Overview of China Nuclear Waste Vitrification

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About Wuhan and WHUT

Wuhan city:
1) At the intersection of Yangtze River.
2) Largest city in Central China.
3) 3500-year history.

WHUT:
1) Student: ~50,000; faculty: ~3,300.
2) Ranking in the world: ~400 (THE Ranking).
3) Best University in glass and ceramics (in China).

Bird view of WHUT
About SMART Lab

Faculty and student:

- Faculty: ~65.
- Post-doc.: ~10.
- Student: ~500, Intl. stud.: 15.

Research areas:

- **Glass**
  - Faculty: ~20
  - Student: ~200

- **Silicate materials**
- **Cement**
- **Ceramics**

World-renowned glass scientist @ SMART

- Prof. Zhao
- Prof. Yue
- Prof. Peng
- Prof. Maruo
- Prof. Greaves

Ex-president of ICG

Aalborg, Denmark

cambridge, uk

Director

Adjunct prof.

PSU, US
Background – growing of China nuclear power

Reactors under construction

- China: 30
- Russia: 9
- India: 6
- USA: 5
- South Korea: 4
- UAE: 4
- Japan: 3
- Brazil: 1
- Finland: 1
- Argentina: 1
- Pakistan: 2
- Slovak: 2
- Belarus: 2
- Chinese Taipei: 2

Development plan of China nuclear power:

- 2020: 58 GW;
- 2035: 150 GW.

- ~10% of the total;
- 2nd world largest NNPs country.

Fastest-growing in the world.

-from world nuclear association (2015)
Background – China nuclear waste management

High-level waste

Optional

Intermediate/low-level waste

Glass

Cement
A typical China Nuclear Waste

- High Fe, Na, S, RE.

<table>
<thead>
<tr>
<th>(Oxides)</th>
<th>(Total oxides in VPC simulant)/(g • L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>9. 116</td>
</tr>
<tr>
<td>BaO</td>
<td>0. 010</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>1. 625</td>
</tr>
<tr>
<td>Cs₂O</td>
<td>0. 695</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>20. 513</td>
</tr>
<tr>
<td>K₂O</td>
<td>1. 293</td>
</tr>
<tr>
<td>La₂O₃</td>
<td>15. 177</td>
</tr>
</tbody>
</table>

- Waste loading in BSi glass: 16%. 
FeP glass immobilizing Re

\[ x\text{CeO}_2-(100-x)(36\text{Fe}_2\text{O}_3-10\text{B}_2\text{O}_3-54\text{P}_2\text{O}_5) \text{ in mol\%} \]

Photos of FeP glasses containing different amounts of Ce
FeP glass immobilizing Re

XRD patterns of FeP glasses

- Monazite (CePO$_4$) formed, when $X \geq 9$.
- Monazite is a durable phase.

FeP glass immobilizing Re

- FePO₄ formed, when X≥18.
- FePO₄ is an undurable phase.

Glass-ceramics

Motivation

Barium borosilicate glass

( improve sulfate solubility )

Zirconolite, titanite phases

( improve TRUs solubility )

Barium borosilicate glass-ceramics containing zirconolite, titanite phases

**Motivation**

- **Barium borosilicate glass**
  - Improve sulfate solubility
- **Zirconolite, titanite phases**
  - Improve TRUs solubility

**Melting-thermal treatment**

- 1200°C-3h
- $T_g<T<T_c$ -4h

Barium borosilicate glass-ceramics containing zirconolite, titanite phases
# BaBSi glass-ceramics (Nd effect)

## Composition of glass-ceramics (wt%)

<table>
<thead>
<tr>
<th>Samples</th>
<th>SiO₂</th>
<th>B₂O₃</th>
<th>Na₂O</th>
<th>BaO</th>
<th>CaO</th>
<th>TiO₂</th>
<th>ZrO₂</th>
<th>Nd₂O₃</th>
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</thead>
<tbody>
<tr>
<td>Nd–0</td>
<td>27.50</td>
<td>11.00</td>
<td>5.50</td>
<td>11.00</td>
<td>12.77</td>
<td>18.19</td>
<td>14.03</td>
<td>0</td>
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<td>Nd–2</td>
<td>26.50</td>
<td>10.60</td>
<td>5.30</td>
<td>10.60</td>
<td>12.77</td>
<td>18.19</td>
<td>14.03</td>
<td>2</td>
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<tr>
<td>Nd–4</td>
<td>25.50</td>
<td>10.20</td>
<td>5.10</td>
<td>10.20</td>
<td>12.77</td>
<td>18.19</td>
<td>14.03</td>
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<td>Nd–8</td>
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<td>9.40</td>
<td>4.70</td>
<td>9.40</td>
<td>12.77</td>
<td>18.19</td>
<td>14.03</td>
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<tr>
<td>Nd–10</td>
<td>22.50</td>
<td>9.00</td>
<td>4.50</td>
<td>9.00</td>
<td>12.77</td>
<td>18.19</td>
<td>14.03</td>
<td>10</td>
</tr>
<tr>
<td>Nd–12</td>
<td>21.50</td>
<td>8.60</td>
<td>4.30</td>
<td>8.60</td>
<td>12.77</td>
<td>18.19</td>
<td>14.03</td>
<td>12</td>
</tr>
</tbody>
</table>

## Photos of glass-ceramics

- (a) 6 wt% Nd₂O₃
- (b) 12 wt% Nd₂O₃
BaBSi glass-ceramics

XRD patterns with different contents of Nd$_2$O$_3$ 

Fluoride wastes from molten salt reactors

- MSR utilizes liquid molten fluoride salts as coolant, or even the fuel in the molten salt mixture.

- Reprocessing includes fluorination, distillation to separate uranium and other FPs from fluoride salts.

- Typical simulated fluoride wastes (mol%)
  - 18.8LiF-23.8NaF-0.1MgF₂-57KF-0.3PF(SrF₂-SrF-CeF₃)
  - 8.4CsF-8.3SrF₂-37.8SmF₃-29.7ZrF₄-15.8CeF₄

Yanbo Qiao, et al., China Academy of Sciences.
XRD patterns of FeBP glasses

- Monazite formed when CeF$_3 \geq$20 wt%.
- No crystallization when SrF$_2$ =30 wt%.
Phosphate glass encapsulated waste-form

Experimental

\[ \text{Simulated fluoride wastes} \xrightarrow{\text{sintering}} \text{Fluorapatite, syn-(Ca,Sr)\(_5\)(PO\(_4\))_3F} \]

\[ \text{Raw materials} \xrightarrow{\text{melting}} \text{Low melting phosphate glasses} \]

\[ \text{Fluorapatite crystals with hexagonal structure} \]

\[ (Ca, M)\(_5\)(PO\(_4\))_3F + MF\(_2\) \rightarrow 3(Ca, M)\(_2\)(PO\(_4\))F \]

\[ \text{Cold pressing} \xrightarrow{\text{sintering}} \text{Waste-form body} \]

\[ \text{Glass-encapsulated phosphate wasteform} \]

**XRD pattern and wasteform photo**
(SrF\(_2\) as simulant)
Works doing @ WHUT - ISG corrosion study

As-received ISG sample
Works doing @ WHUT - ISG corrosion study

Assessment of PCT (surface area)

Spheroidization unit

Coating unit

Induction plasma system (40 kW)
Works doing @ WHUT - ISG corrosion study

Assessment of PCT (surface area) – glass spheroidization

Uniform size of glass beads with smooth surface
Summary and outlooks

- HLW generated from defense program is urgent to be vitrified, and a large amount of HLW will be produced from reprocessing of spent nuclear fuel soon.

- R&D of China nuclear waste vitrification is in the preliminary stage, and is very needed, in order to construct our own vitrification facility.
Thanks for your attention and comments!

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