High Temperature Gas-cooled Reactor: Introduction

Hans Gougar, PhD

Nuclear Engineer

NRC HTGR Training July 16-17, 2019
Modular High Temperature Gas-cooled Reactors

- Inherently safe core cannot melt
- High outlet temperature for more efficient electricity production and process heat
- Minimal radiological or dynamic coupling between the reactor and the collocated process heat application
- Environmentally benign, reliable, mature (for a non-LWR)
Electricity Fraction of Industrial Energy Use

U.S. industrial sector energy use by source, 1950–2017

Note: Includes energy sources used as feedstocks in manufacturing products. Electricity is retail purchases. Renewables are mainly biomass.
Source: U.S. Energy Information Administration, Monthly Energy Review, Table 2.4, May 2018
Some Process Heat Applications suitable for Nuclear

- Baseload Electricity
- Electricity & Process Heat
- Electricity & Actinide Management

- LWRs
- HTRs (HTGR, MSR, GFR)
- VHTR
- SFRs
### Potential Markets for Modular HTGR Steam

<table>
<thead>
<tr>
<th>Business Subsector</th>
<th>Target Industry</th>
<th>Required heat input (MWt) between 300°C and 850°C</th>
<th>Number of 150 MWt HTGRs Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum and Coal Products</td>
<td>Refineries</td>
<td>13456</td>
<td>399</td>
</tr>
<tr>
<td>Primary Metal Manufacturing</td>
<td>Iron and Steel mills</td>
<td>3225</td>
<td>226</td>
</tr>
<tr>
<td>Chemical Manufacturing</td>
<td>Basic Chemical Manufacturing (Methanol)</td>
<td>12714</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Ethyl Alcohol</td>
<td>3448</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Plastics Material and Resin</td>
<td>8780</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Alkalies and Chlorine</td>
<td>545</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Fertilizer (Ammonia)</td>
<td>2448</td>
<td>16</td>
</tr>
<tr>
<td>Food Manufacturing</td>
<td>Wet Corn Milling</td>
<td>2239</td>
<td>15</td>
</tr>
<tr>
<td>Mining (exc. oil &amp; gas)</td>
<td>Potash, Soda, Borate</td>
<td>3318</td>
<td>22</td>
</tr>
</tbody>
</table>

Cost of Energy – HTGR vs. Natural Gas


HTR and CCGT NG Electricity Production Price vs. Price of Natural Gas with and w/o carbon tax

HTR and CCNG Steam Production Price vs. Price of Natural Gas with and w/o carbon tax

$2.71 on 2/12

CCGT $50/MT CO₂ Cost

~$4/MMBtu

~$8.5/MMBtu

CCGT, No CO₂ Cost

HTGR

~$4/MMBtu

~$7/MMBtu
Relatively Mature Technology

Proof of Performance

...but the fuels, materials, and methods must be qualified for today’s market and regulatory environment

Engineering Reactors
Current Industrial Interest in TRISO-fueled power

Larger (200-625MWt) Plants for the Grid and Heat Users

Kairos Power

framatome

energy

Microreactors (5-50 MWt) Units for Off-grid, Military Power

GENERAL ATOMICS

STARCORE NUCLEAR

BWXT

HolosGen

US Ultra Safe Nuclear

Local Modular Energy
High Level Safety Design Objectives

• Meet regulatory dose limits at the Exclusion Area Boundary (EAB)
  ❯ 25 rem Total Effective Dose Equivalent (TEDE) for duration of the release from 10 CFR 50.34 (10 CFR 52.79) at EAB for design basis accidents
  ❯ EAB is typically estimated to be approximately 400 meters from the plant for a modular HTGR; supports co-location with industrial facilities

• Meet safety goals for cumulative individual risk for normal and off-normal operation

• Meet the EPA Protective Action Guides (PAGs) at the EAB as a design goal
  ❯ 1 rem TEDE for sheltering
  ❯ Design basis and beyond design basis events are considered
  ❯ Realistically evaluated at the EAB
  ❯ Emergency planning and protection
High Level Safety Design Approach

• Design using materials with properties that retain integrity at high temperature and are chemically stable
  ¢ Helium coolant – neutronically transparent, chemically inert, low heat capacity, single phase
  ¢ Ceramic coated fuel – high temperature capability, high radionuclide retention
  ¢ Graphite moderator – high temperature stability, large heat capacity, long thermal response times

• Design the reactor with inherent and passive safety features
  ¢ Retain radionuclides at their source within the fuel
  ¢ Shape and size of the reactor allows for passive core heat removal from the reactor core through the uninsulated reactor vessel
    • Heat is still removed if the system is depressurized as a result of a breach in the reactor helium pressure boundary
    • Heat is radiated from the reactor vessel to the reactor cavity cooling system (RCCS) panels and rejected passively to the environment
  ¢ Large negative temperature coefficient for intrinsic reactor shutdown
  ¢ No reliance on AC-power to perform necessary safety functions
  ¢ No reliance on operator action and insensitive to incorrect operator actions
Comments to Address Issues from NRC Review

• Training slides are organized according to previously agreed-upon agenda topics and are consistent with previous training courses; therefore, not reorganized around specific learning objectives
• NRC ML numbers have been provided in the Suggested Reading lists where they apply