China's Nuclear Energy Development and SF Management Plans

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Content

1. **Nuclear energy in China**

   background, history, status and plan

2. **Experience and plans of spent fuel(SF) management**

   accumulation, interim storage, transportation and reprocessing

3. **Scenario analysis of SF management**
4. **Conclusion**

Part 1: nuclear energy in China

1. **Nuclear energy in China**

    development environment of energy/nuclear energy

    analysis of energy demand/supply

    role of nuclear in energy mix

    nuclear enrgy state: in operation/construction/planned

    impact of Fukushima nuclear accident

    scenarios of nuclear development

2. Experience and plans of spent fuel(SF) management
3. Scenario analysis of SF management
4. Conclusion

China is a nuclear country with....

a long history but "young"

- First nuclear weapon test in 1964
- One of five nuclear-weapon nations
- In term of peaceful utilization, first Nuclear Power Plant(NPP) in commercial operation in 1994

Qinshan Phase I:

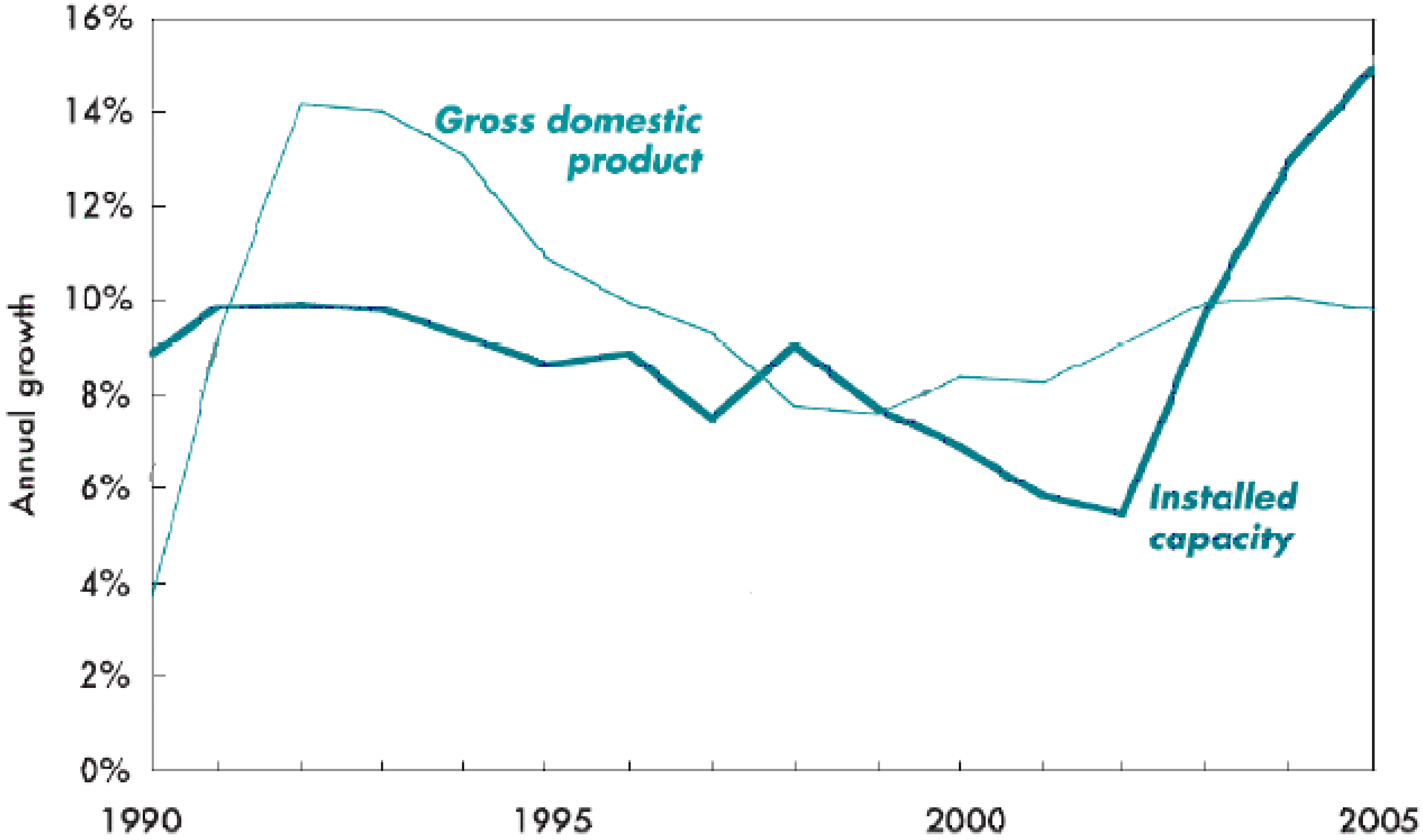
Type: CNP-300, PWR

Grid Connection: 15 Dec. 1991

Location: Haiyan, 100km southwest to Shanghai

Development environment of nuclear

The overall elec. development after 1990



Source: Amb. William Ramsay, China’s power sector reforms, 2006

Electricity supply and demand

Electriciy shortages since 1980s

In 1997, balance between power demand and supply was first maintained

Since 2000, severe power shortages has ocurred and spread:
In 2002, 12 Provinces sufferd from the lack of electricity.
while 2003, 22; 2004, 24; 2005,26

Economy loss around 1 trillion RMB

Projections of electricity development

- **To ensure the electricity supply and keep high economic growth**
- **Focus on energy policy**
- **Future demand and supply were estimated by various research groups**
- **Future demand based on**
  - estimated electricity consumption per capital
  - or estimated electricity consumption per $ GDP
  - or constant annual growth rate of consumption

Demand forecast to 2020

- **Typical forcast of elec. consumption in 2020**

Organization	Date	Electricity Demand in 2020 /TWh
Energy Information Agency	2006	4,256
State Grid Corporation of China	----	4,400
Development Research Center	2004	5,226
China Development Bank	2005	5,280-5,780

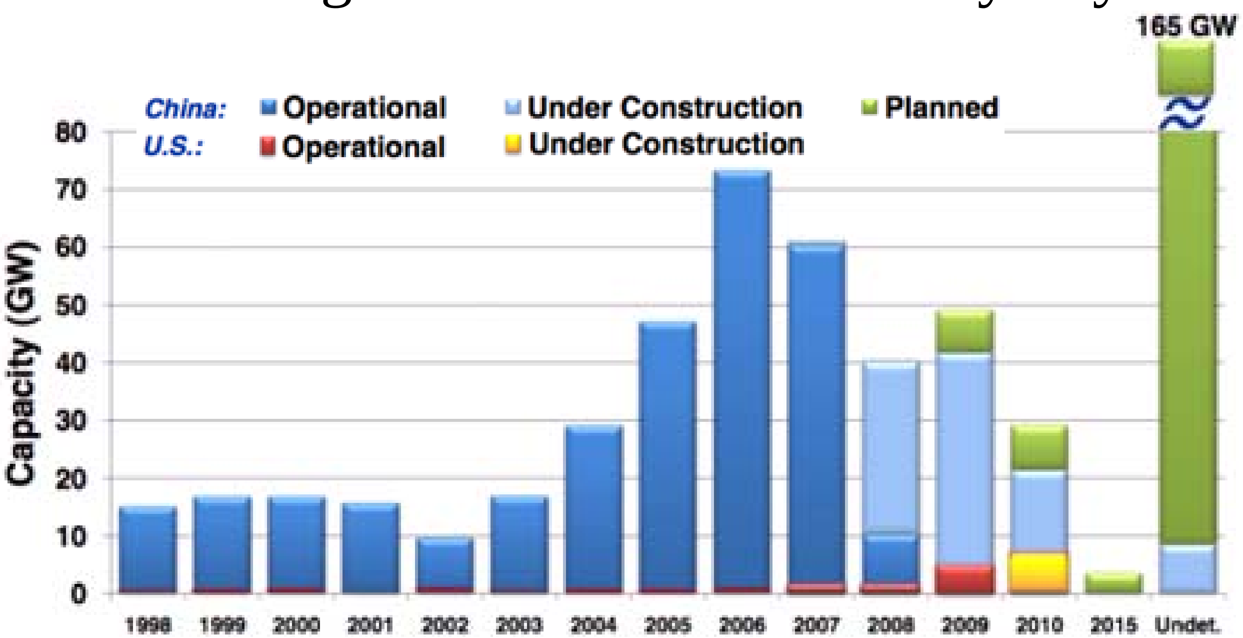
More than doubled electricity will be required based on the consumption in 2004 (2,187 TWh)

Source: Fredrich Kahrl, et al., 2006

Supply forecast to 2020 (1)

Coal occupies dominant place in elec. supply

- Largest coal production and consumption nation
- In 2004, coal-fired electricity was 1,807 TWh, accounting for 82.6% of total generation
- Elec. generation will continually rely on coal heavily



Coal-fired building rate China Vs U.S.

Source: ecopolitology.org/2010/08/26/chinas-massive-coal-fired-power-plant-boom-visualized/

Supply forecast to 2020 (2)

Percentage of coal-fired elec. to gradually decrease due to ....

– Pollutions from mining, transportation, storage and consumption

– Human cost

Supply forecast to 2020 (3)

Hydro is prefered to be expanded explosively

- Regarded as a clean and renewable energy
- Enormous hydropower potential, No. 1 worldwide.
- In 2004, hydro elec. generation was 328 TWh, accounting for 15.0% of total generation
- Explosive increase is expected

Three Gorges dam:

Largest hydro station in term of installed capacity (22.5 GWe)

Dam body completed in 2006

However, around 1.3 million people displaced for its construction

Supply forecast to 2020 (4)

Other alternatives

– Oil and gas
  - Accounting for small parts of elec. generation in 2004
  - Limited due to their increasing dependence on imports
– Wind, solar and biomass
  - Steady and large-scale development can be expected
  - Only amount to a small share in term of electricity generation.

Motives to develop nuclear

- **An inevitable complement**
  - Net growth of elec. demand is 2,100~3,500 TWh
  - Insufficient net growth of supply from other fuels
  - Gap between demand and supply is around 350 ~650 TWh
- **Large capital investment**
  - mainly from central finance
  - strong stimulation to local economic growth
- **Excellent safety record**
  - no severe reactor accident from 1986 to 2004
  - regarded as clean, safe and economic energy

Change of nuclear plans(1)

Proposed nuclear plans 2007-2011:

Time	Organization	In operation 2020 /GWe	In construction 2020 /GWe
Oct. 2007	National Development and Reform Commission	40	18
Mar. 2008	National Energy Administration	>50	
Jun. 2008	State Council	86	16
Jun. 2010	Unknow	70-80	
Jan. 2011	China Daily	86	

Change of nuclear plans(2)

After Fukushima nuclear accident:

- **16 March 2011:**
  - All approval process of new projects to halt
  - The Shidaowan HTR, though ready for first concrete, was also delayed
  - Safety checks of operating plants, as well as those in construction, were undertaken
- **March 2011:**
  - HUANG Xiaojing, Fujian province governor: "Fujian has three nuclear power plants, and that is enough. Projects that have not been completed must not be continued"

Change of nuclear plans(3)

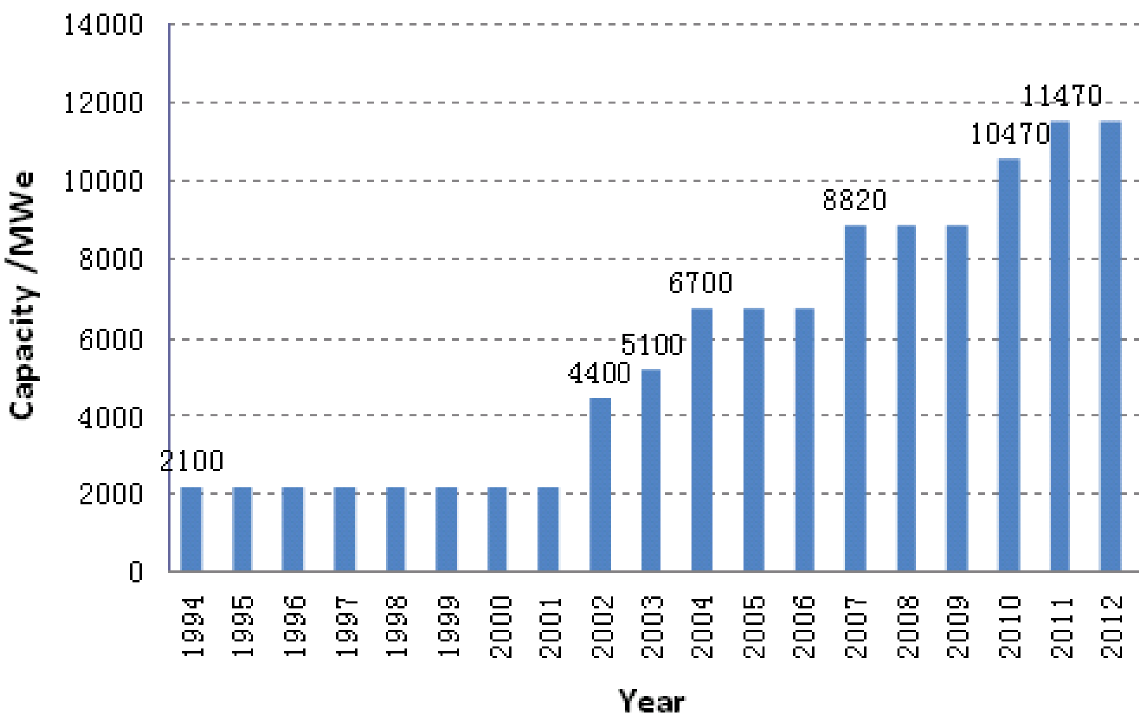
After Fukushima nuclear accident:

- **Aug 2011:**
  - Safety checks completed
- **Feb 2012:**
  - A report on nuclear saftety approved by the state council
  - Nuclear power plants in construction and operation at the highest levels of safety
- **March 2012:**
  - China Daily: "China will soon resume the approval and construction of nuclear power plants "

Growth of nuclear capacity

Speed slow

- First units in operation: 1994
- Today, 14 units in operation
- Total 11.5GWe in commission after 18 years (<0.7G/a)



Case in the U.S.

1959: 1st nuclear unit in operation

1967: 25.6 GWe in operation

1974: 66.9 GWe in operation

3.2 G/a or 4.4 G/a, in average

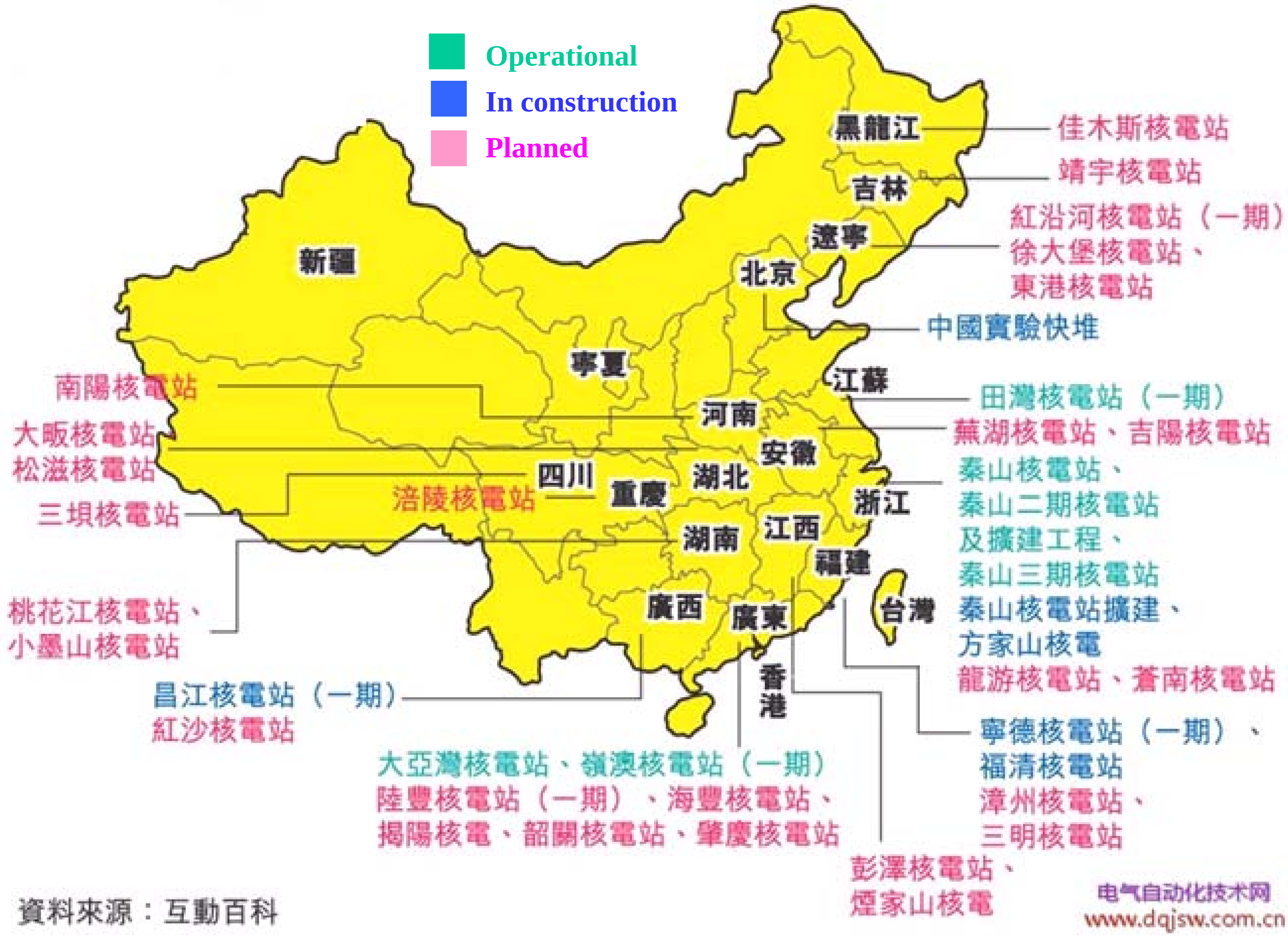
Units in operation

Unit	Net capacity /MWe	Type	First commercial operation
Daya Bay 1&2	900*2	PWR (French M310)	1994
Qinshan Phase I	300	PWR (CNP-300)	1994
Qinshan Phase II, 1	600	PWR (CNP-600)	2002
Qinshan Phase III, 1	700	HWR (Candu 6)	2002
Ling'ao Phase I, 1	1000	PWR (French M310)	2002
Qinshan Phase III, 2	700	HWR (Candu 6)	2003
Qinshan Phase II, 2	600	PWR (CNP-600)	2004
Ling'ao Phase I, 2	1000	PWR (French M310)	2004
Tianwan 1&2	1060*2	PWR (VVER)	2007
Qinshan Phase II, 3	650	PWR (CNP-600)	2010
Ling'ao Phase II, 1	1000	PWR (CPR-1000)	2010
Ling'ao Phase II, 2	1000	PWR (CPR-1000)	2011
Qinshan Phase II, 4	650	PWR (CNP-600)	Apr. 10, 2012

Units in construction and planned

- **26 units in construction**
  - 26.2 GWe in total
  - Started construction in 2007~2010
  - Scheduled to operation in 2012 ~2015
- **27 units planned**
  - 14 projects with 28.6 GWe in total
  - Including HTR and 3 inland projects (Taohuajiang, Xianning and Pengze)
- **Additional ~120 units proposed**

layout of China's nuclear units

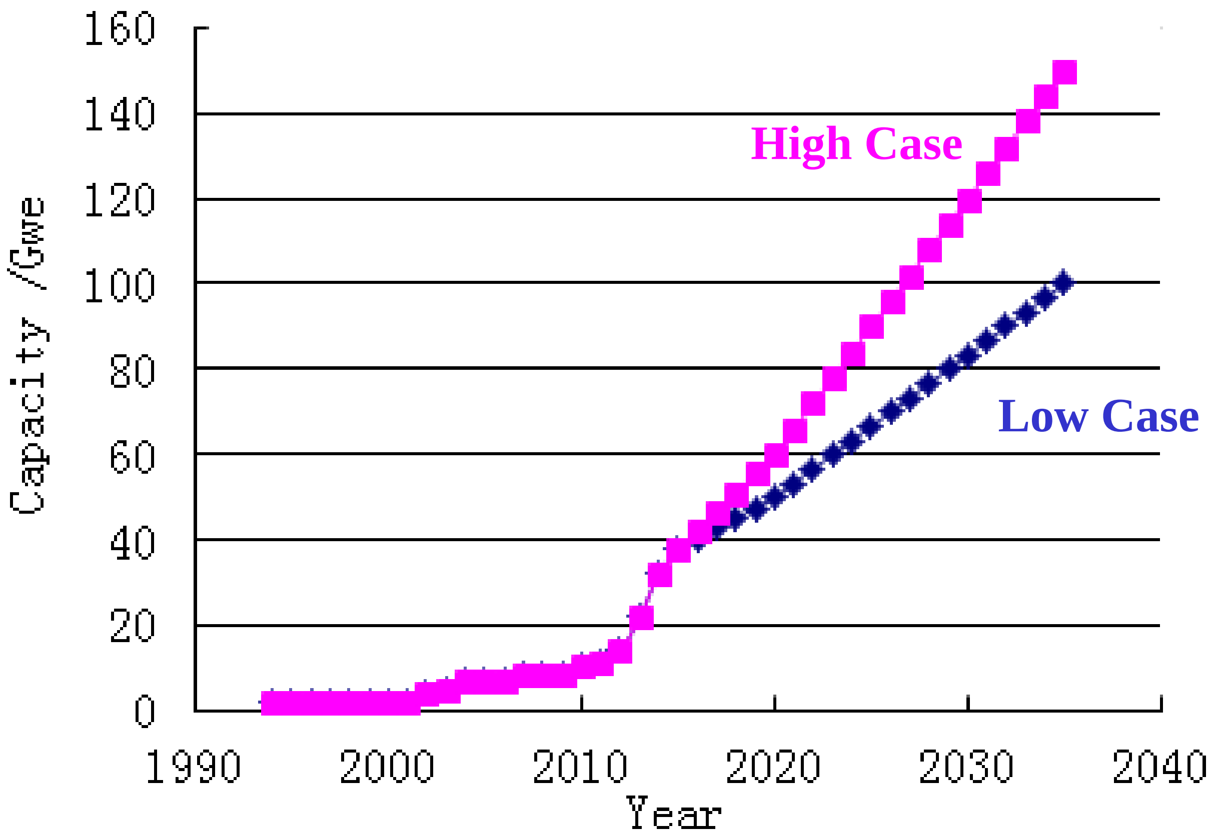


Scenarios of nuclear development

- **Assumption and envisaged cases**
  - All 26 units (26.2 GWe) current in construction will be in operation without significant delay.
  - High case: 60GWe in 2020, 150 GWe in 2035
    - 60 GWe: 11.5 GWe in operation, 26.2 GWe in construction, and most (22.3 of 28) planned units
    - Linear increase between 2020 and 2035
  - Low case: 50GWe in 2020, 100 GWe in 2035
    - 50 GWe: 11.5 GWe in operation, 26.2 GWe in construction and some of (12.3 of 28) planned units
    - Linear increase between 2020 and 2035

Scenarios of nuclear development

Nuclear capacity growth in two envisaged cases



Year	low case /GWe	high case /GWe
2011	11.47	11.47
2020	50	60
2025	66.7	90
2030	83.3	120
2035	100	150

Part 2: Experience of SF management

1. Nuclear energy in China
2. **Experience and plans of SF management**
   - **mass of discharge SF: calculation**
   - **SF transportation**
   - **interim storage: AR and AFR**
   - **reprocessing**
3. Scenario analysis of SF management
4. Conclusion

Calculation of discharged SF(1)

- **The detailed data of discharged SF is not available**
- **The mass of SF can be estimated be the expression**

annual thermal energy output, GWth/a

net electric capacity, GWe

capacity factor

$$M = \frac{Q}{B_d} = \frac{Pe \cdot CF \cdot 365}{\eta_{th} \cdot B_d}$$

Mass of unloaded SF per year, tHM/a

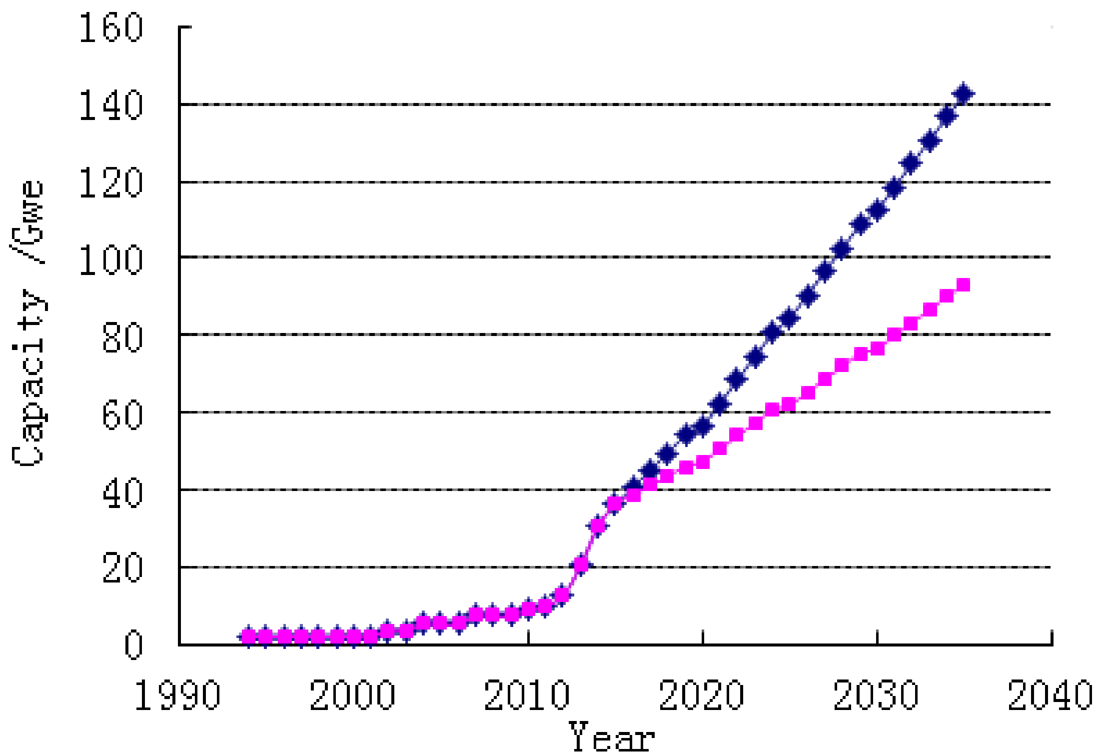
average discharged burnup, GWd/tHM

thermal efficiency, GWe/GWth

Though the expression is capable of obtaining the mass of SF from all reactor types. Only PWRs are taken into consideration in our study

Calculation of discharged SF(2)

- **All symbols modified according to PWR**
  - Pe : by deduction of the capacity of HWR, HTR and FR



Year	low case /GWe	high case /GWe
2011	10.07	10.07
2020	47.4	56.6
2025	62.1	84.6
2030	76.7	112.6
2035	93.4	142.6

Calculation of discharged SF(3)

- **All symbols modified according to PWR**
  - Bd: given as 33GWd/tHM and 50GWd/tHM respectively for calculation earlier and no earlier than 2004
  - η_{th}: given as 0.33 for PWR
  - CF: given as 0.85

Capacity factors of NPP in China

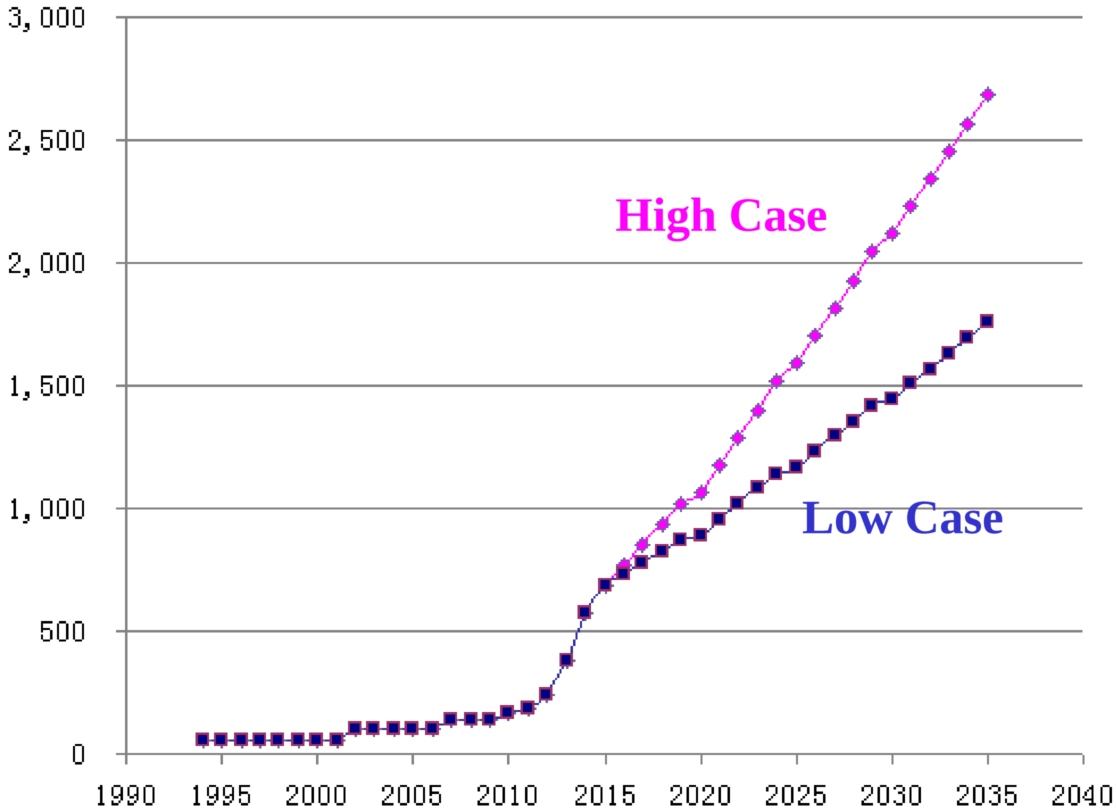
Unit	2000	2001	2002	2003
Daya Bay 1	86.7%	88.0%	89.7%	89.6%
Daya Bay 2	88.0%	90.9%	82.0%	84.5%
Ling'ao Phase I-1	- -	- -	92.0%	76.8%
Ling'ao Phase I-2	- -	- -		85%
Qinshan Phase I	76.8%	93.9%	67.8%	- -
Qinshan Phase II-1	- -	- -	74.9%	81.2%

Capacity factors of Daya Bay NPP (1&2)

2004	2005	2006	2007	2008	2009	2010	2011	2012
87.8%	100%	80.3%	91.2%	99.8%	91.2%	89.1%	100%	99.9%

Calculation of discharged SF(4)

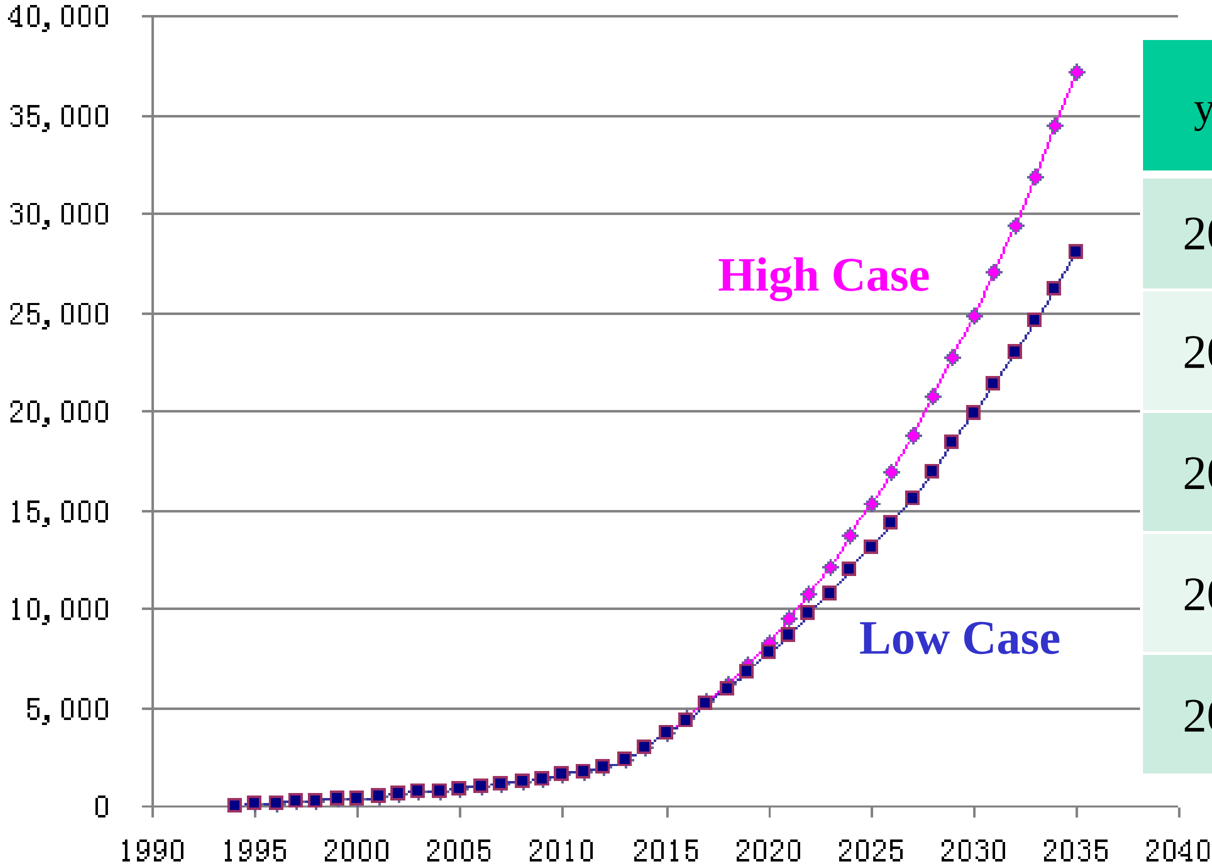
Annual discharged SF



year	high case /tHM	low case /tHM
2012	238	238
2020	1064	891
2025	1591	1167
2030	2117	1443
2035	2681	1756

Calculation of discharged SF(5)

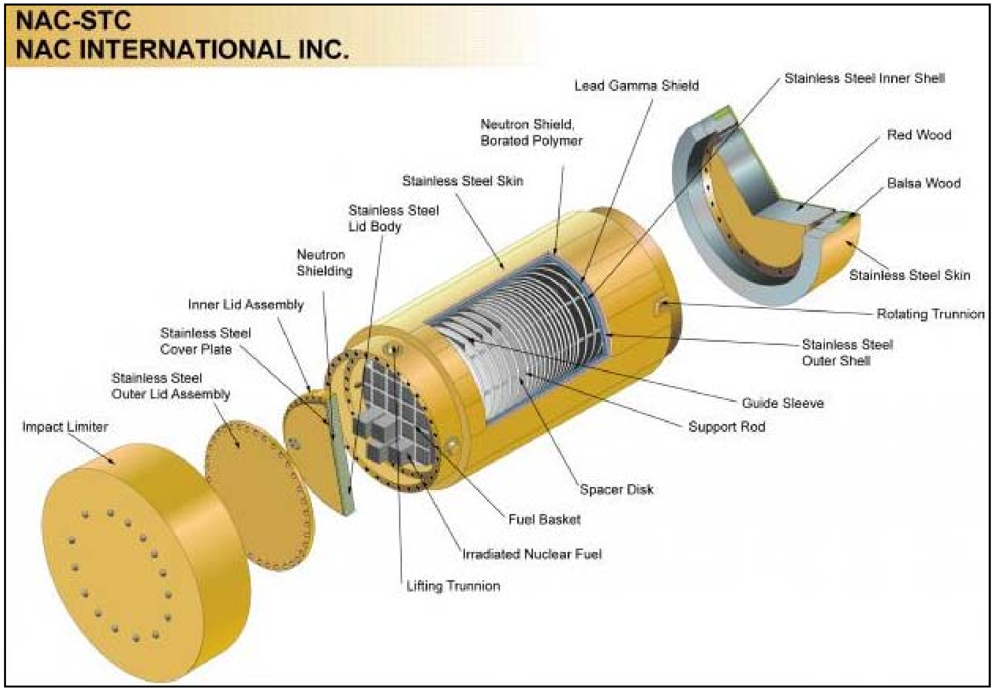
Accumulated discharged SF



year	High case /tHM	Low case /tHM
2012	1767	1767
2020	8281	7732
2025	15257	13091
2030	24865	19829
2035	37144	27983

Experience of transportation

- **Cask:** NAC-STC for SF transportation
- Ministry of Environmental Protection first licensed the metal cask for SF transport in 2003



- 26 (17*17) PWR assemblies in each cask
- Mass of U: 464 Kg/assembly
- Enrichment: 1.7<(wt% ^{235}U)<3.3
- Burnup: < 40 GWd/tU

Source:www.mep.gov.cn/gkml/hbb/haq/201003/t20100329_187512.htm

Experience of transportation

- First transportation of SF from commercial reactor:

    In 2003, from Daya Bay to Lanzhou

    About 3720 km, through 7 provinces

    Road transportation, route[a]: 大亚湾核电站省道 深圳 高速 广州 高速 长沙 高速 武汉 高速 信阳 高速 漯河 高速 郑州高速 洛阳高速 秦东镇（省界）高速 西安 高速 咸阳 G312 兰州 G312 武威 G312 404厂

- In 2006-2010, 56 (cask·time) transportations with total journey of more than 210,000 (cask · km) [b]

    Including SF from research reactors

    Totally >300 tHM of commercial SF (about ½ of loading) delivered from Daya Bay to Lanzhou

    Meaning that most SF discharged before 2001 have been transported.

a : www.mep.gov.cn
b : www.cnnc.com.cn/publish/portal0/tab618/info51136.htm

Experience of interim storage

At Reactor (AR) storage:

Reactors in construction or planned supported with SF storage capacity over 20 yr.

NPP name	Storage method	AR storage capacity/yr	Estimated year of filled up
Daya Bay 1&2	Wet storage	10	2003 and 2004
Qinshan Phase I	Dense-pack wet size expansion	35	2025
Qinshan Phase II 1 & 2	Dense-pack wet	20	2022 and 2024
Ling'ao Phase I 1 & 2	Dense-pack wet	20	2022
Qinshan Phase III 1 & 2	wet and dry storage	40	2042 and 2043
Tianwan Phase I 1 & 2	Dense-pack wet	20	2026 and 2027

Source: Yun Zhao, China's spent nuclear fuel management: current practices and future trend, 2011

Experience of interim storage

Away From Reactor(AFR) storage:

– A centralised wet SF storage facility built at Lanzhou Nuclear Fuel Complex

25 km northeast of Lanzhou

Total AFR storage capacity 550 tHM

Including 500 tHM for commercial reactors and 50 tHM for research reactors

– According to estimation that >300 tHM SF were transported from Daya Bay NPP, the available capacity is < 200 tHM

– Reportedly, storage capacity to be increased by 550tHM

– Possible to build a 3,000-ton SF pool as part of its commercial reprocessing plant (Deng, 2010)[a].

a : Yun Zhao, China’s spent nuclear fuel management: current practices and future trend, 2011

Experience of interim storage

SF storage pool attached to the pilot reprocessing plant

Borated stainless steel frame for SF high-density storage.

Experience of reprocessing

A pilot reprocessing facility

- At Lanzhou Nuclear Fuel Complex
- Throughput: 50 tHM/a
- In Dec. 2010, hot test of power reactor SF reprocessing conducted successfully
- Considered to be extended to 80 tHM/a[a], or 100 tHM/a [b]

a : www.9abc.net/index.php/archives/13993
b : Hui Zhang, On China's Commercial Reprocessing Policy

Plans of reprocessing

A large-scale commercial reprocessing plant

- Throughput: 800-1000 tHM/a
- In Nov. 2007, an agreement signed with AREVA to set up a 800tHM/a reprocessing plant.
- However, only one small step of a long march
- Schedule: Construction completed no earlier than 2020, and in commission after 2025

a : www.9abc.net/index.php/archives/13993

Part 3: scenario analysis of SF mgmt.

1. Nuclear energy in China
2. Experience and plans of SF management
3. **Scenario analysis of SF management**
   - **scenario: model and assumption**
   - **results of discussion**
4. Conclusion

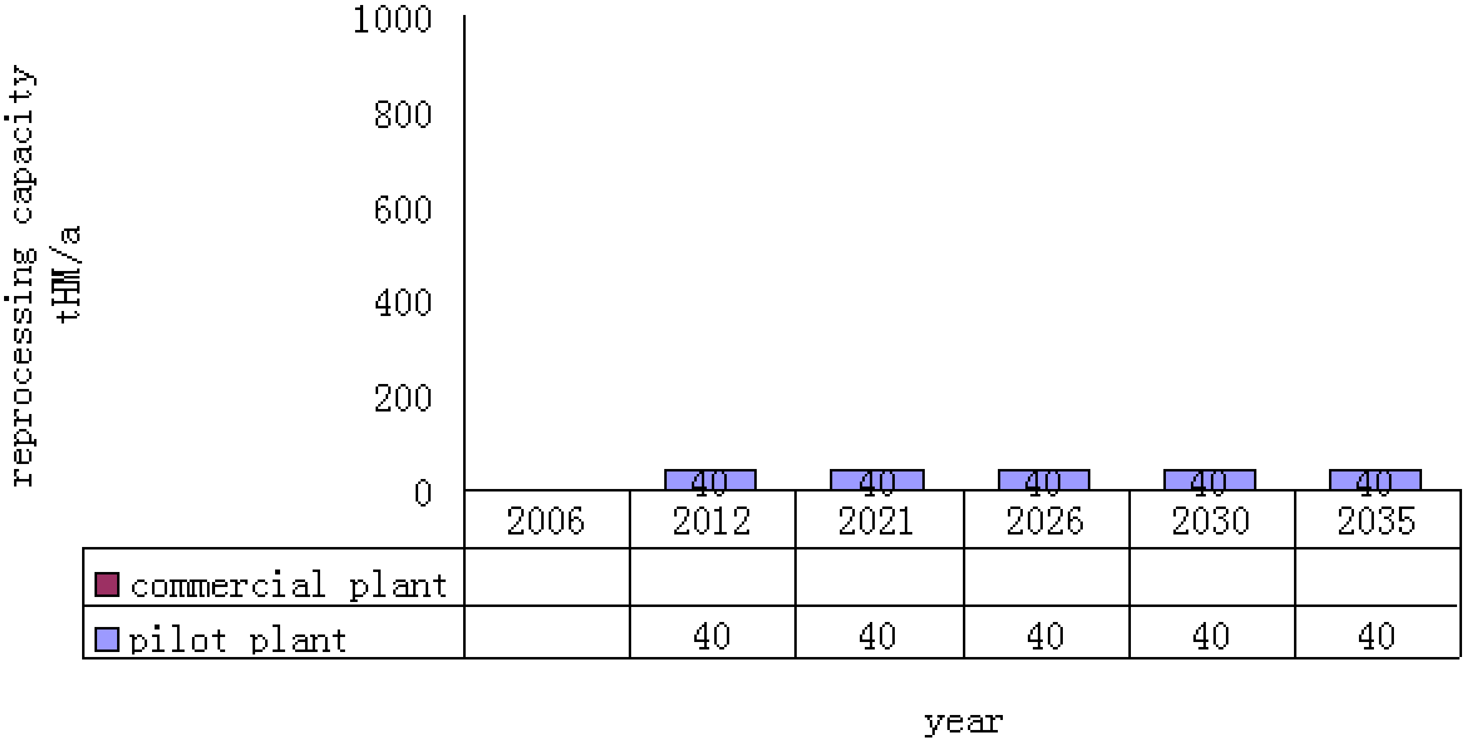
Scenario assumptions

Reference Scenario:

Pilot reprocessing plant:

average 40tHM/a from 2012, without extension

No more reprocessing plants in operation before 2035



Scenario assumptions

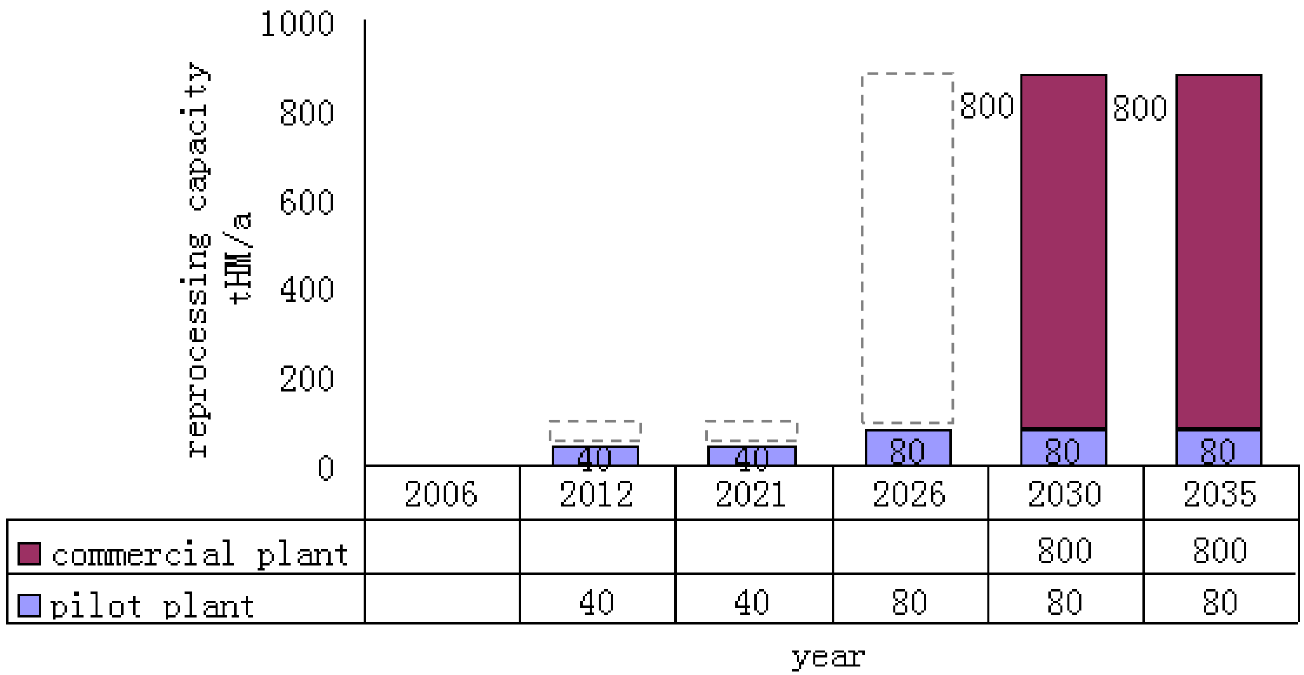
Scenario A: less-reprocessing-case

Pilot reprocessing plant:

40tHM/a from 2012, expanded to 80 tHM/a in 2026

Large-scale commercial plant:

in operation with full capacity from 2030



Scenario assumptions

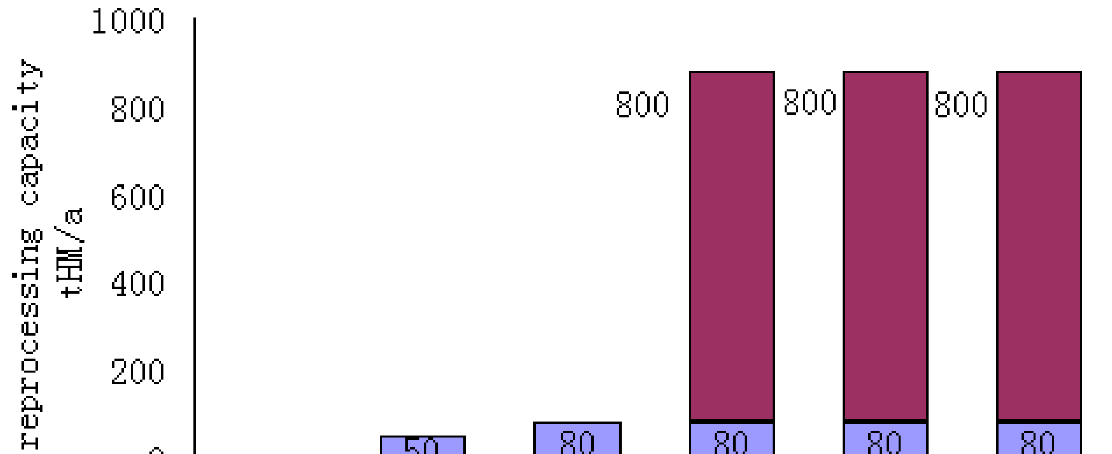
Scenario B: more-reprocessing-case

Pilot reprocessing plant:

50tHM/a from 2012, expanded to 80 tHM/a in 2021

Large-scale commercial plant:

in operation with full capacity from 2026



	2006	2012	2021	2026	2030	2035
commercial plant				800	800	800
pilot plant		50	80	80	80	80

year

Scenario calculation

constitute of SF

- with ORIGEN2 calculation
- all SF stored for 10 a for decay before reprocessing
- without regard to nuclide decay after reprocessing

Mass composition of element in SF

	Uranium g/tSF	U-235 g/tSF	Pu g/tSF	MA g/tSF	FPs* g/tSF
33 GWd/tU	9.56E5	7.97E3	8.68E3	1.03E3	2.82E4
50 GWd/tU	9.34E5	6.68E3	1.23E4	1.88E3	4.26E4

*: involatile FPs during reprocessing

Result: accumulated SF

accumulated SF (/tHM)

		2012	2020	2025	2035
Nuclear high case	A: more-rep.	1955	7831	14407	27494
	B: less-rep.	1965	7921	14657	31744
Nuclear low case	A: more-rep.	1955	7282	12241	18333
	B: less-rep.	1965	7372	12491	22583
Reference Scenario	Low nuclear growth with least repro.	1965	7372	12510	27022

Discussion: stored and reprocessed SF

According to present assumption

- **very limited reduction of stored SF in 2025 (<4.3%)**
- **the amount of stored SF increase steadily in full time scale**

In term of SF reduction, the large-scale plant is highly effecient.

- **remarkable reduction by 2035 (maximum 22.8%) due to large scale plant**

Discussion: impact on transportation

Today's transportation capacity

- **Capacity: maximum 135 tHM per year**
- **much greater than repro. capacity of pilot plant**

Without large-scale reprocessing plant....

- **current transportation able to provide SF for pilot plant.**

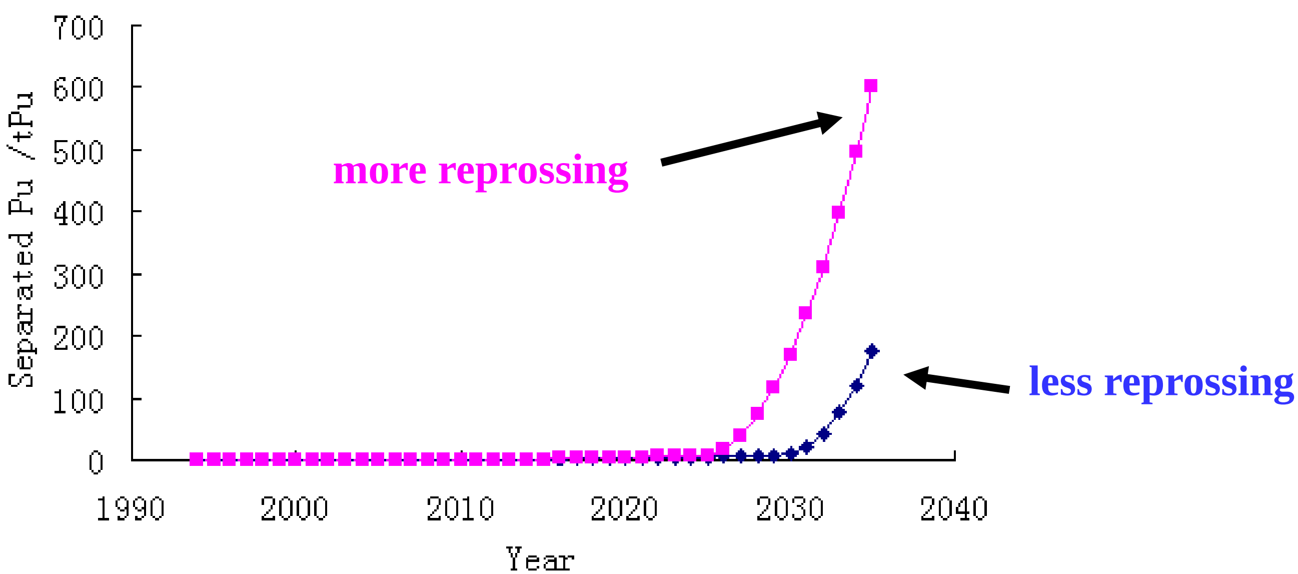
However....

- **AR storage pools in Qinshan Phase I & II and Ling'ao NPP nearly full in 2022-2025**
- **Impact of "March 11 accident" to reduce highly dense storage of SF in AR pools**

Result: separated Pu

Scale of reprocessing: only factor to determine the amount of separated Pu

/tPu	2012	2020	2025	2035
A: more-rep.	0.43	3.91	7.38	602.7
B: less-rep.	0.35	3.12	5.21	176.2



Discussion: separated Pu

Simplified situation

- typically, ~4t Pu is required for first loading of a FR with 1GWe capacity.
- ~2.8 t Pu per year for reloading

Construction of FR stagnated due to the delay of first 4t Pu supply

No significant impact on the operation of the firest FR

/tPu	2012	2020	2025
A: more-rep.	0.43	3.91	7.38
B: less-rep.	0.35	3.12	5.21

Discussion: impact on repository

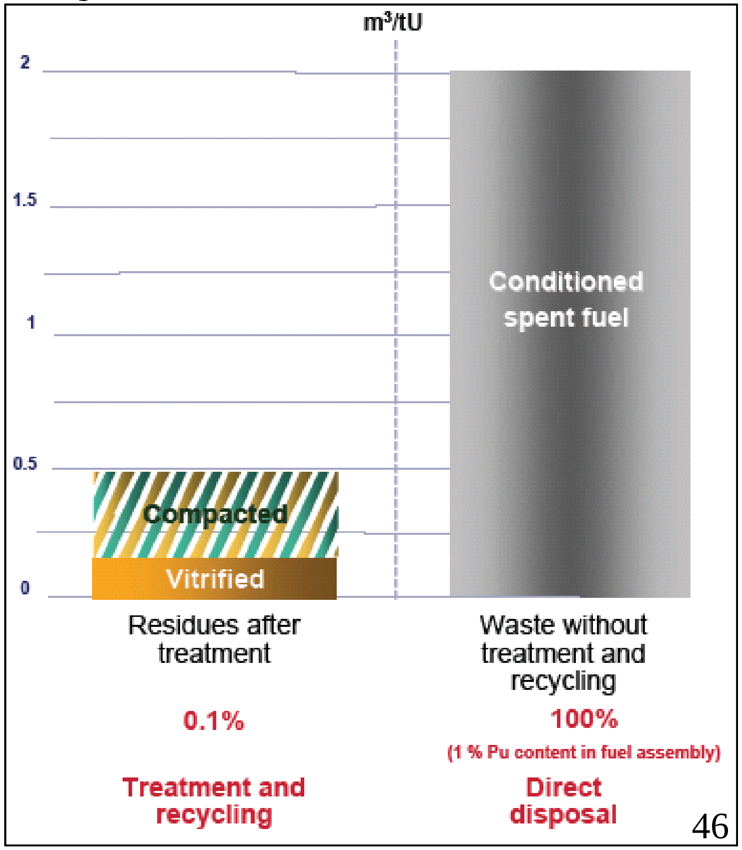
Volume reduction by SF reprocessing

- without reprocessing: 2m^3 / tHM SF to repository
- after reprocessing, waste to repository: 0.5m^3 / tHM SF

But, more repository spaces needed for vitrified waste than directly disposed SF

- higher density of ^{90}Sr and ^{137}Cs
- thermal output increased

From literature, reprocessing helps to expand the benefit of repository



Patrice Bernard, 2006

Discussion: impact on repository

Yucca Mountain Repository

- **capacity: 70,000 tHM SF**
- **as reference repository**

Stock of SF in 2035

- ~55,000 tHM without reprocessing
- >32,000 tHM with maximum reprocessing
- reprocessing seems to have little impact on the requirement for first repository in this time scale
- no urgent requirement for geological repository untill 2050

Part 4: conclusion

1. Nuclear energy in China
2. Experience and plans of SF management
3. Scenario analysis of SF management

4. Conclusion

China is a unique country with....

large population and responsibility

rapid grow economic strength and environmental crisis

Nuclear is an inevitable choice to solve the hunger for secured energy supply

China is a nuclear country with....

small installed nuclear capacity

huge potential and ambitious plan

limited experience in SF management

unclear or undetermined roadmap

Nuclear strategy needs to be discussed openly

Thank you

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