Technical Meeting on the Management of Spent Fuel (Pebbles and Compacts) from High Temperature Reactors(EVT2404558)

Spent fuel management in HTR-PM

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Outline

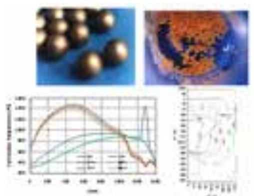
- *1. Introduction of HTR-PM*
- *2. Features of HTGR spent fuel*
- *3. Spent fuel management in HTR-PM*
- *4. Final management of spent fuel*
- *5. Standards for spent fuel management*

1. Introduction of HTR-PM

- *HTGR in China*
- *Main features of HTR-PM*

HTR development in China

- *China chooses pebble bed HTR*
- *Research was started in 1970s*
- *Benefited from international cooperation*



Fundamental R&D

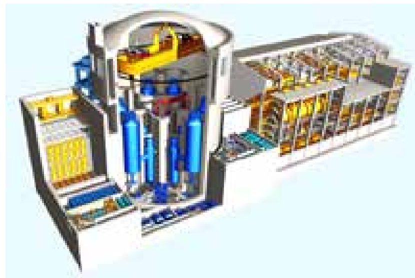
1970s

Test reactor

1986-, HTR-10

Demonstration plant

2001-, HTR-PM



Commercial plant

2014~, HTR-PM600

Mission of HTGR in China

- Supplement to PWRs
  - for power generation, especially to replace coal-fired power plant in popular region
- Co-generation
  - of steam and electricity,
  - & Hydrogen production in future
- Technology Innovation
  - Supported as one of National Key Science and Technology Projects
  - Establishment of whole supply chain

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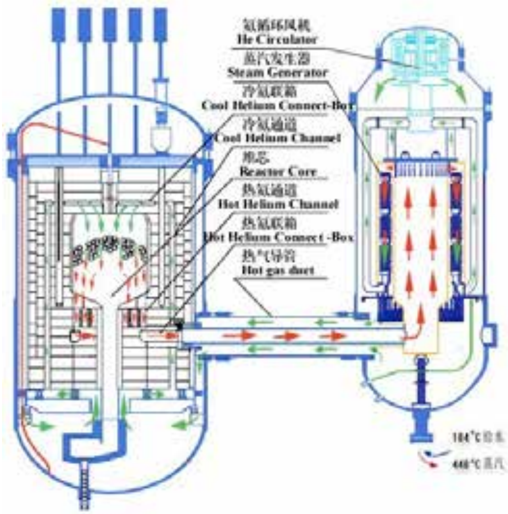
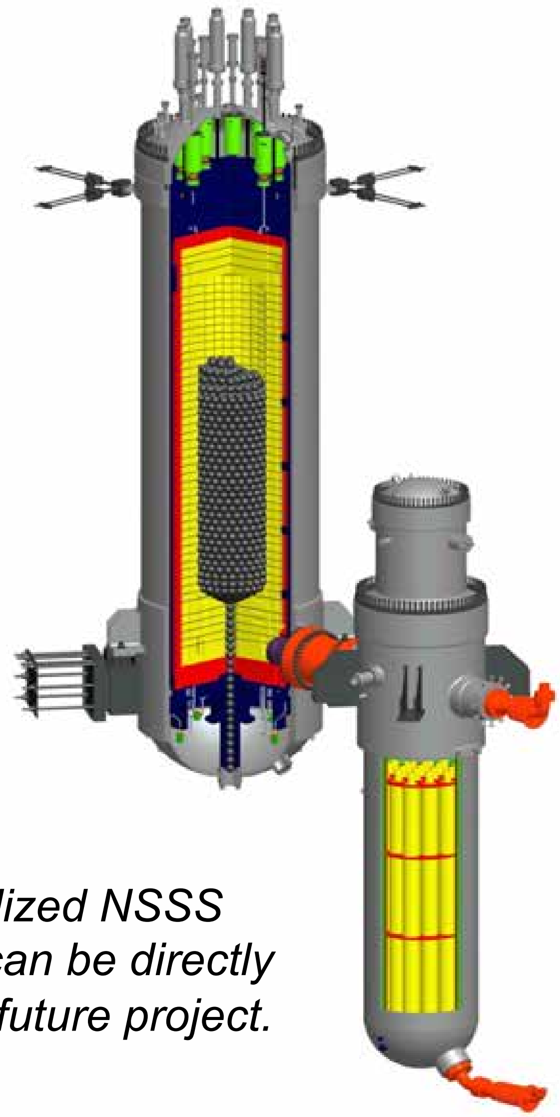
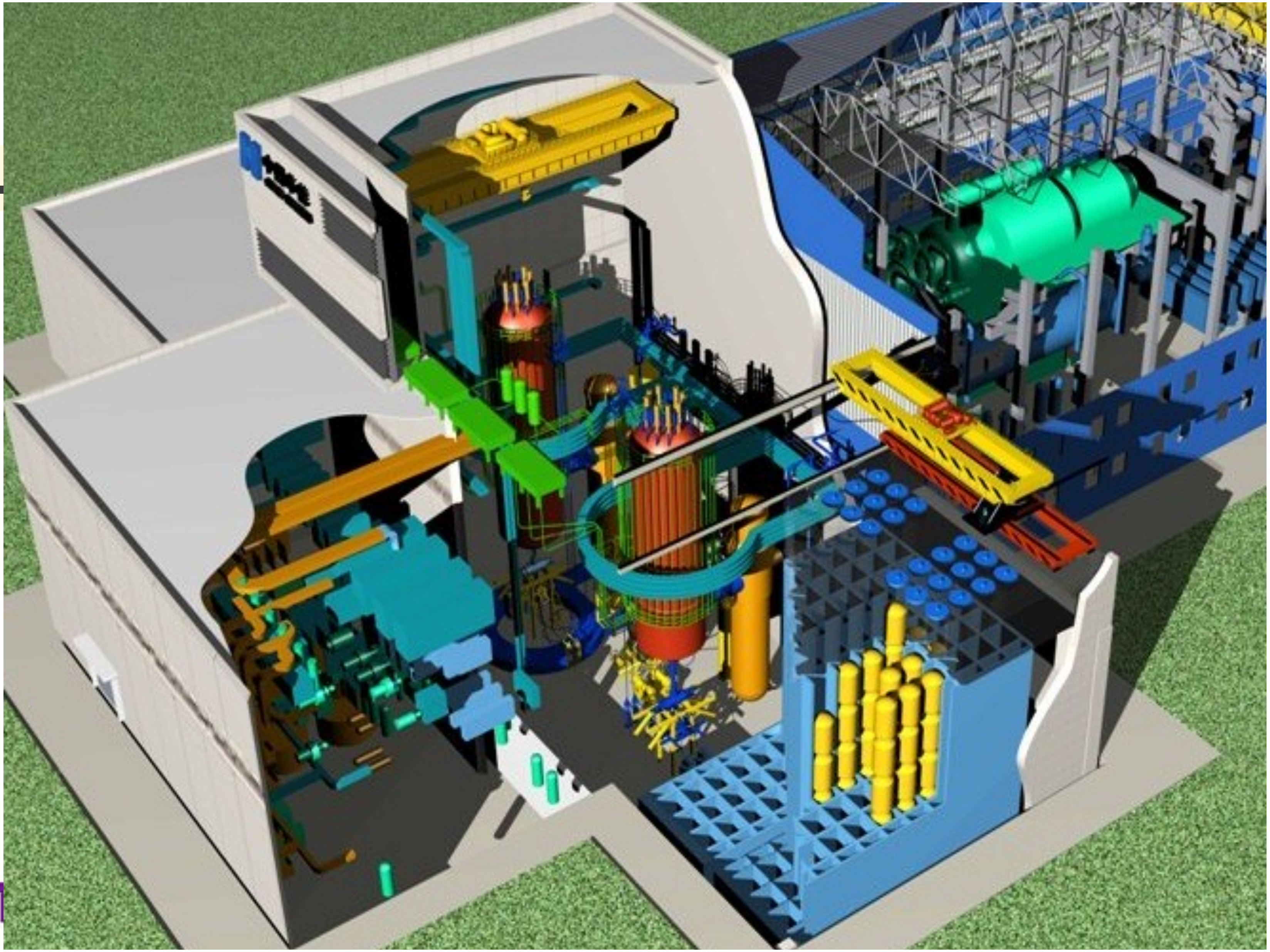
HTR-PM features

- *Technology based on HTR-10*
  - *Single zone core*
  - *Side by side arrangement of reactor & SG*
  - *Super heat steam*
  - *Modular desgin*



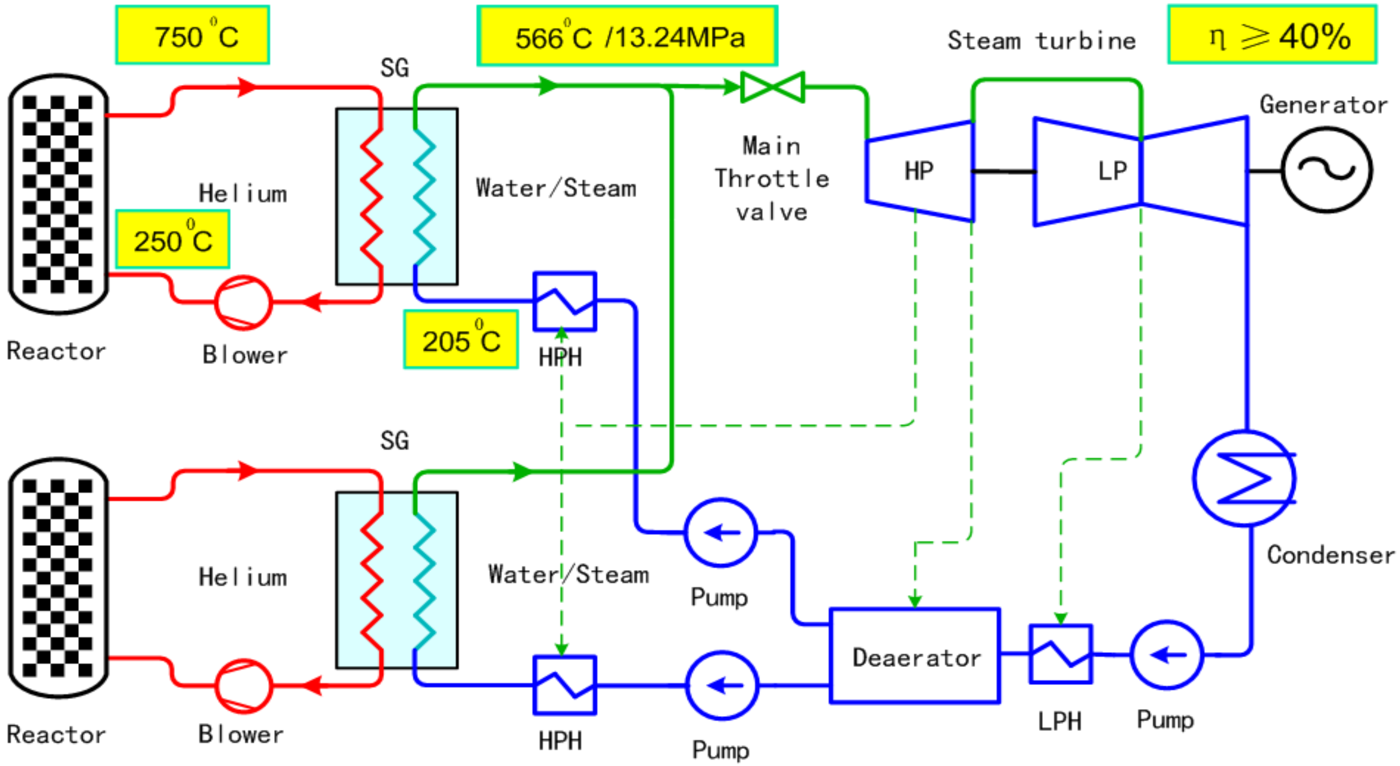
- *Standardized NSSS module can be directly used for future project.*





Multiple NSSS modules with 1 turbine

- 2 NSSS modules connected with 1 turbine in HTR-PM
  - 6 modules will be connected with 1 turbine in HTR-PM600

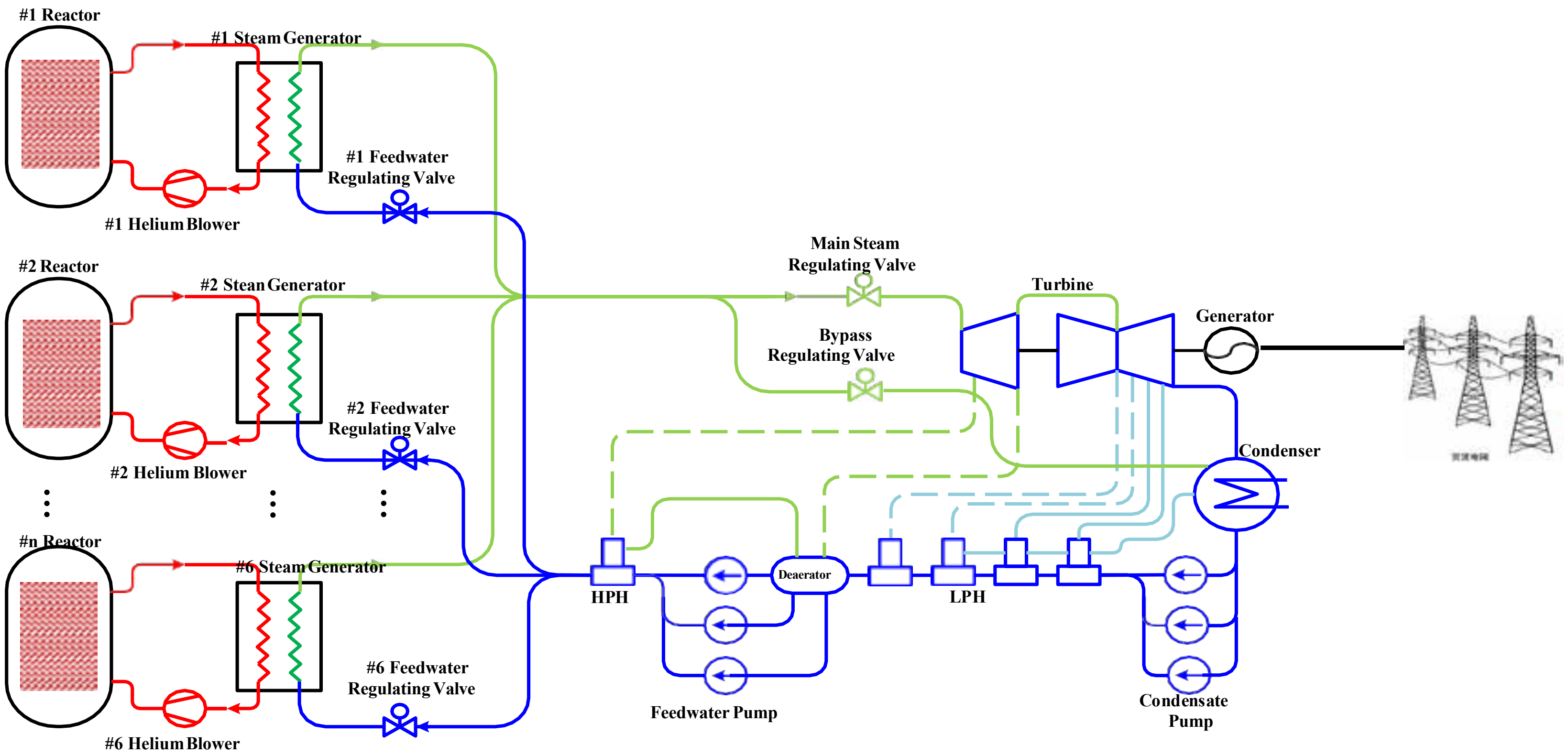


HTR-PM Main Parameters

Plant electrical power, MWe	211
Core thermal power, MW	250
Number of NSSS Modules	2
Core diameter, m	3
Core height, m	11
Primary helium pressure, MPa	7
Core outlet temperature, °C	750
Core inlet temperature, °C	250
Fuel enrichment, %	8.5
Steam pressure, MPa	13.9
Steam temperature, °C	541

Xuwei Project, HTR-PM600S + HPR1000, cogeneration of steam and electricity, for petro-chemical plant

Multiple NSSS modules with one turbine, also flexible with co-generation



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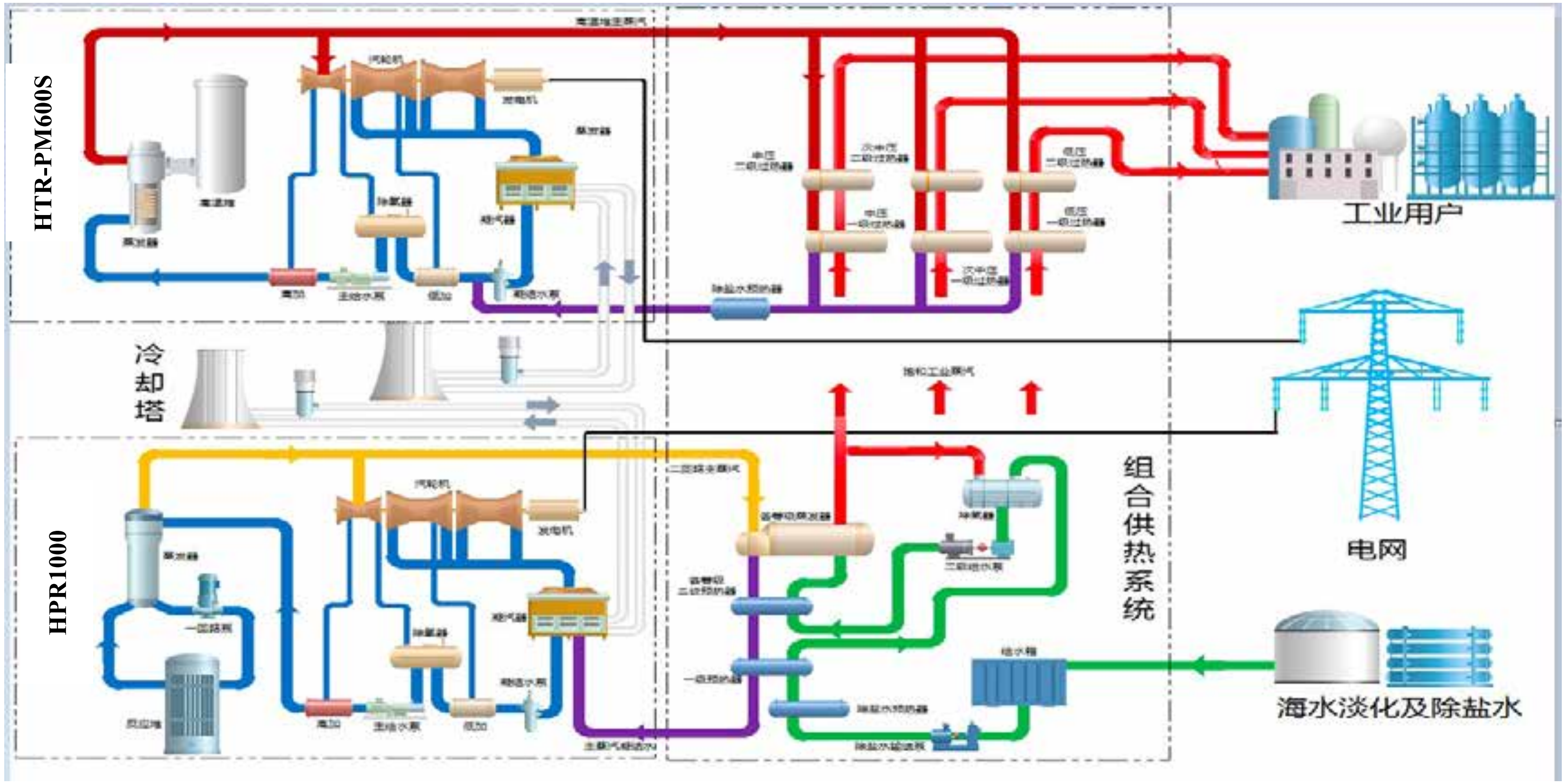
HTR-PM600S work with PWR to co-generate high temperature steam

Government approved in Aug. 19, 2024

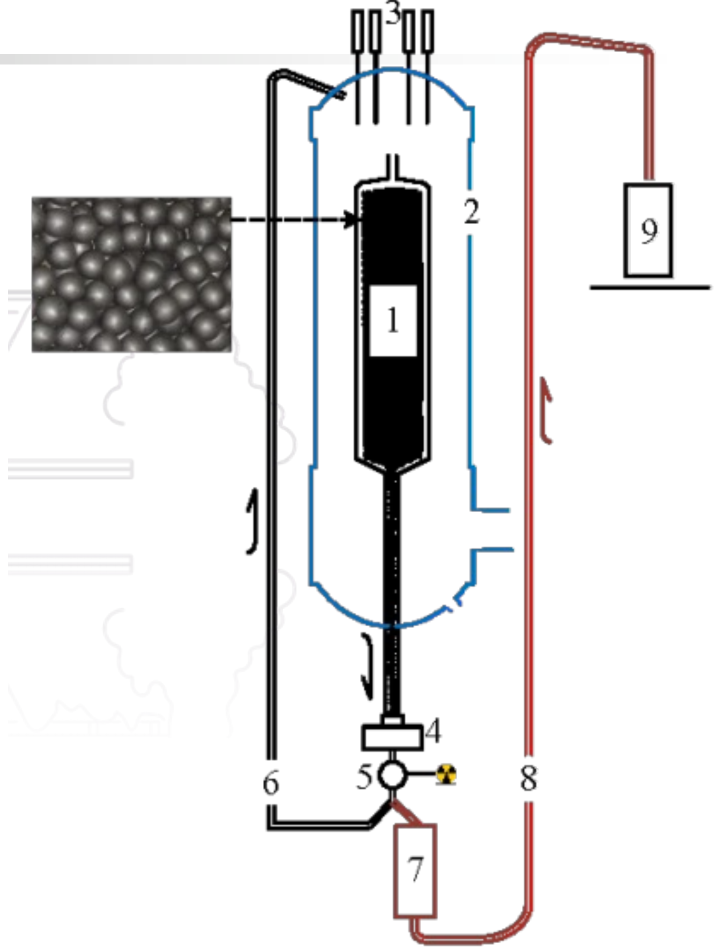


2. Features of HTR spent fuel

- *Numbers*
- *Neutronics*
- *Thermal hydraulics*
- *Mechanical*

Numbers for Pebble bed HTR

- *On-line fuel loading*
- *400 spent fuel/ day /module for HTR-PM*
- *Unified high burnup for spent fuel: ~90GW/tU, measured for each pebbles*



Neutronics

- *High burnup*
- *Relatively less fossil isotopes left*
- *Less power density (normal operation & decay heat)*
- *Large volume of graphite matrix:*
  - *7g HM+200g graphite matrix*
- *TRISO coated particle*
  - *Very robust*

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Heavy metals in HTR spent fuel

Mass of fissile material in reactor systems with different fuel cycles in equilibrium state

reactor system	HTR			LWR
designation	HEU	MEU	LEU	LEU
isotopic concentration	Th +93% U	Th +20% U	8.6% U	3.2 %U
Burnup MWd/kg	100	100	100	35.7
Inventory: kg/GWd_e				
Pa233	68.5	38.4	-	-
U233	470.8	218.3	-	-
U235	488.0	431.5	762.1	1380.9
Np239	0.2	2.5	5.8	0.1
Pu239	1.6	39.3	183.3	317.3
Pu241	0.8	17.4	76.7	51.9
U3+U5+Pu9+Pu1	921.2	706.5	1022.0	1750.1

Radioactive in spent fuel

- *Decay can solve many problems (for prismatic)*

Table 3.2. Quantities of radioactive nuclides in HTGR fuel

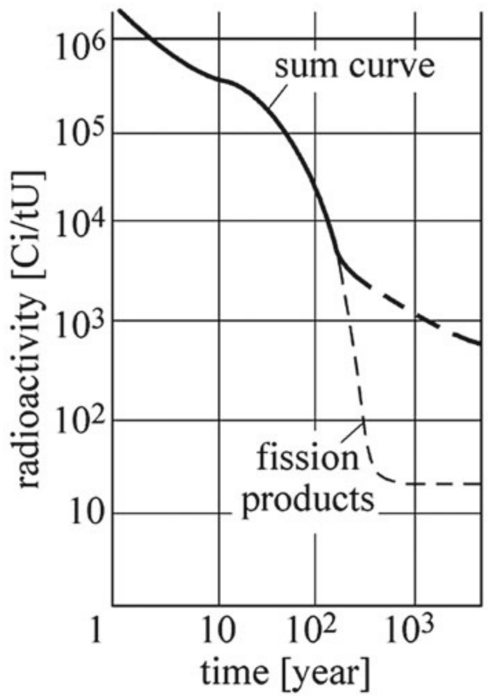
	Nuclide quantity (Ci/MTIHM)		
	10 years after discharge	100 years after discharge	1,000 years after discharge
Actinides (and daughters)	14,500	5,800	4,400
Fission products	967,000	111,000	3
Carbon-14	20	20	18
Tritium	80	<1	~0

ORNL/TM-12077, Options for Treating High-Temperature Gas-Cooled Reactor Fuel for Repository Disposal. 1992

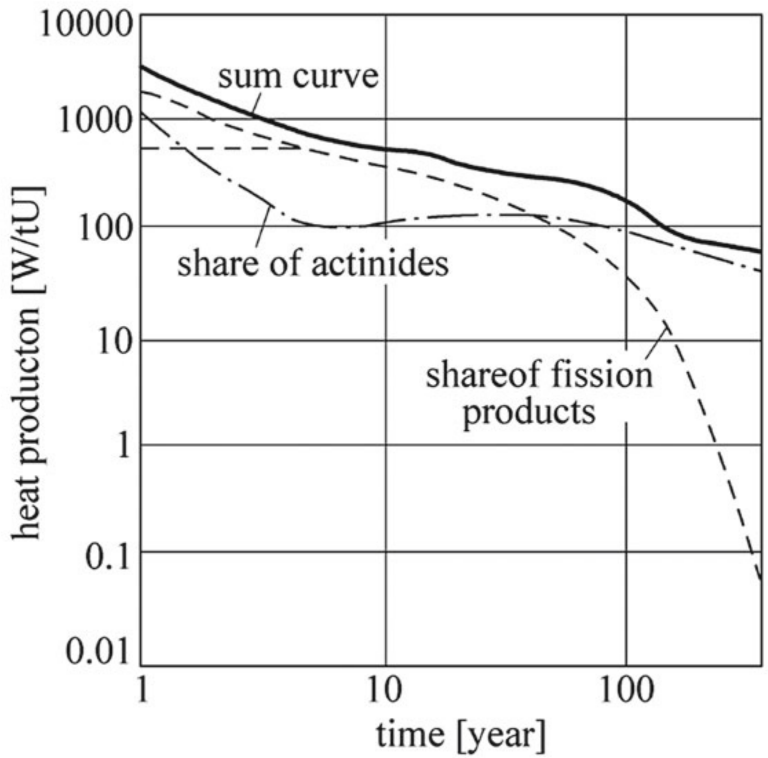
Thermal hydraulics

- *Good thermal conductivity, because of graphite matrix*
- *High temperature performance, because of full ceramic*
- *Less power density (decay heat)*

Decay heat for spent fuel



activity of spent fuel (related to 1t of uranium)



decay heat (related to 1t uranium)

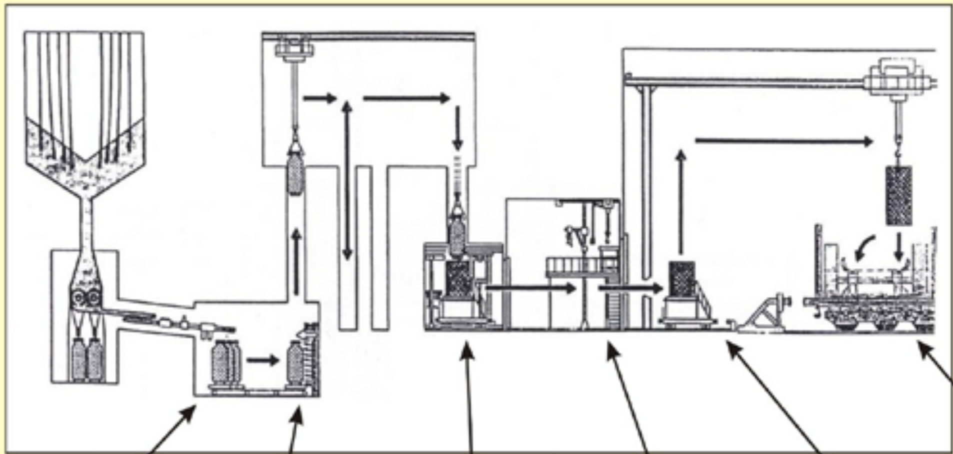
Mechanical

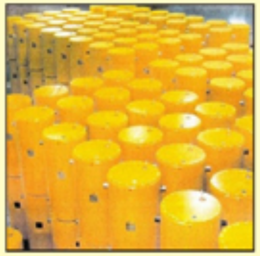
- *High strength, because of graphite matrix*
- *Somewhat fragile, because of graphite matrix*
- *Pebbles*

3. Spent fuel management in HTR-PM

- *Life cycle consideration*
  - *Manufacturing, irradiation, intermediate storage, interim storage, final treatment*
  - *Strategy: Intermediate storage in site, then transfer to national disposal facility*
  - *Optimized in the context of national policy for spent fuel:*
    - *Reprocessing of spent fuel, for LWR & SFR*
    - *But inventory of HTR spent fuel is too small*

THTR spent fuel management





Step 1
Filling of the containers with spherical elements

Step 2
Intermediate storage of the containers in the spherical element store

Step 3
Placing the containers with spherical elements into the CASTOR THTR casks

Step 4
Handling of the CASTOR THTR casks on the working platform

Step 5
Outward transfer of the CASTOR THTR casks with the fuel transfer carriage

Step 6
Crane loading

305 CASTOR casks in 57 shipments to BZ Ahaus (as of April 1995)
Residual fissile material in core: 0.976 kg (required < 2.5 kg)

Interim storage of spent HTR fuel (pebble type) at Jülich, Germany

3. Spent fuel management in HTR-PM

- *Optimization the time period of intermediate storage*
  - *Intermediate storage for whole plant life time, for HTR-PM*
    - *First HTR plant in China*
    - *National disposal facility is not fixed*
  - *Maybe 10 years for intermediate storage, + interim storage for whole plant time, for HTR-PM600S,*
    - *More spent pebbles will produced*
    - *Separate interim storage building is more economic*
    - *More HTR-PM600S are expected, national-wise optimization is possible*

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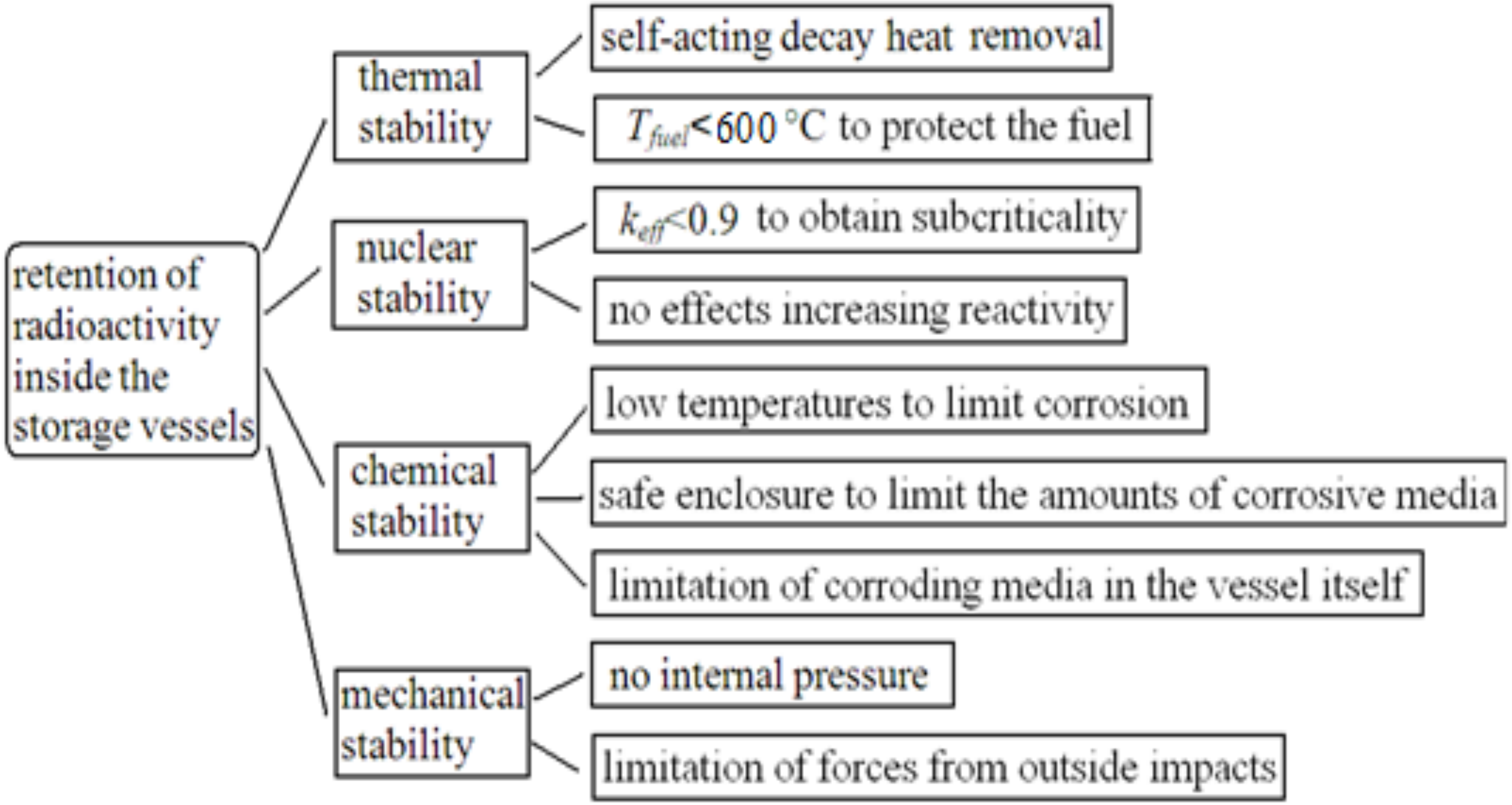
3. Spent fuel management in HTR-PM

- *Optimization of engineering solution of intermediated storage*
  - *Dry storage strategy is chosen*
    - *Low power density*
    - *HTR core and HTR fuel do not favor water*
    - *Experience from Germany AVR and THTR*
  - *Canister + concrete storage well + air cooling*

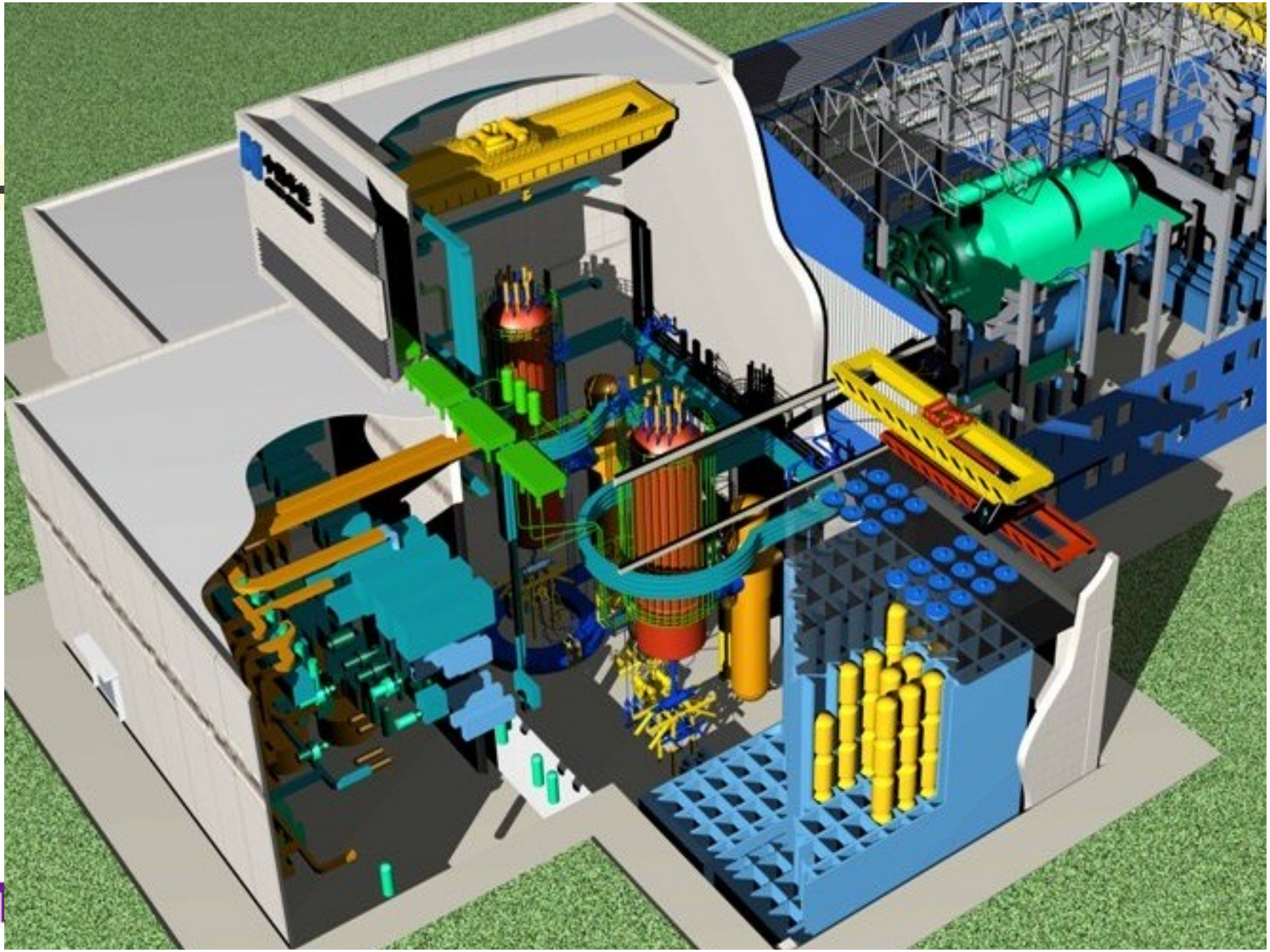
  - *Safety requirement*
    - *Criticality, cooling/temperature, shielding, sealing, handling, future transportation*

Detailed safety requirement



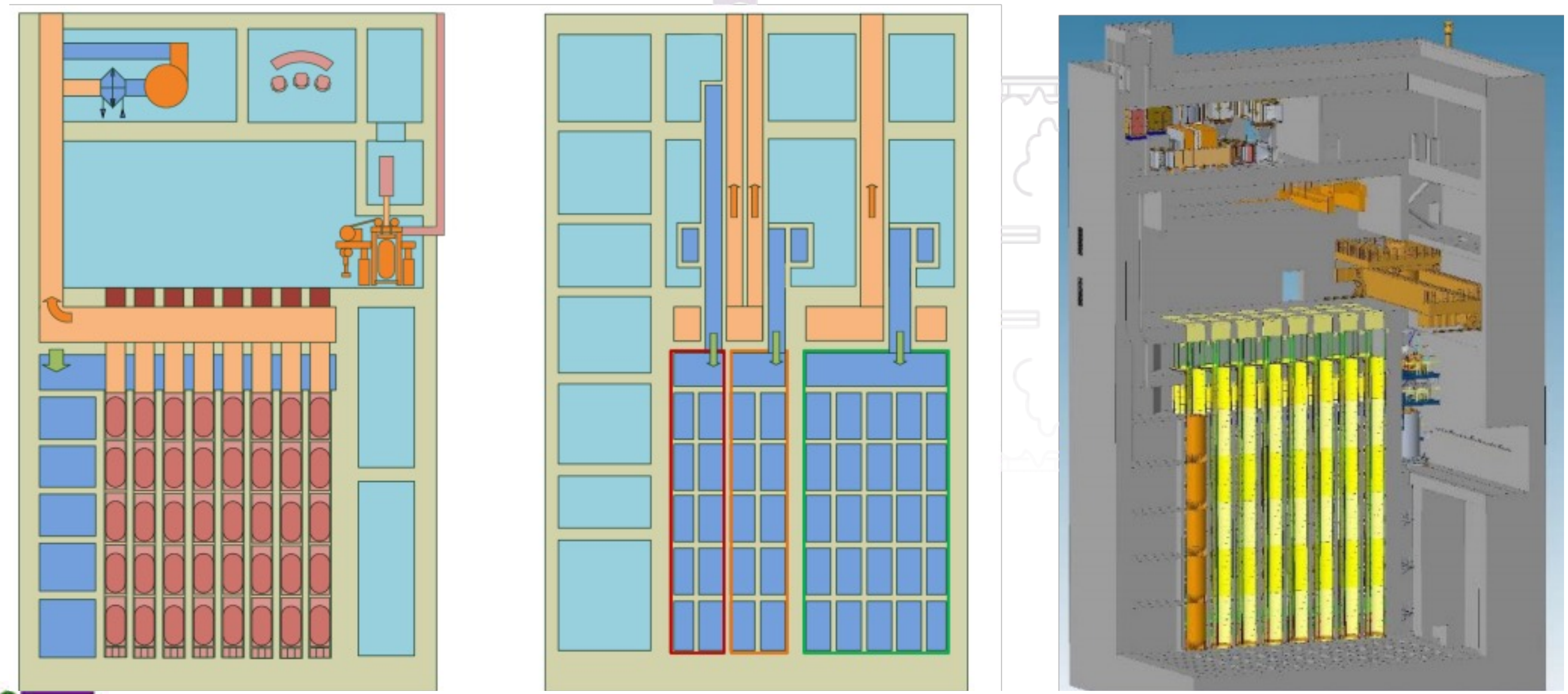
3. Spent fuel management in HTR-PM

- *Optimization of engineering solution of intermediated storage*
  - *Special arrangement of cooling:*
    - *Forced cooling for early stage, natural circulation is possible for later stage or accident condition*
  - *Storage building is nearby reactor building,*
    - *transfer of spent fuel pneumatically inside pipe*



Intermediate Storage of Spent Fuel: Building

HTR-PM Spent Fuel Storage System (SFSS)

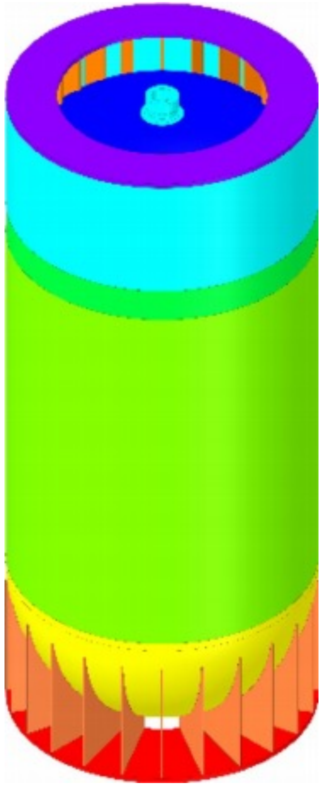


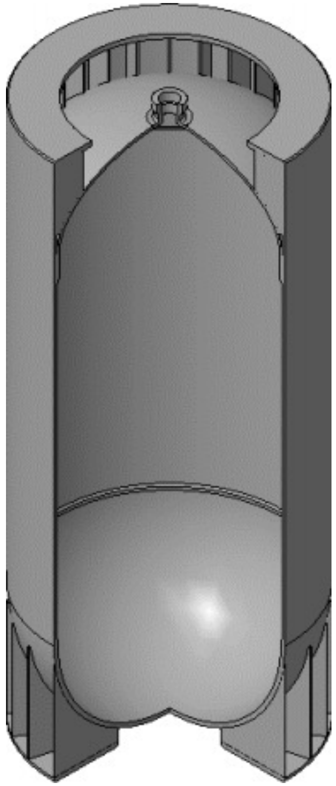
3. Spent fuel management in HTR-PM

- *Optimization of storage canisters*
  - *Much large than that in THTR*
  - *Optimize the size of canisters, volume of storage building, cooling performance*
  - *Taking advantages of continuous filling of spent fuel to canisters*
  - *Shielding is enhanced by concrete structure*
  - *Additional outer containers (casks) will be used for future transport*
    - *This cask will be compatible with transport truck for LWR spent fuel*

Intermediate Storage of Spent Fuel: Canister

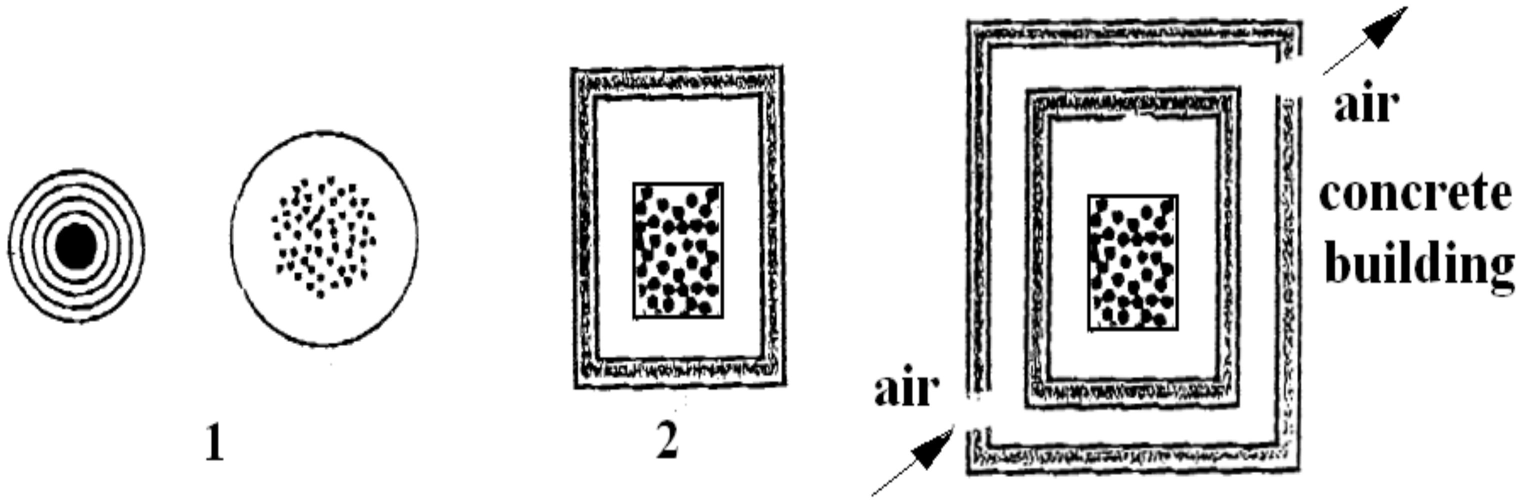
- *Movable Canister for HTR-PM*
  - *Capacity: 40,000 FE/canister*
  - *Material: SUS304 stainless steel*
  - *Thin-walled*
  - *Capable for handling*





Concepts of dry storage canister

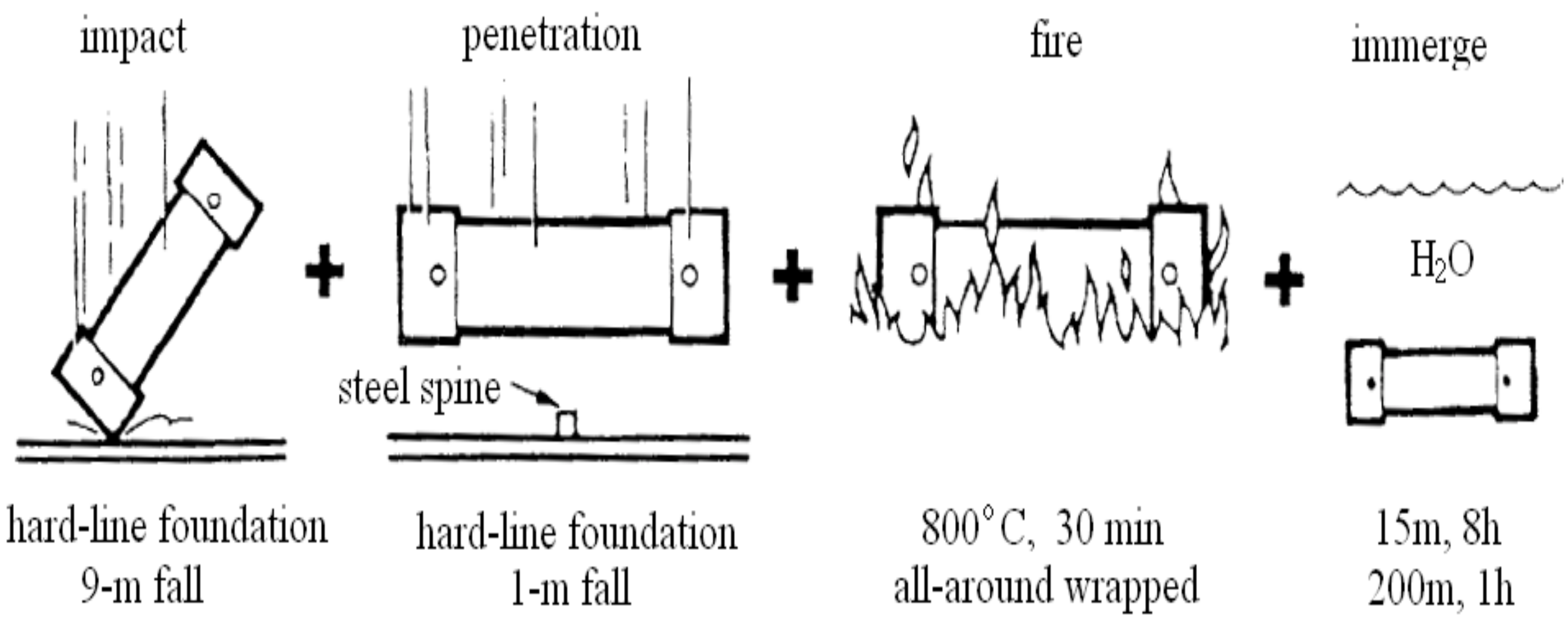
- *Good performance of TRISO coated particle is important*



1: fuel element,
2: cast iron vessel

concept of spent fuel canister for modular HTR

Requirement for spent fuel transport



Requirements for transport and intermediate storage vessels (German conditions)

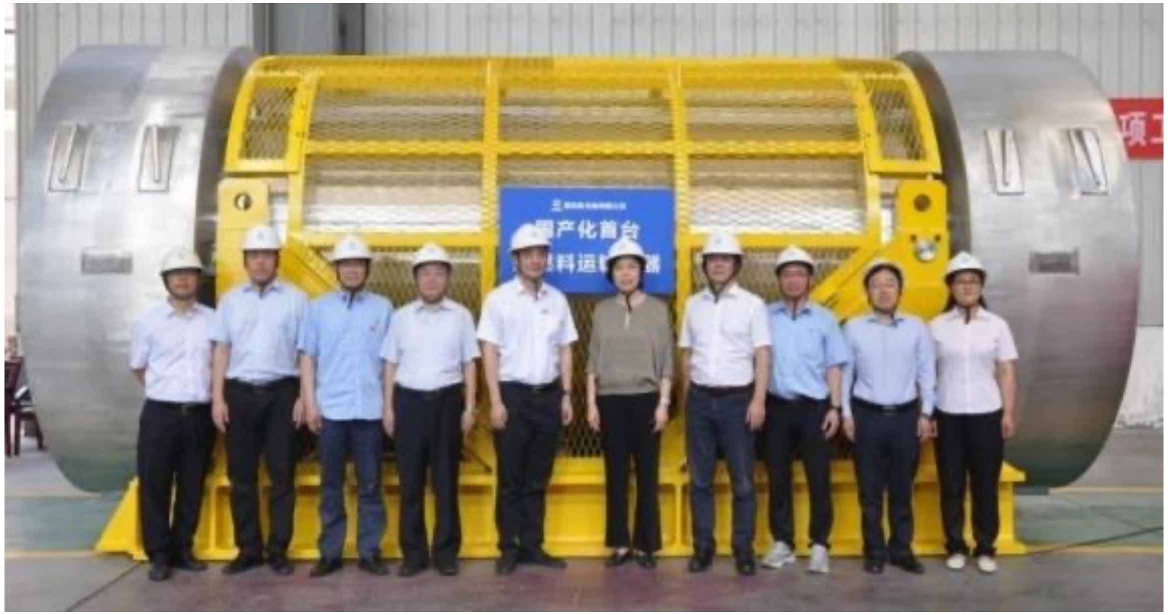
Spent Fuel Transport in US

- *Spent Fuel Transport cask*
- *A Case for PWRs: NAC-STC cask supplied by NAC, USA, 26 assemblies*

https://www.nacintl.com/solutions/transportation/transportation-systems

Chinese Spent Fuel Transport cask

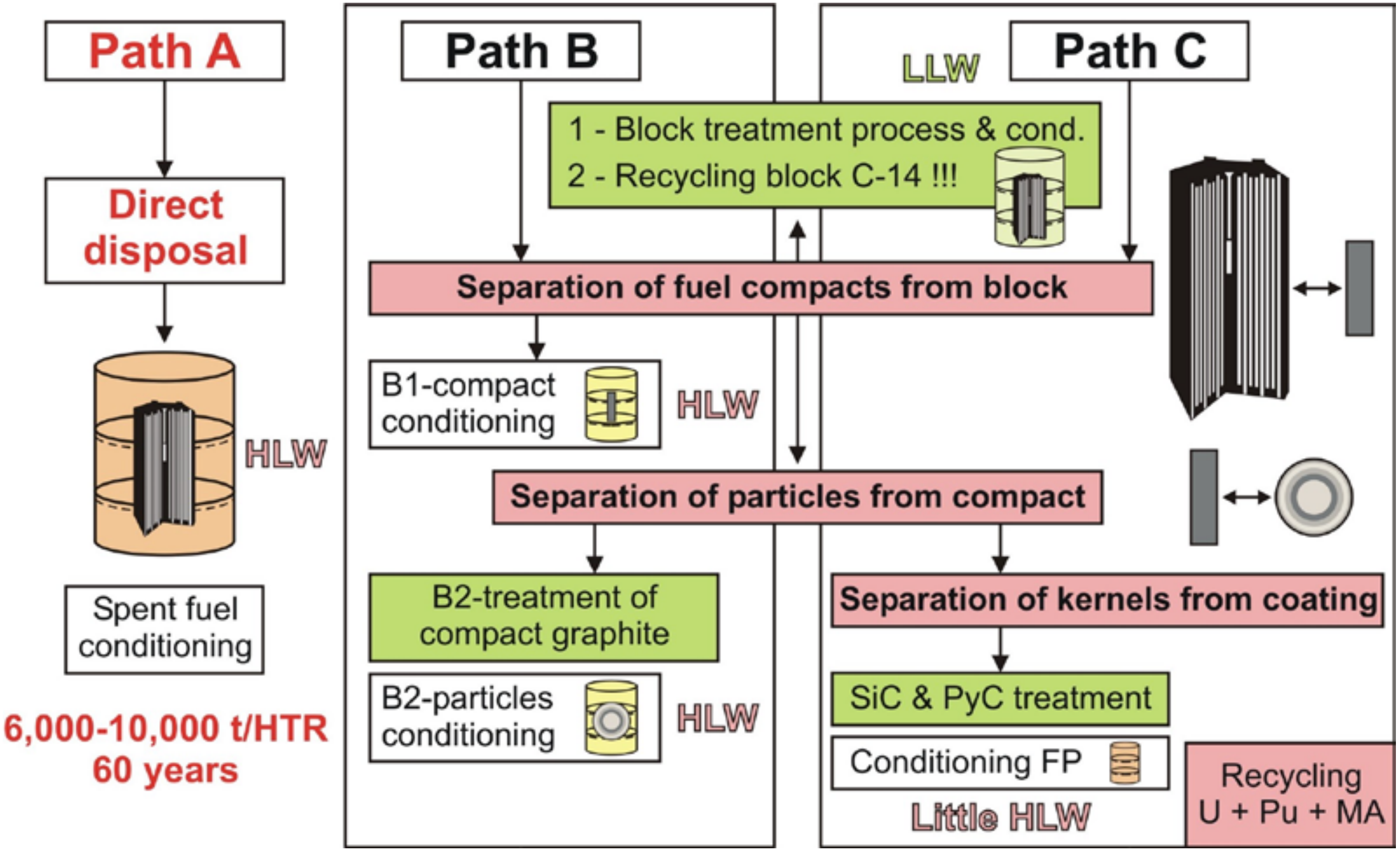
- *21 assemblies*



4. Final management of spent fuel

- *HTR spent fuel is special*
- *HTR spent fuel can be reprocessed*
- *HTR spent fuel is suitable for directly final disposal*

Back-end options



Recycling of coated particle fuel

- *useful* for recovery of U from production scrap
- *mandatory* for closed U-Pu and Th-U fuel cycles, symbiotic fuel cycles and for transmutation ("deep burn")
- *useful* for separation of fuel from matrix material and coatings (different waste classification)

Existing methods: Grinding, pneumatic projection against hard wall:

- low efficiency, high energy consumption;
- possible need to use pressurized gases in hot cells;
- production of toxic or explosive dust, safety concerns;
- high level of noise or vibration;
- pollution with abrasion products;
- high wear and tear, limited lifetime, high capital and operating costs

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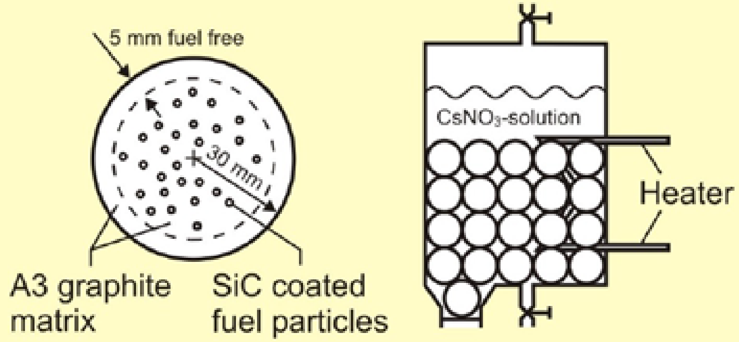
Fütterer, JRC, SELFRAC 2010

Chemical disintegration of fuel spheres

I. Filling of graphite pores with CsNO3-solution



- boiling of $CsNO_3$-solution containing fuel elements
- cool down of the closed boiling vessel
- inert gas (AR) added to the vacuum volume ⇒ Macro pores completely filled with $CsNO_3$-solution
- removal of excess $CsNO_3$-solution
- drying of fuel elements in a warm Ar flow

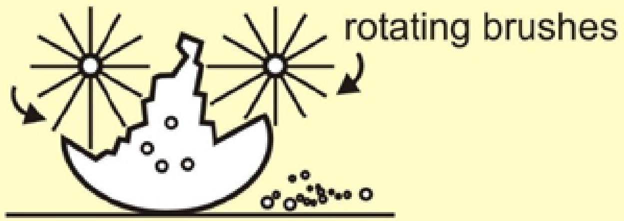
II. Partial oxidation of fuel elements

- oxidation with oxygen at 350 °C for 1 d ⇒ 15 - 20 % burn-off: strength loss of graphite > 95 %
- removal of CO (cont. C-14) by conversion to $CaCO_3$

Chemical disintegration of fuel spheres

III. Fuel element desintegration

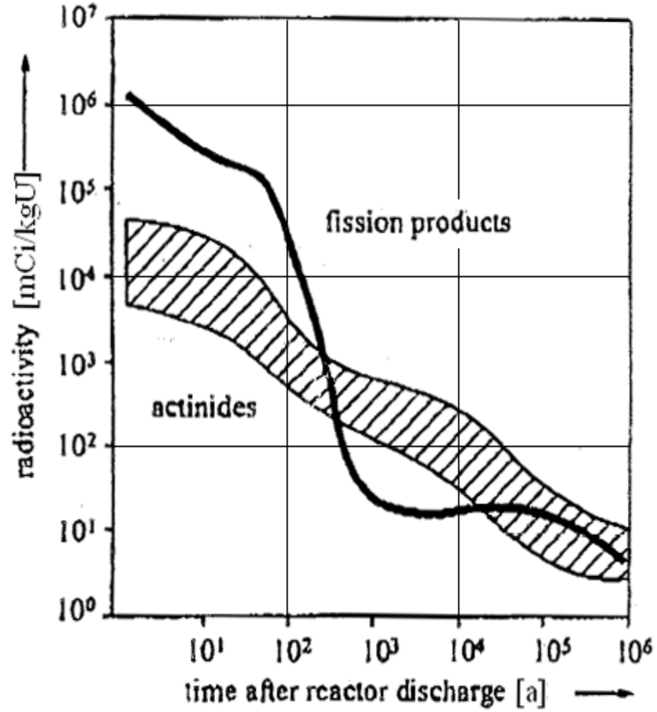
- rotating metal brushes desintegrate fuel elements to graphite powder (for waste disposal) and coated particles (cp)
- cp-graphite separation by cyclon technique (perhaps flotation)
- further cp-handling as usual



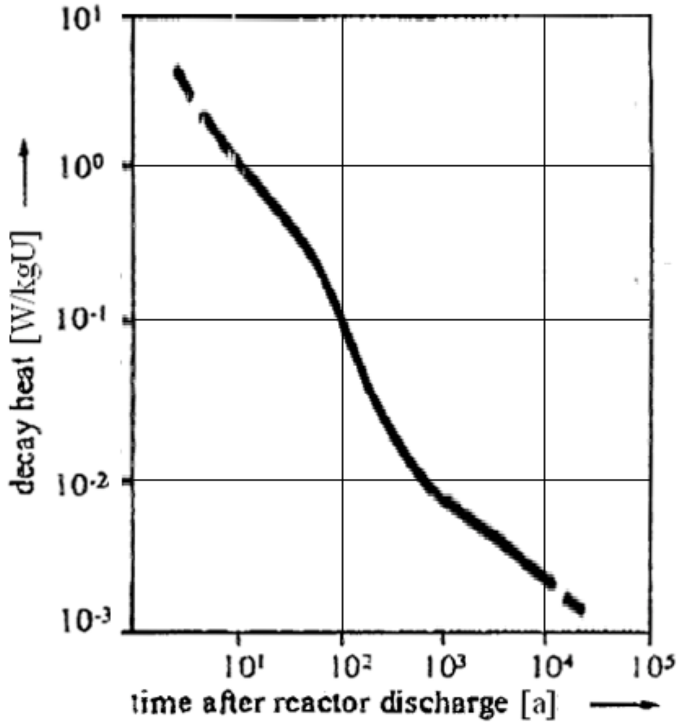
Advantages

- very few cp are destroyed by desintegration (conventional method : up to 50 % destruction)
- amount of CO_2 to be retained < 80 % of the conventional method :
- smaller amount of waste (C mainly as element instead of $CaCO_3$)

Final storage of spent fuel elements



activity



decay heat

Activity (a) and decay heat of (b) the Uranium fuel of spent fuel elements depending on time (relevant forth phase of direct final storage)

5. Standards for spent fuel management

- *Dry storage of HTR spent fuel does not have systematic requirement*
- *Germany and China have some experience*
- *HTR-PM in China has a engineering solution*
- *Optimization base on small amount and large amount of spent fuel may be different*
- *Standards for intermediate, interim, final storage, even reprocessing of HTR spent fuel need more efforts and operation experience feedback*

Conclusion remarks

- *HTR spent fuel is special*
- *Consideration for whole life cycle required*
- *Dry storage for intermediate storage is demonstrated in Germany and China*
- *More optimization and systematical requirement is expected, based on more experience feedback*

Thanks for your

listening & question!

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