INL/MIS-21-62424-Revision-0

Changing the World's Energy Future

Modular High Temperature Gas-Cooled Reactor: Licensing Part III

April 2021

Jason Albert Christensen

Idaho National Laboratory

INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC

INL/MIS-21-62424-Revision-0

Modular High Temperature Gas-Cooled Reactor: Licensing Part III

Jason Albert Christensen

April 2021

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Modular High Temperature Gas-Cooled Reactor: Licensing III

CNSC Seminar

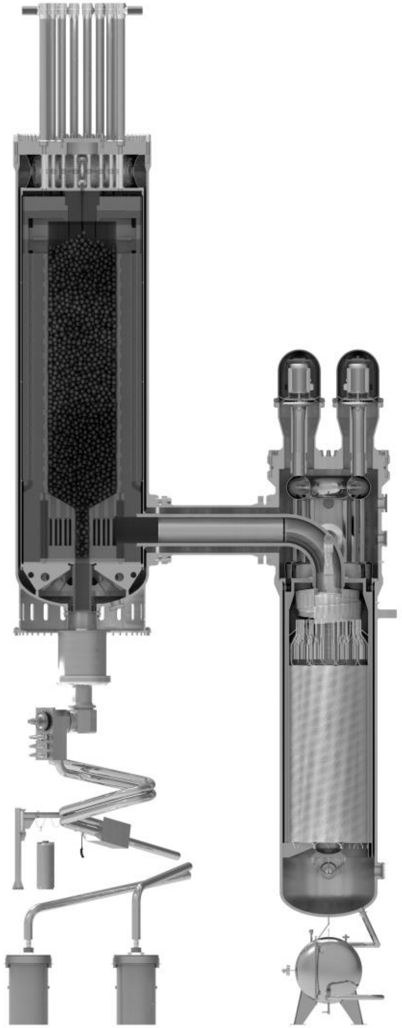
Idaho National Laboratory

Outline

- Recent Licensing Experience- Advanced and Micro- Reactors
  - Recent Designs
  - Additional Designs
  - Licensing Challenges for advanced reactors
    - Functional Containment
    - Emergency Planning Zones
    - Autonomous and Remote Operation
    - Transportation
    - Manufacturing Licenses
    - NRC License vs. DOE Authorization
    - Siting and Environmental Impact

Recent Designs

- X-energy Xe-100
  - Pebble Bed HTGR
  - Approximately 76 MWe
  - Selected by DOE as part of the Advanced Reactor Demonstration Program (ARDP) in 2021
  - Uses high-assay low-enriched uranium (HALEU) tristructural isotropic (TRISO) fuel pressed into billiard ball sized “pebbles”



*X-energy.com/reactors/xe-100

Recent Designs Continued

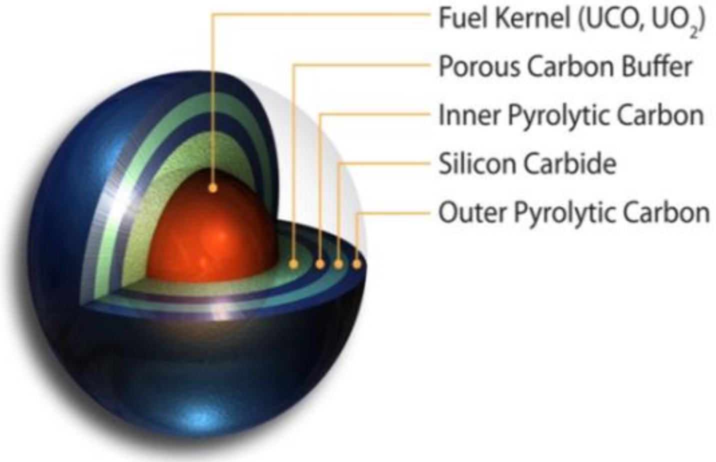
- X-energy Xe-100 can be scaled into a ‘four-pack’ that produces around 320 MWe
- Designed for a 60-year operational life with online refueling
- Can be used as base-load or load following
- Modular Design- most components manufactured in factories and shipped to construction location
- ‘Safety Perimeter’ is just 400 yards (Emergency Planning Zone)
- X-energy is one of two companies actively manufacturing TRISO fuel
  - TRISO-X

Additional Designs

- BWX Technologies Advanced Nuclear Reactor (BANR)
  - HTGR microreactor
  - Commercially transportable via rail, ship, or truck
  - Expected to provide about 50MWth
  - Expected by the early 2030’s
- Transformational Challenge Reactor (TCR)
  - Not an HTGR, but will provide innovations that will serve all new designs
  - Designed and built to demonstrate advances in:
    - Modeling and simulation
    - Advanced methods of manufacturing
    - Advanced materials

TRISO Fuel

- First developed in the late 1950's in the UK
- First demonstration in US at Peach Bottom Unit 1
- Significant development and over the last 15 years
  - Quality control has improved greatly
- Fuel Kernel surrounded by four barrier layers that provide accident protection
  - Considered to be its own containment vessel
  - Part of the "modular HTGR functional containment"
- Currently manufactured by X-energy (TRISO-X) and BWXT
- Chosen for Transformational Challenge Reactor



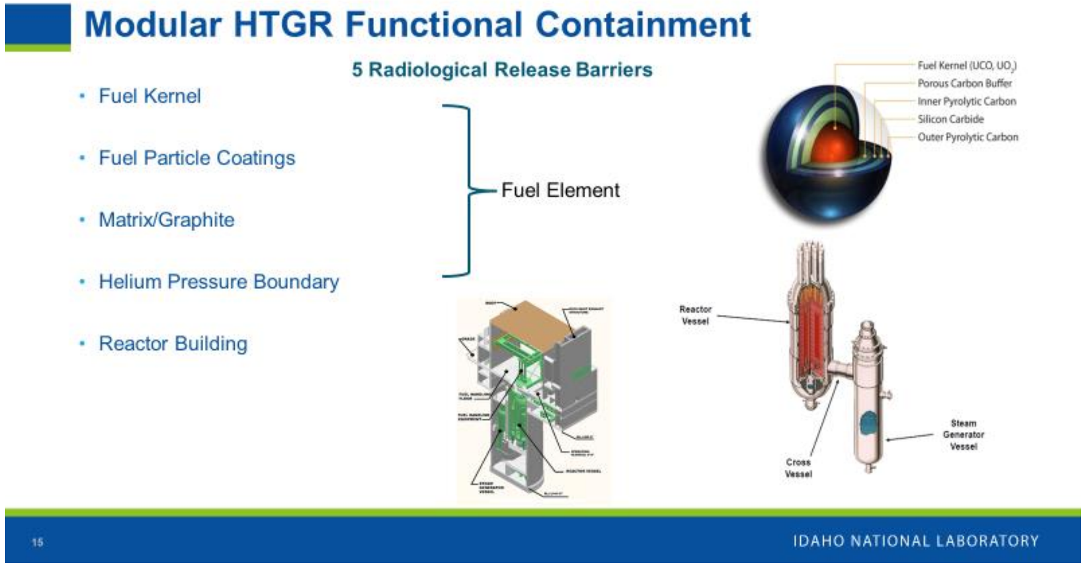
Licensing Challenges for Advanced Reactors

- Significant licensing challenges are presented as companies design and submit license applications for advanced reactors
  - Emergency Planning
  - Advanced Manufacturing
  - Transportation
  - Digital Controls and Autonomous/Remote Operations
  - Staff, Training, and Qualification Requirements
  - Manufacturing Licenses
  - Security and Safeguards
  - Siting and Environmental Impact
  - Inspection and Oversight
  - NRC licensing vs. DOE authorization

Let’s focus on a few of these licensing challenges and compare to CNSC regulations

Functional Containment

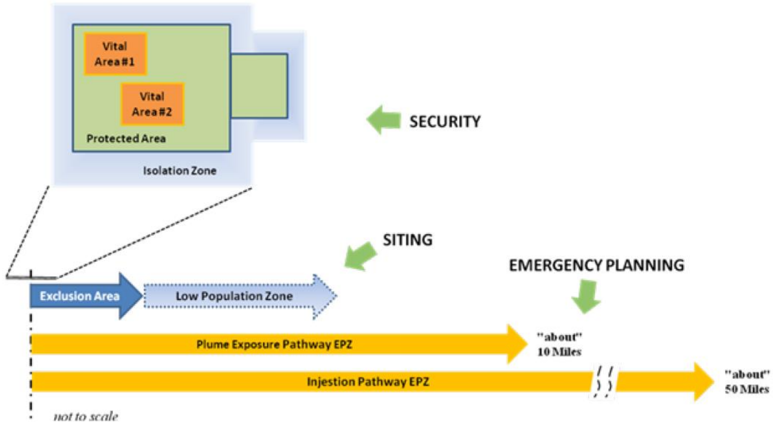
- Traditional U.S. and Canadian reactors have large containment systems to ensure that radionuclide inventory is controlled and not released
- New mHTGR designs meet the Fundamental Safety Function of Radionuclide Retention without the traditional containment structure
- NRC and DOE regulations are not currently suitable to support licensing without a containment dome



How does the concept of functional containment fit within CNSC regulations?

Emergency Planning Zones

- Traditional emergency planning (10CFR Part 50 App. E) zones:
  - Were designed for conventional large LWRs with much larger radionuclide inventory
  - Require major interactions with local, state, and federal emergency response organizations
  - Are built around a plume exposure pathway (~10 mi) and an ingestion pathway (~50 mi)
  - Are expensive and impractical for today's new advanced reactors



Emergency Planning Zones Cont’d

- NRC has a proposed rulemaking (10CFR Part 50.160)
  - Provides an emergency plan that is
    - Performance-based
    - Technology-inclusive
    - Risk-informed
  - Proposes a new, scalable plume exposure pathway EPZ
  - Credits the safety enhancements and smaller radionuclide inventory of advanced designs
  - Allows for significant cost reductions while maintaining EP response
  - Expected late 2021

Autonomous and Remote Operations

- Current NRC requirements require a licensed operator to be on-site at the controls during operation
  - This includes a specified number of licensed operators and support staff
- Some advanced and micro-reactors are intended to be used in:
  - Remote locations, or locations where a traditional control room is impractical
  - Emergency response roles
  - Military use
- Many of these reactors are designed to be controlled from a centralized location that operates (or monitors) multiple reactors

Does CNSC have any history with autonomous control or remote operation?

Autonomous and Remote Operation

- Regulatory issues to consider:
  - Cyber security
    - Remote operation requires sending controls information across the internet
  - Autonomous operations
    - Removes licensed operators from the controls
  - Digital controls
    - Current regulations heavily favor analog controls
    - Regulations will have to be developed to allow use of digital systems
  - Reduced staffing
    - Operating multiple reactors in one location with digital controls offers the ability to reduce staffing levels

Transportation

- Some designers are developing reactors that are shipped from manufacturing facilities with new or spent fuel
  - This is a new process for nuclear regulators
  - Current regulations do not address this new area
- New regulations will need to be developed, and designers will have to consider additional items for licensing such as:
  - Packaging design to house reactor
  - PRA approaches for transportation
  - Meeting Dept. of Transportation requirements
  - Emergency response during transport

What history does CNSC have with transportation of reactors?

Manufacturing Licenses

- Many developers are designing reactors that can be built in modules and shipped to sites
  - Saves significant time and reduces overall cost of the reactors
- In other cases, such as many micro-reactors, designers are planning to construct, fuel, refuel/defuel, and decommission their reactors in a single manufacturing center
- Both options would require an NRC manufacturing license
  - Licenses for modular construction have been issued before
  - Licenses for manufacturing centers to receive, install, remove, and store fuel have never been pursued previously and will require significant development

NRC License vs. DOE Authorization

- NRC licenses commercial reactors and test facilities as well as prototypes
- DOE maintains limited authorization authority to construct, operate, and regulate research-oriented non-power production facilities at U.S. Government-owned sites
- Both maintain are rigorous and ensure the health and safety of the public, workers, and the environment
- There are situations where an NRC license must be pursued:
  - When a demonstration of an entire reactor system is being built/operated with the ultimate goal of commercial operation
- It is expected that many advanced and micro- reactor developers will pursue both NRC licensing and DOE authorization to demonstrate and develop their designs

How does CNSC regulate test facilities vs. commercial reactors?

Siting and Environmental Impact

- NRC and DOE regulations are designed for today's large LWR fleet that remain in one location from construction to decommissioning
- Advanced and micro-reactors have many mobile applications and could be shipped to many different sites during their lifespan
- Existing requirements are inadequate
  - NRC and stakeholders (including U.S. Congress) are engaged in discussions regarding Generic Environmental Impact Statements (GEIS) and other paths
  - GEIS and other paths are intended to streamline environmental reviews via a performance-based and technology-inclusive approach

Has CNSC reviewed siting and environmental impact regulations for HTGRs?

Idaho National Laboratory