Safety and Environmental Activities for ARIES IFE Chamber Study

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Outline

- **Proposed Approach for Concept Definition Phase**
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  - **Institutional Breakdown**
- **Proposed Approach for Detailed Assessment Phase**
  - **Safety and Environmental Criteria**
  - **Institutional Breakdown**
  - **Release Limits and Inventories**
  - **Safety Functions: Accident Identification and Safety Assessment Examples**
  - **Safety Design Integration**

Proposed Approach for Concept Definition Phase

- Detailed design and may safety-important aspects of the facility will not be known in sufficient detail for a full safety and environmental assessment
- Need a variety of safety and environmental metrics to be used to compare different concepts at this early concept definition phase
- These metrics are based on four factors
- Mobilizable tritium, activation products and dust/debris
- Decay heat
- Chemical reactivity/combustible gas generation
- Waste/environmental issues
- It may not be possible to apply all the metrics to a given concept, however they should be used to the extent possible
- In some cases, it may only be possible to make a judgement as to whether a concept has reasonable potential to meet a particular metric

Mobilizable In-vessel Tritium Inventories

- Less than 100 g-T and/or less than 100 g dust
  - Excellent – can meet no evacuation with little confinement
- 100 g to 1 kg-T and/or 100 g to 10 kg dust
  - Acceptable – some confinement degradation is acceptable and yet still meet no-evacuation
- More than 1 kg-T and/or 10 kg dust
  - Poor – significant confinement performance expected under all conditions to meet no-evacuation

Decay Heat and Activation Product Mobilization

- Peak temperature less than 500°C
  - Excellent – little activation product mobilization expected, not a major threat
- Peak temperature 500 to 800°C
  - Acceptable – activation product mobilization is a concern and this source term must be considered; can probably accept some confinement degradation and still meet no-evacuation with proper design
- Peak temperature greater than 800°C
  - Poor – significant activation product mobilization expected; level of confinement needed may be high and may threaten ability to meet no-evacuation

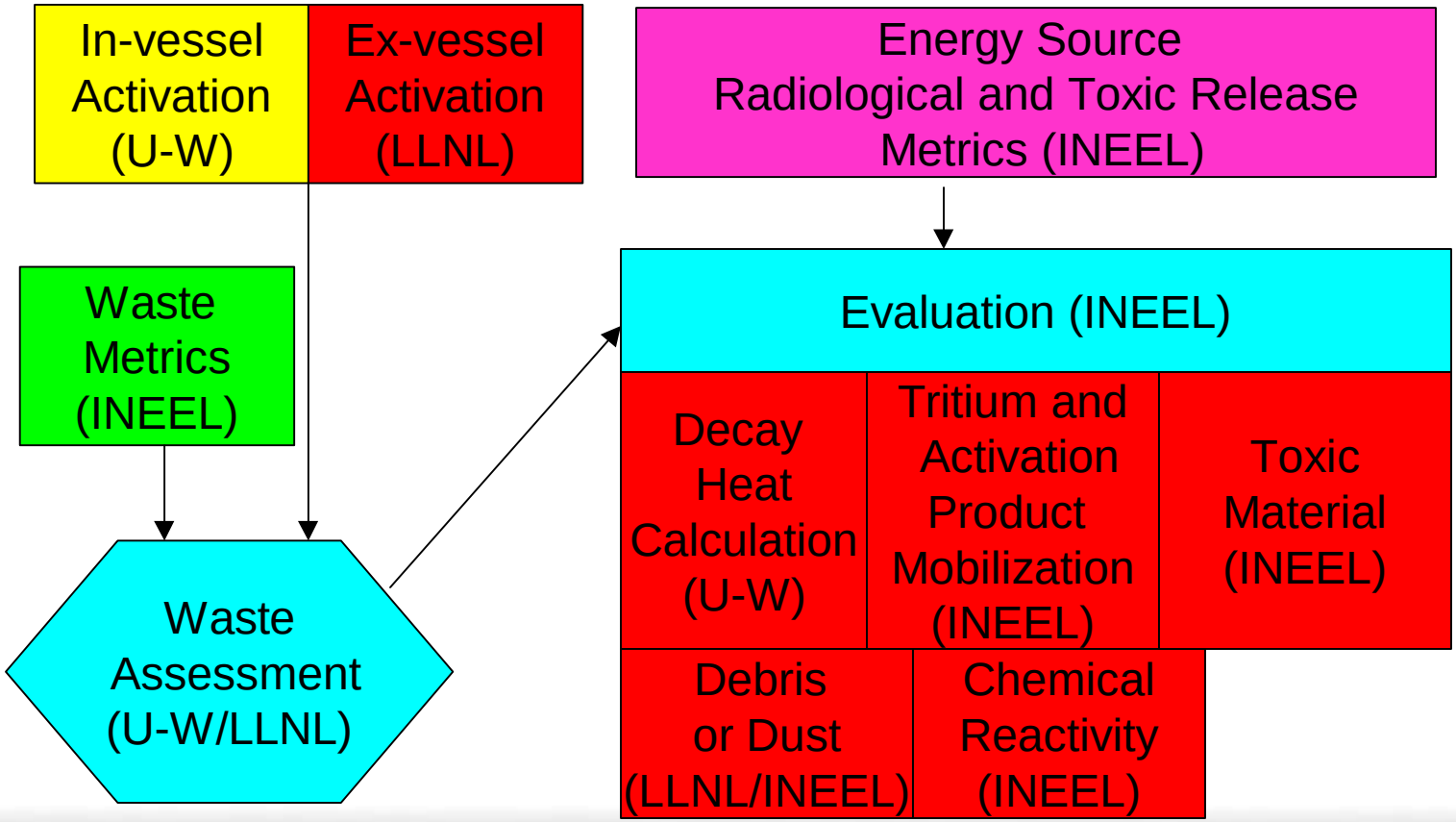
Chemical Reactivity/Combustible Gas Generation

• Inert coolant	• Excellent - no reactions than can threaten confinement
• Endothermic reaction	• Acceptable – cannot be self-sustaining and removes energy from system; must still consider the need for and ability of confinement to accommodate any reaction products
• Exothermic reaction	• Poor – could be self-sustaining; energy production could lead to overheating of structures and additional mobilization of radioactivity; confinement of reaction products is a concern and hydrogen production is a major concern with water coolant

Waste/Environmental

- Waste volume
  - Low ex-vessel activation (WDR < 1, low contact dose rates)
    - Excellent – good potential for recycle or clearance
  - Significant ex-vessel activation (WDR > 1, high contact dose rates)
    - Poor – low potential for recycle or clearance
- Radiotoxicity
  - WDR < 1 in all components
    - Excellent
  - WDR > 1 in some components
    - Acceptable if total volume of waste is significantly reduced
- Mixed hazardous waste
  - None
    - Excellent
  - Some
    - Poor/Unacceptable

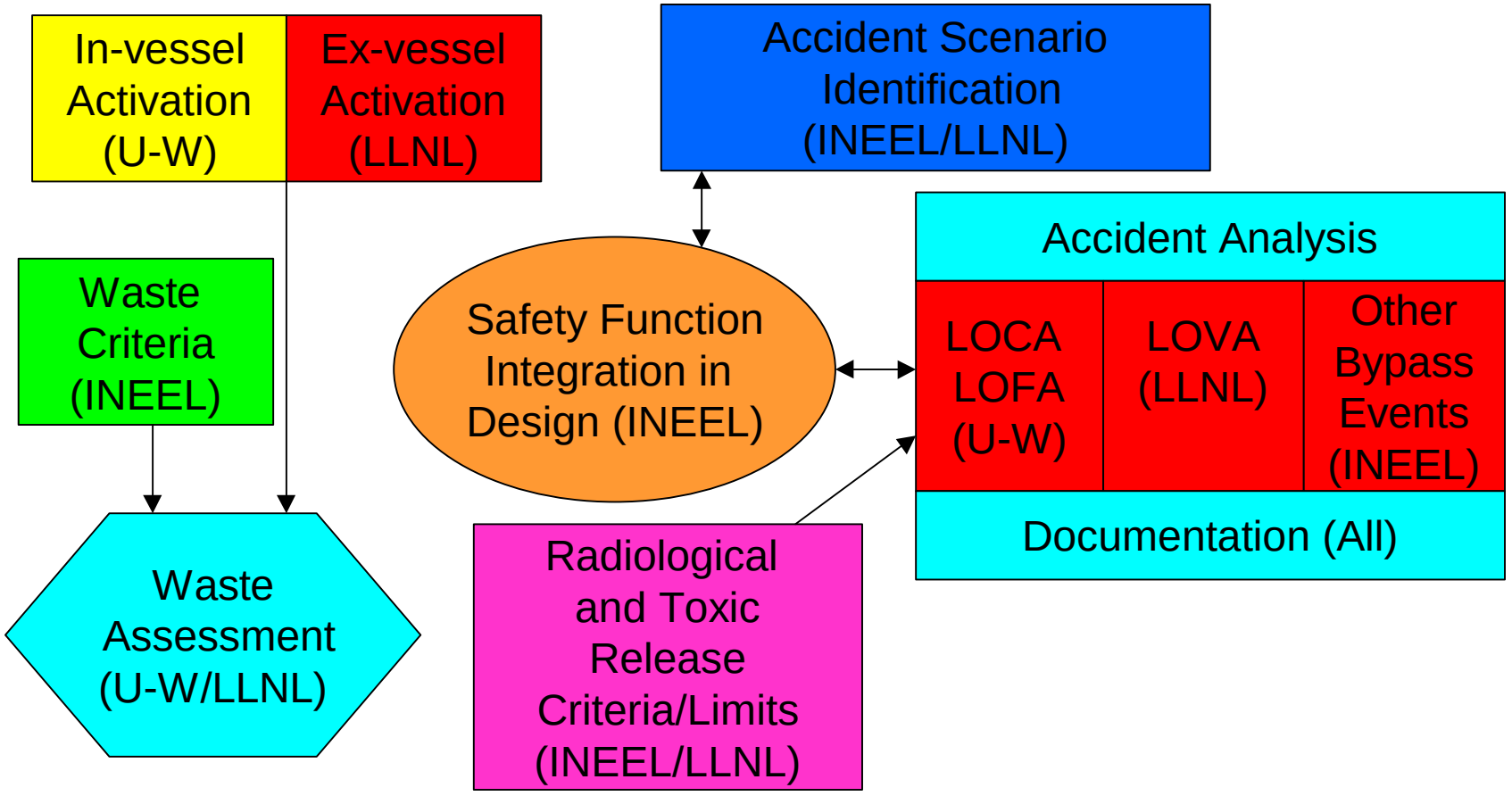
S&E Responsibilities for IFE Chamber Study Concept Definition Phase



Proposed Approach for Detailed Design Study

- The DOE Fusion Safety Standard (FSS) identifies all applicable safety and environmental criteria
- Use structure of DOE FSS to systematically evaluate and develop solutions for safety and environmental concerns with IFE chamber designs
- DOE FSS addresses confinement of radiological and hazardous material as the key public safety function
- DOE FSS then addresses each potential energy source that could threaten confinement and thus challenge public safety
- Waste assessment should include characterization of the hazard (Class C, Class A, Cleared), the volume of material, and the ability to recycle the material

S&E Responsibilities for Detailed IFE Chamber Study



Meeting the no-evacuation criteria is the key public safety requirement in the DOE Fusion Safety Standard.

Meeting no-evacuation involves examining a spectrum of events that challenge the key safety functions (e.g. confinement) to ensure that the worst case has been identified. Then, in none of the identified events can the dose to the most exposed individual exceed 1-rem. This can be accomplished by:

- Minimization of radiological inventories by smart materials choice
- Establishment of the appropriate level of radiological confinement such that the 1 rem limit is met under a broad range of accident conditions
- Development of passive means to implement the key safety functions (e.g., confinement) and to mitigate the potential safety concerns that could threaten or challenge the confinement under accident conditions. The in-vessel challenges include decay heat, chemical reactivity, coolant internal energy, plasma energy/shutdown.

Release Limits and Inventories

- Establish release limits for tritium and activation products to meet no-evacuation criterion
- Establish location and amount of radioactive and toxic material in the chamber and associated systems

Material	1- Rem Release Limit	Inventory
Tritium as HTO	150 grams -T	tbd in structure
		tbd in coolant
Activation products	tbd Curies	tbd Curies
Activated debris	tbd grams	tbd kg

Use sum of fractions rule if more than one source is involved in an accidental release

Establish Confinement Barriers

- The level of mobilizable material influences the degree of radiological confinement that is needed (General example is shown below)
- Actual confinement boundaries need to be worked out between safety specialists and designers

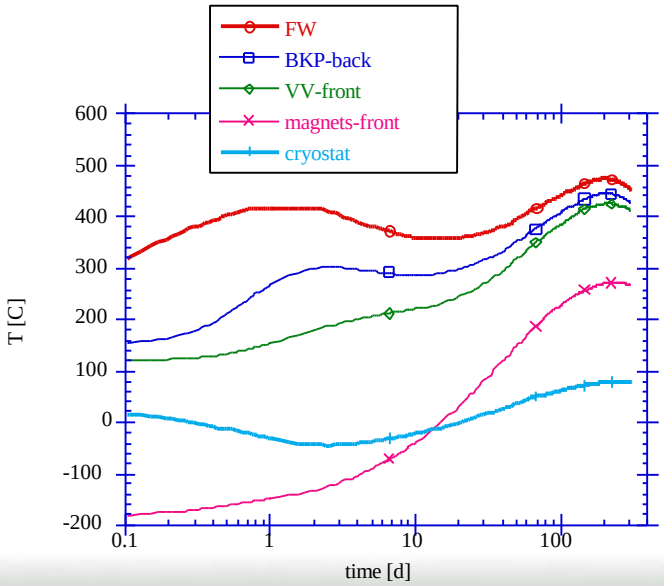
Mobilizable Inventory	**Qualitative statement about degree of confinement needed**
< 100 g-T and/or < 100 g dust	Can meet no-evacuation dose with little confinement
100 g – 1 kg-T and/or 100-g – 10 kg of dust	Some confinement degradation is acceptable and yet still meet no-evacuation dose
>1 kg-T and/or >10 kg of dust	Significant confinement performance expected under all conditions to meet no-evacuation dose

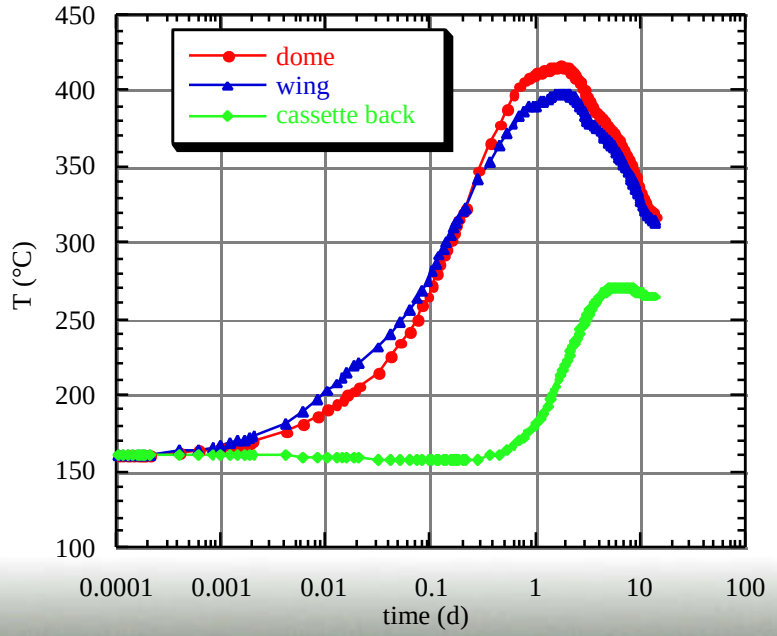
What accidents should be considered?

- loss of coolant/decay heat driven transients
- loss of flow
- confinement degradation/bypass events
- loss of vacuum
- ex-vessel events that require plasma shutdown
- plasma anomalies and transient overpower
- initiating events in balance of plant systems (e.g., loss of off-site power)
- operator errors
- external events

Decay Heat Removal

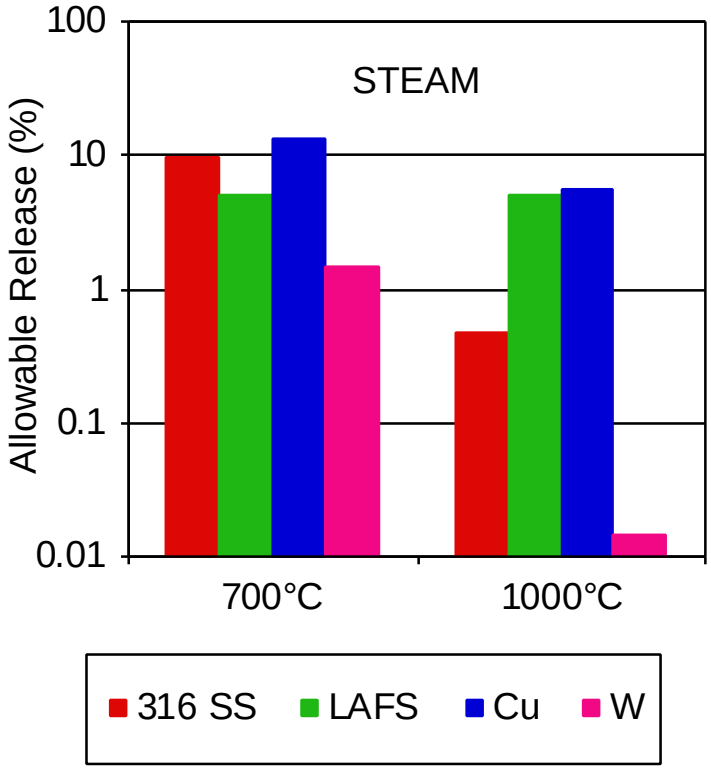
From FSS: The design of fusion facilities should provide a reliable means to remove any undesirable afterheat generated by activation products produced by neutron absorption in structures such that the public safety function of confinement is assured. The need for and reliability of afterheat removal systems should be commensurate with the role of afterheat removal in complying with evaluation guidelines. Passive means are preferable to active means because they are simpler, more reliable, and often less costly than active means. For facilities with high levels of afterheat, the concepts of redundancy, diversity, and independence should be considered in the design of afterheat removal systems.

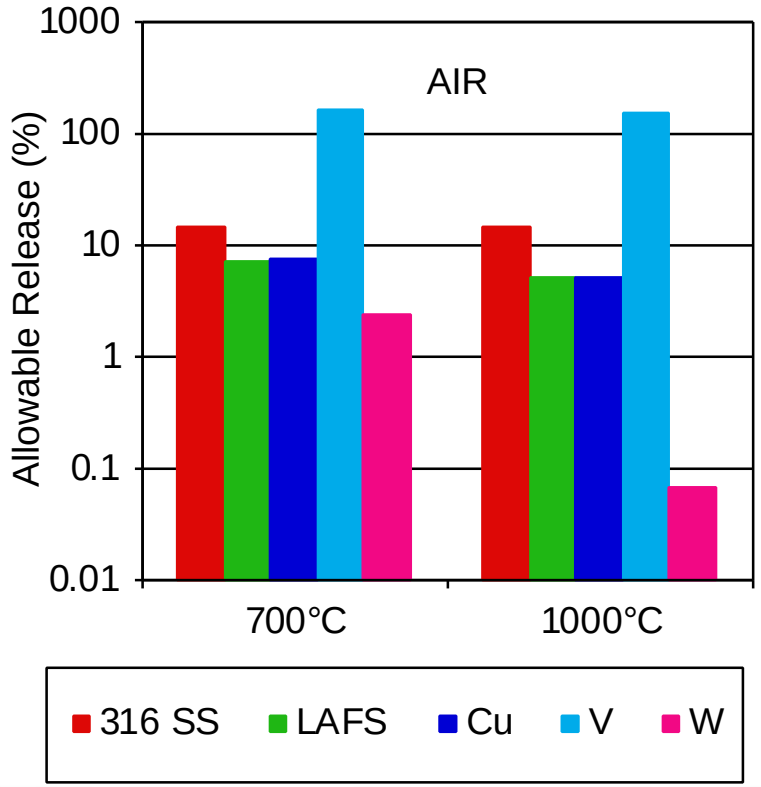




Activation Product Mobilization

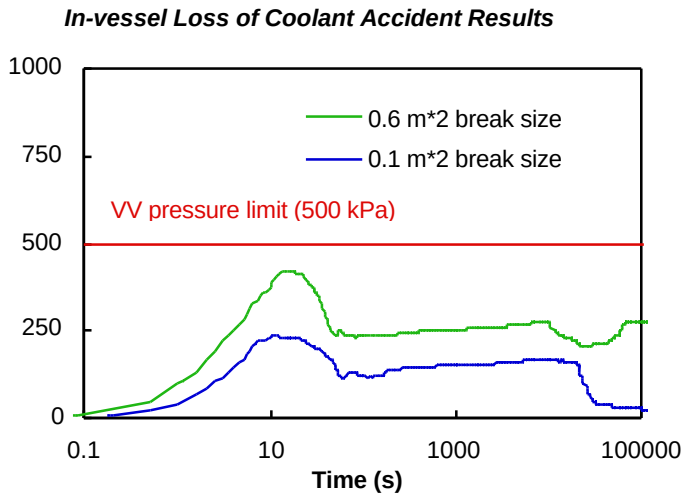
Key issue: Keeping temperatures low enough to minimize oxidation driven mobilization from structures





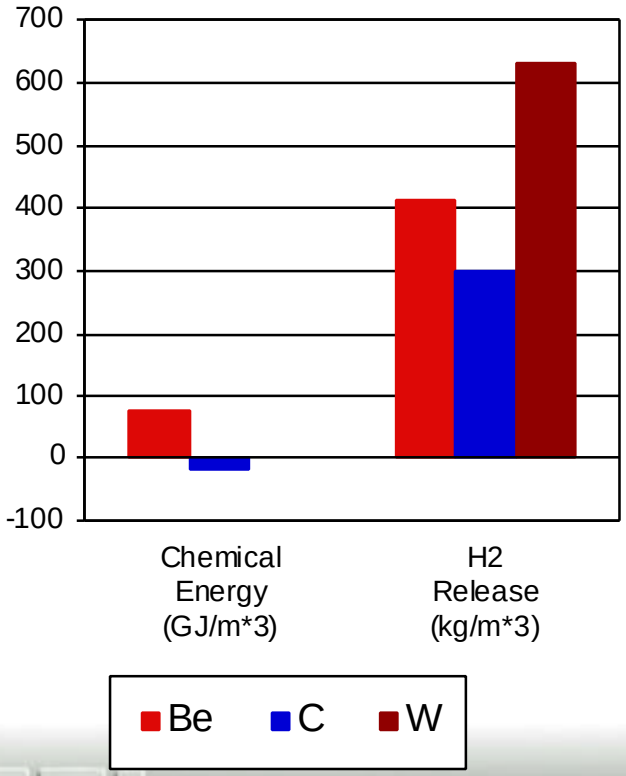
Control of Coolant Energy

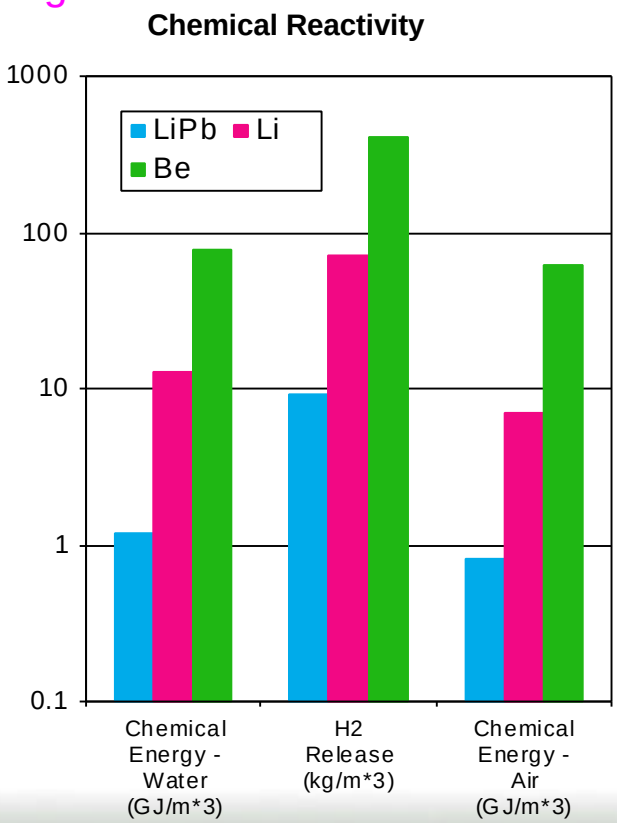
From FSS: The design of active liquid cooling of fusion components (e.g., water and cryogenic liquids), should incorporate means to accommodate the accidental release of the liquid to ensure that confinement barriers are not breached and that crucial safety equipment is not flooded in a manner that could result in exceeding evaluation guidelines. Special consideration should be given to the effect of large spills of cryogenic liquids on the structural integrity of affected structures, systems, or components (e.g., embrittlement and building pressure change).



Control of Chemical Energy

From FSS: Fusion facilities should be designed such that chemical energy sources are controlled during normal conditions, anticipated operational occurrences, and off-normal conditions so as to minimize energy and pressurization threats to radioactivity and hazardous material confinement barriers. Design measures should assure that evaluation guidelines are met.





Rapid Plasma Shutdown

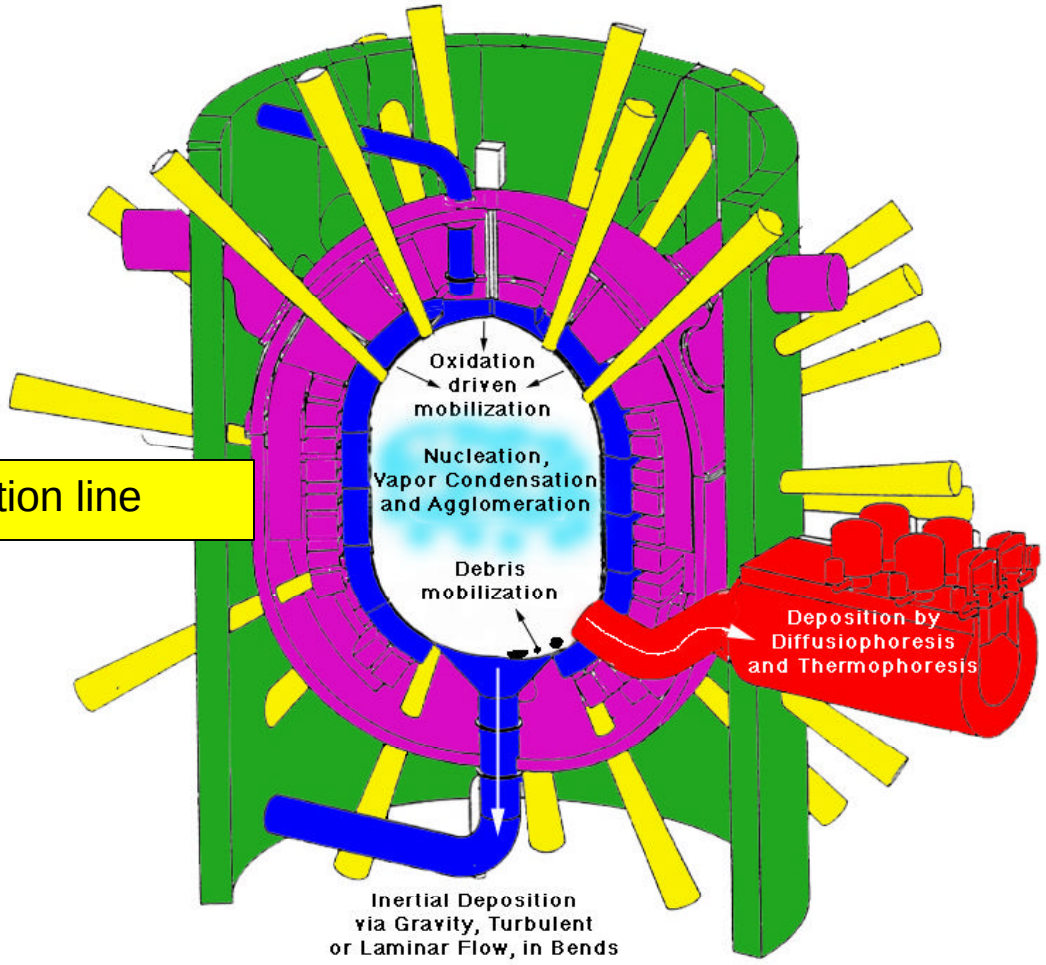
- From FSS: A means of rapid plasma shutdown should be provided for fusion facilities, if required to ensure that evaluation guidelines are met. The level of required reliability, redundancy, and diversity of such a system, its effectiveness, and speed of action should be such that safety functions required to meet evaluation guidelines are assured. Consideration should be given to heat, particle, magnetic, and mechanical loads on confinement barriers resulting from transient overpower events and plasma abnormalities (e.g., vertical displacement events or plasma disruptions in tokamaks) in assessing the need for rapid plasma shutdown.
- Key Issue: Does IFE need a rapid reactor shutdown system (< one second) to mitigate consequences from ex-vessel events?

Results from ITER suggest that events that bypass of radiological confinement barriers, such as a loss of vacuum event, need to be examined

Leakage to the environment

Non-nuclear room

Bypass penetration line



Strong safety-design integration will help meet safety and environmental requirements and improve the overall safety and environmental attributes of a concept

- Safety Requirements Definition
- Smart Materials Choice
- Safety analysis ←→ Design iteration to improve safety function implementation
- Confinement
  - Decay heat removal
  - Chemical energy control
  - The need for safety grade reactor shutdown
- Improve robustness of the integrated system response to off-normal events
- Waste Management Assessment