Impact of Nuclear Data on Design Work for High Temperature Gas-cooled Reactors

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Examples of HTGR  High Temperature Gas-cooled Reactors

**VHTR: Very High Temperature Reactor**

HTGR with outlet coolant of 950°C (1,233K),
proposed in Generation IV International Forum (GIF)

**GTHTR: Gas Turbine High Temperature Reactor**

300MWe, GTHTR-300C as the VHTR, proposed by JAEA to GIF

**HTTR:** 30MWth engineering test reactor in JAEA/Japan.
Outlet coolant upto 950°C

**HTR-10:** 10MWth experimental reactor in China.
Outlet coolant upto 700°C
HTGRs (shutdown, operating and design phase)
Generation IV International Forum: GIF

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant
# Generation IV Nuclear Energy Systems

<table>
<thead>
<tr>
<th>Generation IV System</th>
<th>Acronym</th>
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<tbody>
<tr>
<td>Gas-Cooled Fast Reactor System</td>
<td>GFR</td>
</tr>
<tr>
<td>Lead-Cooled Fast Reactor System</td>
<td>LFR</td>
</tr>
<tr>
<td>Molten Salt Reactor System</td>
<td>MSR</td>
</tr>
<tr>
<td>Sodium-Cooled Fast Reactor System</td>
<td>SFR</td>
</tr>
<tr>
<td>Supercritical Water-Cooled Reactor System</td>
<td>SCWR</td>
</tr>
<tr>
<td>Very-High-Temperature Reactor System</td>
<td>VHTR</td>
</tr>
</tbody>
</table>
Nuclear Data for HTGRs

Nuclide:

- mainly \( \text{UO}_2 \), Graphite(C), He
  - U-235, Pu-241: (n,f) and (n,g) reactions
  - U-239, Pu-239, Pu-240: (n,g) reaction
  - C: elastic and (n,g) reactions
  - B: (n,a) reaction
  - MAs (Cm-244) and LLFPs: generation and transformation

* C: up to 99 vol.% in the HTTR core

Very High Temperature:
not only Fuel, but also Coolant and Structural Materials
History of Nuclear Data in HTTR Calculation

1990-1996 HTTR design (ENDF/B-IV)
    Development of double-heterogeneous model

1996-1998 The first criticality analysis
    (ENDF/B-IV, JENDL3.1, JENDL3.2, etc)

1999-2002 Raise-to-power-up tests analysis
    (ENDF/B-IV, JENDL3.2, JENDL3.3)

2002- Safety Demonstration tests analysis (JENDL3.3)
HTTR & HTR-10

TRISO fuel (about 1mmO.D.)
in HTTR and HTR-10
GTHTR

Heat Exchanger

Reactor

Power Conversion

Reactor Core

annular core
Discrepancy of $k_{eff}$ values

- **at zero power**
  - HTTR first criticality
    - Overestimation; about $1.3\%\Delta k$
  - HTTR excess reactivity at full core
    - Overestimation; about $0.5\%\Delta k/k$

- **at power operation**
  - HTTR excess reactivity at full core
    - Underestimation; about $1.5\%\Delta k/k$

(calculation: MVP with JENDL-3.3)
keff change by JENDL3.2 to 3.3

Pin-Cell:
- about 0.6%Δk less at zero-power
- about 0.9%Δk less at power operation

Whole-Core:
- about 0.4%Δk less at zero-power
- about 0.9%Δk less at power operation

Temperature?
Temperature dependence of JENDL3.2 and 3.3

Pin-cell calculation of HTTR fuel
Temperature dependence in four-factor

![Diagram showing temperature dependence](image)

- Ratio of $k_{inf}$ ($J33/J32$)
- Temperature (K)
- ε
- f
- η
- p

Nuclear Science and Energy Directorate, HTGR Cogeneration Design & Assessment Group
2005 Symposium on Nuclear Data, February 2 - 3, 2005
Neutron Spectra

640 Groups by MVP/JENDL3.3

Neutron Energy (eV)

Lethergy flux (-)

PowerOperation

Zero Power
Temperature dependence of $\eta$

\[ \eta = \frac{\nu \cdot \Sigma_f \cdot \phi}{\Sigma_a \cdot \phi} \propto \frac{\sigma_{f}^{U235}}{\sigma_a^{U235}} \]

$\nu$: const.
$\phi$: const.
$\Sigma_a^{U235} \gg \Sigma_a^{U238}$

The diagram shows the ratio of J33/J32, neutron flux, and neutron energy (eV) with three different states: Zero Power, Power Operation, and $\sigma_{f}$. The neutron flux is plotted against neutron energy with a logarithmic scale. The graph illustrates how temperature dependencies affect these parameters.
Carbon Cross Section: Scattering

At zero power, the influence of $S(\alpha, \beta)$ on the $k_{inf}$ value is larger, about 0.3\%Δk.

At 1200K, the influence will be negligible.

$k_{inf}$ deference between free-gas and $S(\alpha, \beta)$ model for HTTR
**Carbon Cross Section: Capture**

<table>
<thead>
<tr>
<th></th>
<th>JENDL-3.3</th>
<th>ENDF/B-6.8</th>
<th>JEFF-3.0</th>
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</thead>
<tbody>
<tr>
<td>JENDL-3.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (barn)</td>
<td>4.74273</td>
<td>4.74260</td>
<td>4.74260</td>
</tr>
<tr>
<td>Elastic (barn)</td>
<td>4.73920</td>
<td>4.73924</td>
<td>4.73920</td>
</tr>
<tr>
<td>Capture (barn)</td>
<td><strong>0.00353</strong></td>
<td><strong>0.00336</strong></td>
<td><strong>0.00336</strong></td>
</tr>
</tbody>
</table>

<0.01% difference

4.8% larger than others!
Carbon Capture in HTR-10

Yasunobu Nagaya, at.al, Physor 2004
Carbon Capture in HTTR

Discrepancy of keff and nuclide data

Mionoru Goto, at. ul, ICENES 2005
Example of burn up calculation

Burn-up (days)

20,000 MWD

Previous method for HTTR design

SRAC

SRAC/MVP-BURN
JENDL3.3, JENDL3.3

DELIGHT/MVP-BURN
(ENDF/B-IV, JENDL3.3)
## GTHTR Calculation with JENDL3.3

**Kinetic of Fuel Pin Cell Calculation at B.O.C.**

<table>
<thead>
<tr>
<th></th>
<th>SRAC</th>
<th>MVP</th>
<th>Change Δk/k</th>
</tr>
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<tbody>
<tr>
<td>HTTR</td>
<td>1.3429</td>
<td>1.3497</td>
<td>-0.37%</td>
</tr>
<tr>
<td>GTHTR300</td>
<td>1.4079</td>
<td>1.3988</td>
<td>+0.46%</td>
</tr>
</tbody>
</table>
GHTR and high burn up

Concept of Super High Burn-up GHTR

- Soft spectrum : high ratio of $\phi_{th}/\phi_f$
- Lower damage (also high temperature)
- Long operation (x10 LWR)
- Simple fuel management
- Lower TRU waste (x0.1 LWR)
- High fuel economy (x2-10 MW/t-U LWR)
- Enhanced safety

Design concept as "DEEP BURN" proposed by GA/USA
Nuclear Data for Deep Burn type GHTR

Important Nuclides

- U-235, Pu-241, Pu-242
- U-238, Pu-239, Pu-240, Np-237
- Cm-244, Am-241, Am-243
- C : S(α,β), Capture, 14-C
- C, SiC, ZrC (damage)
- LLFPs, Ag
Summary

The $k_{eff}$ discrepancies between the nuclear data libraries, JENDL-3.3, ENDF/B-6.8 and JEFF-3.0, are caused 0.4%Δ$k$ by difference of graphite capture cross section, and contributions of U-235 and U-238 to the discrepancies are small as negligible. For the HTGRs annular core, there is above 1.0%Δ$k$ difference between calculations and experiments. JENDL-3.3 gives slightly better $k_{eff}$ than others.
Substantial Destruction of Transuranics Achieved in Deep-Burn MRSs

LWR spent fuel actinides

Deep Burn 1 Pass

Deep Burn 2 Pass

from LWRs DB-MHR 1P DB-MHR 2P
Np-237 4.81% 1.98% 0.17%
Pu-238 1.39% 3.94% 3.89%
Pu-239 53.00% 3.46% 0.64%
Pu-240 21.50% 8.46% 0.40%
Pu-241 7.79% 8.66% 0.44%
Pu-242 4.72% 7.92% 4.43%
Pu-243 0.00% 0.00% 0.00%
Pu-244 0.00% 0.00% 0.00%
Am-241 5.67% 0.97% 0.03%
Am-242 0.02% 0.01% 0.00%
Am-243 1.04% 1.74% 1.37%
Cm-242 0.00% 0.32% 0.06%
Cm-243 0.00% 0.01% 0.01%
Cm-244 0.00% 1.98% 6.13%
Cm-245 0.00% 0.20% 0.53%
Cm-246 0.00% 0.02% 0.35%
Cm-247 0.00% 0.00% 0.01%
Cm-248 0.00% 0.00% 0.00%

100.00% 39.70% 18.50%