Synergies Between Generation-IV and Advanced Fusion Power Plant R&D Programs

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Outline

• Background
  ➢ Gen IV Program
  ➢ Fusion Power Plant Programs

• Materials

• Environmental Impact

• Economics & Energy Products

• Summary/Recommendations
New Era of Nuclear Power Research

- Energy policy that includes nuclear fission and fusion
- Gen-IV: New vision/direction for fission research
- Funding levels rebounding
- New fusion power plant design efforts
- Return to ITER
Generation IV

- Highly economical
- Enhanced Safety
- Minimized Wastes
- Proliferation Resistance

Generation I
Early Prototype Reactors

- Shippingport
- Dresden, Fermi-I
- Magnox

Generation II
Commercial Power Reactors

- LWR: PWR/BWR
- CANDU
- VVER/RBMK

Generation III
Advanced LWRs

- System 80+
- EPR
- AP600
- ABWR

Generation IV

- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030
Generation IV

- International process to evaluate contributed concepts and develop roadmap
- Six design concepts chosen
  - VHTR – high temperature H₂ production
  - SCWR – improved economics with similar tech.
  - GFR – actinide management
  - LFR – small modular “battery”
  - SFR, MSR – greater consideration in other countries
- Fission research budget steered towards these concepts
Advanced Fusion Power Plants

- **ARIES**
  - Long history of studying many concepts including Tokamaks, Stellarators, and IFE

- **HAPL (High Average Power Lasers)**
  - Inertial fusion energy reactor design program

- **ZP3 (Z-Pinch Power Plant)**
  - Low rep-rate z-pinch driven reactor design program
Fusion & Fission Materials

- Probably most important technical obstacle
- Fusion environment has necessitated search for low activation steels tolerant to radiation damage
- Fission has had it easy, relatively...(on paper)
  - Many challenges have arisen in operation
- Gen IV fission has environment similar to fusion in many ways
## Materials

<table>
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<th></th>
<th>Fission</th>
<th>Fusion</th>
<th>Gen IV</th>
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<tbody>
<tr>
<td>Coolant</td>
<td>H₂O, CO₂</td>
<td>H₂O, He, Li, PbLi, FLiBe</td>
<td>H₂O(SC), He, Pb, PbBi, Na, FLiBe</td>
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<tr>
<td>Particle Energy</td>
<td>&lt; 1-2 MeV</td>
<td>&lt; 14 MeV</td>
<td>&lt; 1-2 MeV</td>
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<tr>
<td>Temperatures</td>
<td>&lt; 400 °C</td>
<td>300-1000 °C</td>
<td>300-1000 °C</td>
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<tr>
<td>Max. displacement damage</td>
<td>~ 200</td>
<td></td>
<td>15-200</td>
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<tr>
<td>He/dpa</td>
<td>~0.1 appm/dpa</td>
<td>10 appm/dpa</td>
<td>~0.1 appm/dpa</td>
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<tr>
<td>Stresses</td>
<td>Moderate, nearly constant</td>
<td>Moderate, nearly constant</td>
<td>Moderate, nearly constant</td>
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</table>
Computational Materials

• Experimental programs cannot provide data for breadth of materials and irradiation conditions

• Emerging multi-scale modeling capability
  - Model individual radiation-induced events
  - Model accumulation of microstructural changes
  - Model changes in engineering properties due to these changes

• Requires experimental data for validation
  - Limited resources require careful selection of experimental scenarios
Environmental Impact

• Gen IV & Fusion both recognize potential risk to environment and public health

  ➢ Safety goals and requirements

  ➢ Waste minimization

  ➢ Regulatory reform
Safety

Common safety goal/criterion

No offsite evacuation plan required

• Defined as requirement for fusion in 1996
• Defined as goal of Gen IV program in 2000
• Challenge to demonstrate and develop public and regulator confidence
Waste Minimization

• Qualitative and quantitative difference in waste streams
  
  ➢ HLW
    • Fusion has set design requirement of no HLW
    • Fission cannot avoid HLW
      – Advanced Fuel Cycle Initiative (AFCI) aims to minimize this
  
  ➢ LLW
    • Comparable quantities
  
  ➢ Clearable material
    • Some Gen IV designs will reduce fission to similar to fusion
Regulatory Framework

- Modern nuclear power plant regulation is strongly focused towards light water reactors
- Future (pre-Gen-IV) fission plants will already be driving changes
  - Changed fuel forms and source terms
  - Alternative coolants and relaxed containment requirements
- Fusion will benefit from process of change AND particular changes
Economics & Energy Products

• Similar financial profiles
  - Capital intensive
  - High operating costs - low fuel costs
  - Available for many energy products

• Future economic environment uncertain
  - Prices of competing energy sources
  - Impact of environmental regulations
  - Capital markets and interest rates
  - Relative importance of energy products
  - **Real cost of nuclear construction**
Nuclear Hydrogen

• $\text{H}_2$ identified for important role in long-term energy security

• Nuclear Hydrogen Initiative
  ➢ Research underway for high temperature thermo-chemical cycles to be coupled to high temperature fission plants
  ➢ Fusion offers similar high temperatures

• Could spark major industrial interest in nuclear technology
Summary

• Gen-IV and fusion power research programs have common goals and promise
  ➢ Energy security
  ➢ Environmental stewardship

• Gen-IV and fusion power research programs have similar obstacles and issues
  ➢ Advanced materials for extreme environments
  ➢ Regulatory reform for non-LWR reactors
  ➢ Economic uncertainties and profiles
Recommendations

• Consider Gen IV fission systems as a stepping stone to a future that includes fusion

• Increased interaction between fission and fusion communities

• Formal leveraging of common research priorities