang Autonomous Region

---”Red book” 2009: the new discovered uranium resources during 2007-2008 about 71,400 t categorized as Reasonable assured resources and inferred resource.

---Based on recent report, China would have a huge potential of U resource. E.g. could several million ton deposited; only 40-50 % area surveyed.

---China’s U resource supply “ enough for near-term; secure for mid-term; big potential in the future”

China’s demand for natural uranium

---For the rapid growth (60GWe), by 2020 China could use around 50% known uranium resource(171 KtU) .

---however, China’s reactors using 1/3 fuel from domestic resource ,others from oversea. If keep this mode, China’s own uranium would supple for next 20 yrs.

China actively accesses to oversea uranium

---In 2006, the China National Nuclear Oversea Uranium Resource Development Company (NNOURD) set up—a deal with Australia: 20,000 t of uranium /yr.

---also a deal with Canada in 2004: access to Canada's uranium mine.

---NNOURD claimed to secure over 200,000 t uranium reserves in Africa, Australia, Canada, and Central Asia.

---CGNPC: also invested to ensure its nuclear fuel supplies.

China's exploration and investment in Domestic and oversea uranium resource should not constrain China's development of nuclear energy for next several decades.

Energy security consideration-cont'd

---However, Chinese domestic uranium reserves alone should not be the determinant for a closed fuel cycle . Should depend on INTERNATIONAL uranium market.

--In fact, China is taking strategy for U resource: " domestic production + oversea exploitation + world trade of uranium"
CNNC actively participating in exploration & mining abroad

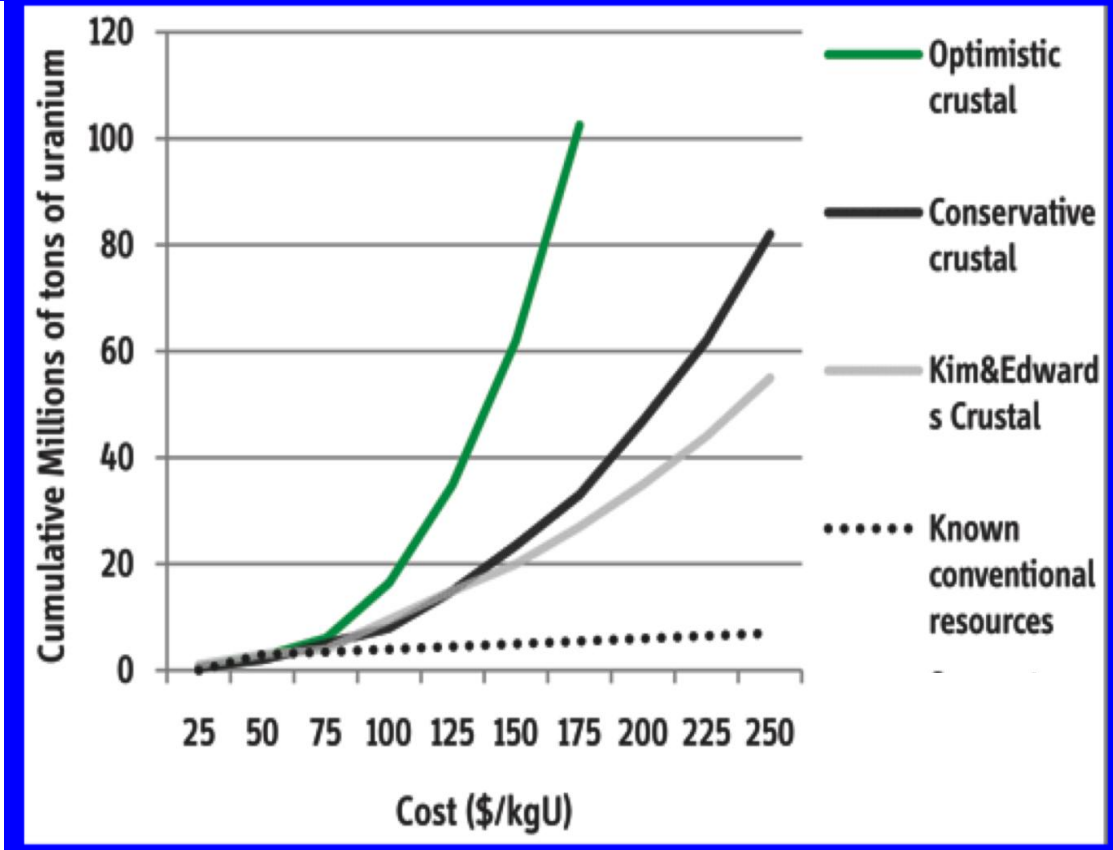
---China now relies on two resources (domestic & abroad) and two market (domestic & abroad)

---Moreover, uranium suppliers are diverse geographically and politically---unlikely to collude to raise prices or limit supplies

---In addition, e.g. S.Korea and Japan have no domestic natural production, but still have nuclear energy programs.

- ***Uranium 2007: Resources, Production and Demand*** (Red Book)
  ---Known U~5.5 MtU, Undiscovered U~10 MtU.
  ---By 2006, 66.6 k tonnes for the 435 reactors;
  ---Nuclear power projection from 372 GWe (in 2007) to between 509 GWe (+38%) and 663 GWe (+80%) by 2030 which demands 94 k tonnes and 122 k tonnes.

- ***Based on the 2006 nuclear electricity generation rate and current technology, the identified resource base will remain sufficient for 100 years.***



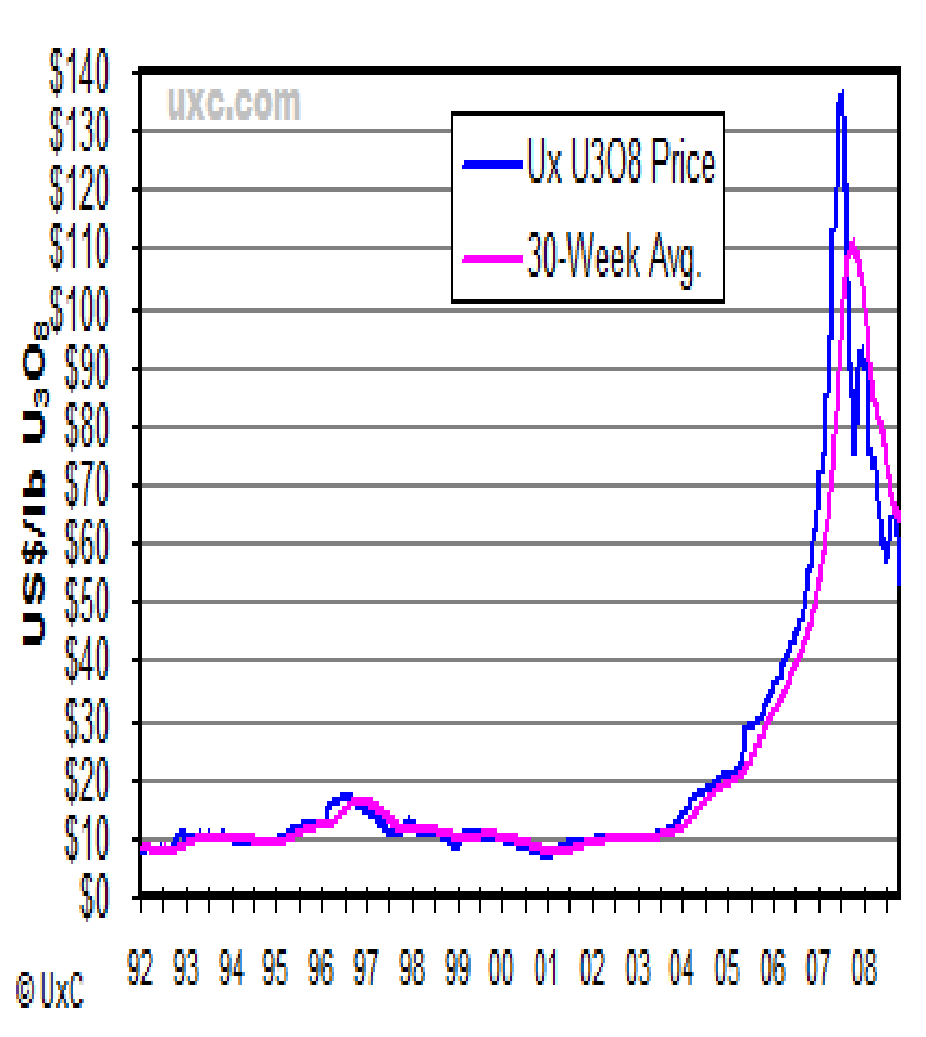
Source: "Long-Term Uranium Supply Estimates," Schneider and Sailor, Nuclear Technology, June 2008, p.379.

---NEA high scenario for once-through LWRs 4.5 million tons by 2050
---Linear increase to 4000 GWe in 2100 would require 25 million tons.

Note:

---total world uranium resources are dynamic and related to commodity prices. Higher price—more exploitation—more resource.

---Moreover, 4500MtU in the oceans, could be extracted at significant high price (say, e.g. +300)---thus it will support the power reactors with once-through cycles for many centuries.



Waste volume considerations

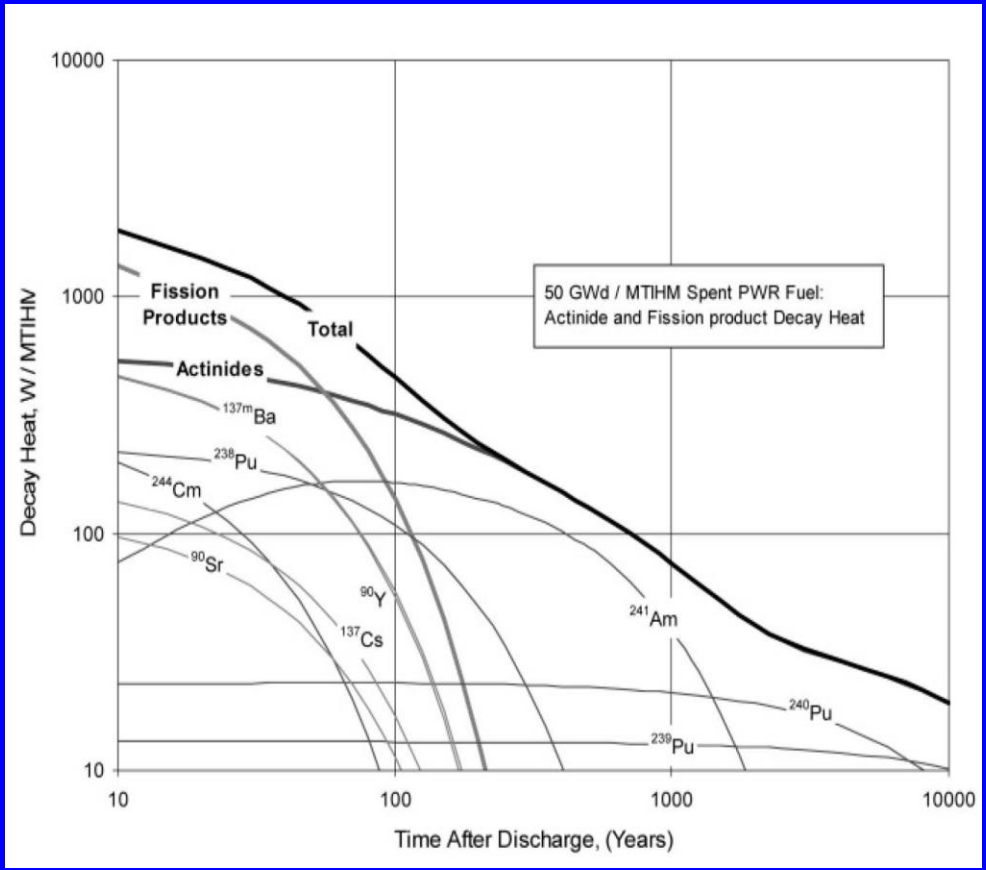
- **The loading of YM-like repository is constrained By the temperature limits (due to the high decay heat from SF) not by the physical volume).**

The temperature limits:

--- Peak rock temperature midway between adjacent drifts must remain below the local boiling point (96 C

—to allow water to drain through the repository at all time

---Peak rock temperature at drift walls must remain below 200 ºC to keep structural integrity of the Repository.

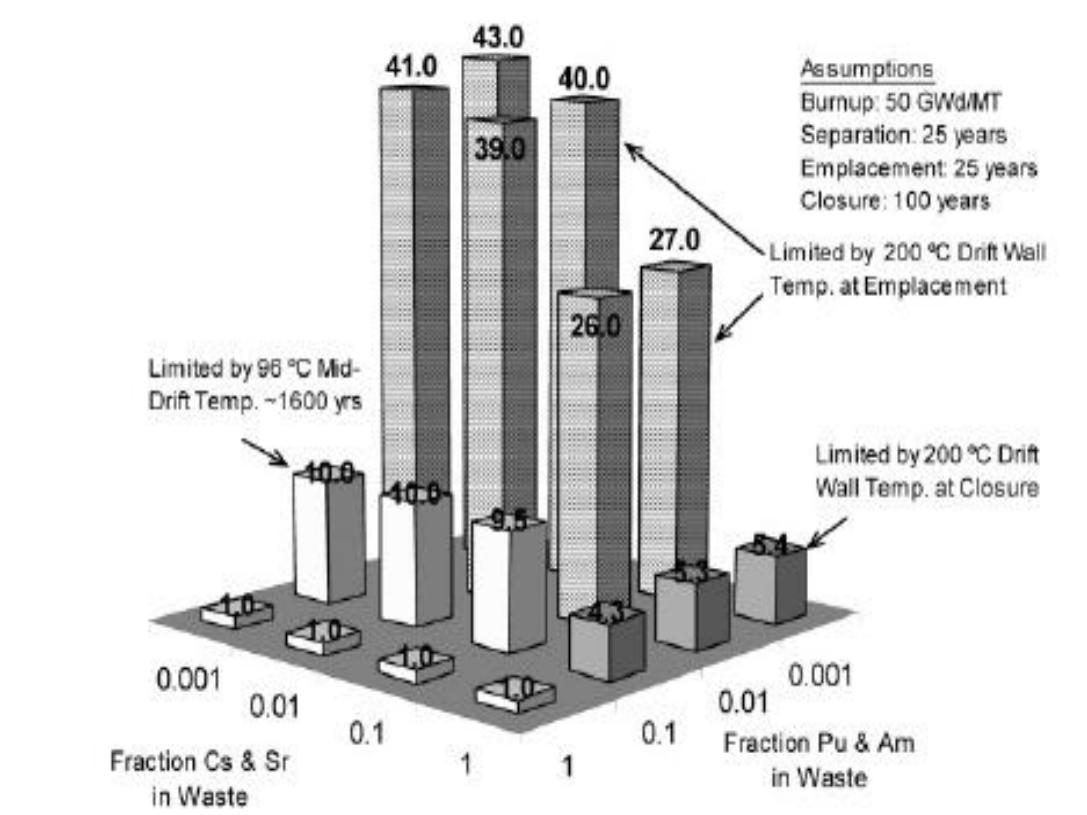


Contributions to decay heat from a spent fuel as a function of time

---For regular reprocessing: increasing the drift loading—a factor of 5.

---For Mox case: very small benefit, only a factor of 1.087.

---If 99.9% Pu, Am, Np removed & 99.9% Cs, Sr and dtrs removed: a factor above 40.



R. Wigeland,et al., NuclearTechnology,vol.154 (April2006)

- **Under all scenarios, a location is required for geological disposal of HWL. The question is whether such space is limited in China .**

---One major motivation for US reprocessing and recycling (under Advanced Fuel Cycle Initiative or GNEP) is: potential increase in utilization of space in a geologic repository like YM (due to the legislated limitation of the loading for YM is 70,000 t and too difficult to get a second site).

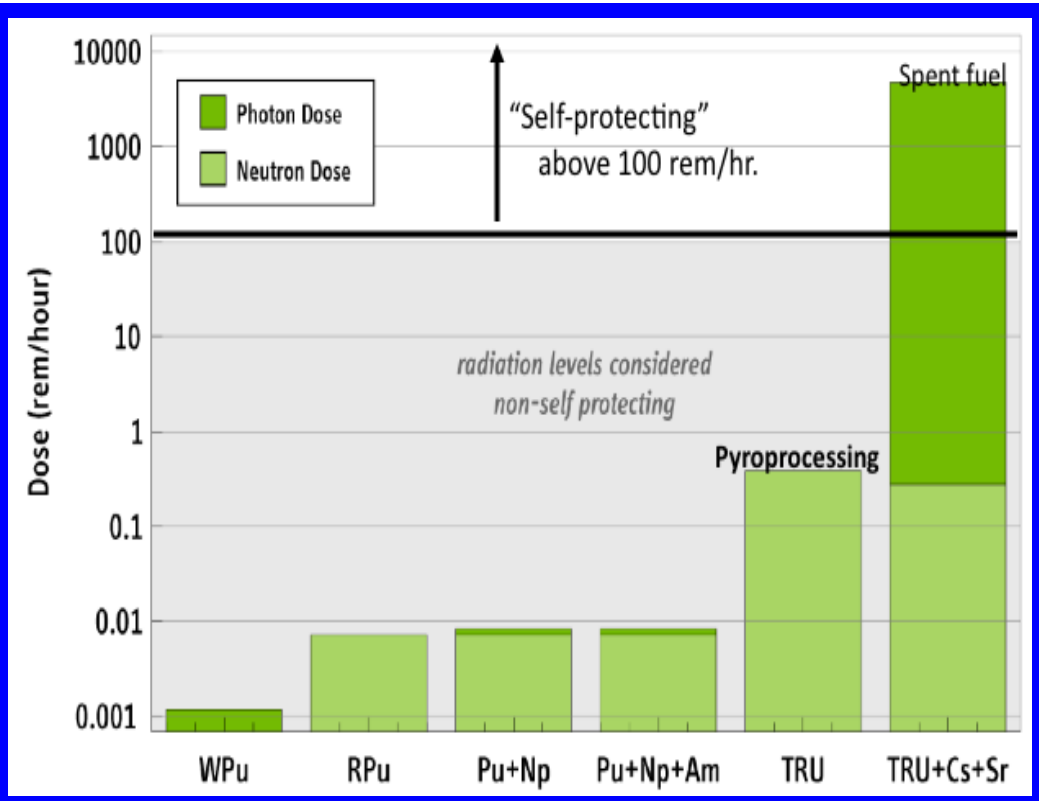
Note: US congress rejected the domestic GNEP

---However, China should not have such a limit. In fact, China's Beishan area could have a huge capacity, and maybe more sites (if needed).

Nuclear proliferation

- **Reactor-grade plutonium is weapon usable; reprocessing—separated Pu easy taken, unlike SF "self-protecting" —nuclear proliferation**

Figure: Dose rate from 4,4 kg of Various transuranic mix.
Source: Kang & von Hippel, SGS 2009



Nuclear proliferation—cont'd

- Civilian Pu stocks will soon exceeds its small military Pu stocks-- increase cost and burden of safeguards and physical protection
  e.g. reprocessing of 800 tHM/yr---8 t separated Pu/yr, much higher than WgPu in stocks.
- Could affect other non-weapon states concerning reprocessing—provide cover for proliferation
- China concerns about Japan's Pu, China's own reprocessing would make it difficult to dissuade others.
- If no reprocessing, would set up an good example for other countries

Recommendations

- Other countries experience shows that plutonium recycle is much more costly, much less safe and secure than LWR once-through cycle. China should do its own assessment of the cost of Pu recycle.

- Known resources of low-cost uranium worldwide are sufficient for this century. China can invest more in improving estimates of U resource, taking strategy for oversea exploitation, word trade , uranium stockpiling.

Recommendations (cont'd)

- **Before the cost and risks of reprocessing and l fast breeder technologies are reduced, China should take an interim storage approach--- offers a safe, flexible ,and cost-effective near term approach to SF management.**

- **This interim storage option will give China a substantial opportunity to carefully develop a long-term policy for the nuclear fuel cycle.**