Recent Progress of Spent Spherical Fuels Research for China's HTR

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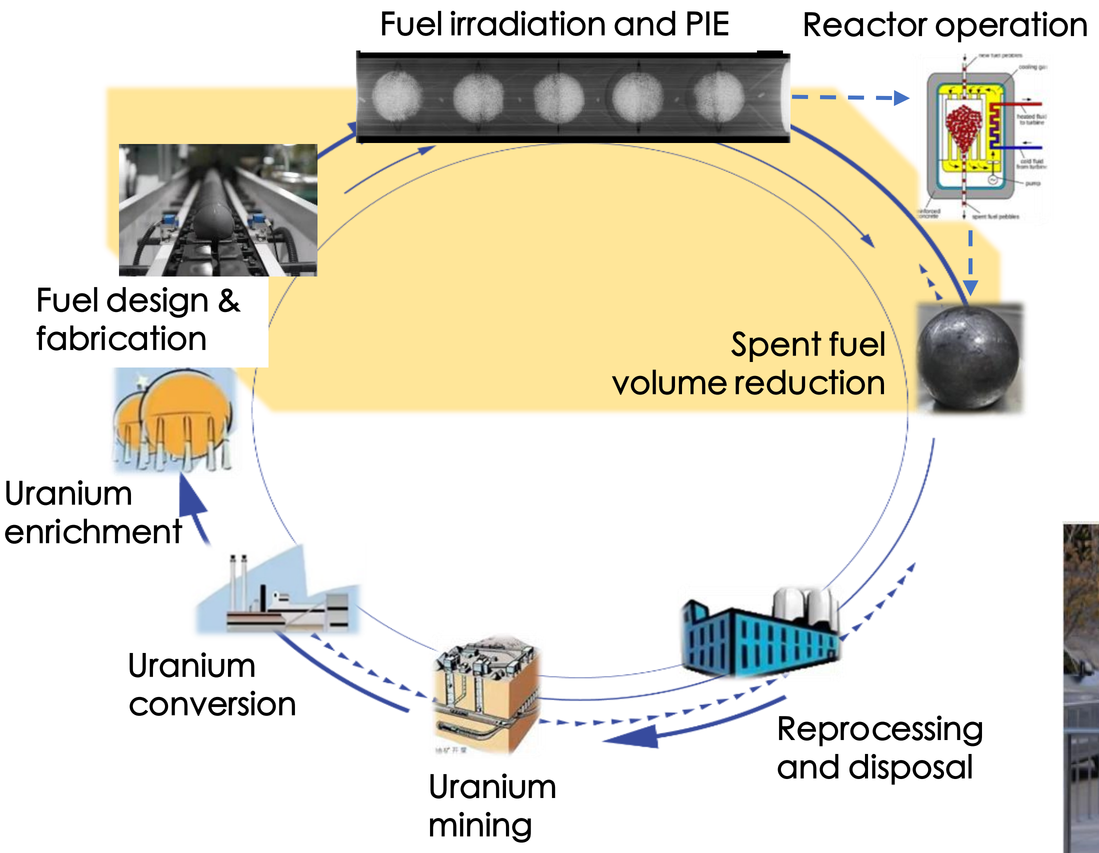
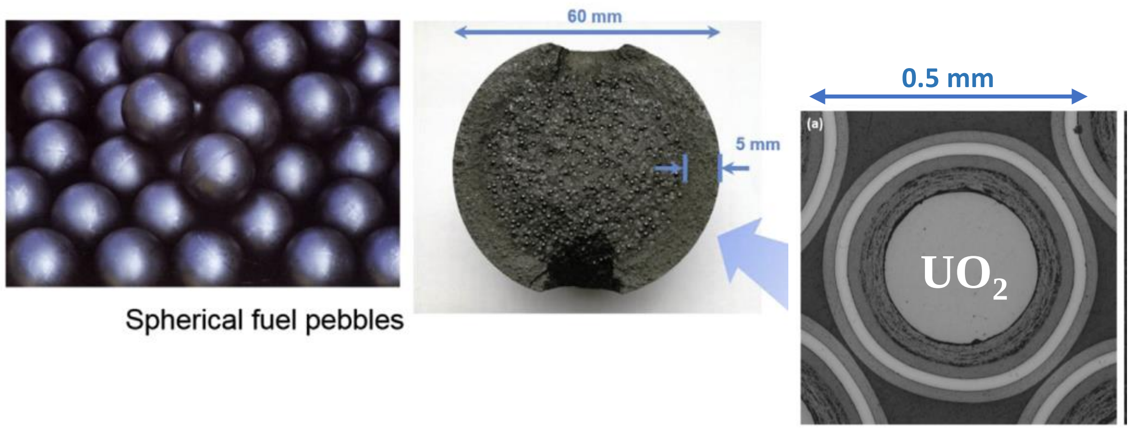
Our Team





Spherical fuel pebbles

- Division of New Materials, Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing, China

Reporter Introduction

- Dr. Xiaotong CHEN, Associate Professor
- Research fields
  - Performance evaluation of advanced fuel elements
  - Head-end Reprocessing of HTR spent fuel element
  - Source term analysis of HTR irradiated fuels

Outline

01. Introduction of China’s HTR fuels

02. Source term research of China’s HTR irradiated fuels

03. Head-end reprocessing research for China’s HTR spent fuels

04. FP release research on AIROX of UO_2 kernels

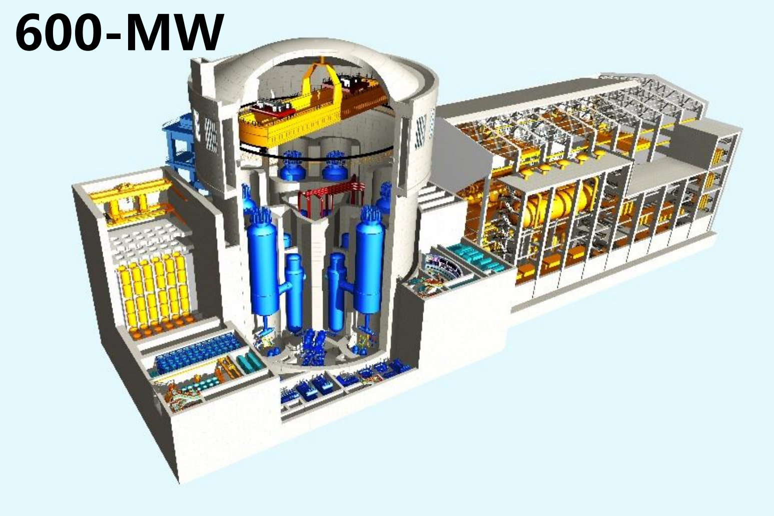
05. Conclusion and acknowledgement

01 Introduction of China’s HTR fuels

Fuel Pebbles discharged from HTR in China

HTR-10 in INET of Tsinghua University, Beijing, China

HTR-PM demonstration plant in Shidao Bay Shandong Province, China

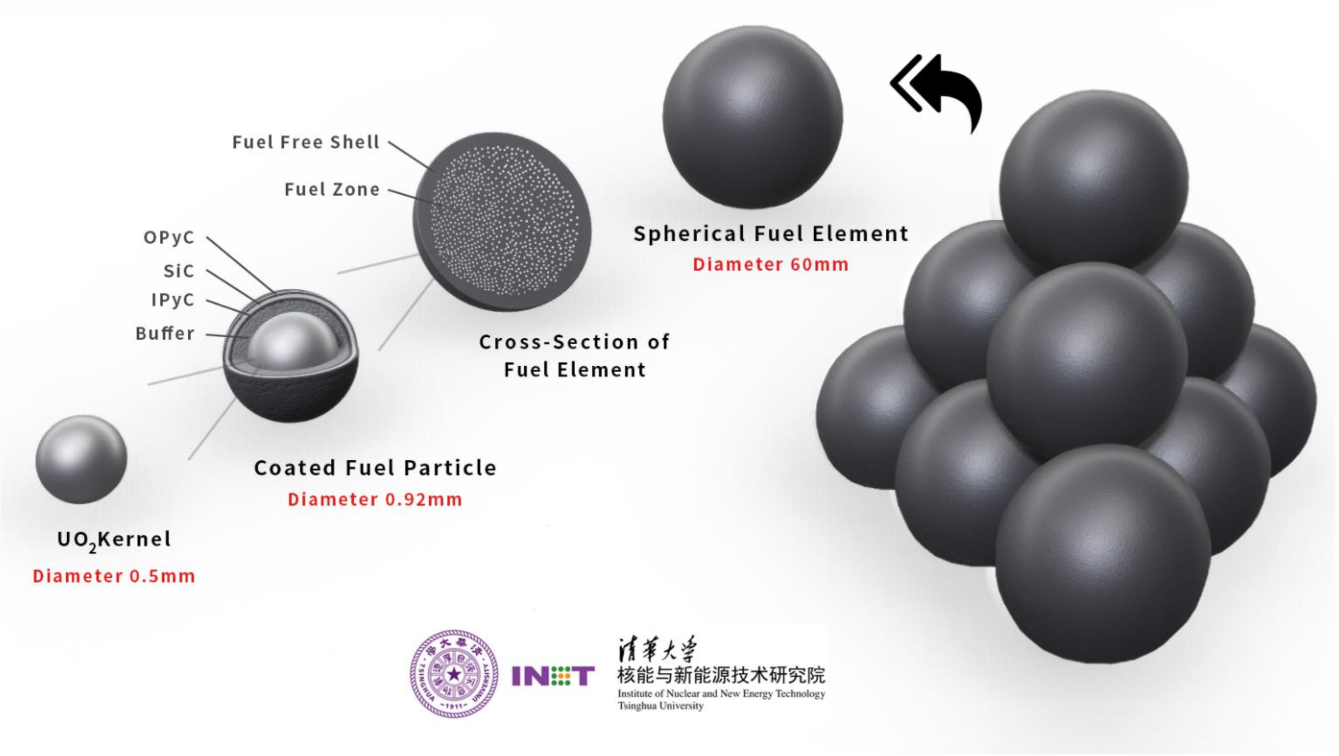


HTR-PM600 nuclear power plants planned in China by 2030, cogeneration of high temperature steam and electricity

- Irradiated fuel pebbles in HTR-10 reactor core
- Some pebbles in INET's Hotlab for research

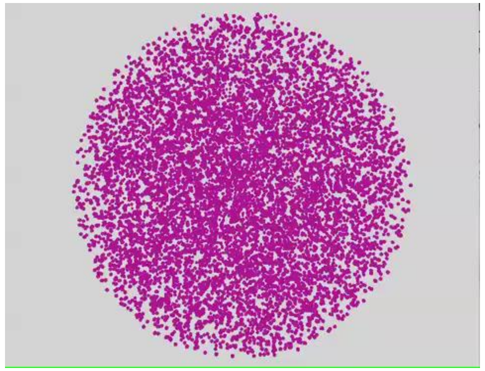
- 400 SFPs /module/day

HTR's spherical fuels in China

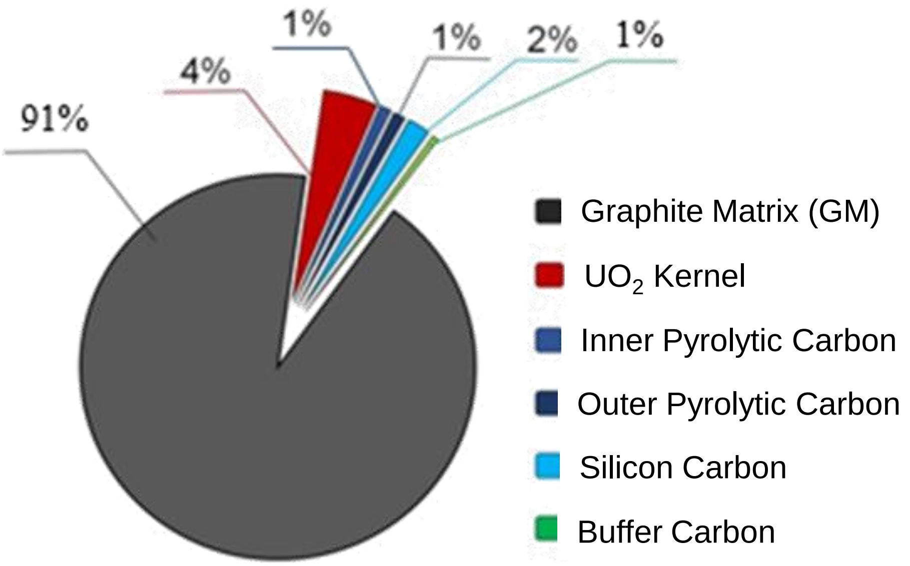


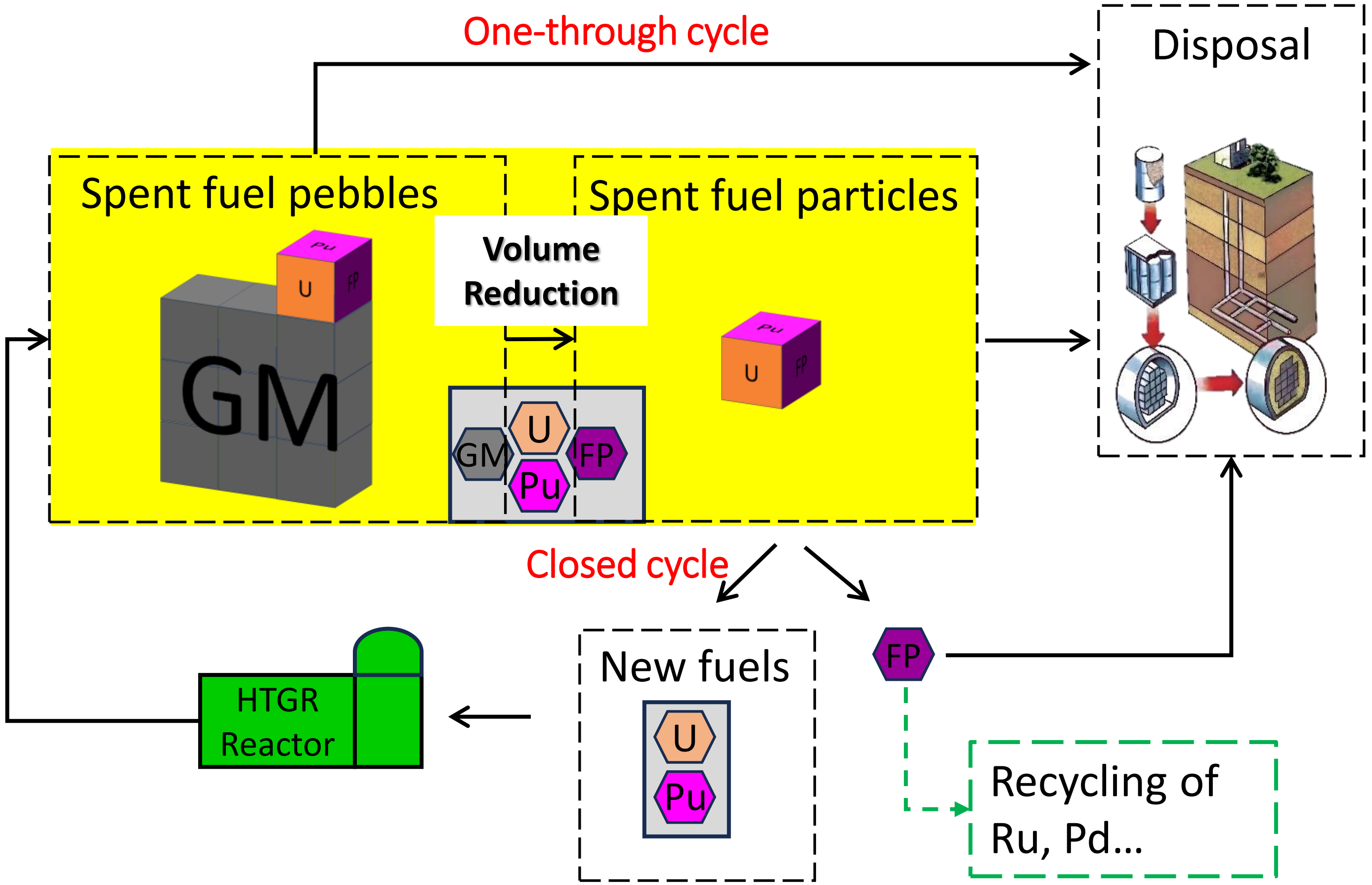
HTR spherical fuels design standard in China

	U-loading	Other indexes
HTR-10	5g/FE	Almost the same
HTR-PM	7g/FE	
HTR-PM600	7g/FE	



Separation of particles from graphite matrix

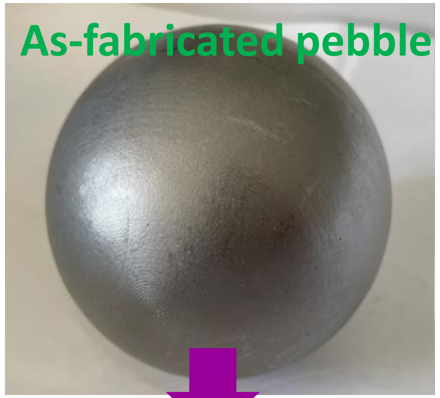


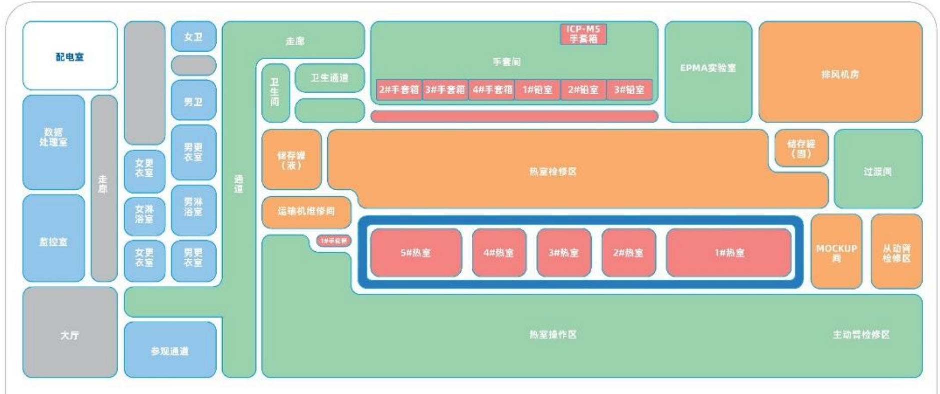


- Separating particles from graphite matrix to reduce the spent fuel volume
- Classifying the radioactive waste to different levels

02 Source term research of China’s HTR irradiated fuels

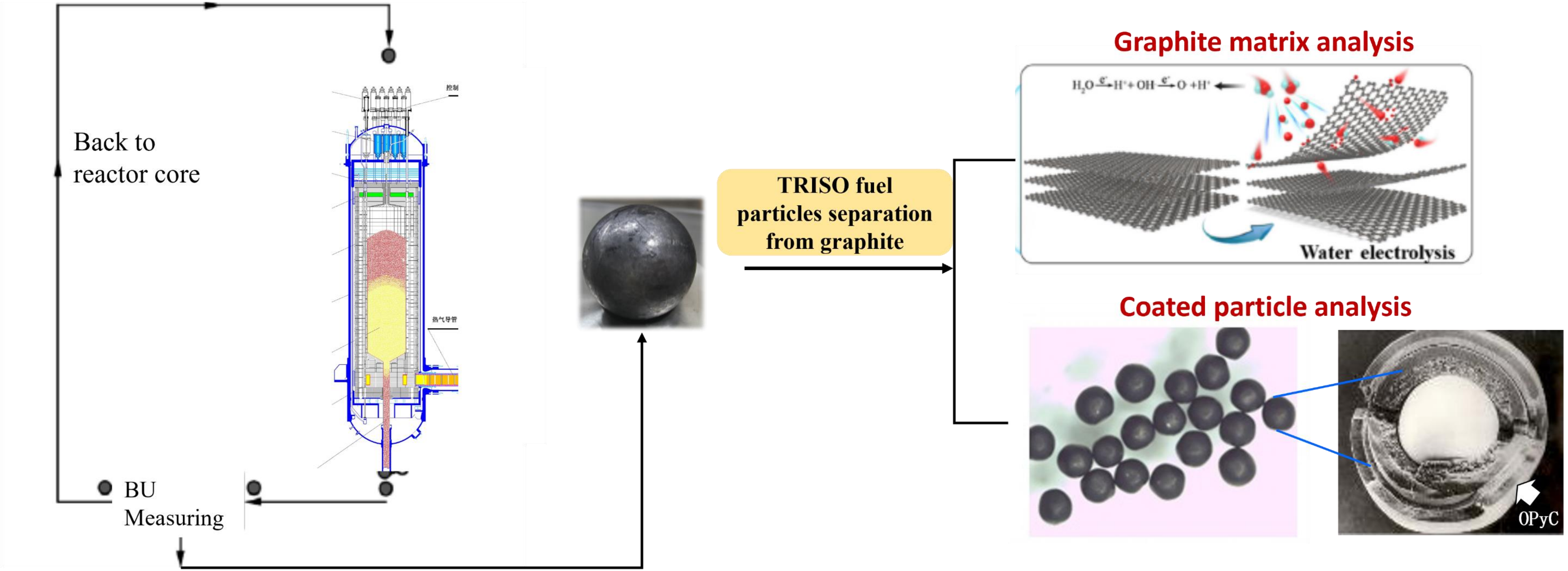
INET Hot Cell for China’s HTR fuels



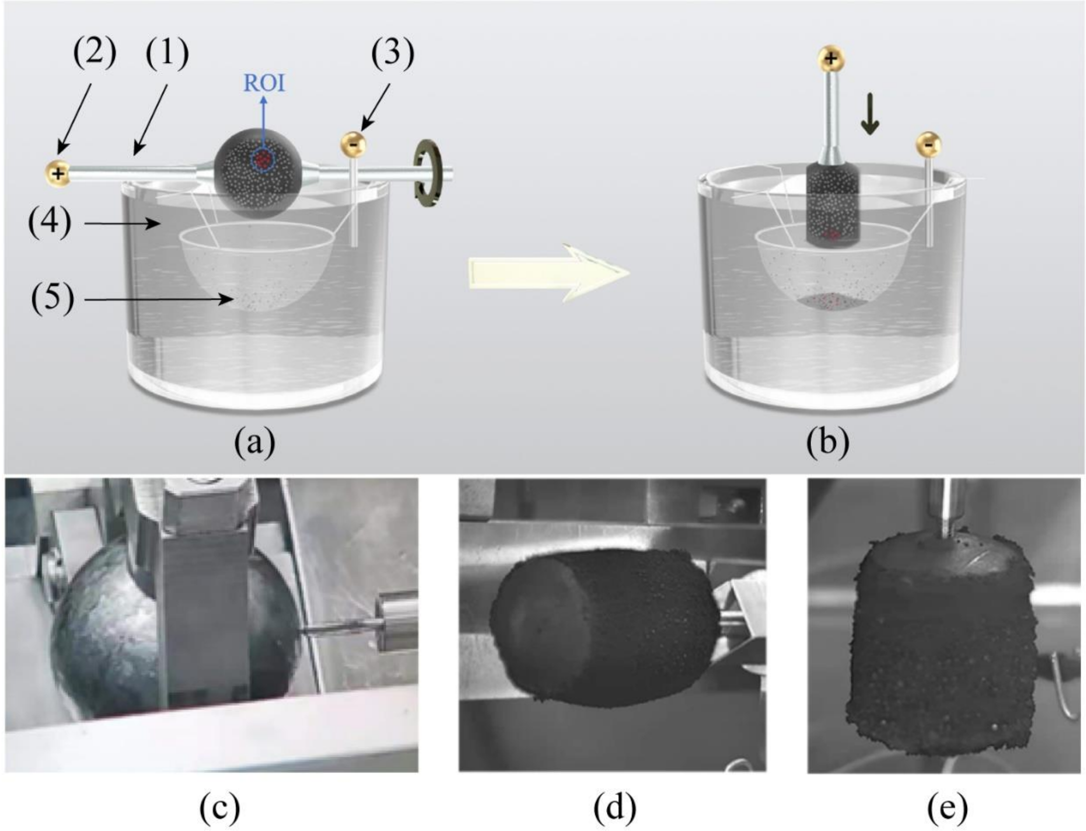


INET’s Hot cell specially for irradiated fuel pebbles

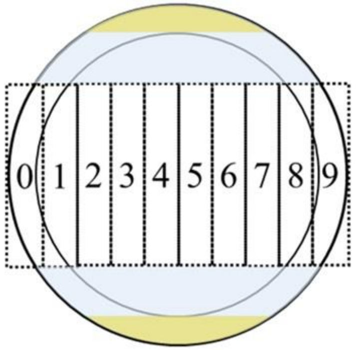
Source term analysis for China's HTR fuels



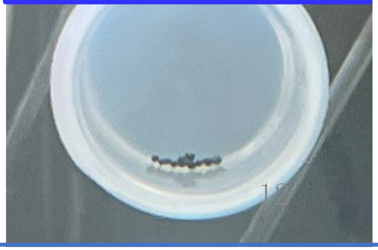
Source term of graphite matrix



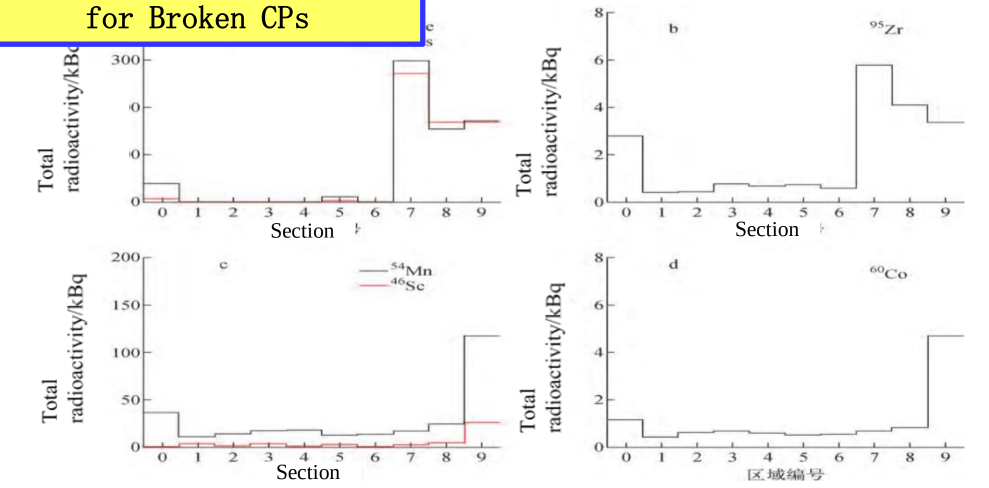
Two-step deconsolidation, separating CP from graphite matrix in 5-10mm section



Irradiated TRISO particles



Preliminary positioning for Broken CPs



Section

Source term of TRISO layers

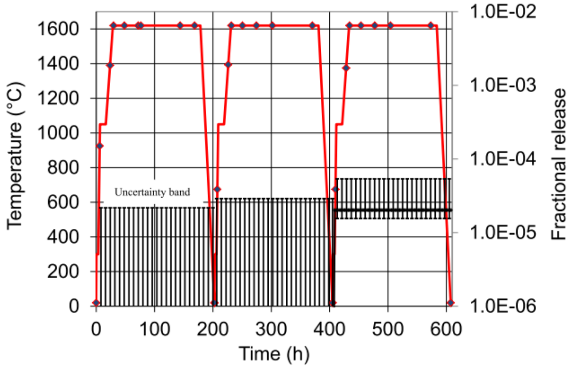


Fig. 5. HTR-PM 1 Kr-85 fractional release plus uncertainty.

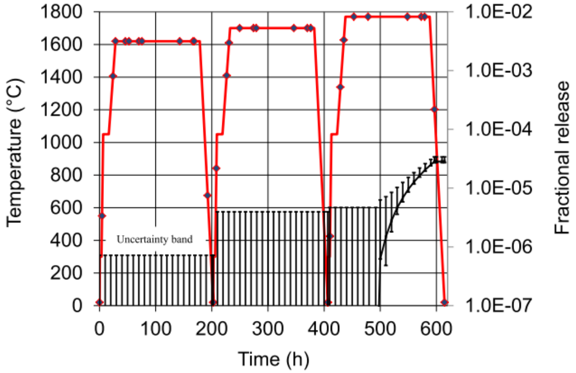
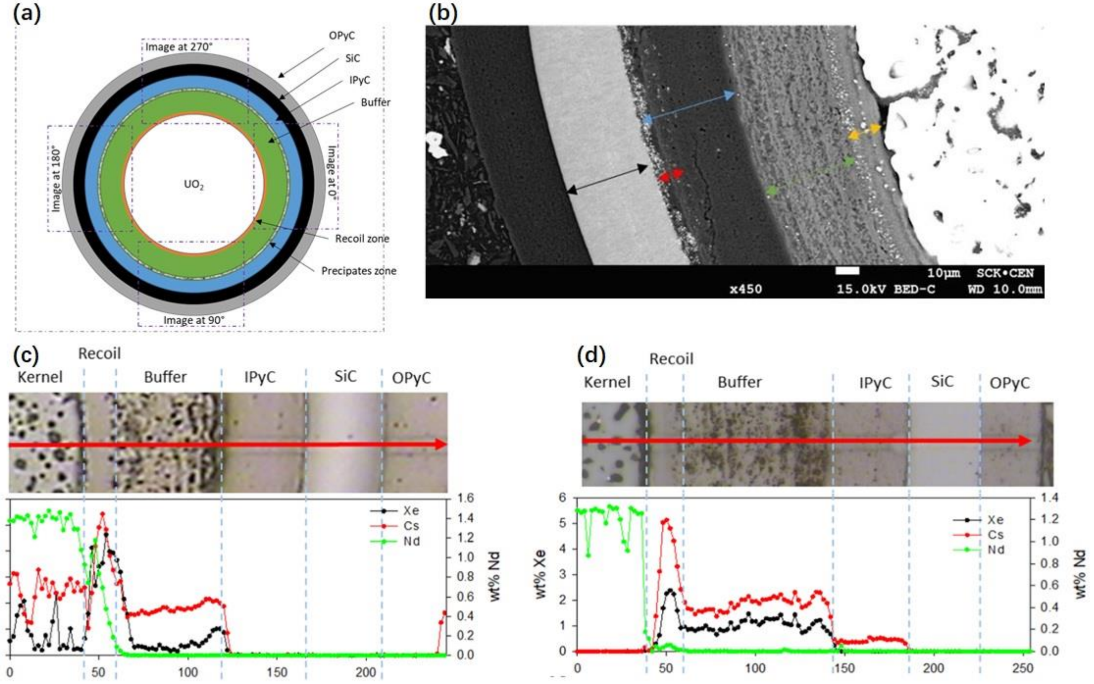


Fig. 11. HTR-PM 2 Kr-85 fractional release plus uncertainty.

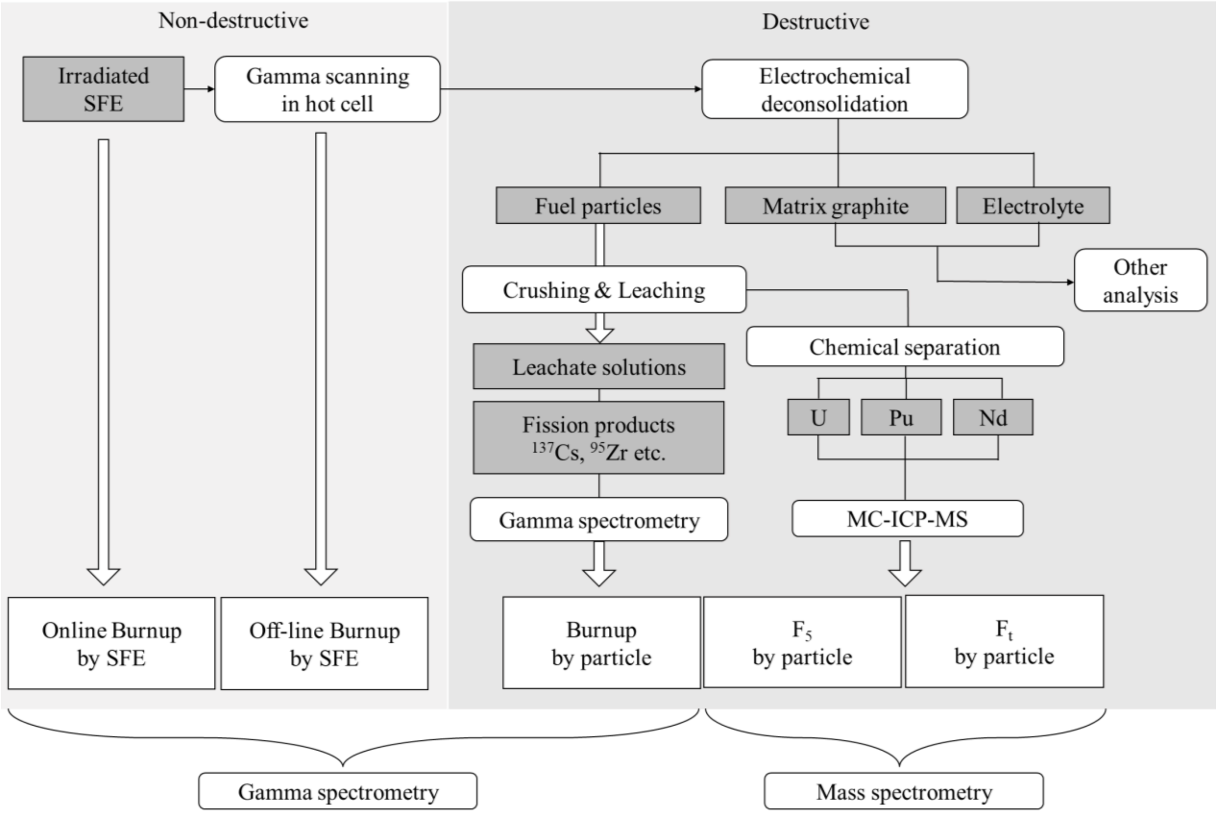


Composition analysis of HTR-PM particles as-irradiated (left) and heated (right)

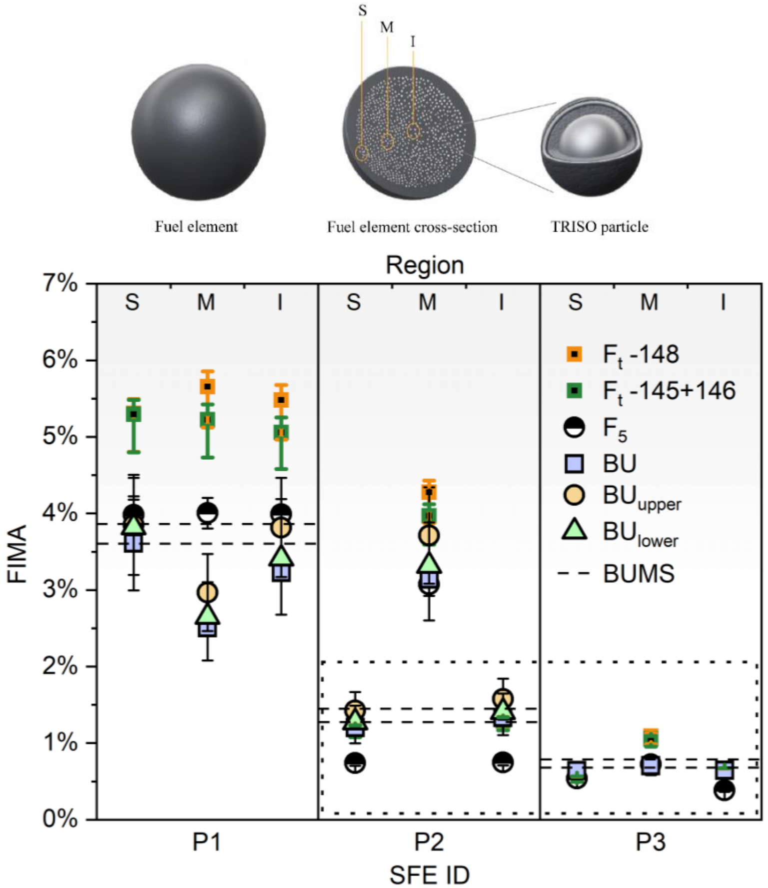
- evident FP sedimentation at the interface of IPyC and SiC layers
- small separation between UO_2 kernel and recoiling layers, also between IPyC and SiC layers
- buffer layers densification at recoiling position

Daniel Freis, Abdel El Abjani, Dragan Coric, Ramil Nasyrow, Joseph Somers, Chunhe Tang, Rongzheng Liu, Bing Liu, Malin Liu Burn-up determination and accident testing of HTR-PM fuel elements irradiated in the HFR Petten, ***Nuclear Engineering and Design***, 2020, 357, 110414

Source term in UO_2 kernel



Flow chart of the experimental process

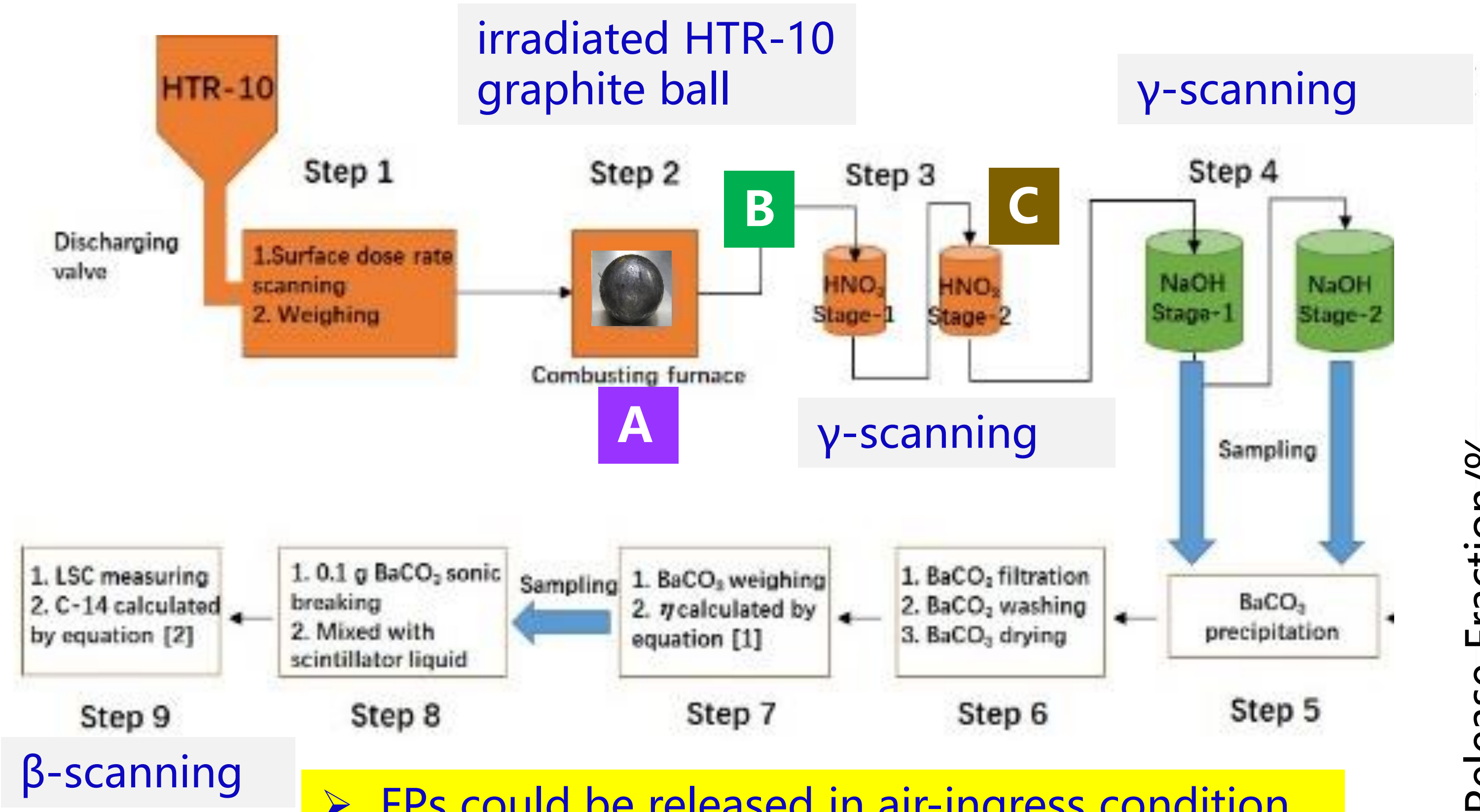


Comparison of burnup using gamma and mass spectrometry

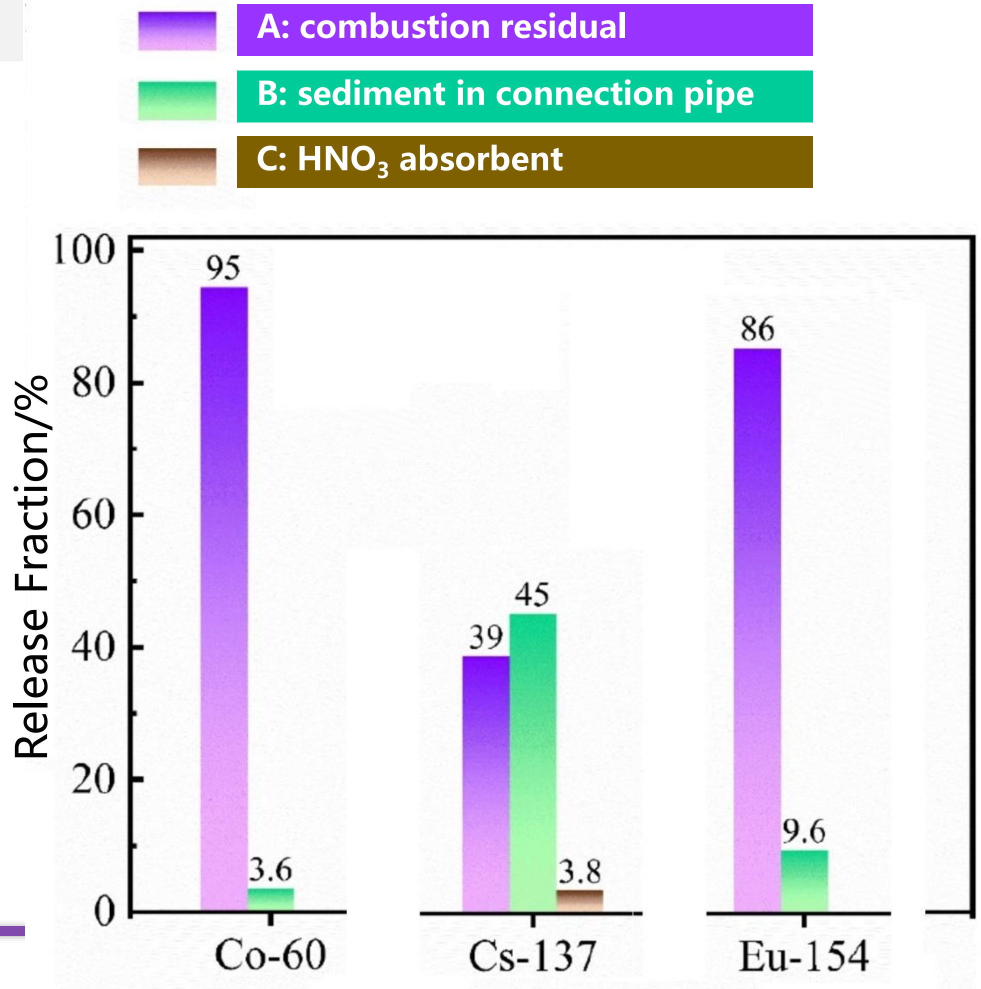
Taowei Wang, **Xiaotong Chen***, Linfeng He, Liguo Zhang, Caixia Li, Hongsheng Zhao, Youlin Shao, Bing Liu*, Chunhe Tang, Yaping Tang. A Comparison Study on the Burnup of HTR-10 Fuels Using ratiometric and Mass Spectrometric Methods. ***Progress in Nuclear Energy***, 2023, 156, 104535.

03 Head-end reprocessing research for China's HTR spent fuels

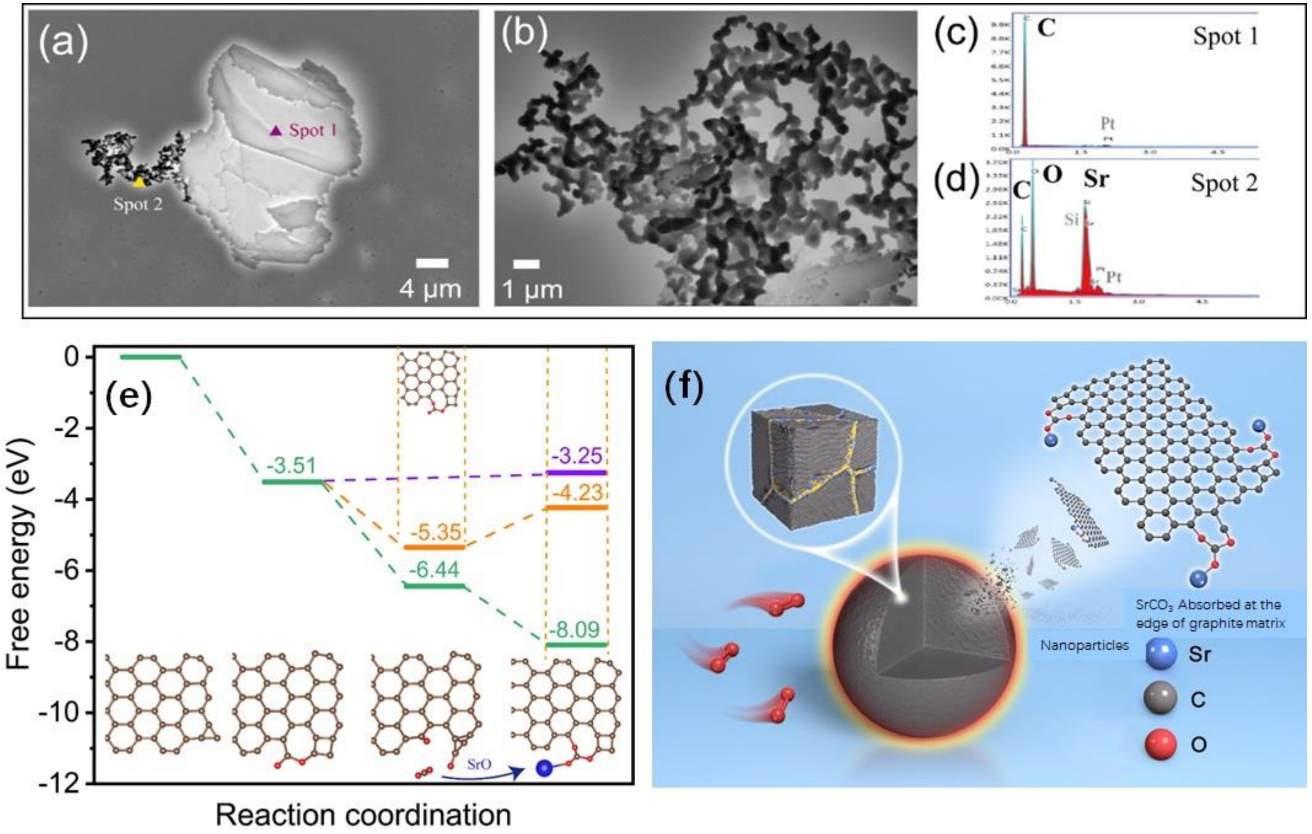
Oxidation of graphite matrix



- FPs could be released in air-ingress condition.
- The specific activity of C-14 for one graphite sphere is 6.2 E+6 Bq.



Chemical speciation of released Sr

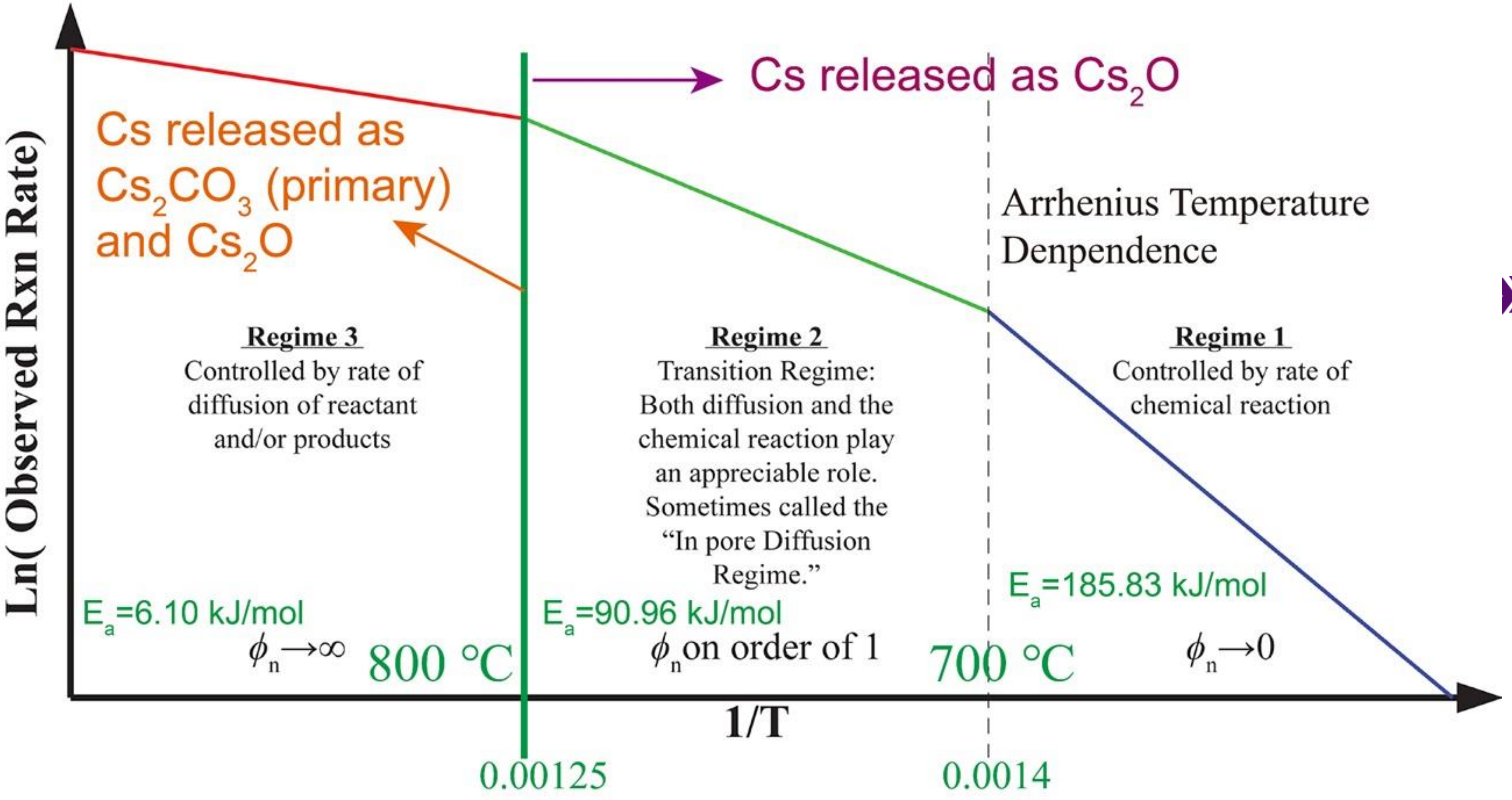


- The released Sr chemical speciation was extrapolated as $SrCO_3$
- The main morphology of the released fragment was identified as clusters anchored at the edge of graphite.

Wei Zhang, Hongwei Zhu, Zelin Gao, Taowei Wang, Rina Wendu, Gang Xu, Shuxian Hu*, **Xiaotong Chen***, Bing Liu*, Yaping Tang. Carbonate of Strontium anchored at the edge of graphite. ***Nuclear Materials and Energy***. 2023, 101448

Chemical speciation of released Cs

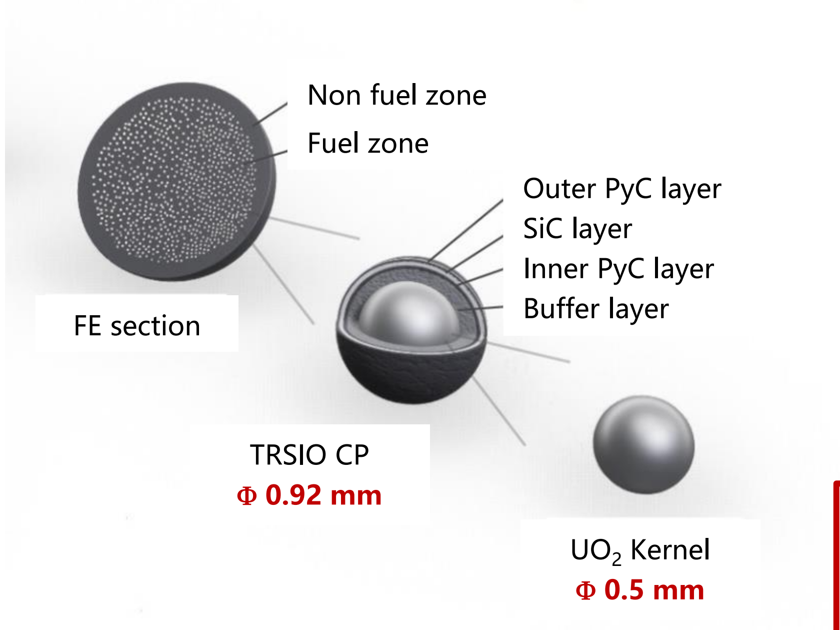
$$Cs_2O(l)+CO_2(g) \rightleftharpoons Cs_2CO_3(l)$$



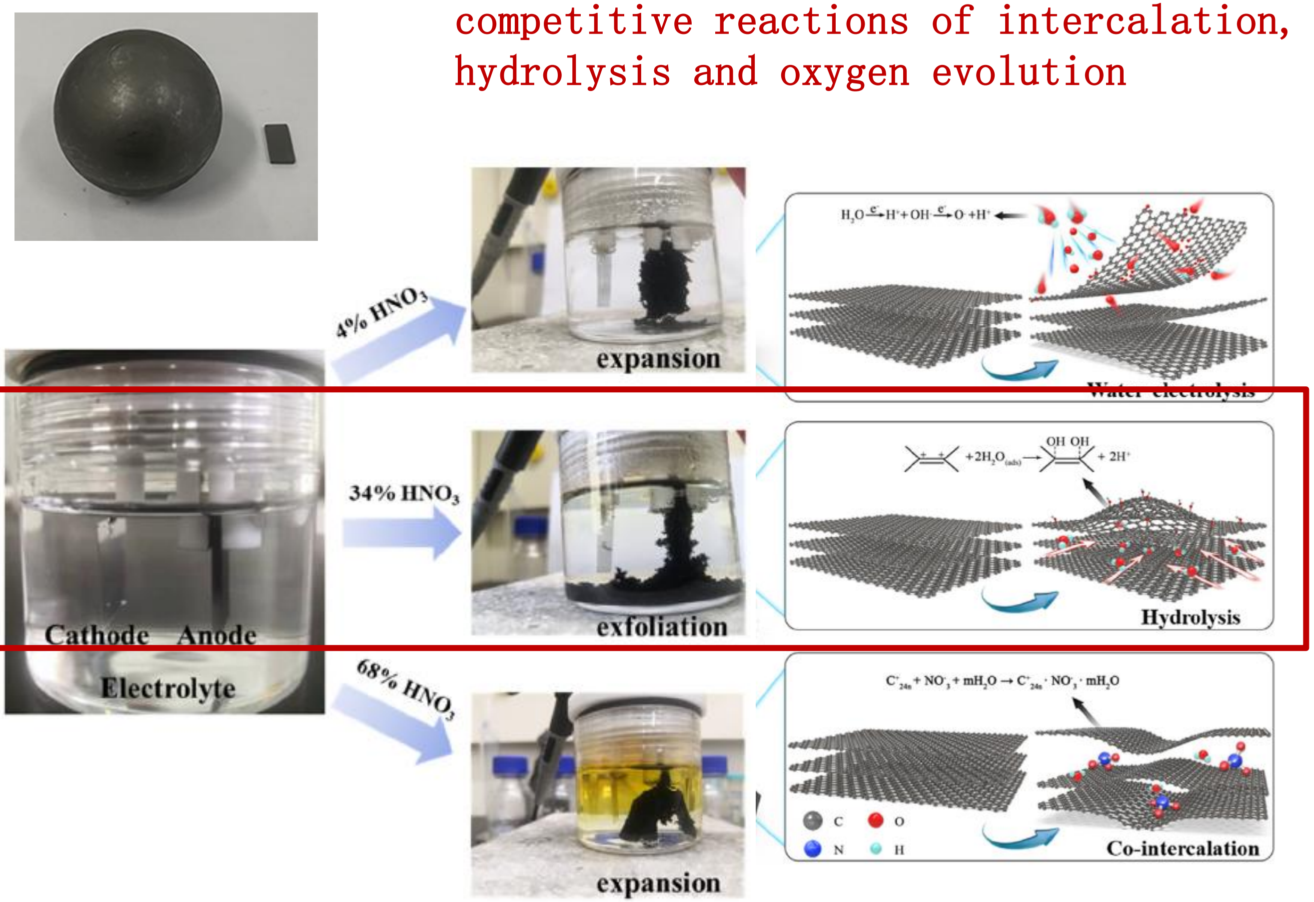
- The chemical species of Cs release is controlled synergistically by graphite oxidation and temperature.

Wei Zhang&, Hongwei Zhu, Zelin Gao, Gang Xu, **Xiaotong Chen***, Bing Liu*, Yaping Tang, **Temperature dependence of Cs release during oxidation of Cs-loaded graphite.** *Progress in Nuclear Energy*, **2023, 164,104847.**

Electrolytic deconsolidation of graphite matrix



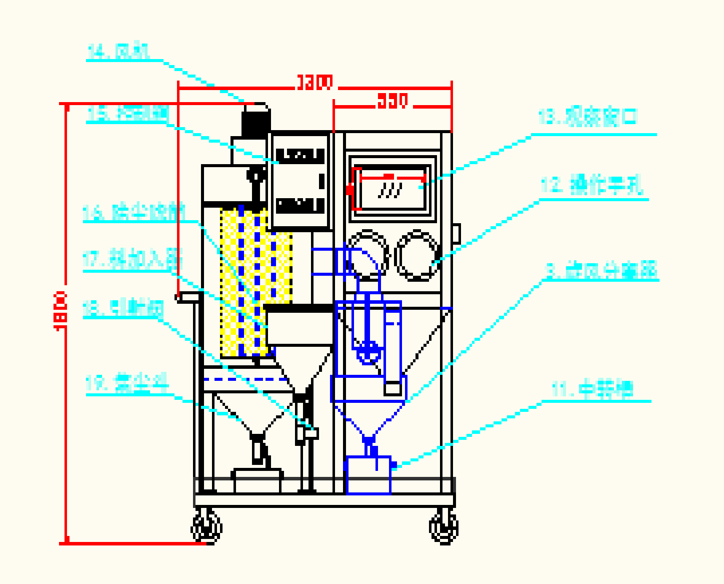
competitive reactions of intercalation, hydrolysis and oxygen evolution



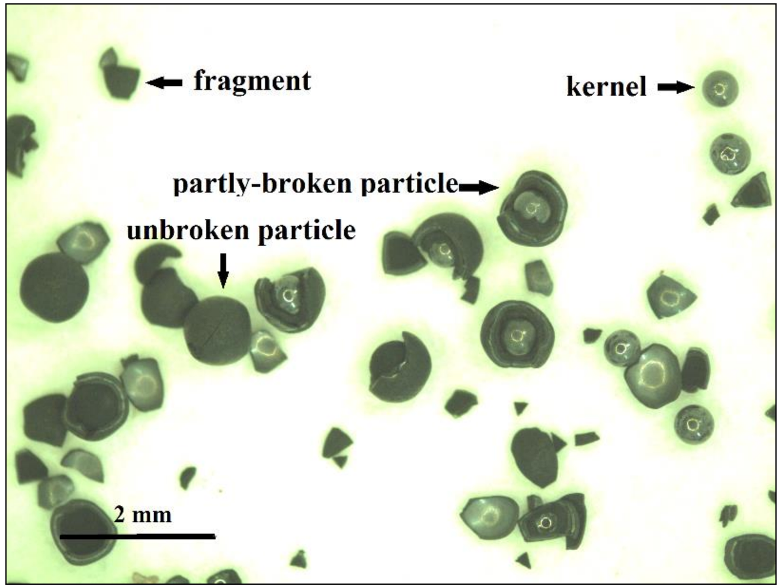
- Two issues:
  - clear interfaces between deconsolidated sub-samples
  - protecting outer PyC layer
- Two key parameters:
  - **HNO_3 concentration (34 wt%)**
  - current intensity (2-6 A)

Zengtong Jiao, Chi Zhang, Wei Zhang, Linfeng He, Zhenming Lu, Meili Qi, Caixia Li, Suwei Cheng, Gang Xu, **Xiaotong Chen***, Bing Liu*, Yaping Tang. Effect of water molecules co-intercalation and hydrolysis on the electrochemical deconsolidation of matrix graphite in aqueous nitric acid. ***Carbon***. 2022, 192, 187.

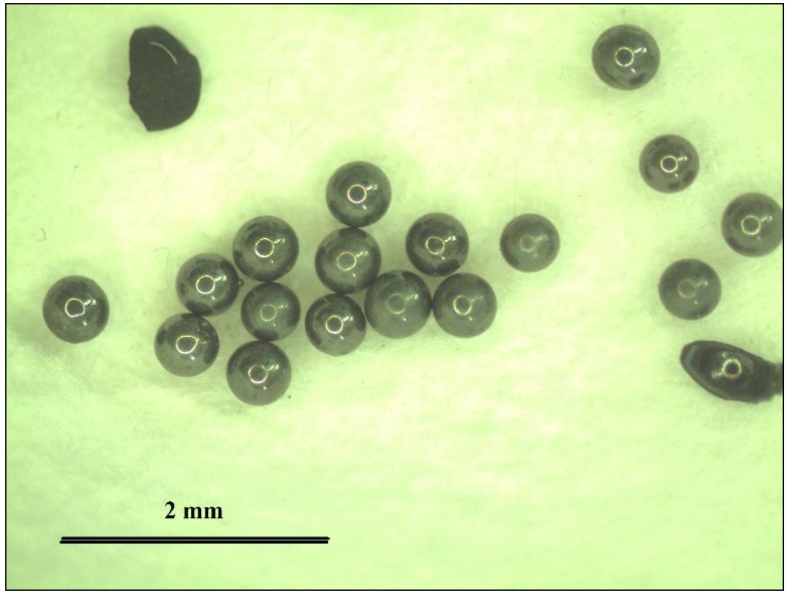
Mechanical separation of kernels from particles



- Jet milling-airflow flotation separation rack system



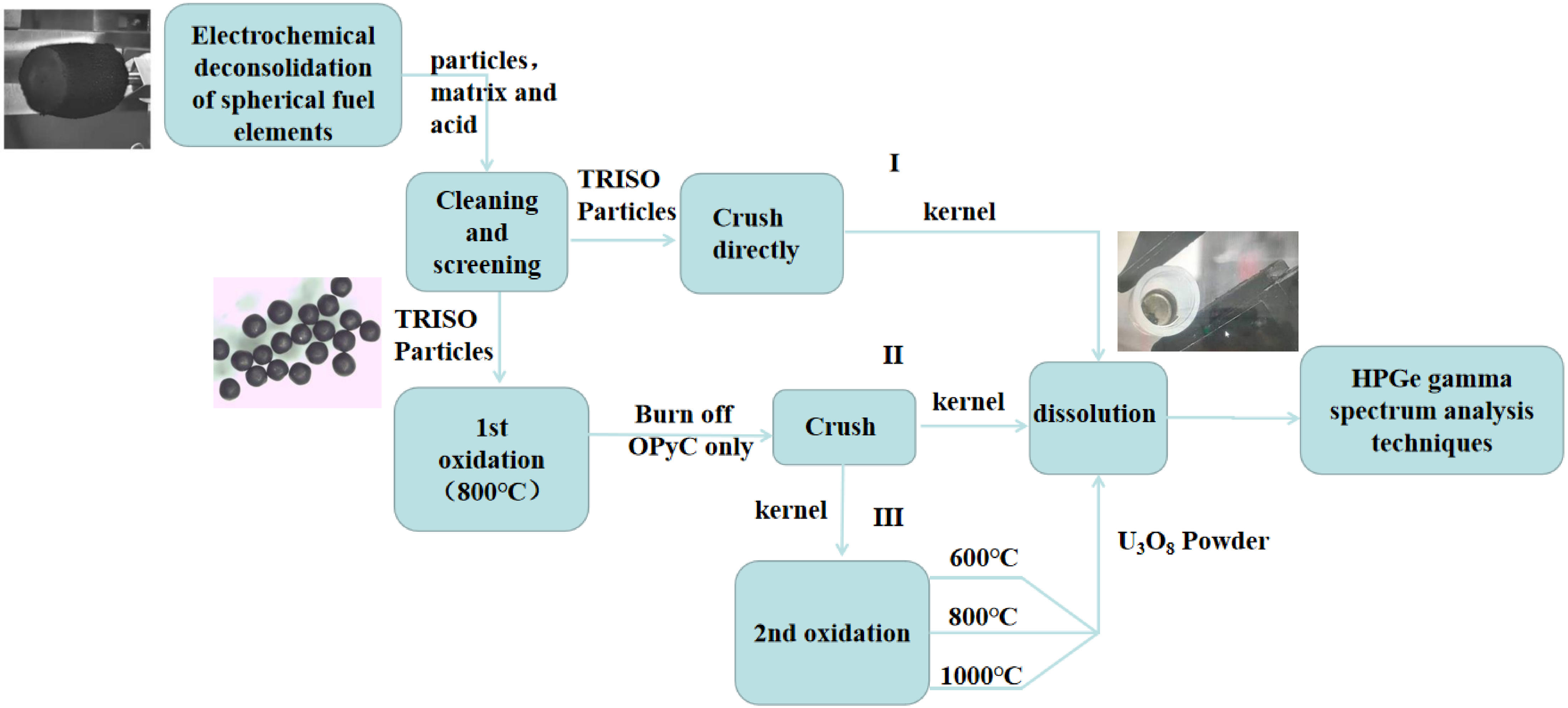
- Jet milling of coated fuel particles to break coated particles



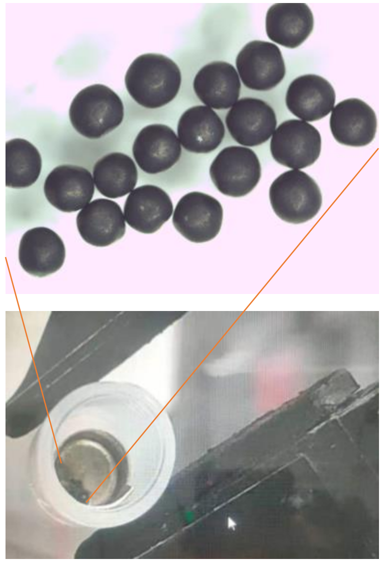
- Airflow flotation of broken particles to separate surrogate UO_2 kernels

04 FP release research on AIROX of UO_2 kernels

Thermal oxidation of spent UO_2 kernels

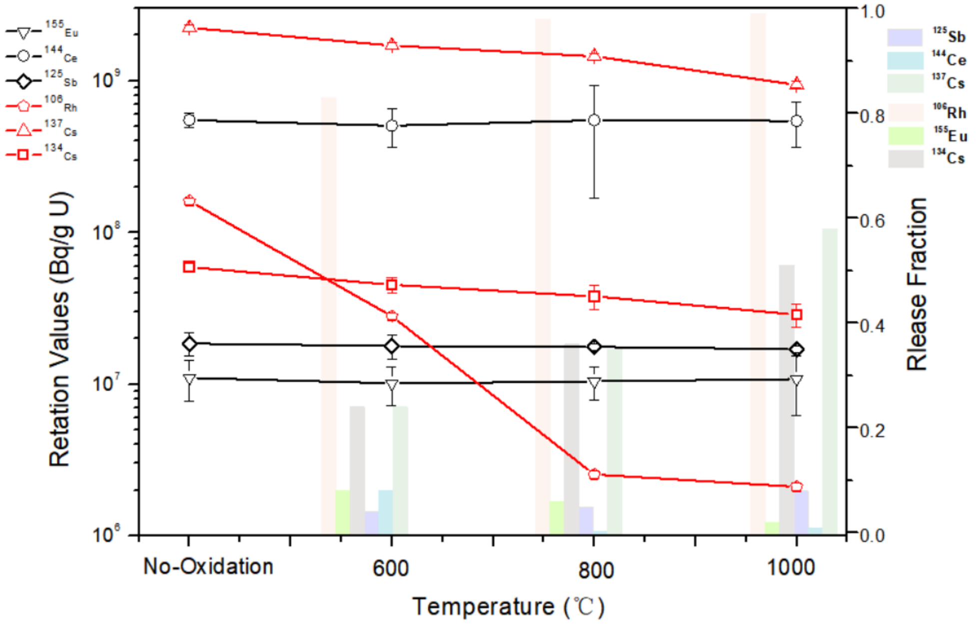


FP release fraction during oxidation



CPs separation and crushing

Oxidation at 600/800/1000℃



- Cs and Rh/Ru in broken particles presented evidently release during high temperature oxidation.
- Over 50% of both Cs-134 and Cs-137, and almost 100% percent of Rh/Ru would be released when the heating temperature was as high as 1000ºC.
- Ce, Eu ,and Sb didn’t show apparent releasing, which was attributed to stable thermodynamics behaviors in UO_2 kernels.

05 Conclusion and acknowledgement

Conclusion

- The spent fuel research for China's HTR covered source term analysis, process study on several head-end methods, and preliminary work on AIROX of irradiated UO_2 kernels.
- Head-end reprocessing of spent special fuel targeted to separate particles from spent spherical fuels and finally reduce the volume of HLW. The radioactive nuclides transformed and released during the process should be paid close attention.
- The AIROX results showed evident release of Cs and Ru during UO_2 kernels annealing, which agreed well with previous studies. However, the tested spent fuels were discharged for several years and some nuclides with short half-lives could not be detected.

Acknowledgement

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- **THANKS FOR YOUR ATTENTION!**