I^2S-LWR

Integral Inherently Safe Light Water Reactor

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IRP

Integral Inherently Safe Light Water Reactor – I^2S-LWR

DOE NEUP IRP
3-year program; recently started

IRP FOA requirements:
- Large (~1,000 MWe) PWR for US market - economics
- Inherent safety

Multi-institutional, multi-disciplinary:

Lead: Georgia Tech (B. Petrovic, PI)
Ten other partnering organizations:
Universities: U. of Michigan, U. of Tennessee, Virginia Tech, U. of Idaho, Morehouse College
National Lab: INL
Industry: Westinghouse and Utility: Southern Nuclear
Int'l (U. of Cambridge, UK; Politecnico di Milano, Italy)

Concept Requirements (excerpted from DOE solicitation)

- "This IRP should focus on larger (around 1000 megawatt electric) light water reactor designs…"
- ".. that further improve the performance and inherent safety compared to existing Generation III+ light water reactor systems."
- "In addition to safety and reliability, consideration should be given to improved performance compared to existing Generation III+ designs with respect to each of the Generation IV performance goals, including sustainability (fuel utilization/waste minimization), economics, proliferation resistance, and physical protection."

I2S-LWR Approach

Advanced, passively safe, large LWRs

Demonstrated economics

+

Inherently safe SMRs

Inherent safety

Economics (through modularity)

yet to be demonstrated

→

I^2S-LWR

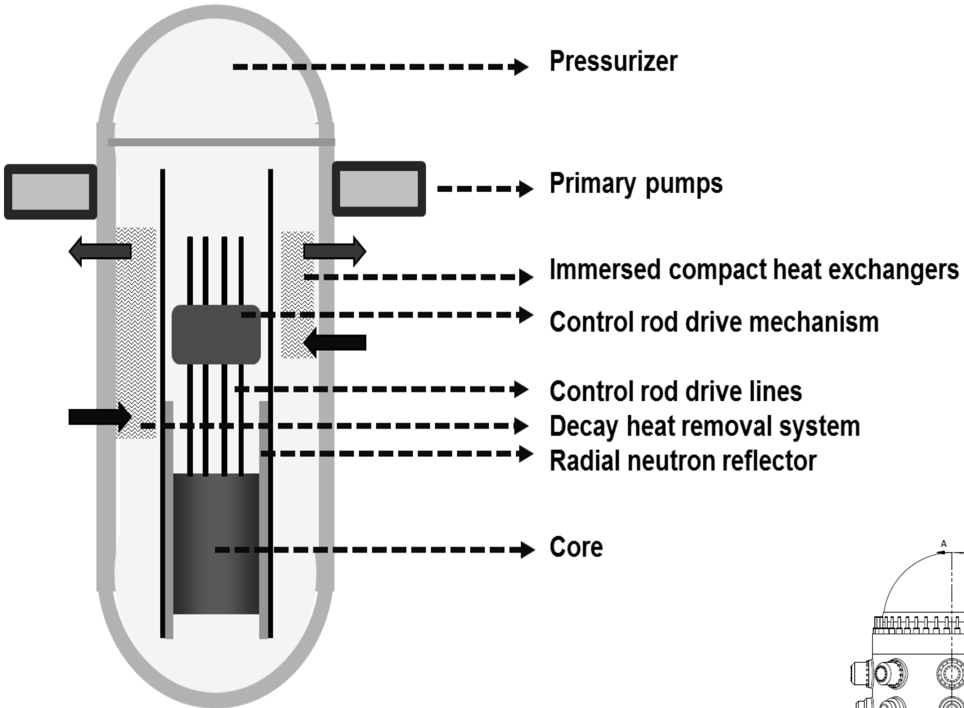
Integral inherently safe LWR

- 1,000 MWe class (economics)
- Integral primary circuit
- Inherent safety features
- Indefinite passive decay heat removal (under LOOP)
- Seismic isolators

+

Fuel with Enhanced Accident Tolerance

Reactor Layout

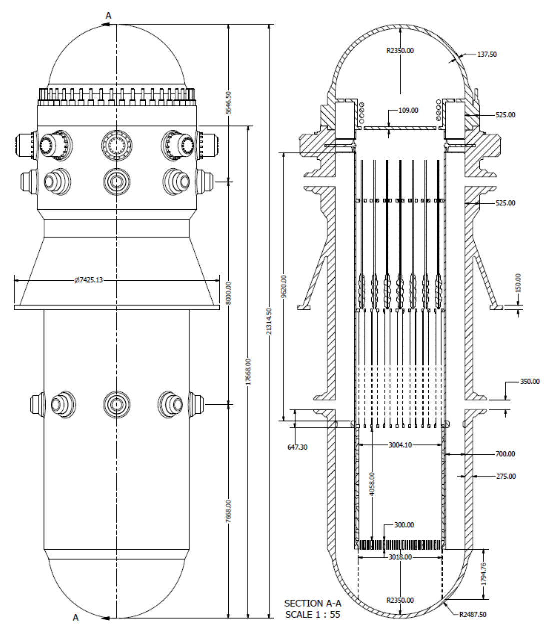


Core:

- Similar to 2-loop PWR core
- 121 FA, 12-ft active
- 19x19 square lattice
- cylindrical fuel rods
-

Main difference to 2-loop PWR

- ~700 MWe → ~1,000 MWe



Challenge

Compared to current PWRs:

- Higher power density core
- Yet, aim to have more accident tolerant fuel

Note that in this IRP project:

- ATF is not the only objective of the project
- E-ATF cannot be addressed at the same level of depth/detail as in IRPs devoted to ATF
- Aim to maximize synergy and use results of other DOE-funded projects

I2S-LWR Fuel/Cladding System

Fuel/cladding system - rationale

Fuel
- High-conductivity fuel
- High HM load

Cladding
- Primary choice – advanced steel
  (not coated cladding, not SiC - examined by other groups)
- Advanced steel – strength, reduced oxidation rate
- Leverage results of other projects
- Use/update as results of other IRPs become available
  (coated cladding not excluded)

→ U_3Si_2 fuel + advanced steel cladding

Selected options for fuel/cladding materials and geometry configuration

	Primary choices	Secondary choices
Fuel material	U_3Si_2	Grain-coated $U^{15}N$ (coating: U_3Si_2)
Cladding material	Advanced steel (e.g., ODS FeCrAl)	SiC composite
Fuel geometry	Pellets or slugs, w/ or w/o central void	Petal-shape pellets
Lattice type	Square	Hex

Fuel/cladding system
Economics justification in I2S-LWR

I^2S–LWR

New fuel/clad system is enabling technology, aiming to:

- Enable high power density core
- Enable more compact NPP footprint
- Enhance safety

Resulting in:

- Neutronics: FCC increases 15-20%
- More compact NPP layout: capital cost reduced
- Inherent safety: some safety systems potentially eliminated, capital cost reduced

Thus, the trade-off is:

- Reduce capital cost (front-loaded, main portion of COE)
- Increase subsequent FCC

Experimental Programs

- Two experimental campaigns will be performed in support of the fuel/clad design:
  - one will be focused on the fretting wear resistance and mechanical properties of the candidate materials selected for the cladding
  - one will be aimed at investigating thermo-physical properties of silicide fuels and their behavior when interacting with air/water/steam

Considering to add tests:

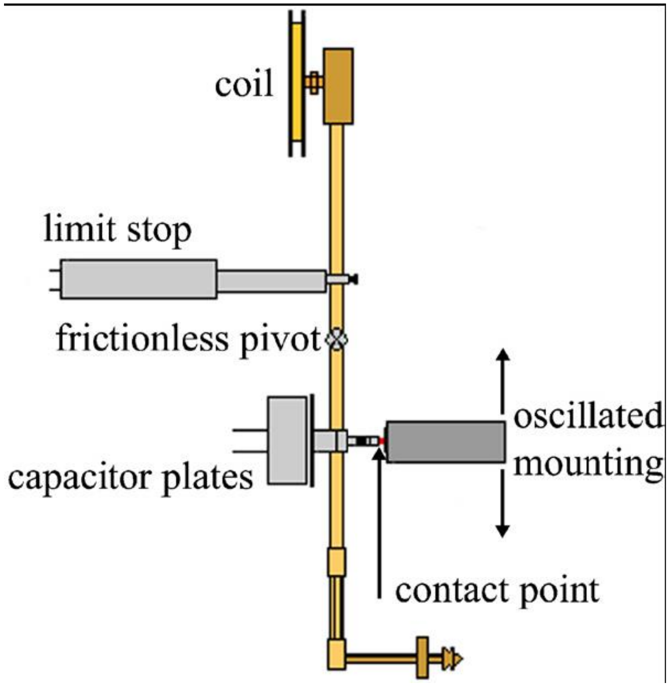
fuel/clad diffusion

silicide irradiation/swelling test

Experimental Program: Cladding (Georgia Tech) Nanoscale tests of fretting wear resistance of Zircaloy, advanced steels and SiC

- The Nanoindenter at Georgia Tech will be used to perform the nano-fretting testing. Cladding materials will be tested: Zircaloy, SiC, and advanced steels
(high power density→increased coolant flow rate→potentially increased fretting wear)

- Nano-fretting is an accelerated reciprocating wear test, which allows oscillation of sample while applying a known load. It differs from conventional wear testing (carried out using the nano-scratch and wear module) as it uses a large radius spherical probe, giving low contact pressures. It is a high cycle test, with up to 1 million cycles in one experiment, and it uses very small amplitude oscillations, allowing reproduction of true-fretting (partial slip) to nano-wear (full slip)



Schematic diagram of the oscillated nanoindentation arrangement (Wilson et al., 2008)

Experimental Program: Cladding (U. Idaho)
Mechanical Properties of advanced steels, SiC and Zircaloy

- While a wealth of information on mechanical properties exists for the considered materials, not all data needed for this project are available.

- To fill gaps in available data, high temperature tensile tests and low cycle fatigue tests of SiC and advanced steel sheets will be performed.

- Zircaloy will also be tested to provide the reference case. The equipment used will be an ATS 2335 Creep Tester that can perform tensile creep testing up to 1000°C in air.

Experimental Program: Fuel / Uranium silicide

Thermal analysis

- Using the U-Si phase diagram as a guide, some thermo-physical properties of uranium silicide will be investigated.
- These will include the changes in phase, as well as the effect of temperature on non-stoichiometry.
- A simultaneous thermal analysis unit (STA Q600) connected to a mass spectrometer is available for this purpose.
- Of interest will be the stoichiometry of the intermetallic as a function of temperature: specifically, thermogravimetric analysis will be used to determine the change in mass associated with the appropriate stoichiometric ratios.

U_xSi_y corrosion testing

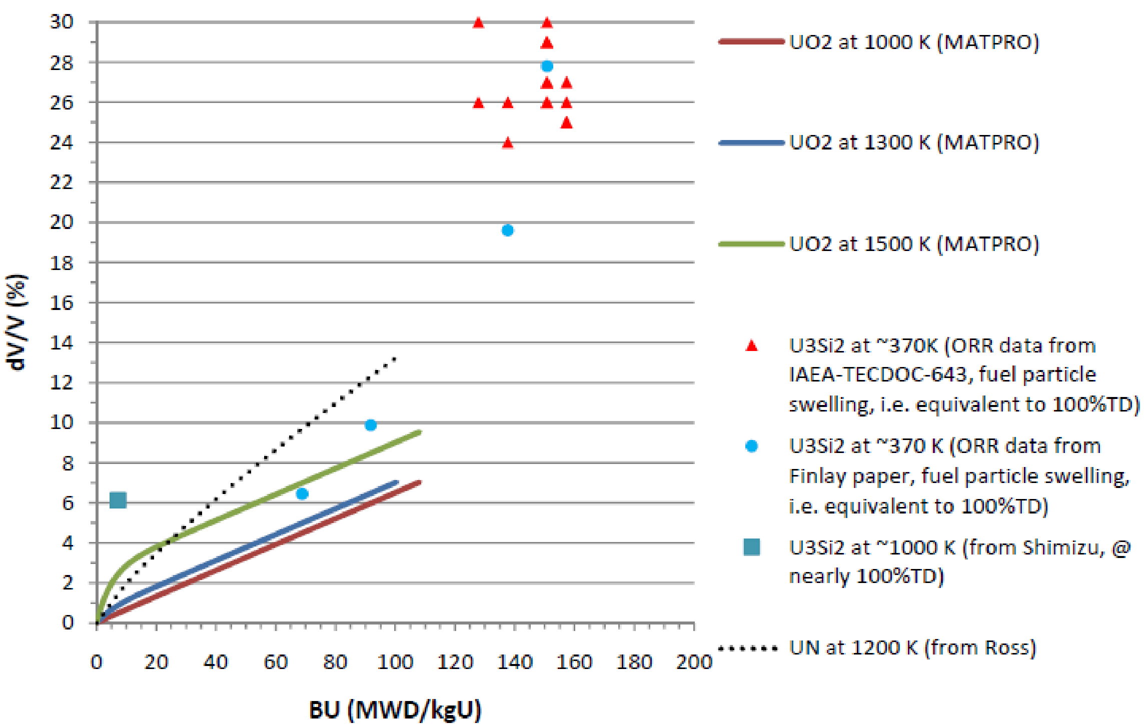
- To study performance under steam/water exposure, tests will be done in air/steam environments.
- Oxidation tests will be carried out under dry air and air/steam environments at temperatures ranging from 300ºC to 1200ºC using Cahn thermogravimetric analysis (TGA) or thermal balances, where the kinetics of oxidation reactions will be determined.
- Samples will be exposed under these conditions for up to 150 hours after which they will be removed from the furnace and characterized for the corrosion extent and products. Various U_xSi_y stoichiometries will be used.
- Two Cahn D101 microbalances are available at GT to the project, with an accuracy of 10^{-6} g, to study kinetics of corrosion reaction under each condition. Weight change values will be used to determine the possible reaction mechanisms and corrosion kinetics.

Irradiation-induced fuel swelling

Need data at representative PWR temperature and discharge burnup
However, for U_3Si_2 available experimental data are only at:

- high temperature BUT low burnup (square marker below);
- high burnup BUT low temperature (triangle and circle markers below)

Obtain data from ATR irradiation? (Other projects and/or add to this IRP)



U_3Si_2-cladding diffusion

OBJECTIVE: investigate compatibility of U_3Si_2 with various cladding materials by testing the mutual diffusion of the respective species when fuel and cladding samples are put in contact

Planning to add this test

Summary

- IRP focused on reactor design,
with E-ATF as one of its objectives
- Limited fuel/clad development/testing

Plan

- Database of relevant properties, identify gaps in data to properly choose tests
- Establish design constraints
- Establish reference design

- Refine/perform experiments: on cladding, on fuel
- Add fuel/cladding diffusion tests
- Irradiation of U_3Si_2 in ATR to obtain critically needed data including swelling (coordinated with other projects)