UCS Perspectives on NRC Licensing of Advanced Reactors and Fuels

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"Advanced" Isn't Always Better
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- New UCS report documents serious safety and security issues with non-light-water reactor (NLWR) designs
- Our research does not substantiate the notion that any NLWR we considered
  - meets the Advanced Reactor Policy Statement's expectation for enhanced safety margins
  - warrants the broad weakening of regulatory standards that the NRC is considering

ARDP goal: commercial reactors

- The Congressionally mandated timeline for startup of NRC-licensed facilities under the Advanced Reactor Demonstration Program (ARDP) by 2027 is very aggressive
  - ARDP calls for commercial demonstration plants
  - Clear implication is that the purpose of these facilities will be to produce electrical power and serve as models for subsequent commercial units
    - Chris Levesque (TerraPower): “A big piece of the private investment will be the revenue stream” (NIC Summit, 3/23/21)
    - Clay Sell (X-Energy): “We are demonstrating a full-scale commercial plant just like the plant we will sell …” (Senate testimony, 3/25/21)

NRC licensing of demonstration reactors

- But the NRC has not yet determined whether the criteria of 10 CFR 50.43(e) can be satisfied for a DC, COL, or OL without "acceptable testing" of prototype plants for either the Natrium SFR or Xe-100 HTGR designs
- During preapplication reviews in the 1990s, the NRC expected prototype testing for both SFRs and HTGRs
- If the NRC does decide prototype testing is necessary, it must soon determine what additional safety features the prototypes will need, and for how long
- The NRC must base its licensing timetable on its statutory obligation to protect public health, safety, and security—and should not compromise its standards to meet an arbitrary and unrealistic schedule imposed by Congress

Need for prototype testing

- UCS does not believe that the ARDP designs are mature enough to be safely, securely, and reliably deployed as commercial power reactors on the current schedule
  - Applies to basic designs as well as fuels and materials
- Past demonstration reactors were not sufficiently representative of currently proposed designs to provide adequate support for NRC licensing decisions: thus prototype testing will be needed
- Premature commercial deployment poses safety risks with regard to
  - reluctance to carry out required testing that might affect revenue
  - the impact of grid requirements on reactor operation (e.g. flexible power operations at Columbia Generating Station)

SFR design comparison

	EBR-II	Natrium
Power level	62.5 MWth	840 MWth
Driver fuel	HALEU (19% U-235)	HEU (50-80% U-235)
Blanket fuel	Yes	No
Sodium void worth	negative	positive
Primary coolant pumps	centrifugal (+ 1 auxiliary electromagnetic)	electromagnetic only
Emergency shutdown cooling	Direct Reactor Auxiliary Cooling System	Reactor Vessel Auxiliary Cooling System

The myth of SFR passive safety

- "The positive sodium void worth is a concern in the passive safety argument. Because of it, one must qualify any characterization of the PRISM response as "passively safe" by pointing out that this is conditional on the sodium remaining below the boiling temperature. Should sodium boiling begin on a core-wide basis under failure-to-scram conditions, the reactor would be likely to experience a severe power excursion." – NUREG-1368

NUREG-1368 on the need for a PRISM prototype

- "The DOE/GE approach for the PRISM is to build a prototype reactor test facility … given the uncertainties in the reactivity feedbacks and the degree to which these feedbacks are dependent on the design of the reactor, this is clearly the preferred approach."
- "Similarly, the review of a design without a conventional containment building was based on a mechanistic analysis of a range of probability events and on the potential for demonstrated capability of the design (via prototype testing) to perform as predicted."

HTGR design comparison

	THTR	Fort St. Vrain	Xe-100
Power level	750 MWth	840 MWth	200 MWth (x4)
Reactor type	Pebble-bed	Prismatic-block	Pebble-bed
Fuel type/ composition	BISO $(Th,U)O_2$	TRISO $(Th,U)C_2$	TRISO UCO
U enrichment	HEU	HEU	HALEU (15.5% U-235)
Average burnup	< 6%	~ 13% (fissile)	> 17%
Emergency shutdown cooling	Active	Active	Passive (Reactor Cavity Cooling System)
Pressure vessel	prestressed concrete	prestressed concrete	steel

Xe-100 violates well-established safety limits

- Peak fuel temperature following an HTGR depressurized loss-of-coolant accident must remain below 1600°C to ensure TRISO fuel integrity
- However, this temperature limit is apparently exceeded for the 200 MWth Xe-100

Table 2
Comparative overview: Xe-100 reference and performance parameters.

	Units	Xe-100	
Design Parameters:			
Thermal power rating	MW	165	200
Core diameter	m	2.4	2.4
Average core height	m	8.93	8.93
Core volume	m^3	41.343	41.343
Average burn-up	MWd/t_{HM}	165,000	164,000
Fueling regime (# of passes)		6	6
Avg. residence time in core	EFPD*	1,549	1,273
Number of fueling zones		1	1
Moderation ratio (avg. in core)	N_C/N_U	551	551
Number of fuel spheres		223,000	223,000
Calculated thermal performance:			
Power peaking factor	Q_{max}/Q_{avg}	3.55	3.14
Max. power rating of fuel sphere	kW/FS	2.62	3.50
Avg. core power density	MW/m^3	3.99	4.84
Packing of the pebble bed	Pebbles/m^3	5,394	5,394
Primary coolant temperatures	°C	260/750	260/750
Mass flow	kg/s	64.9	78.6
Primary system pressure	MPa	6.0	6.0
Max. fuel temp during:			
*Normal operation (9.6% core bypass flow** assumed)*	°C	886	873
DLOFC (nominal ± 20 °C)	°C	1,561	1,711

Mulder, E.J., and W.A. Boyes. 2020. "Neutronics Characteristics of a 165 MWth Xe-100 Reactor."
Nuclear Engineering and Design 357: 110415.

NUREG-1338 on the need for an MHTGR prototype

- "Based on judgments of the adequacy of existing operating experience, the novel design features proposed, and the status of the present technology base, the staff requires that testing and operation of a prototype test reactor, located at an isolated site, be mandatory before design certification."
- "Acceptance of a design without a containment building … would require demonstration via a full-size prototype test at an isolated site of the fission product-retention capability of the design."

Regulatory engagement plans

- "A Regulatory Review Roadmap for Non-Light Water Reactors" (December 2017):
  - "Prospective developers and applicants are encouraged to work as early as possible with the NRC to clearly define the testing to be performed in a prototype plant, including expected results and associated criteria, and to determine how to address the licensing of a prototype plant and prototype testing in the regulatory engagement plan."
- If the NRC has not already done so, it should immediately begin this discussion with the ARDP participants to address the need for prototype testing

Recommendations

- The NRC should define the additional design features that both ARDP demonstration plants must have to ensure public health and safety during the prototype testing phases
- Both the Natrium and Xe-100 (first module) FOAK units should include
  - Conventional leak-tight containment buildings
  - Safety-grade emergency diesel generators
  - Active emergency cooling systems

Acronyms

- **ARDP: Advanced Reactor Demonstration Program**
- **FOAK: First of a Kind**
- **HALEU: High-Assay Low Enriched Uranium**
- **HEU: Highly Enriched Uranium**
- **HTGR: High-Temperature Gas-Cooled Reactor**
- **PRA: Probabilistic Risk Assessment**
- **SFR: Sodium-cooled Fast Reactor**
- **TRISO: Tristructural Isotropic**
- **UCS: Union of Concerned Scientists**