

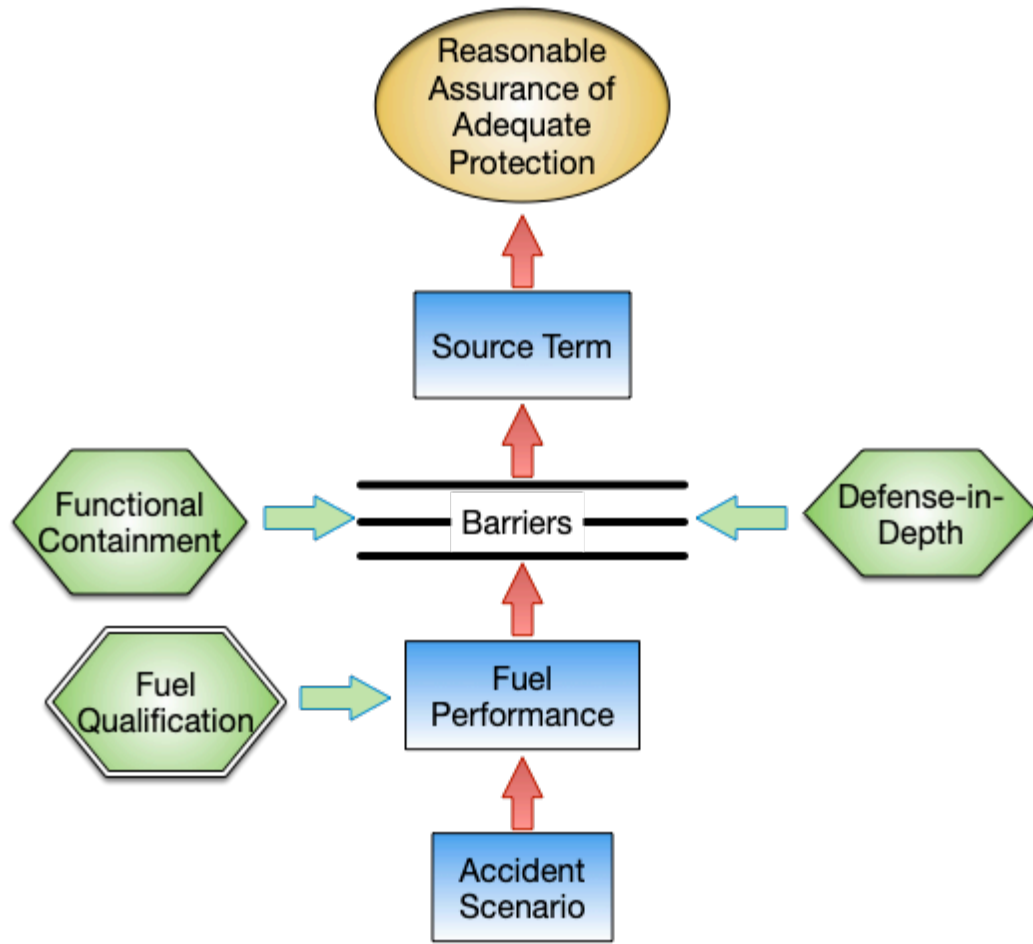
MSR Fuel Salt Qualification Guidance Development

ORNL-GAIN MSR Workshop

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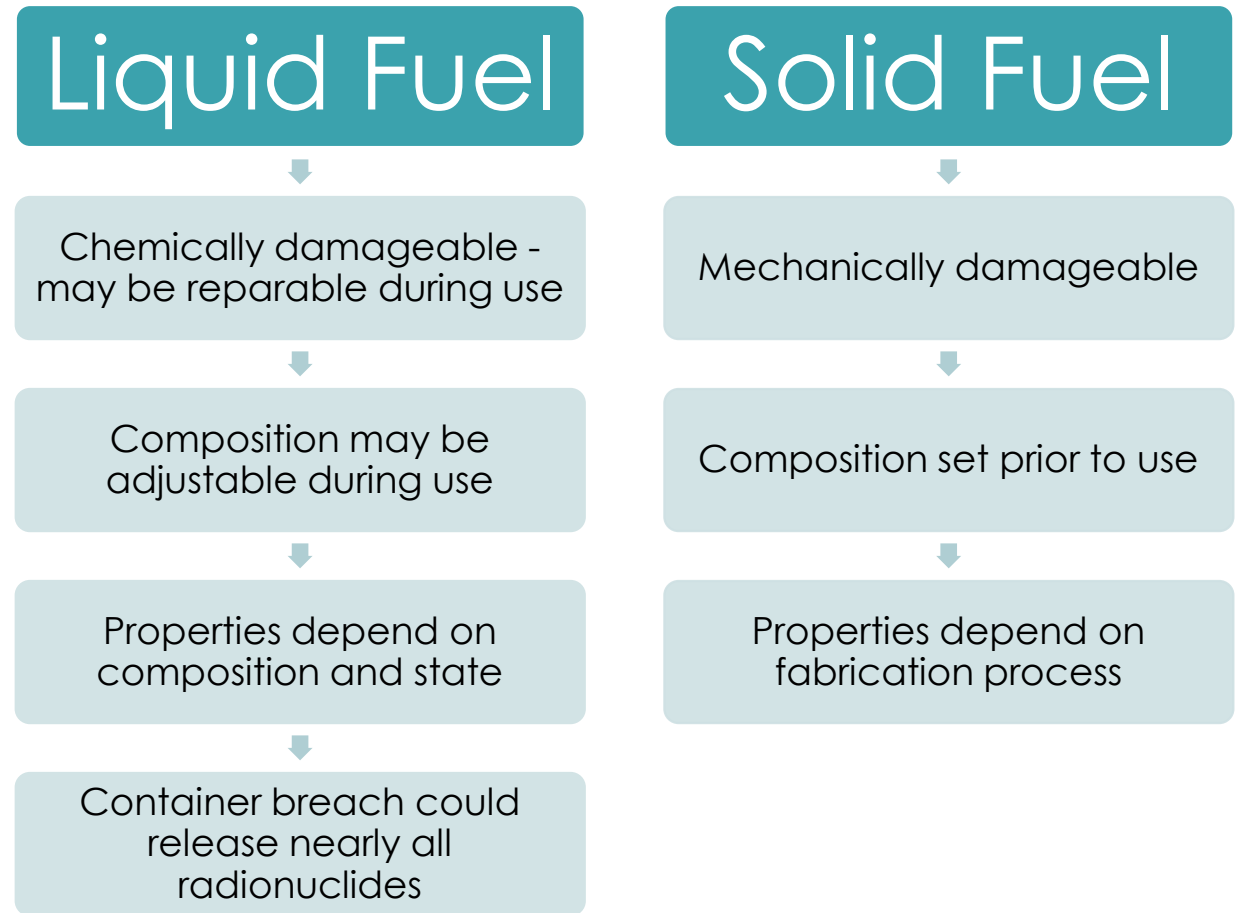
Fuel Qualification is an Element in Achieving Sufficient Understanding of Fuel Behavior



Fuel qualification is a process which provides high confidence that physical and chemical behavior of fuel is sufficiently understood so that it can be adequately modeled for both normal and accident conditions, reflecting the role of the fuel design in the overall safety of the facility. Uncertainties are defined so that calculated fission product releases include the appropriate margins to ensure conservative calculation of radiological dose consequences. - ML17220A315

Liquid Fuel Has Substantial, Fundamental Differences From Solid Fuel

- Liquid salt fuel
 - Serves as nuclear fuel and primary heat transfer media
 - Must meet requirements for both purposes



Common Salt Properties and Plant Functions Enable a General Liquid Fuel Salt Evaluation Method

- Specific accident sequences are design dependent
- Basic operational and safety functions are common to any nuclear power plant
- Halide salt characteristics are common to any MSR
 - High boiling points (low pressure)
 - Low Gibbs free energy (low chemical potential energy)
 - Natural circulation heat transfer properties
- Fuel salt interacts with its container layers via common chemical and physical mechanisms - for example via
 - Thermal energy transfer, chemical reactions, and mechanical processes

Method Tailors Solid Fuel Qualification Process To Characteristics and Functions of Liquid Salt Fuel

- Modifications both add and remove issues from solid fuel qualification process – for example
 - Fuel salt is not a manufactured product
 - Liquids cannot be mechanically damaged
 - Fuel salt also serves as the primary reactor coolant
- Fuel salt properties determine its capability to adequately support achievement of fundamental safety functions (FSFs)
- Fuel salt regulatory basis derives from the role of the fuel salt in establishing compliance with existing regulations

Liquid Fuel Salt Does Not Have a Mechanically Determined Lifetime

- Identification of life-limiting failure and property degradation mechanisms that occur as a result of irradiation during reactor operation remains key focus
- Fuel salt lifetime is the period during which it
 1. Contains adequate quantities of fissile materials,
 2. Does not include too many neutron absorbers, and
 3. Maintains acceptable thermophysical and thermochemical properties
- Composition may be adjustable during operation to compensate for degradation

Functional Containment is Important to How MSRs Provide Adequate Radionuclide Retention

- Barrier performance must be degraded to release radionuclides into the environment
 - Performance degradation can occur through failure or bypass
- Fuel salt properties that stress barriers cause them to be more likely to release radionuclides - for example
 - Increased temperature increases radionuclide vapor pressure in cover gas and well as decreasing strength of container
- Different performance requirements for materials normally in contact with salt versus those that only need to withstand accidents

Fuel Salt Boundary Breach Accident Progression Part of Performance Based and Deterministic Fuel Qualification

- Multiple locations in 10 CFR require evaluation of a postulated fission product release from core into containment
- Fuel salt or cover gas cannot directly stress exterior containment layers without first breaching an inner containment layer
- High radiation and high temperatures immediately outside fuel salt boundary substantially circumscribes characteristics of materials adjacent to fuel salt container
- Focus is on fuel salt properties that must be known to adequately model accident progression and interaction characteristics with materials within containment

Fuel Related Advanced Reactor Requirements Are Similar for Liquid and Solid Fuel

- Example

- 10 CFR 50.43(e)(1)(i) requires that the performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof
- Fuel salt thermophysical and thermochemical properties provide the information necessary to model its role in enabling plant safety features to perform safety functions
- Fuel salt properties vary with both composition and temperature
- Fuel salt properties need to be determined across the range of temperatures and compositions that span potential operational and accident conditions
- Quality of the fuel salt property data needs to be sufficient to enable modeling the role of the fuel salt in achieving the plant FSFs

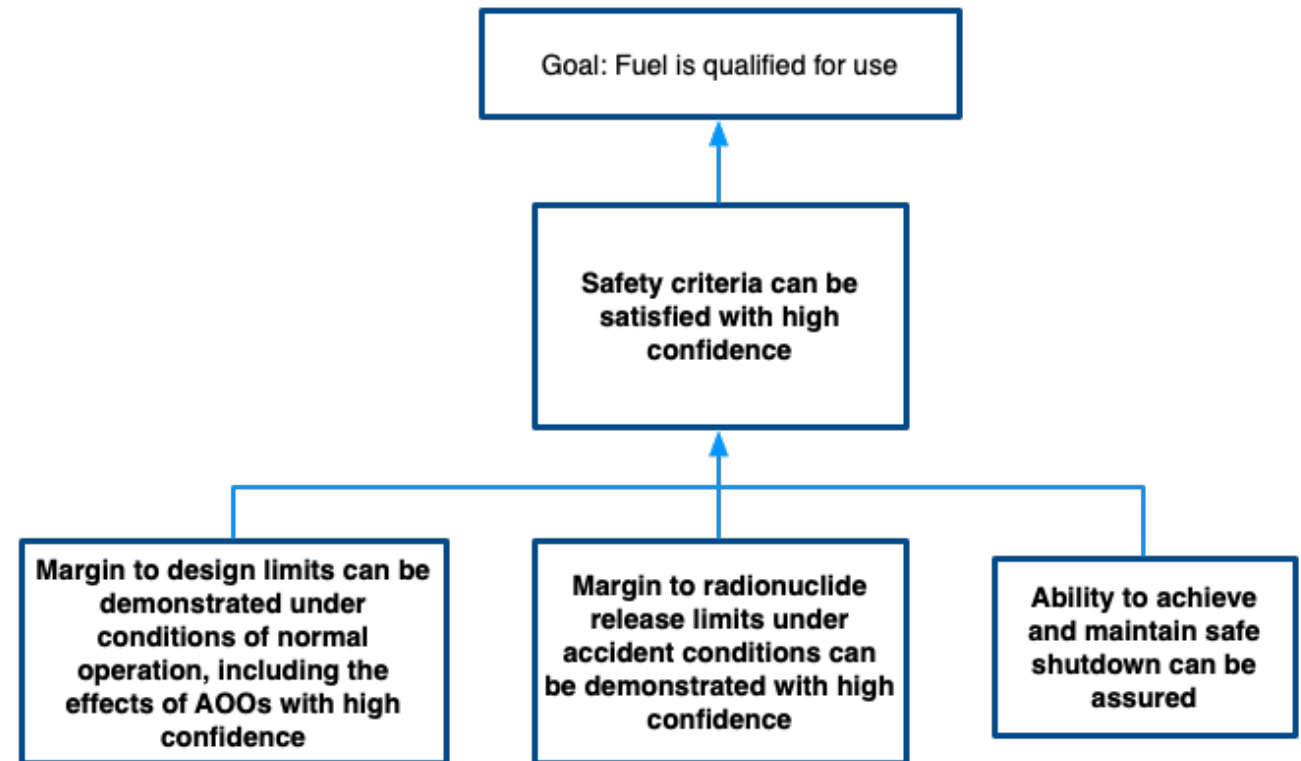
Liquid Fuel Salt Must Meet the Safety Intent of the Coolant Related GDC or ARDC (as appropriate)

- Example

- GDC 15 requires that the coolant system be designed so that the design conditions of the reactor coolant pressure boundary are not exceeded during either normal operations or AOOs
 - ARDC 15 removes pressure from the reactor coolant boundary function
- Key design choice of MSR that employ functional containment is which layer or set of layers comprise the reactor coolant boundary
 - Layer(s) credited to achieve the safety function must meet the requirement
- If normally salt wetted layer is credited, fuel salt conditions that would damage the layer must be detected and corrected before causing significant damage

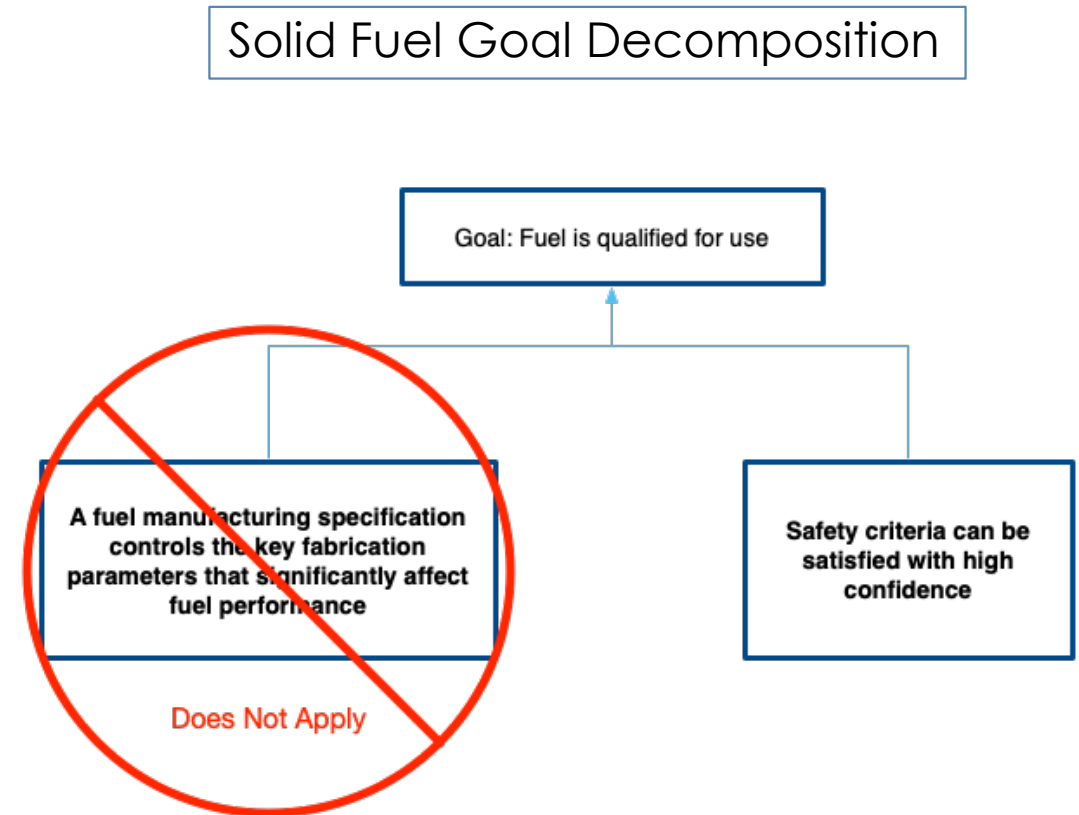
Liquid Salt Fuel Assessment Framework Follows Template Developed for Solid Fueled Advanced Reactors

- Top-down approach used to decompose top level goal of *fuel is qualified* to lower level supporting goals
 - Qualifying fuel develops high confidence that the fuel will adequately perform its role in enabling the facility to achieve its safety objectives
- Lower level supporting goals are further decomposed until clear objective goals are identified that can be satisfied with direct evidence



Liquid Fuel is a Synthesized Not a Fabricated Product

- Bulk properties can be determined by measuring properties of product samples
- Neither the fabrication based definition of fuel qualification nor manufacturing specification branch of fuel assessment employed for solid fuel advanced reactors applies to liquid fuel



Qualification is Based Upon Understanding the Chemical and Physical Properties of Representative Fuel Samples

- Liquid state significantly changes the physical behavior of fuel
 - Liquids do not accumulate internal stresses
 - No history dependent properties
 - Flow homogenizes fluid properties
 - No position dependent properties
 - No size dependent properties
- Chemical and physical properties are set by elemental composition and temperature
 - Independent of isotopic content

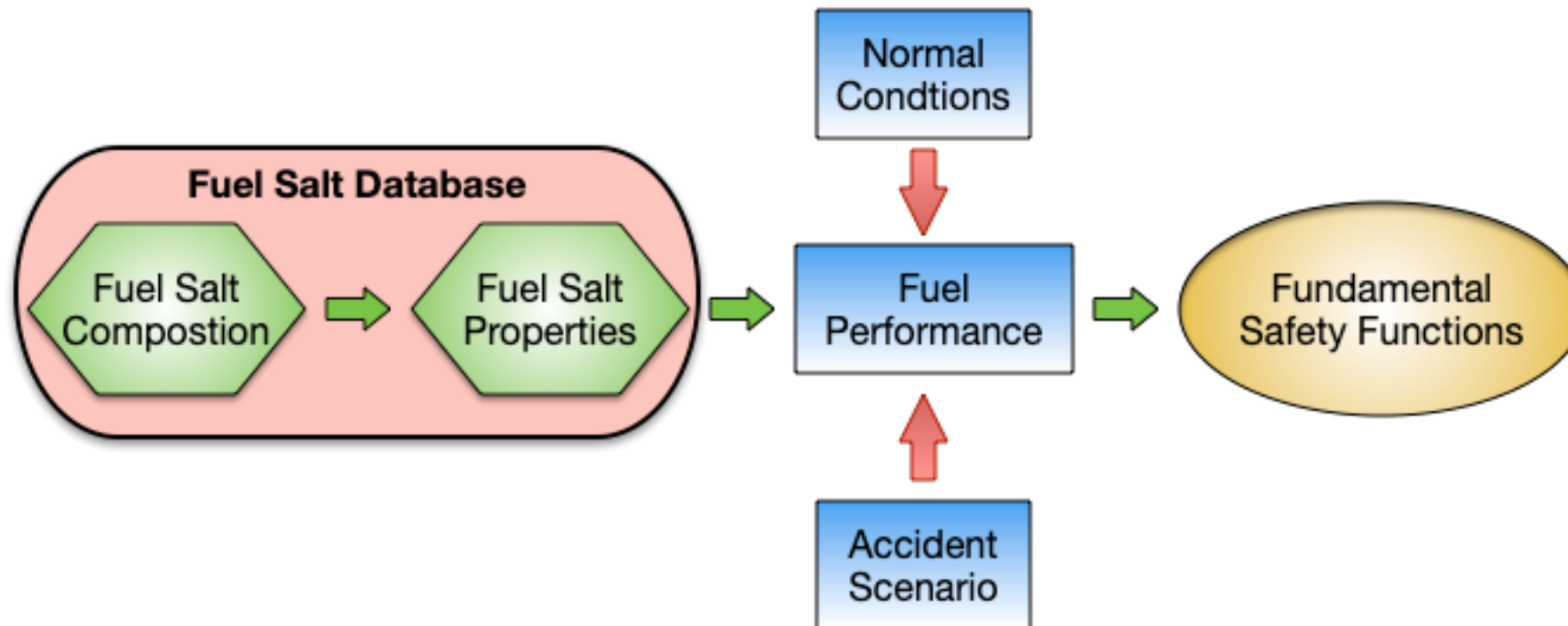
Small minimally-radioactive liquid fuel salt samples provide representative physical and chemical properties

Liquid Fuel Salt Qualification Establishes Acceptable Salt Composition Range That Maintains Safety Functions

- Liquid fuel salt is a Newtonian fluid
 - Heat transfer and fluid flow behave in well known manners
 - Continuous variance in physical properties with composition
- Reasonable assurance of adequate protection derives from a combination of measured salt composition and knowledge of resulting chemical and physical properties
- A liquid fuel salt property database would capture the relationship between fuel salt composition and properties

Fuel Salt Properties Support Modeling Reactor Performance Under Normal and Accident Conditions

- Heat transfer in Newtonian fluids is determined primarily by density, viscosity, and heat capacity
 - Thermal conductivity and radiative heat transfer parameters can become important in specialized situations



Fuel Salt Supports the Plant SSCs in Achieving the FSFs and Regulatory Requirements

- Qualification focuses on identification and understanding of fuel salt property degradation mechanisms that occur as a result of irradiation during reactor operation
 - Property repair (composition adjustment) may be incorporated into normal operation
- During normal operations and AOOs fuel salt properties must result in sufficient margin from damage to safety-related SSCs
- Under accident conditions the fuel salt properties must not result in sufficient damage to safety-related SSCs to prevent them from achieving their function