Integral Inherently Safe Light Water Reactor (I²S-LWR) Concept

Razvoj koncepta integralnog lakovodnog reaktora s inherentnim sigurnosnim karakteristikama

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Outline

• Georgia Institute of Technology (Georgia Tech) and Nuclear and Radiological Engineering (NRE) Program

• Nuclear Power in US and Worldwide

• Development trends:
  – New construction in USA
  – SMRs and “Safety-by-Design”
  – High-temperature high-efficiency reactors

• Next generation LWRs: Integral Inherently Safe Light Water Reactor – I²S-LWR

• Concluding remarks

• Q&A
Introductory Remarks on Nuclear Power in USA and Worldwide
Worldwide use of nuclear power

- 2012: 435 reactors, 370.0 GWe (NN 3/2012)
- 2013: 433 reactors, 371.5 GWe (NN 3/2013)
- About 1/6-th world electricity
- Over 60 new reactors in 14 countries under construction (WNA, 2/2013)
- Major source of electricity in several countries

**Power Reactors by Type, Worldwide**

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th># Units (in operation)</th>
<th>Net MWe</th>
<th># Units (forthcoming)</th>
<th>Net MWe</th>
<th># Units (total)</th>
<th>Net MWe</th>
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<tbody>
<tr>
<td>Pressurized light-water reactors (PWR)</td>
<td>267</td>
<td>246 555.1</td>
<td>89</td>
<td>93 014</td>
<td>356</td>
<td>339 569.1</td>
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<tr>
<td>Boiling light-water reactors (BWR)</td>
<td>84</td>
<td>78 320.6</td>
<td>6</td>
<td>8 056</td>
<td>90</td>
<td>86 376.6</td>
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<tr>
<td>Gas-cooled reactors, all models</td>
<td>17</td>
<td>8 732</td>
<td>1</td>
<td>200</td>
<td>18</td>
<td>8 932</td>
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<td>Heavy-water reactors, all models</td>
<td>51</td>
<td>25 610</td>
<td>8</td>
<td>5 112</td>
<td>59</td>
<td>30 722</td>
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<tr>
<td>Graphite-moderated reactors, all models</td>
<td>15</td>
<td>10 219</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>10 219</td>
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<tr>
<td>Liquid-metal-cooled reactors, all models</td>
<td>1</td>
<td>560</td>
<td>4</td>
<td>1 516</td>
<td>5</td>
<td>2 076</td>
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<td><strong>Totals</strong></td>
<td><strong>435</strong></td>
<td><strong>369 996.7</strong></td>
<td><strong>108</strong></td>
<td><strong>107 898</strong></td>
<td><strong>543</strong></td>
<td><strong>477 894.7</strong></td>
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</table>

Nuclear power plants in the U.S.

- 100 operating reactors in 31 states
- Close to 20% electricity produced
- 65 PWRs, 35 BWRs
- ~102 GWe

(source: NEI)
Nuclear Power Plants – Most Expensive Electricity?
Nuclear power has low electricity production cost (lowest-cost source of electricity over the past 10+ years; it will be initially higher but still competitive for the newly constructed NPPs)

(Source: NEI)
Nuclear Power – What is New in USA?
Nuclear power plants – past/present/future

- Generation I
  - Early Prototype Reactors
  - Shippingport
  - Dresden, Fermi I
  - Magnox

- Generation II
  - Commercial Power Reactors
  - LWR-PWR, BWR
  - CANDU
  - AGR

- Generation III
  - Advanced LWRs
  - ABWR
  - System 80+
  - AP600

- Generation III +
  - AP1000
  - Evolutionary Designs Offering Improved Economics for Near-Term Deployment

- Generation IV
  - Highly Economical
  - Enhanced Safety
  - Minimal Waste
  - Proliferation Resistant

Timeline:
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030
Nuclear power – What is new in the US?

- New Gen-III+ build in US
- New/advanced designs
  - Gen-IV
  - SMRs
  - Other (I²S-LWR)
- Impact of The Great East Japan Earthquake (Fukushima)
- Push for “Accident Tolerant Fuel (ATF)” [fuel with enhanced accident tolerance…]
- Nuclear Waste – Long term considerations
  - Yucca Mountain (intended site of deep geological nuclear waste repository)
  - Interim Storage
  - Blue Ribbon Commission on America’s Nuclear Future – Final Report
- New/old fuel cycle options
  - Thorium fuel
New construction in the U.S.

- 4 new units (AP1000) under construction in USA: 2 in Georgia (Vogtle 3 and 4) and 2 in South Carolina (V.C. Summer 2 and 3); each unit 1,170 MWe
- TVA: 2 projects to complete
  - Watts Bar 2, PWR (1,180 MWe)
  - Bellefonte 1, AL (1,260 MWe), project started in 1974, suspended in 1988, 8/2011 approved, targeting 2018-2020
New construction in the U.S.

- 2 new units (AP1000) under construction in Georgia, Vogtle 3 and 4 (2x1,170 MWe)
- [Vogtle 3 and 4 Construction Photos](Georgia Power Company.pdf)
New/advanced designs

- New/advanced designs
  - “Gen-IV” (Generation IV nuclear power plants) – 6 types

- New/advanced designs pursued at GT NRE
  - SMR (Small Modular Reactors), up to several hundred MWe
    - Reduces the required investment from several billion $ to <$1B
    - Extremely high interest recently
  - I²S-LWR
    - Inherent safety features
  - Liquid-salt cooled reactors (LSCR), ORNL
    - High temperature, high efficiency, low reject heat, low pressure
  - Hybrid systems
    - high temperature nuclear + energy storage for process heat
    - Nuclear + Renewables (NuRenew)
  - Fusion-fission hybrid (Dr. W. Stacey)
Nuclear power plants – past/present/future

- Early Prototype Reactors
  - Shippingport
  - Dresden, Fermi I
  - Magnox

- Commercial Power Reactors
  - LWR-PWR, BWR
  - CANDU
  - AGR

- Advanced LWRs
  - ABWR
  - System 80+
  - AP600

- Evolutionary Designs Offering Improved Economics for Near-Term Deployment
  - AP1000

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant

Generation IV

- Gen III
- Gen III+
- Gen IV


SMRs Other?
Fukushima?
Safety?
State-of-the-art: Safe enough?

- Gen. III+ Advanced Passively Safe Nuclear Power Plants
- Safety systems operate based on laws of nature (gravity, natural circulation), thus don’t require external power, and much less likely to fail than active systems

- Is it safe enough?
- Can it be safer?

Personal perspective:
- ALWRs (and Gen-II LWRs) - extremely safe for all planned/foreseen events
- Inherent safety may (significantly?) improve response to unforeseen events (Fukushima-type scenario)
Inherent safety - examples

Small power reactors
- Large surface-to-power ratio
- Decay heat removal by conduction

Integral primary circuit configuration
- All primary circuit components within the reactor vessel
- Eliminates large external piping
- Since it does not exist, cannot break it
- No possibility for LB-LOCA
SMR
Small Modular Reactors
SMRs – Summary and Personal Perspective

• Attractive safety (in most cases promoted through integral configuration)
• Emphasis on modularity and transportability
• Power limited to a few hundred MWe
• Economic competitiveness “yet to be demonstrated”
  – “Economy of scale” impact overused as counter-argument (neglects that SMRs may use design features not accessible to large reactor)
  – Licensing cost is a real issue (but it may be overcome)

Personal perspective
• SMRs can be economical
• SMRs offer a viable option for certain markets
• One size does not fit all; certain markets favor/prefer larger units
Integral Inherently Safe Light Water Reactor (I²S-LWR)
U.S. DOE – U.S. Department of Energy

NEUP – Nuclear Engineering University Programs

IRP – Integrated Research Project

Only one Integrated Research Project awarded each year for a new reactor concept
DOE NEUP IRP: (Nuclear Engineering University Program – Integrated Research Project)

Integral Inherently Safe Light Water Reactor (I²S-LWR) Concept

IRP – DOE’s flagship research program in nuclear engineering for universities (only 1 to 3 awarded annually)

FY13 IRP solicitation requirements:
- Large PWR for US market - economics
- Inherent safety beyond Gen-III+

Multi-institutional, multi-disciplinary team: 
**Lead: Georgia Tech**
B. Petrovic (PI), NRE/ME/MSE faculty

Ten partnering organizations:
- U. of Michigan, U. of Tennessee, Virginia Tech, U. of Idaho, Morehouse
- National Lab: INL
- Industry: Westinghouse
- Utility: Southern Nuclear
- International: Politecnico di Milano, Italy; U. of Cambridge, UK
- Pending: University of Zagreb, Florida Institute of Technology

<table>
<thead>
<tr>
<th>Team Members</th>
<th>Co-PIs/Co-Is</th>
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<tr>
<td><strong>Lead</strong></td>
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<tr>
<td>Georgia Tech (GT)</td>
<td>B. Petrovic (PI)</td>
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<tr>
<td></td>
<td>F. Rahnema (Co-PI)</td>
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<tr>
<td></td>
<td>C. Deo, S. Garimella, P. Singh, G. Sjoden (Co-Is)</td>
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<td>University of Idaho (U-Id)</td>
<td>I. Charit (Co-PI)</td>
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<td>University of Michigan (U-Mich)</td>
<td>A. Manera (Co-PI)</td>
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<td>T. Downar, J. Lee (Co-Is)</td>
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<td>Morehouse College (MC)</td>
<td>L. Muldrow (Co-PI)</td>
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<td>University of Tennessee (UTK)</td>
<td>B. Upadhyaya, W. Hines (Co-PIs)</td>
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<tr>
<td>Virginia Tech (VT)</td>
<td>A. Haghighat (Co-PI), Y. Liu (Co-I)</td>
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<td>Westinghouse Electric Company (WEC)</td>
<td>P. Ferroni (Co-PI)</td>
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<td>F. Franceschini, M. Memmott (Co-Is)</td>
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<td>Southern Nuclear (SNOC)</td>
<td>R. Cocherell (Co-PI)</td>
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<tr>
<td>Idaho National Laboratory (INL)</td>
<td>A. Ougouag (Co-PI), G. Griffith (Co-I)</td>
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<td><strong>Int’l</strong></td>
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<tr>
<td>Politecnico di Milano, Milan, Italy (PoliMi)</td>
<td>M. Ricotti (Co-PI)</td>
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<tr>
<td>University of Cambridge, Cambridge, UK (U-Cambridge)</td>
<td>G. Parks (Co-PI)</td>
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<tr>
<td><strong>Consultant</strong></td>
<td>H. Garkisch</td>
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# I²S-LWR concept – Top level requirements

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<thead>
<tr>
<th>Requirement</th>
<th>Target</th>
<th>Comment</th>
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<tbody>
<tr>
<td><strong>APPLICATION-DRIVEN REQUIREMENTS</strong></td>
<td></td>
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<tr>
<td>Power</td>
<td>&gt;910 MWe</td>
<td>1,000 MWe</td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td>For markets preferring large plants</td>
</tr>
<tr>
<td>Electricity production efficiency</td>
<td>&gt;32%</td>
<td>35%</td>
</tr>
<tr>
<td>Electricity production efficiency</td>
<td></td>
<td>Competitiveness; reduced reject heat</td>
</tr>
<tr>
<td>Design lifetime</td>
<td>60 years</td>
<td>100 years</td>
</tr>
<tr>
<td>Design lifetime</td>
<td></td>
<td>Competitiveness; economics, sustainability</td>
</tr>
<tr>
<td>Reactor pressure vessel</td>
<td>Same size as or smaller than current large PWRs</td>
<td></td>
</tr>
<tr>
<td>Reactor pressure vessel</td>
<td></td>
<td>Manufacturability</td>
</tr>
<tr>
<td><strong>FUEL-RELATED REQUIREMENTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel/cladding system</td>
<td>Enhanced accident tolerance*</td>
<td></td>
</tr>
<tr>
<td>Fuel enrichment</td>
<td>Viable reloading with &lt;5% enriched fuel</td>
<td>Improved fuel cycle with 5-8% enriched fuel</td>
</tr>
<tr>
<td>Fuel enrichment</td>
<td></td>
<td>Option to use existing infrastructure for &lt;5% enrichment</td>
</tr>
<tr>
<td>Refueling</td>
<td>Multi-batch, refueling interval 12 months or longer</td>
<td>Options for 12-18-24 months refueling</td>
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<tr>
<td>Refueling</td>
<td></td>
<td>Offer longer cycles when required by utilities</td>
</tr>
<tr>
<td><strong>SAFETY AND SECURITY</strong></td>
<td></td>
<td></td>
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<tr>
<td>Security, safeguards and proliferation resistance</td>
<td>As in current LWRs or better</td>
<td></td>
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<tr>
<td>Safety indicators</td>
<td>CDF &lt;3x10⁻⁷</td>
<td>CDF &lt;1x10⁻⁷</td>
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<tr>
<td>Safety indicators</td>
<td>LERF &lt;3x10⁻⁸</td>
<td>LERF &lt;1x10⁻⁸</td>
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<tr>
<td>Safety indicators</td>
<td></td>
<td>Improve safety indicators relative to current Gen-III+ passive plants</td>
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<tr>
<td>Safety philosophy/systems</td>
<td>Inherent safety features</td>
<td></td>
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<tr>
<td>Safety philosophy/systems</td>
<td>Full passive safety</td>
<td></td>
</tr>
<tr>
<td>Safety philosophy/systems</td>
<td>High level of passivity</td>
<td></td>
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<tr>
<td>Safety philosophy/systems</td>
<td></td>
<td>Eliminate accident initiators    Eliminated need for offsite power in accidents</td>
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<tr>
<td>Grace period</td>
<td>At least 1-week</td>
<td>Indefinite for high percentage of considered scenarios</td>
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<tr>
<td>Decay heat removal</td>
<td>Passive system with air as the ultimate heat sink</td>
<td>Resistance to LOOP and Fukushima-type scenarios</td>
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<tr>
<td>Seismic design</td>
<td>Single compact building design</td>
<td>Seismic isolators</td>
</tr>
<tr>
<td>Seismic design</td>
<td></td>
<td>Allows siting at many locations</td>
</tr>
<tr>
<td>Other natural events</td>
<td>Robust design</td>
<td></td>
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<tr>
<td>Other natural events</td>
<td></td>
<td>Address unforeseen events</td>
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<tr>
<td>Monitoring</td>
<td>Enhanced, in normal and off-normal conditions</td>
<td>Address Fukushima issues with SFP</td>
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<tr>
<td>Spent fuel pool safety</td>
<td>Monitoring</td>
<td></td>
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<tr>
<td>Spent fuel pool safety</td>
<td>Passive cooling</td>
<td></td>
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<tr>
<td>Spent fuel pool safety</td>
<td></td>
<td>Remove reliance on repository availability at certain date</td>
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<tr>
<td><strong>DEPLOYMENT REQUIREMENTS</strong></td>
<td></td>
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<tr>
<td>Economics</td>
<td>Competitive with current LWRs</td>
<td></td>
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<tr>
<td>Deployment</td>
<td>Near-term: 5% enriched fuel</td>
<td>Long-term option: up to 8% enriched silicide fuel</td>
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<tr>
<td>Deployment</td>
<td>Option: use of oxide fuel</td>
<td>Path to accelerated deployment</td>
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<tr>
<td>Operational flexibility</td>
<td>2-batch and 3-batch, ≥12-month cycle</td>
<td>5% and 8% 12-18-24 months cycle</td>
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<tr>
<td>Operational flexibility</td>
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<td>Diverse market needs</td>
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<tr>
<td>Operational flexibility</td>
<td></td>
<td>Reduced effluents (environmental)</td>
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<tr>
<td>D&amp;D</td>
<td>Easily returned to green site</td>
<td>Sustainability and public acceptance</td>
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</table>
I^{2}S-LWR Concept Overview
I²S-LWR approach to advanced, safe and economical nuclear power plant (extending SMR safety concept to large plants)

Advanced, passively safe, large loop LWRs
- Demonstrated economics

Integral configuration SMRs
- Credible
- Inherent safety features

I²S-LWR
- Large (GWe-class) LWR
- Economics
- Inherent safety features
- Addresses Fukushima concerns

Fully passive DHRS
- Extended to indefinite coping time
- Enhanced accident tolerance fuel
- Seismic isolators (compact design)
I²S-LWR concept - design objectives – what and how?

- **Economics**
  - Large (1 GWe-class)
    » Compact core
    » Compact integral HX

- **Inherent safety features**
  - LWR of integral design

- **Fukushima concerns and lessons learnt**
  - Indefinite passive decay heat removal
    » Natural circulation
    » Rejection to ambient air

- **Fuel with enhanced accident tolerance**
  - Silicide or nitride (high conductivity)
  - Advanced steel cladding (reduced oxidation at high temperatures)

- **Enhanced seismic resistance**
  - Seismic isolators
Main challenges (i.e., why not already done?)

Compared to current PWRs:
• Integral configuration → compact core
• Compact core → higher power density core
• Yet, aiming at more accident tolerant fuel
• Requires novel fuel/clad design → require major testing and licensing efforts

• Primary HX inside the vessel
• SMR power in such configuration limited to a few hundred MWe
• Requires novel design of several key components
  – Primary HX
  – …
I²S-LWR approach to advanced, safe and economical nuclear power plant (extending SMR safety concept to large plants)

Advanced, passively safe, large loop LWRs
Demonstrated economics

Integral configuration SMRs
Credible
Inherent safety features

I²S-LWR
Large (GWe-class) LWR
Economics
Inherent safety features
Addresses Fukushima concerns

Fully passive DHRS
Extended to indefinite coping time
Enhanced accident tolerance fuel
Seismic isolators (compact design)

Key enabling technologies

Technologies developed for SMRs:
• Integral layout
• Integral primary components

I²S-LWR specific, novel technologies:
• High power density fuel/clad system (silicide fuel)
• High power density (micro-channel type) primary HX mC-PHX
• Steam Generation System (mC-PXH + Flashing Drum)
Additional design features/challenges
(a.k.a. the devil is in the “details”)

- Reactor pressure vessel size
- High power density core (flow, vibrations, …)
- Feasibility of compact HX for nuclear application and this power level (likely feasible, but is it practical/economical?)
- Licensing of a new fuel form/design
- Demonstration of the novel decay heat removal concept
- Integrating/harmonizing all components and systems
Enabling Technologies
Key enabling technologies

Technologies developed for SMRs
- Integral layout
- Integral primary components

I²S-LWR specific
- High power density fuel/clad system
- High power density primary HX
- Innovative steam generation system (SGG)
Rationale and selected options for fuel/cladding materials and geometry configuration

• Fuel
  • High-conductivity fuel
  • High HM load

• Cladding
  • Reduced oxidation rate

• Primary choice: Silicide \((U_3Si_2 + \text{advanced FeCrAl ODS})\)
Fuel Pellet Materials

- Higher U loading of $\text{U}_3\text{Si}_2$ vs. $\text{UO}_2$ enables acceptable cycle length at higher specific power and improves fuel management
- Better thermal conductivity lowers T and stored fuel energy
- Swelling = ?

<table>
<thead>
<tr>
<th>Fuel</th>
<th>$\text{U}_3\text{Si}_2$</th>
<th>$\text{UO}_2$</th>
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<tbody>
<tr>
<td>Theoretical density (g/cm$^3$)</td>
<td>12.2</td>
<td>10.96</td>
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<tr>
<td>HM Theoretical density (g/cm$^3$)</td>
<td>11.3</td>
<td>9.66</td>
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<tr>
<td>Thermal conductivity (unirradiated) (W/m K)</td>
<td>9-20</td>
<td>5-2</td>
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<td></td>
<td>(300-1200°C)</td>
<td>(300-2000°C)</td>
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<tr>
<td>Specific heat J/kg K</td>
<td>230-320</td>
<td>280-440</td>
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<tr>
<td></td>
<td>(300-1200°C)</td>
<td>(300-2000°C)</td>
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<tr>
<td>Melting point °C</td>
<td>1665</td>
<td>2840</td>
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Innovative steam generation system (SGG)

- Integral compact primary HX
  - Microchannel HX
  - High power density

- Combined with external steam drum
I2S-LWR Layout
Integral configuration:
- Primary coolant circulates within RPV only
- All primary circuit components (except main pumps) located within the RPV
- 4 SGG subsystems (2 paired modules each): Primary heat exchangers (inside RPV) and flashing drums (outside RPV, inside containment)
- 4 full passive DHRS
I²S-LWR Reactor Layout
Integral Configuration

3-D printed mockup 1:30 scale
Examples of a Student Senior Design Project: I²S-LWR Integral vessel layout, 3D CAD model

Devised layout, developed 3D CAD model, printed in 1:30 scale (80 cm tall)
Core layout and fuel assembly design

- 121 assemblies core configuration, steel radial reflector
- 12 ft active fuel height
- Similar to 2-loop cores but with ~40% higher power rating
- 19x19 assembly, 0.360” fuel rod OD, p/d=1.325

<table>
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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Lattice type</td>
<td>19×19, square</td>
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<tr>
<td>Fuel type</td>
<td>U₃Si₂</td>
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<tr>
<td>Cladding material</td>
<td>Advanced SS</td>
</tr>
<tr>
<td>Fuel rods per assembly</td>
<td>336</td>
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<tr>
<td>Fuel rod outer diameter (mm)</td>
<td>9.144</td>
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<tr>
<td>Cladding thickness (mm)</td>
<td>0.406</td>
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<tr>
<td>Pellet-clad gap width (mm)</td>
<td>0.152</td>
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<tr>
<td>Pellet outer diameter (mm)</td>
<td>8.026</td>
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<tr>
<td>Pellet inner void diameter (mm)</td>
<td>2.540</td>
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<tr>
<td>Fuel rod pitch (mm)</td>
<td>12.106</td>
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<td>Assembly pitch (mm)</td>
<td>231</td>
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</table>
Core Concept (5% enrich)

Scoping study on fuel assembly level
- UO$_2$ (17x17) or U$_3$Si$_2$ (19x19) fuels
- SS and Zirc-4 Clad
- Evaluated Fuel Cycle Impact on selections
- Included soluble boron and IFBA coatings
- Tentative core design:
  - 19x19 assembly with U$_3$Si$_2$ fuel
  - 2850 MWth

...also 5-8% enrichment analyzed: longer cycle (>2 years)
**Fuel Management Schemes for $^{129}$S-LWR**

### 3-batch core with 40 Feed/Reload

- Full 3-D depletion/reshuffling analysis to equilibrium cycle
- 3-batch /40 Feed -> 3 irradiation cycles before discharge (better fuel use)
- 2-batch /60 Feed -> 2 irradiation cycles before discharge (longer cycle)
- Higher BU fuel assemblies on the periphery (VLLLP)

### 2-batch core with 60 Feed/Reload

- [Diagram of 2-batch core with 60 Feed/Reload]
Fuel cycle

- Westinghouse evaluated a number of options:
  - 17x17 and 19x19
  - 5% and 8%
  - 12-18-24 months refueling interval

- Viable options:
  - up to 5% enriched, 12/18-month refueling
  - up to 8% enriched, 12/18/24-month refueling

- FCC
  - Seems within acceptable range
Fuel/cladding system
Economics justification of I²S-LWR

New fuel/clad system is enabling technology, aiming to:
• Enable high power density core
• Enable more compact NPP footprint
• Enhance safety

Resulting in economic advantages and disadvantages:
• Neutronics: FCC increased by 15-20%
• More compact NPP layout: capital cost reduced by ?%
• Inherent safety features: some safety systems potentially eliminated, capital cost reduced by ?%

Thus, the trade-off is:
• Reduced capital cost (front-loaded, main portion of COE)
• Increased subsequent FCC
Safety goals and philosophy

MULTIPLE LINES OF DEFENSE

First line of defense – inherent safety features (eliminate/limit event initiators/precursors)
- Integral primary circuit eliminates occurrence of LBLOCA/IMLOCA and CR ejection
- Seismic insulator eliminate/limit the impact of seismic events
- Partial burying of containment and underground placement of SFP eliminate/limit external events

Second line of defense - prevention
- All safety systems are passive with a high degree of passivity and deterministically address DBAs (prevent core damage)

Third line of defense - mitigation
- Integral configuration with small penetrations limit loss of RPV inventory
- Fuel with enhanced accident tolerance extend grace period
- Passive DHRs extend grace period (potentially indefinitely)
- DPRA-guided design utilizes passive and active systems

Fourth line of defense - protection
- Containment vessel cooling by air or other medium in natural circulation regime
Safety goals and philosophy

- As high level of passivity as possible
- Eliminate accident initiators as far as achievable
- Limit loss of inventory during LOCAs
Safety Systems

- Passive DHRS (Decay Heat Removal System)
- PHX (mC-HX) as passive heat removal system
- HHIT (High Head Injection Tanks)
- Passive containment cooling
Passive Decay Heat Removal System

Goal: long term self-sustained decay heat removal capabilities with no need for intervention in case of an accident, including loss of external power

- Passive, natural circulation
- Ultimate heat sink – ambient air
- Four units, sized for 3 of 4
- Target: indefinite heat removal
Comparison to current large loop PWR

**Similar:**

- Core geometry as 2-loop PWR (121 fuel assemblies)
- Fuel assembly similar to 17x17 PWR fuel assembly
- Core internals and control rods
- Secondary and BOP
- Pumps

**Different**

**CORE:**
- Higher power density (10-30% higher)
- Different fuel form (silicide, …)
- Enrichment potentially increased (up to 8%)
- Different cladding materials (advanced DS steel)
- Potentially different fuel geometry
- [radial reflector]

**INTEGRAL PRIMARY CIRCUIT:**
- Larger reactor vessel (RV)
- PHE (primary heat exchanger) inside RV
- CRDM inside RV
- PZR integrated in RV

**COMPONENTS/SYSTEMS:**
- Compact PHE (micro-channel PHE)
- DHRS (decay heat removal system)
  - Natural circulation
  - Ambient air ultimate heat sink
- Seismic isolators

**SAFETY:**
- Passive → inherent (features)
Summary

- New I²S-LWR concept aims to extend inherent safety features of SMRs to larger power level reactors
  - Large (~1,000 MWe) PWR
  - Integral configuration
  - Inherent safety features
  - Novel fuel design, components, etc.

- Multi-disciplinary, multi-organization project

- Great opportunity for students to participate in the cutting edge research with involvement of industry and national lab
  (Example: GT - senior design class, 45 students in 2013; ~30 expected in 2014)
  Significant leveraging of DOE funding

- Exciting project – developing potentially the next generation of PWR
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Thank you for your attention!