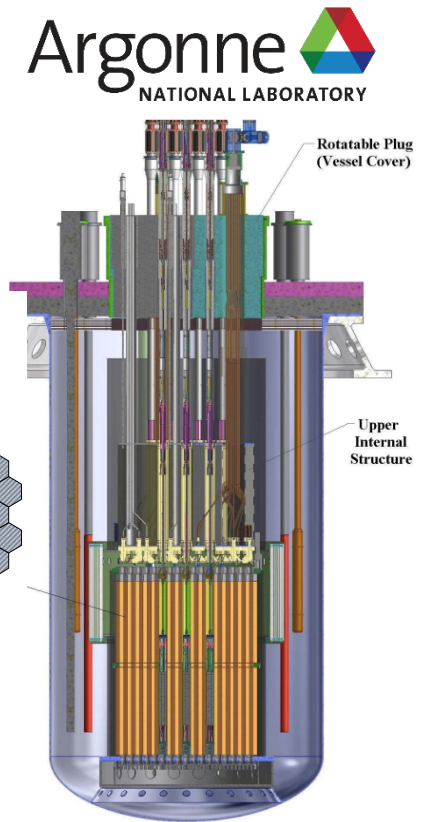
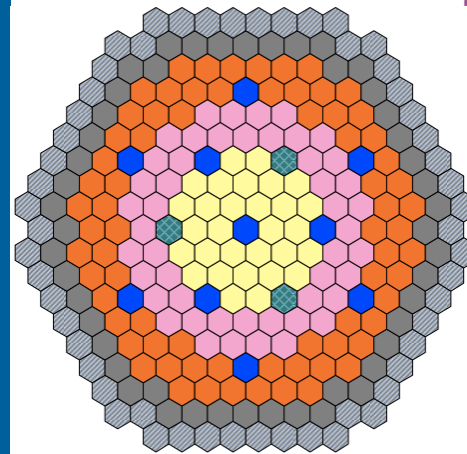


# INTRODUCTION

TANJU SOFU  
ARGONNE NATIONAL LABORATORY

March 26, 2019  
Fast Reactor Technology Training  
U.S. Nuclear Regulatory Commission



# OUTLINE

- Training agenda
  - Day 1
  - Day 2
- Motivations for fast reactors
- Fast spectrum design options
- High-level design approach
- High-level safety approach

# TRAINING COURSE OUTLINE

## Day 1

- Introduction: Motivation and applications, high level design and safety approach
- Historical perspective for fast reactors
- Fast reactor physics
- Fast reactor fuels
- SFR technology overview
- Sodium technology, test facilities, and materials research
- Considerations for operational states
- Overview of past U.S. SFR operations experience and safety testing program

# TRAINING COURSE OUTLINE

## Day 2

- Fast reactor safety design approach
- Safety analyses
- Mechanistic source term calculations
- Fast reactor modeling and simulation tools and methods
- Probabilistic risk assessments
- Overview of LFR technology
- Overview of heat-pipe based micro-reactor technology
- Summary and concluding remarks
- Q&A

# MOTIVATIONS FOR FAST REACTORS

- Fast reactors aim for significant advances in sustainability, safety, reliability, economics, and non-proliferation
- Importance for closed fuel cycle systems to support **sustainability** goals
  - Efficient resource utilization
  - Reduced repository space needed for waste isolation
- Potential for significant design simplifications for improved **reliability** and enhanced **safety**
  - Unique properties for SFR/LFR (very-low Pr#) and MSFR (very high Pr#) coolants allow unpressurized operations
  - Inherent safety for reactivity control, and passive safety for decay heat removal
- Fast reactors can be designed to have a **long core life**, some even without refueling, via use of “breed-and-burn” concept
  - Alternatively, they can be designed for actinide burning

# FAST SPECTRUM DESIGN OPTIONS

- Full range of coolant alternatives
  - Sodium- and lead-cooled fast reactors (SFR and LFR)
  - Heat-pipe cooled fast spectrum micro-reactors
  - Gas-cooled Fast Reactors (GFR)
  - Molten-Salt-fueled Fast Reactors (MSFR)
- Each concept uses different fuel forms
  - SFR with metallic alloys or oxide fuels
  - Micro-reactors with metallic alloys
  - LFR with oxide or nitride ceramic fuels
  - GFR with carbide fuel in SiC-composite cladding
  - MSFR with uranium dissolved in chloride-salt
- SFR, LFR and MSFR systems can employ either a pool- or loop-type plant configuration
  - Each with unique reliability and safety implications for design of the core, reactor/guard vessels, primary and intermediate coolant systems, decay heat removal systems, pumps, refueling and storage systems

} Focal concepts  
for this training

# HIGH-LEVEL DESIGN APPROACH

## Characteristics of SFR and LFR designs with liquid metal coolants

- High core power density (~up to 5X in comparison to an LWR)
  - Compact lattice with triangular pitch
- Large margin to boiling
  - Boiling can only be expected only during highly unlikely accidents with large-scale fuel failures
- Unpressurized heat transport systems
  - No LOCA or need for high-pressure injection system
- High temperature operation (>500°C core outlet temperature)
  - Material challenges due to thermal creep and fast fluence
- Large thermal inertia with long grace period
- Natural circulation potential
  - $\Delta T$  is ~150°C during normal operation (>300°C during accidents) leading to significant sodium inlet/outlet density difference and large buoyancy force

# HIGH-LEVEL DESIGN APPROACH

## Characteristics of SFR and LFR designs with liquid metal coolants

- Interdependent design factors:
  - Fuel type
  - Material compatibilities and corrosion concerns
  - Core configuration and core flow distribution
  - Pumping power
  - Burnup considerations
  - Thermal and mechanical limits
  - Steady-state and transient liquid-metal coolant flow and heat transfer
  - Thermal inertia of coolant inventory
  - Pump coast-down profiles
  - Coolant stratification
  - Decay heat profile
  - Reactivity feedback mechanisms
- Major thermal-fluid design parameters
  - Peak fuel centerline temperature, margin to fuel melting
  - Peak cladding temperature, margin to cladding failure
  - Peak coolant temperature, margin to coolant boiling



# HIGH LEVEL SAFETY APPROACH

- Fast reactor safety and reliability goals are:
  - Improvements in operational safety and reliability
  - Low likelihood and degree of core damage
  - Smaller emergency planning zone
- **Defense-in-depth** is the key concept on which all fast reactor safety is based:
  - Level 1: Prevention of operational failures
  - Level 2: Control of abnormal operation and detection of failures
  - Level 3: Control of accidents within the design basis
  - Level 4: Control of severe plant conditions, including prevention of accident progression and mitigation of consequences
  - Level 5: Mitigation of radiological consequences should significant releases of radioactive materials occur

# PLANT STATES AND DID LEVELS

High probability,  
low consequence

Low probability,  
high consequence



## Defense-in-Depth Levels

Level 1	Level 2	Level 3	Level 4	Level 5
Operational states		Accident conditions		EP&R
Normal Operation	Anticipated Operational Occurrences	Design Basis Accidents	Beyond Design Basis Accidents	Residual risk and practically eliminated accidents

Severe accidents

Plant states considered in fast reactor design  
(safety analyses)

Out of the design  
(source term assessments)

# CLASSIFICATION OF EVENTS

Events	Frequency	Expected Consequences
Anticipated Operational Occurrences (AOOs)	Expected during the lifetime of the plant ( $>10^{-2}$ per reactor year)	None. Maintain large margin to fuel failure
Design Basis Accidents (DBAs): Typically failure of one safety-grade system	Not expected to occur during the lifetime of the plant but anticipated in the design ( $>10^{-4}$ per reactor year)	Minor fuel damage permissible for lower probability events ( $<10^{-3}$ per reactor year). Individual (offsite) exposure below allowable limit
Beyond Design Basis Accidents (BDBAs) : Multiple failures of safety-grade systems, including ATWS and other unprotected events	Highly unlikely accidents not expected to occur during the lifetime of the fleet but considered in the design ( $>10^{-6}$ per reactor year)	Substantial fuel damage permissible for lower probability events ( $<10^{-5}$ per reactor year). Public exposure below allowable limit
Severe Accidents	$<10^{-6}$ per reactor year	Propagation of fuel damage, potentially leading to loss of core integrity and coolable geometry
Early or Large Releases	$<10^{-7}$ per reactor year	Emergency response