



清华大学 核能与新能源技术研究院

Institute of Nuclear & New Energy Technology, Tsinghua University

Partitioning of High Level Liquid Waste

Jing CHEN

Global 2011, Dec. 11-16, 2011



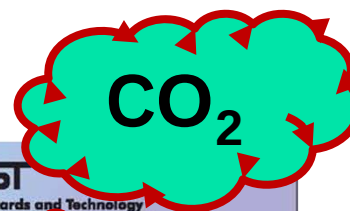


Contents

- **Practical objective**
- **Overview of partitioning in China**



Energy - two devils



PERIODIC TABLE
Atomic Properties of the Elements

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Frequently used fundamental physical constants
For the most accurate values of these and other constants, visit physics.nist.gov/constants
1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s ⁻¹ (exact)
Planck constant	h	6.6261 × 10 ⁻³⁴ J s (exact) ($h = h/2\pi$)
elementary charge	e	1.6022 × 10 ⁻¹⁹ C
electron mass	m_e	9.1094 × 10 ⁻³¹ kg
proton mass	m_p	1.6726 × 10 ⁻²⁷ kg
fine-structure constant	α	1/137.036
Rydberg constant	R_∞	10 973 732 m ⁻¹
	$R_\infty hc$	3.289 842 × 10 ¹⁵ Hz
Boltzmann constant	k	1.3807 × 10 ⁻²³ J K ⁻¹

Standard Reference Data Group
www.nist.gov/srd

Physics Laboratory
physics.nist.gov

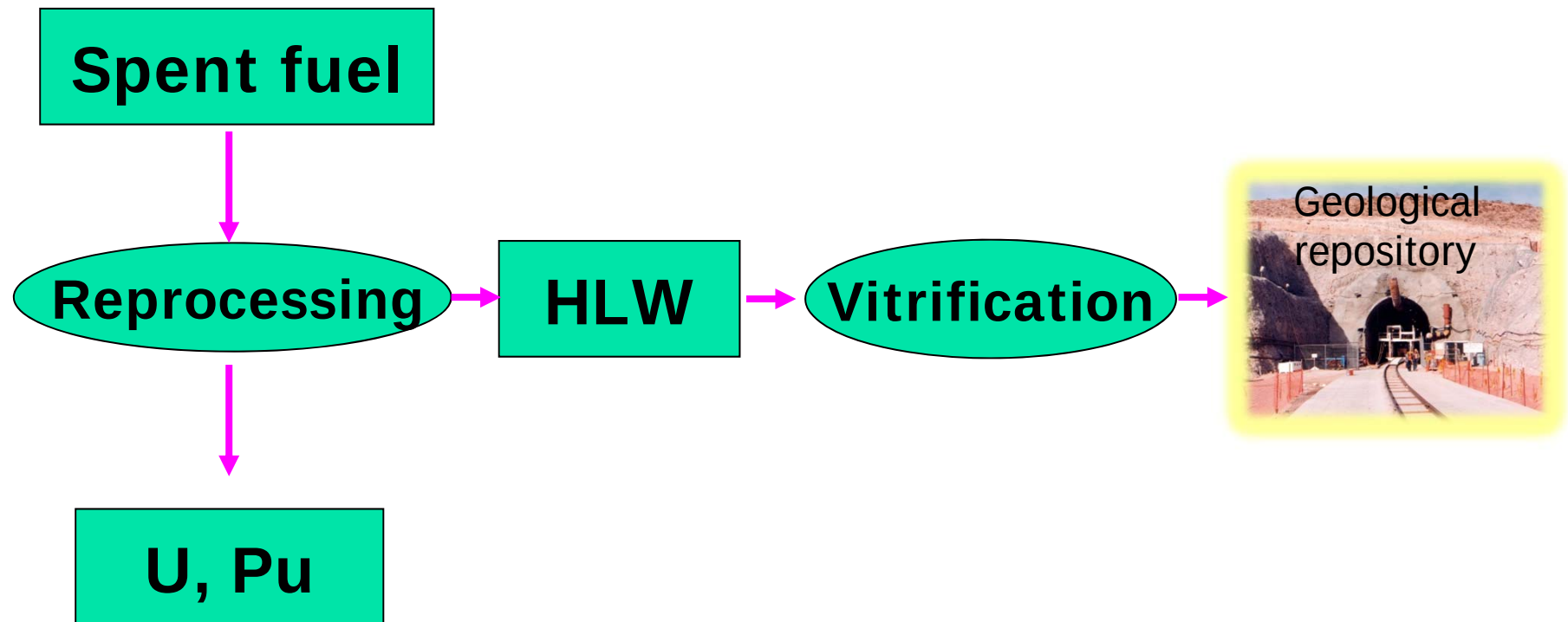
Legend:
Solids (white)
Liquids (blue)
Gases (pink)
Artificially Prepared (yellow)

Group 1 IA	2 IIA											13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA																																																																				
1 ¹ H Hydrogen 1.00794 1s 13.5984	4 ⁴ Be Beryllium 9.012182 1s ² 2s ² 9.3227	3 ³ Li Lithium 6.941 1s ² 2s 5.3917	21 ²¹ Sc Scandium 44.955910 [Ar]3d ¹ 4s ² 6.5615	22 ²² Ti Titanium 47.867 [Ar]3d ² 4s ² 6.8281	23 ²³ V Vanadium 50.9415 [Ar]3d ³ 4s ² 6.7462	24 ²⁴ Cr Chromium 51.9961 [Ar]3d ⁵ 4s ¹ 6.7665	25 ²⁵ Mn Manganese 54.938049 [Ar]3d ⁵ 4s ² 7.4340	26 ²⁶ Fe Iron 55.845 [Ar]3d ⁶ 4s ² 7.9024	27 ²⁷ Co Cobalt 58.933200 [Ar]3d ⁷ 4s ² 7.8810	28 ²⁸ Ni Nickel 58.6934 [Ar]3d ⁸ 4s ² 7.6398	29 ²⁹ Cu Copper 63.546 [Ar]3d ¹⁰ 4s ¹ 9.3942	30 ³⁰ Zn Zinc 65.409 [Ar]3d ¹⁰ 4s ² 9.3942	31 ³¹ Ga Gallium 69.723 [Ar]3d ¹⁰ 4s ² 4p ¹ 5.9993	32 ³² Ge Germanium 72.64 [Ar]3d ¹⁰ 4s ² 4p ² 7.8994	33 ³³ As Arsenic 74.92160 [Ar]3d ¹⁰ 4s ² 4p ³ 9.7886	34 ³⁴ Se Selenium 78.96 [Ar]3d ¹⁰ 4s ² 4p ⁴ 9.7524	35 ³⁵ Br Bromine 79.904 [Ar]3d ¹⁰ 4s ² 4p ⁵ 11.8138	36 ³⁶ Kr Krypton 83.798 [Ar]3d ¹⁰ 4s ² 4p ⁶ 13.9996	37 ³⁷ Rb Rubidium 85.4678 [Kr]5s ¹ 4.1771	38 ³⁸ Sr Strontium 87.62 [Kr]5s ² 5.6949	39 ³⁹ Y Yttrium 88.90585 [Kr]4d ¹ 5s ² 6.2173	40 ⁴⁰ Zr Zirconium 91.224 [Kr]4d ² 5s ² 6.6339	41 ⁴¹ Nb Niobium 92.90638 [Kr]4d ⁴ 5s ¹ 6.7589	42 ⁴² Mo Molybdenum 95.94 [Kr]4d ⁵ 5s ¹ 7.0924	43 ⁴³ Tc Technetium 98 [Kr]4d ⁵ 5s ² 7.28	44 ⁴⁴ Ru Ruthenium 101.07 [Kr]4d ⁷ 5s ¹ 7.3605	45 ⁴⁵ Rh Rhodium 102.90550 [Kr]4d ⁸ 5s ¹ 7.4589	46 ⁴⁶ Pd Palladium 106.42 [Kr]4d ¹⁰ 8.3369	47 ⁴⁷ Ag Silver 107.8682 [Kr]4d ¹⁰ 5s ¹ 7.5762	48 ⁴⁸ Cd Cadmium 112.411 [Kr]4d ¹⁰ 5s ² 8.9938	49 ⁴⁹ In Indium 114.818 [Kr]4d ¹⁰ 5s ² 5p ¹ 5.7894	50 ⁵⁰ Sn Tin 118.710 [Kr]4d ¹⁰ 5s ² 5p ² 7.3439	51 ⁵¹ Sb Antimony 121.760 [Kr]4d ¹⁰ 5s ² 5p ³ 8.6084	52 ⁵² Te Tellurium 127.60 [Kr]4d ¹⁰ 5s ² 5p ⁴ 9.0096	53 ⁵³ I Iodine 126.90447 [Kr]4d ¹⁰ 5s ² 5p ⁵ 10.4513	54 ⁵⁴ Xe Xenon 131.293 [Kr]4d ¹⁰ 5s ² 5p ⁶ 12.1298	55 ⁵⁵ Cs Cesium 132.90545 [Xe]6s ¹ 3.8939	56 ⁵⁶ Ba Barium 137.327 [Xe]6s ² 5.2117	57 ⁵⁷ La Lanthanum 138.9055 [Xe]4f ¹ 5d ¹ 6s ² 5.5769	58 ⁵⁸ Ce Cerium 140.116 [Xe]4f ¹ 5d ¹ 6s ² 5.5387	59 ⁵⁹ Pr Praseodymium 140.90765 [Xe]4f ³ 6s ² 5.4753	60 ⁶⁰ Nd Neodymium 144.24 [Xe]4f ⁴ 6s ² 5.5250	61 ⁶¹ Pm Promethium 145 [Xe]4f ⁵ 6s ² 5.582	62 ⁶² Sm Samarium 150.36 [Xe]4f ⁶ 6s ² 5.6437	63 ⁶³ Eu Europium 151.964 [Xe]4f ⁷ 6s ² 5.6704	64 ⁶⁴ Gd Gadolinium 157.25 [Xe]4f ⁷ 5d ¹ 6s ² 5.8638	65 ⁶⁵ Tb Terbium 158.92534 [Xe]4f ⁹ 6s ² 5.9389	66 ⁶⁶ Dy Dysprosium 162.500 [Xe]4f ¹⁰ 6s ² 6.0215	67 ⁶⁷ Ho Holmium 164.93032 [Xe]4f ¹¹ 6s ² 6.1077	68 ⁶⁸ Er Erbium 167.259 [Xe]4f ¹² 6s ² 6.1843	69 ⁶⁹ Tm Thulium 168.93421 [Xe]4f ¹³ 6s ² 6.2542	70 ⁷⁰ Yb Ytterbium 173.04 [Xe]4f ¹⁴ 6s ² 6.65	71 ⁷¹ Lu Lutetium 174.967 [Xe]4f ¹⁴ 5d ¹ 6s ² 6.97	72 ⁷² Hf Hafnium 178.49 [Xe]4f ¹⁴ 5d ² 6s ² 6.8251	73 ⁷³ Ta Tantalum 180.9479 [Xe]4f ¹⁴ 5d ³ 6s ² 7.5496	74 ⁷⁴ W Tungsten 183.84 [Xe]4f ¹⁴ 5d ⁴ 6s ² 7.8640	75 ⁷⁵ Re Rhenium 186.207 [Xe]4f ¹⁴ 5d ⁵ 6s ² 7.8335	76 ⁷⁶ Os Osmium 190.23 [Xe]4f ¹⁴ 5d ⁶ 6s ² 8.44	77 ⁷⁷ Ir Iridium 192.222 [Xe]4f ¹⁴ 5d ⁷ 6s ² 8.9	78 ⁷⁸ Pt Platinum 195.084 [Xe]4f ¹⁴ 5d ⁹ 6s ¹ 9.0	79 ⁷⁹ Au Gold 196.96657 [Xe]4f ¹⁴ 5d ¹⁰ 6s ¹ 9.1636	80 ⁸⁰ Hg Mercury 200.59 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 9.4	81 ⁸¹ Tl Thallium 204.38 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ¹ 9.5	82 ⁸² Pb Lead 207.2 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ² 9.6	83 ⁸³ Bi Bismuth 208.9804 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ³ 9.7	84 ⁸⁴ Po Polonium 209 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁴ 9.8	85 ⁸⁵ At Astatine 210 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁵ 9.9	86 ⁸⁶ Rn Radon 222 [Xe]4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁶ 10.7485	87 ⁸⁷ Fr Francium 223 [Rn]7s ¹ 4.0727	88 ⁸⁸ Ra Radium 226 [Rn]7s ² 5.2784	89 ⁸⁹ Ac Actinium 227 [Rn]5f ¹ 6d ¹ 7s ² 5.17	90 ⁹⁰ Th Thorium 232.0381 [Rn]5f ² 6d ² 7s ² 6.3067	91 ⁹¹ Pa Protactinium 231.03688 [Rn]5f ³ 6d ¹ 7s ² 5.89	92 ⁹² U Uranium 238.02891 [Rn]5f ³ 6d ¹ 7s ² 6.1941	93 ⁹³ Np Neptunium 237 [Rn]5f ⁴ 6d ¹ 7s ² 6.2657	94 ⁹⁴ Pu Plutonium 244 [Rn]5f ⁶ 7s ² 6.0260	95 ⁹⁵ Am Americium 243 [Rn]5f ⁷ 7s ² 5.9738	96 ⁹⁶ Cm Curium 247 [Rn]5f ⁸ 7s ² 5.9914	97 ⁹⁷ Bk Berkelium 247 [Rn]5f ⁹ 7s ² 6.1979	98 ⁹⁸ Cf Californium 251 [Rn]5f ¹⁰ 7s ² 6.2817	99 ⁹⁹ Es Einsteinium 252 [Rn]5f ¹¹ 7s ² 6.42	100 ¹⁰⁰ Fm Fermium 257 [Rn]5f ¹² 7s ² 6.50	101 ¹⁰¹ Md Mendelevium 258 [Rn]5f ¹³ 7s ² 6.58	102 ¹⁰² No Nobelium 259 [Rn]5f ¹⁴ 7s ² 6.65	103 ¹⁰³ Lr Lawrencium 262 [Rn]5f ¹⁴ 7s ² 7p ¹ 4.9?

Example Element Data (Cerium):
Atomic Number: 58
Ground-state Level: $^1\text{G}_4$
Symbol: Ce
Name: Cerium
Atomic Weight: 140.116
Ground-state Configuration: $[\text{Xe}]4f^15d^16s^2$
Ionization Energy (eV): 5.5387

¹Based upon ^{12}C . () indicates the mass number of the most stable isotope.
For a description of the data, visit physics.nist.gov/data
NIST SP 966 (September 2003)

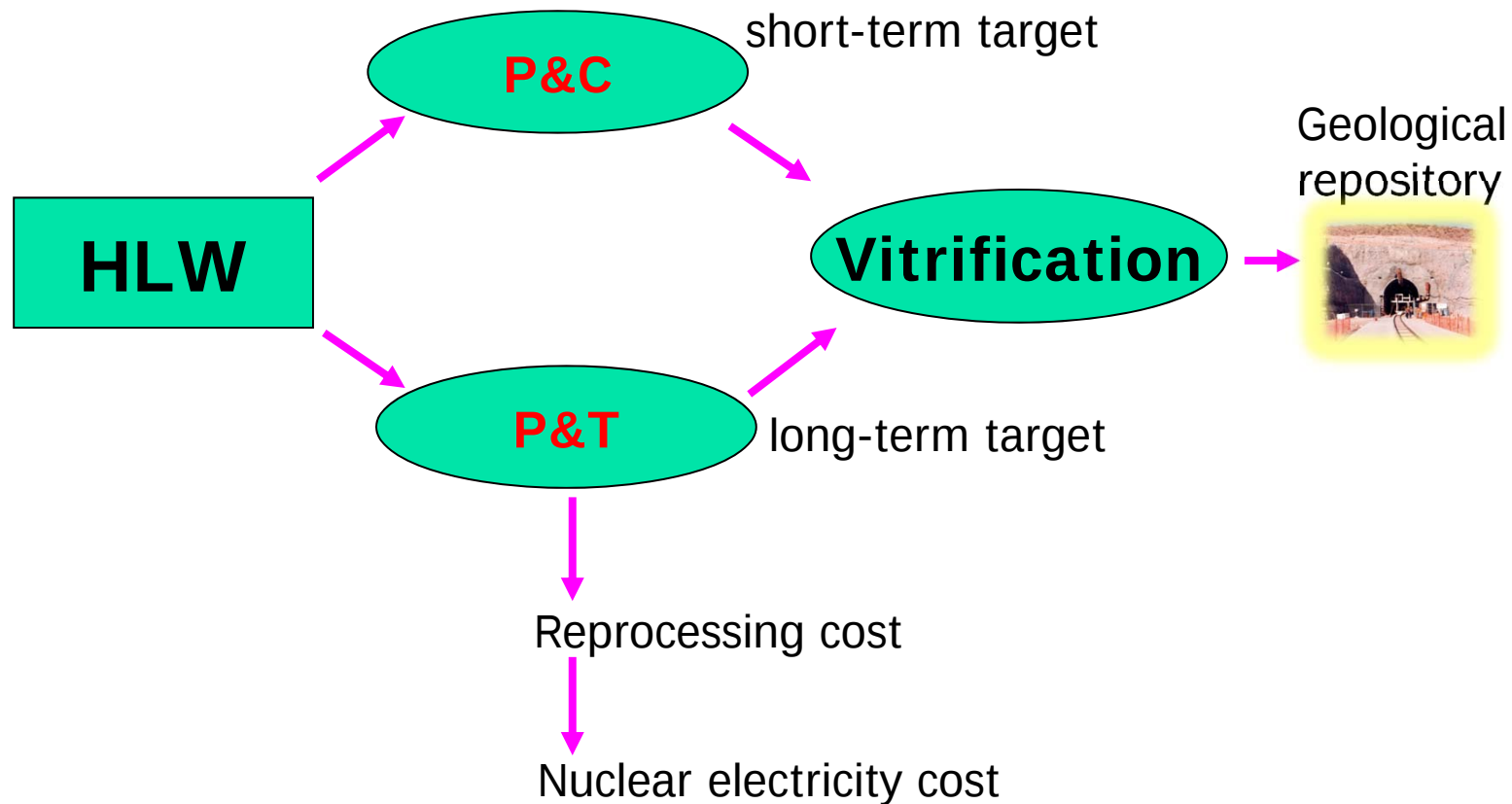
High level liquid waste



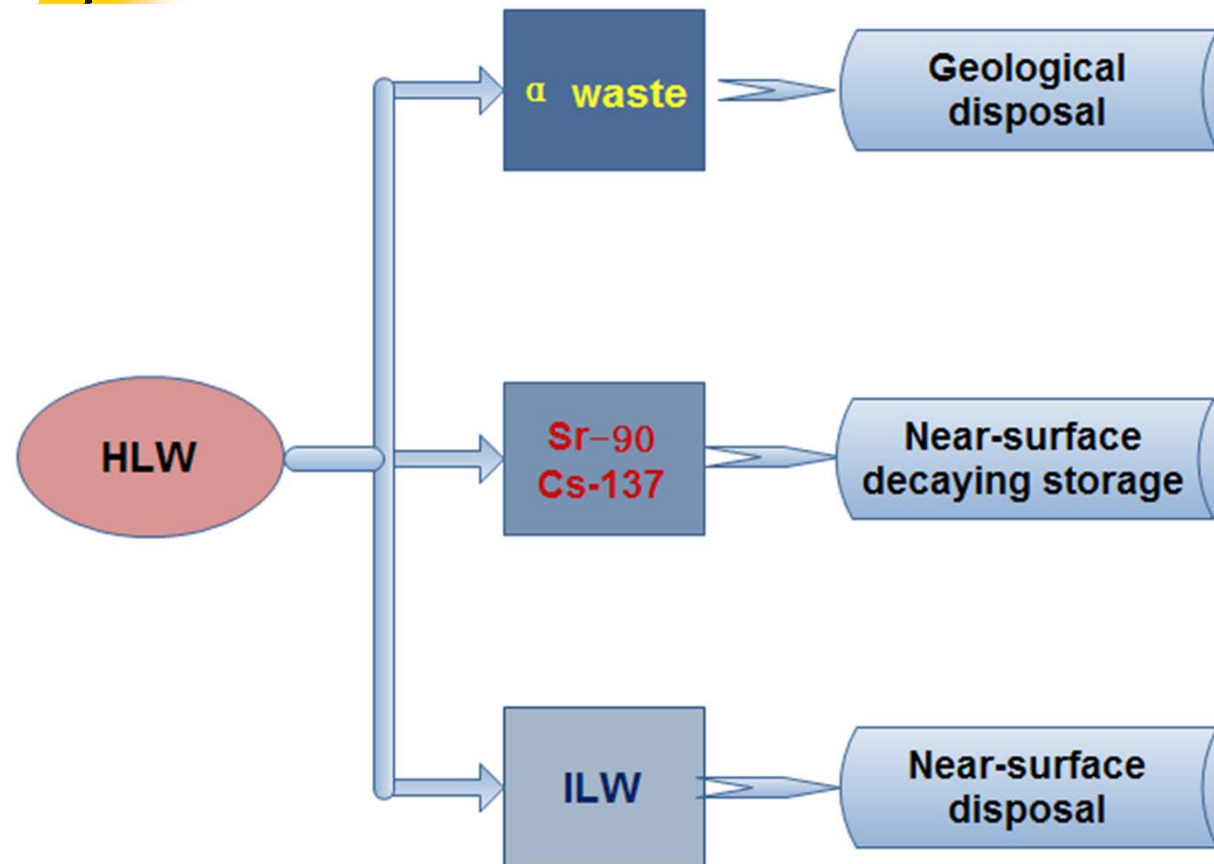
**Long-term risk ?
More repository ?**



HLW management strategy



HLW partitioning objective



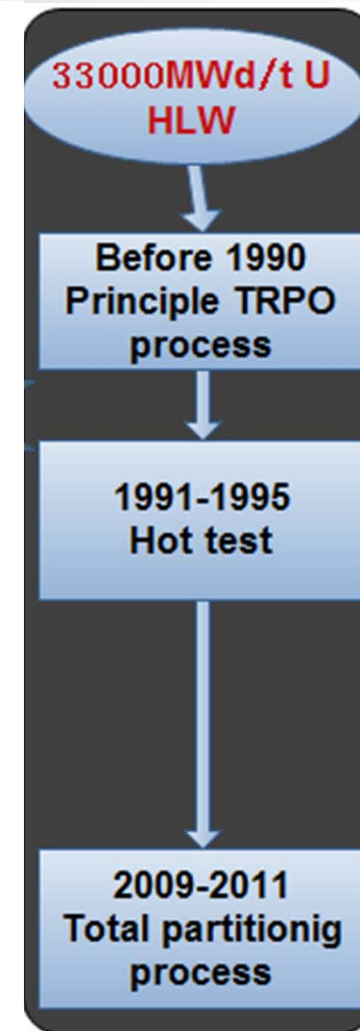
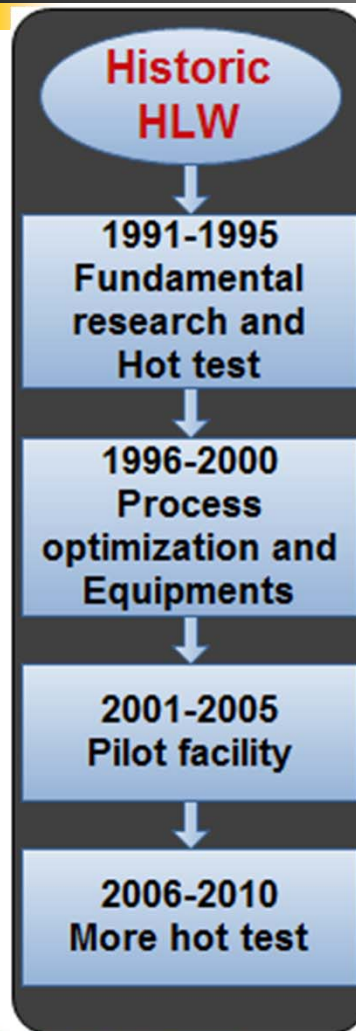


Partitioning objective in China

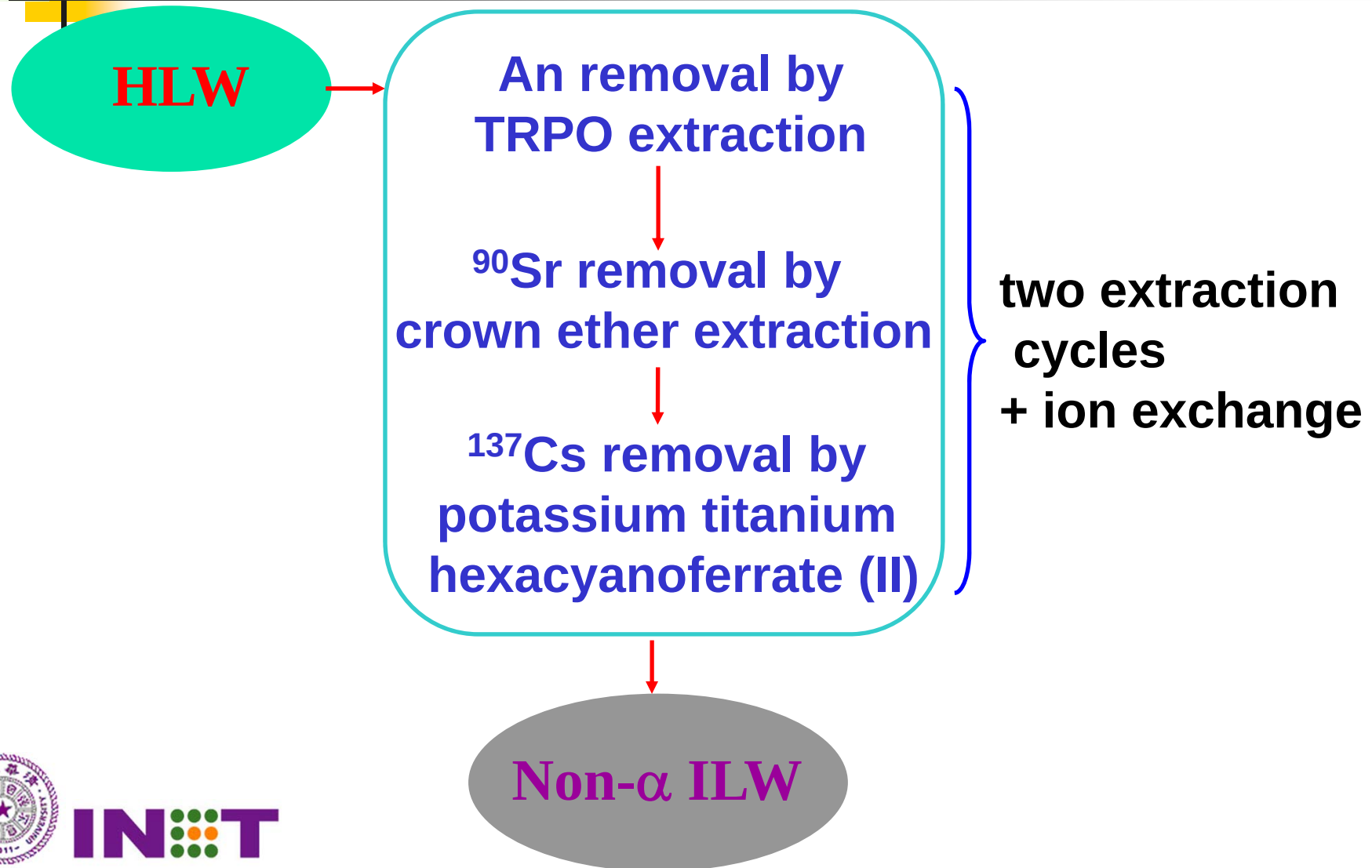
- **α decontamination factor**
 - **$>10^5$ for commercial HLW**
 - **>100 for historic HLW**
- **Sr-90 / Cs-137 decontamination factor**
 - **>1000 for commercial HLW**
 - **>50 for historic HLW**



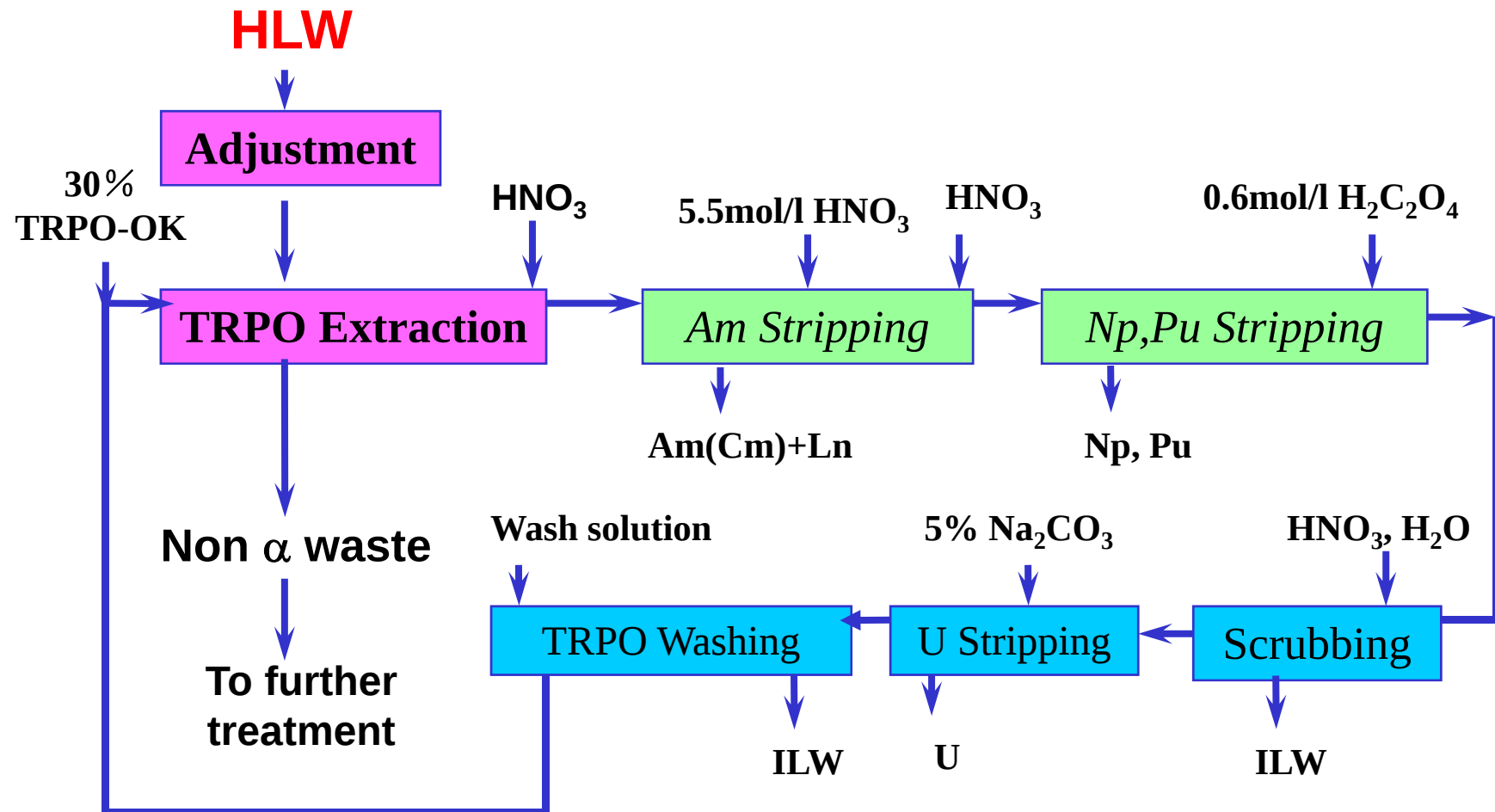
Overview of partitioning



Partitioning process by Tsinghua

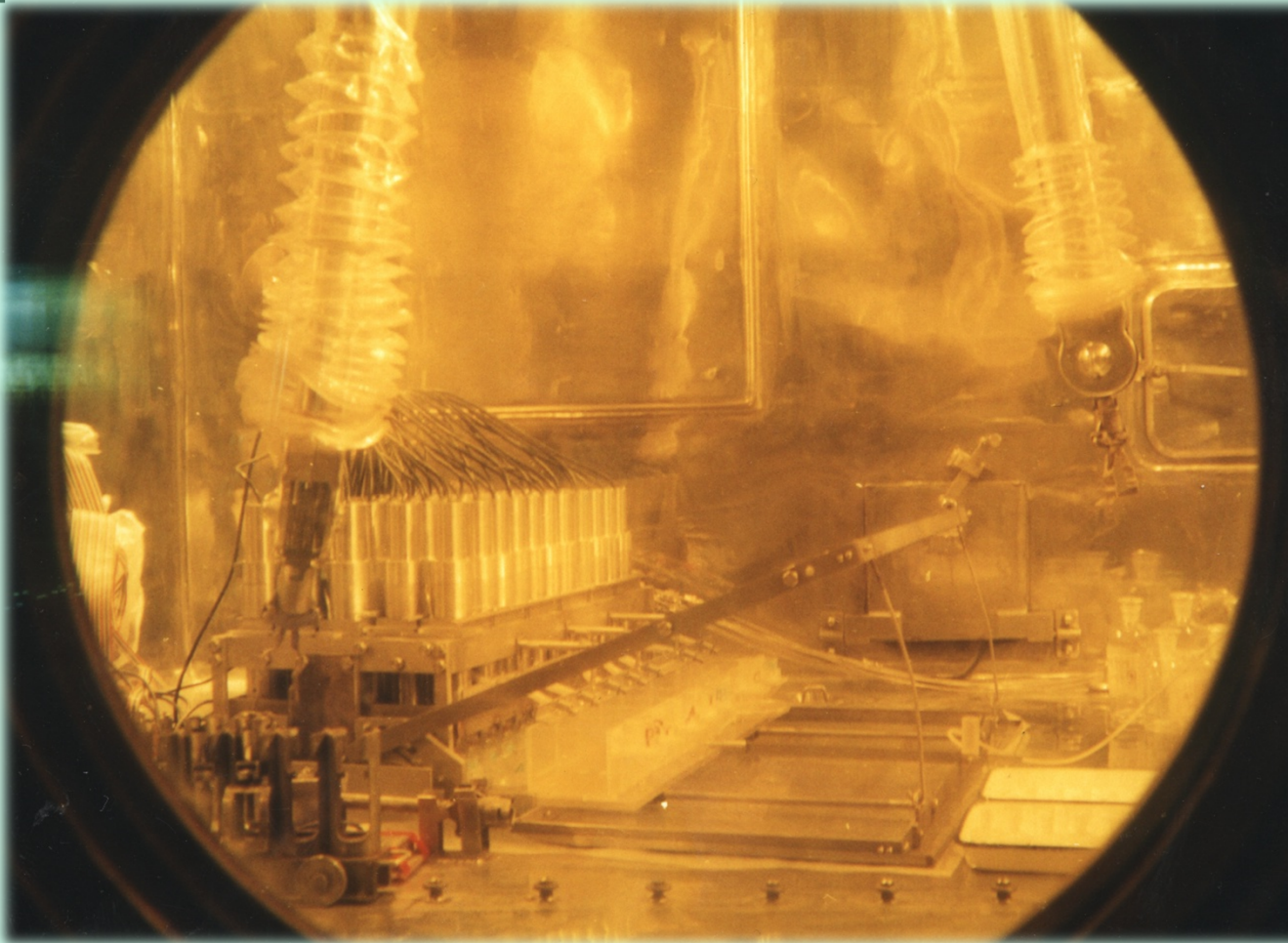


The flow-sheet of the TRPO process



TRPO: trialkylphosphine oxide

Hot test at Tsinghua University (1996)



**50-stage
miniature
centrifugal
contactors**

**Chinese
HLW**



IN:T

Partitioning results for historic HLW

Nuclide	Total α	^{241}Am	^{239}Pu	^{237}Np	U	^{90}Sr	^{137}Cs
D. F.	588	666	695	15.2	10^4	>2500	>200



The pilot test facility (2005)



INOT

>80 hours continuous operation



Exchange column



Pulsed column



Centrifugal contactors



Results of pilot test

Nuclide	D.F.
U	> 3000
Nd (Am)	> 500
Zr (Pu)	> 1000
Sr	~ 160
Cs	~ 100



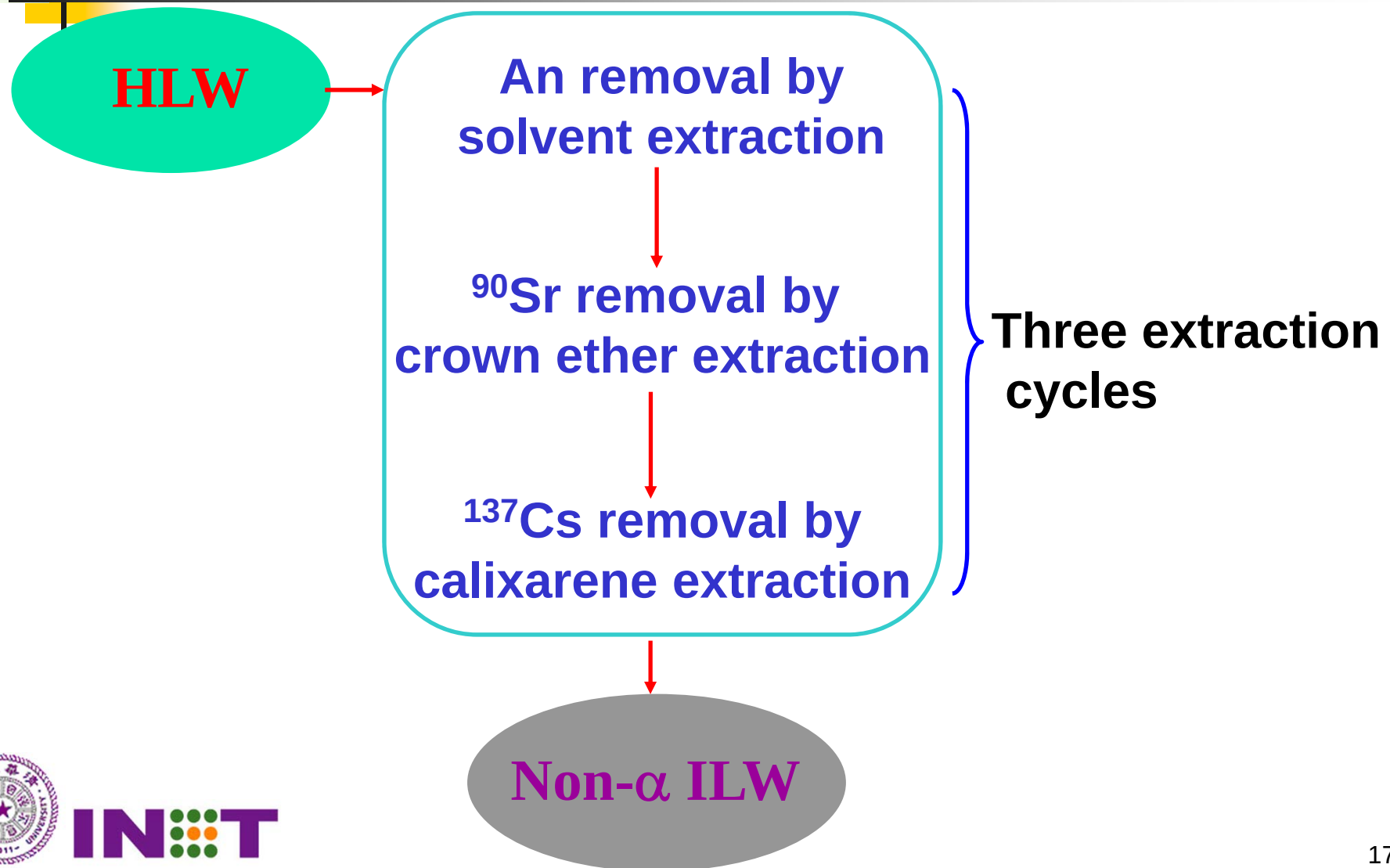


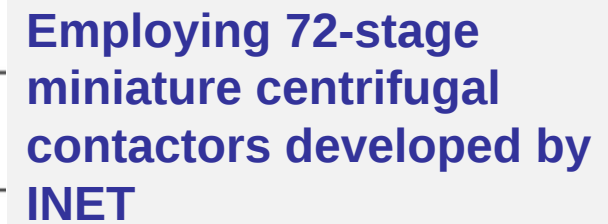
Problem in Cs removal

- It is difficult to control the operation of ion exchange under high radioactive circumstance compared with solvent extraction.
- It is difficult to treat the spent ion exchanger. For example, cyanogen release.

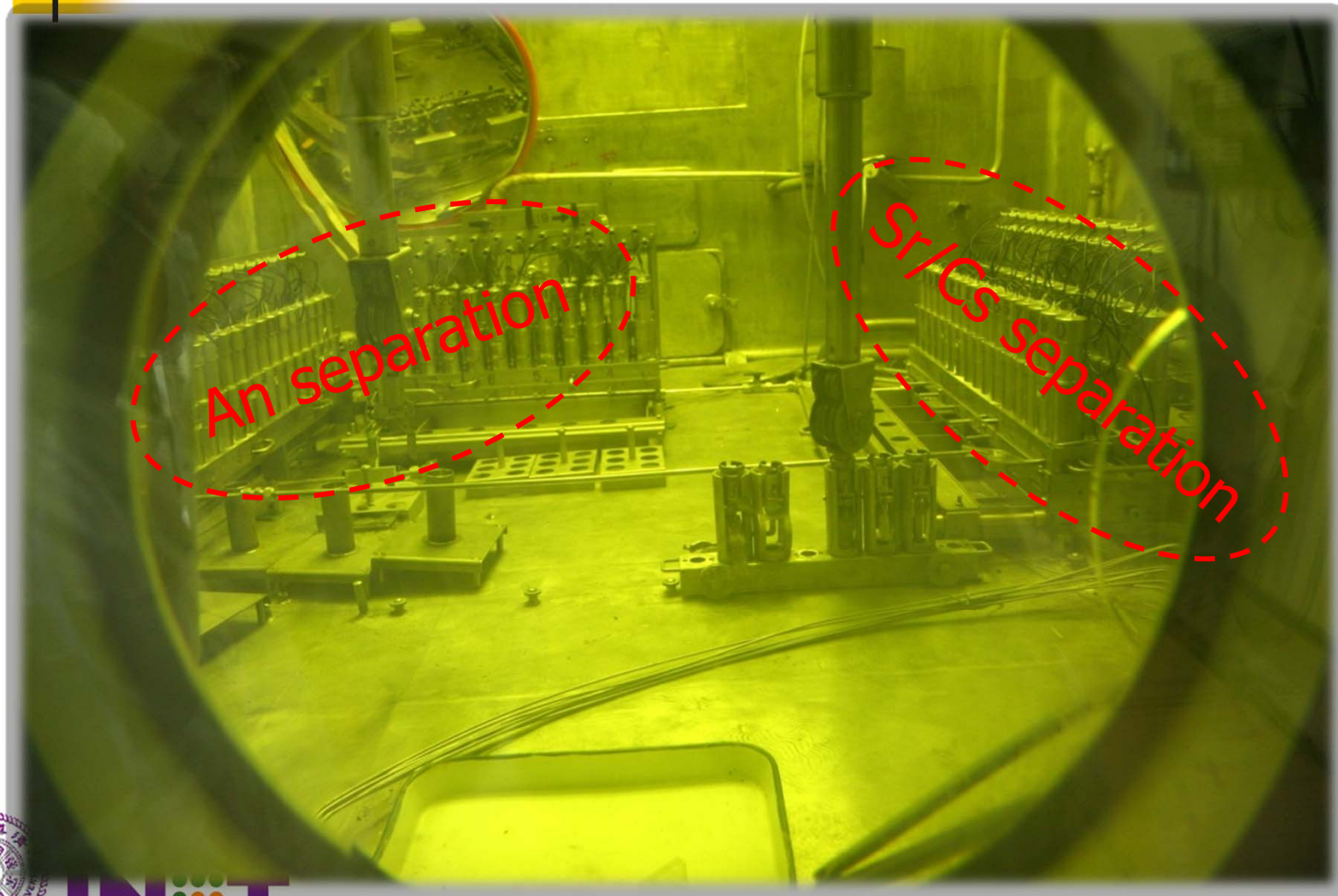


Modified partitioning process



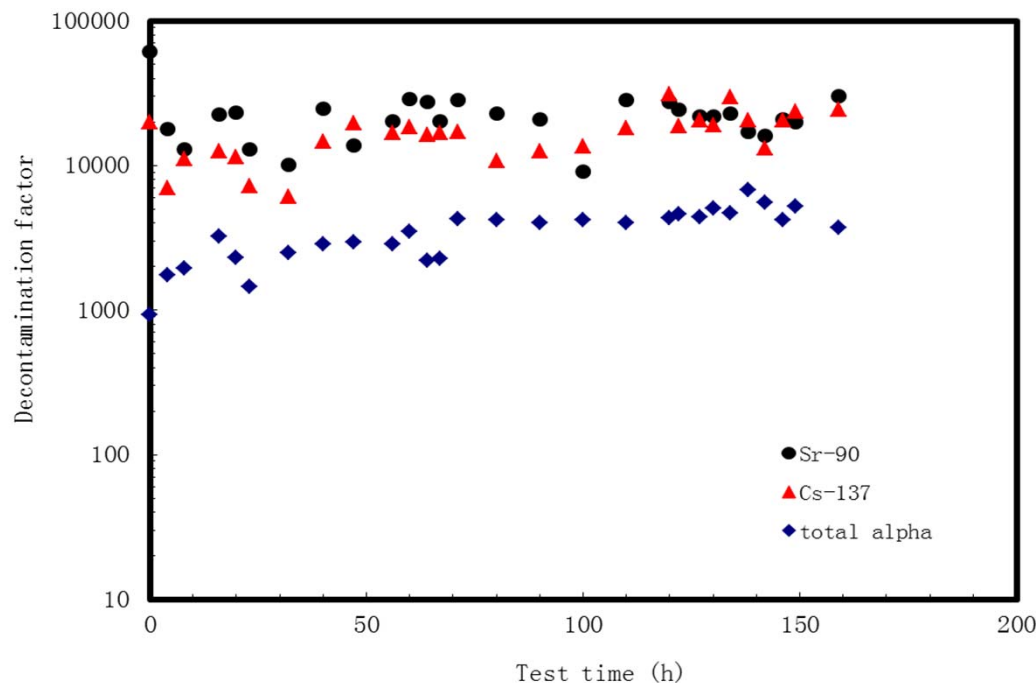


Facility in hot cell



Hot test for modified process

- ~200 hours continuous operation, partitioning ~300Ci HLW
- Average decontamination factors (DF) are **>3000** for An, and **>10000** for Sr-90 and Cs-137.



Enough to change
historic HLW into non- α ILW



Future of partitioning

- Reliability
- Safety
- Cost-effectiveness



Demonstration pilot facility



Thank you !