# Status of ARIES-IFE Safety and Environmental Activities


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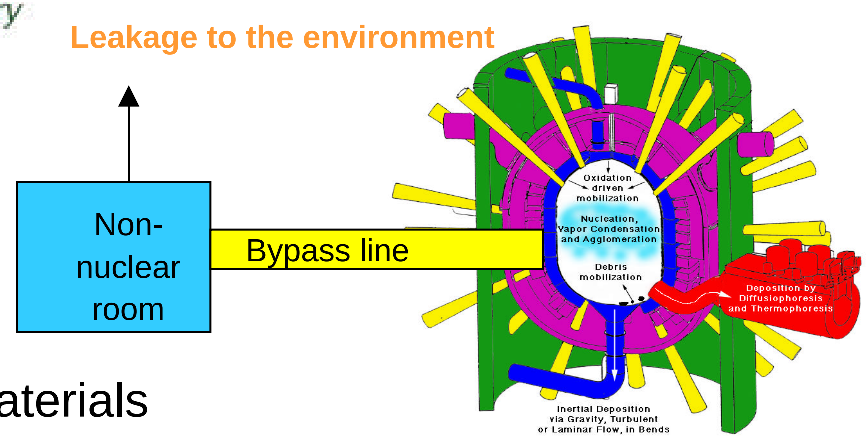
# Overview of Safety and Environmental Activities




- Minimization of radiological inventories through ES&H-conscious materials selection and careful design
- Implementation of radiological confinement in IFE systems recognizing the large number of penetrations in the chamber --> contamination spread and confinement boundaries
- Identification of accident scenarios in IFE systems --> MLD for IFE systems; hydrogen safety issues; operational questions
- Safety analysis of some of these events based existing designs (e.g., SOMBRERO, HYLIFE-II)--> Effect of carbon whisker on LOVA analysis
- Waste management assessments of different configurations focusing on both volume and hazard of waste (e.g final focus magnets)

# Radiological Confinement and Contamination

- Part of radiological confinement is to minimize the spread of radioactive contamination in the facility. Having a large area of contamination can be costly in terms of $, maintenance time, and personnel exposure
  - Will there be contamination up the beam lines in an IFE power plant? If so how much?
  - The contamination “boundary” could be quite large and impede worker activities at the facility
  - The use of open valves that close quickly upon detection of an off normal event does not provide active containment all of the time, only in an off-normal event.
  - This issue continues to need work

# Radiological Confinement

- Confinement buildings have been used in previous IFE studies as the second strong barrier
- There are concerns with this approach related to testing of the boundary for the appropriate leak rate
- The large size of the building could make testing even a moderate leak-rate building a costly operational burden
- Use of the building to get the needed confinement goes against conventional safety wisdom of confining the hazard as close to its source as possible

# Risk Assessment for IFE

- A basic probabilistic risk assessment (PRA) of power plant operation has three main steps, or levels.
- Level 1 is to evaluate sequences of events that result in releases of radiological or toxicological material by using event tree analysis and fault trees of plant systems.
- Level 2 is confinement building breach analysis.
- Level 3 is off-site dose evaluation.
- Other added analyses are external events (e.g., earthquakes, aircraft crash), and PRA of shut down operations (e.g., refueling, maintenance overhauls)

# Initiating Events are the First Step in Event Tree Analysis

- When constructing an event tree of a power plant and how it responds to off-normal events, the initiating events must be identified.
- Initiating events (IEs) can be thought of as “accident starters”.
- Completeness in IEs is very important for accurate risk assessment.
- The IE list must be broad, so that a “practical” level of completeness is achieved. By practical we mean that any event not considered is also not consequential; nothing important has been excluded from the PRA.

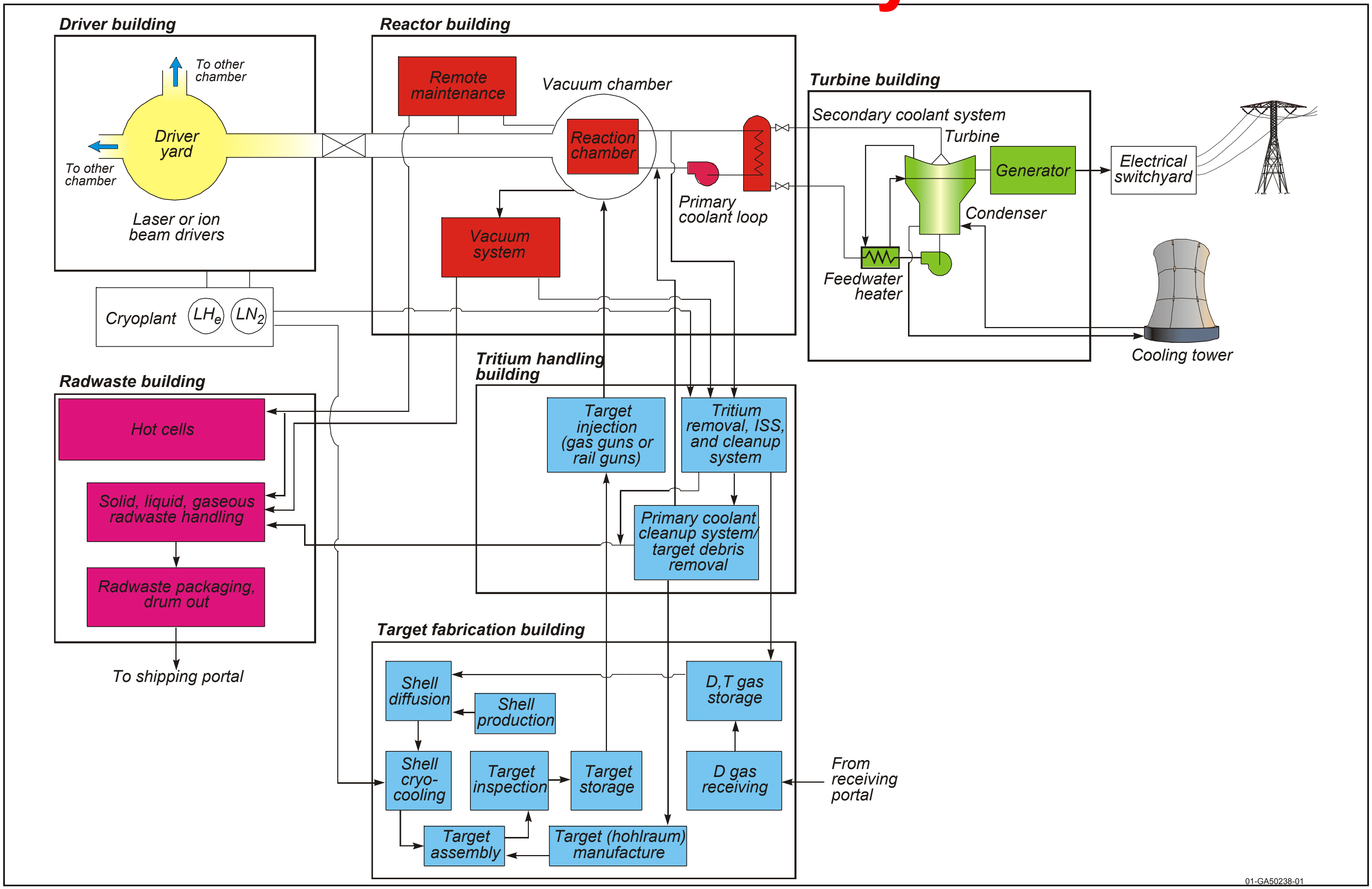
# There are Several Methods Used to Identify IEs

- Preliminary Hazards Analysis (PHA), such as was performed for NIF
- Engineering Evaluation, which includes review of historical accident data from similar facilities, plant operating experience, and safety study reviews
- System-level Failure Modes and Effects Analyses (FMEAs) of a title design
- Master Logic Diagram (MLD), which is a plant level fault tree of possible releases
- Expert opinion solicitation
- Generally, two or more methods are used for IE identification.  The ITER design used PHA early in the design, followed by system level FMEAs and an MLD.  Reviews of that safety work were quite favorable.

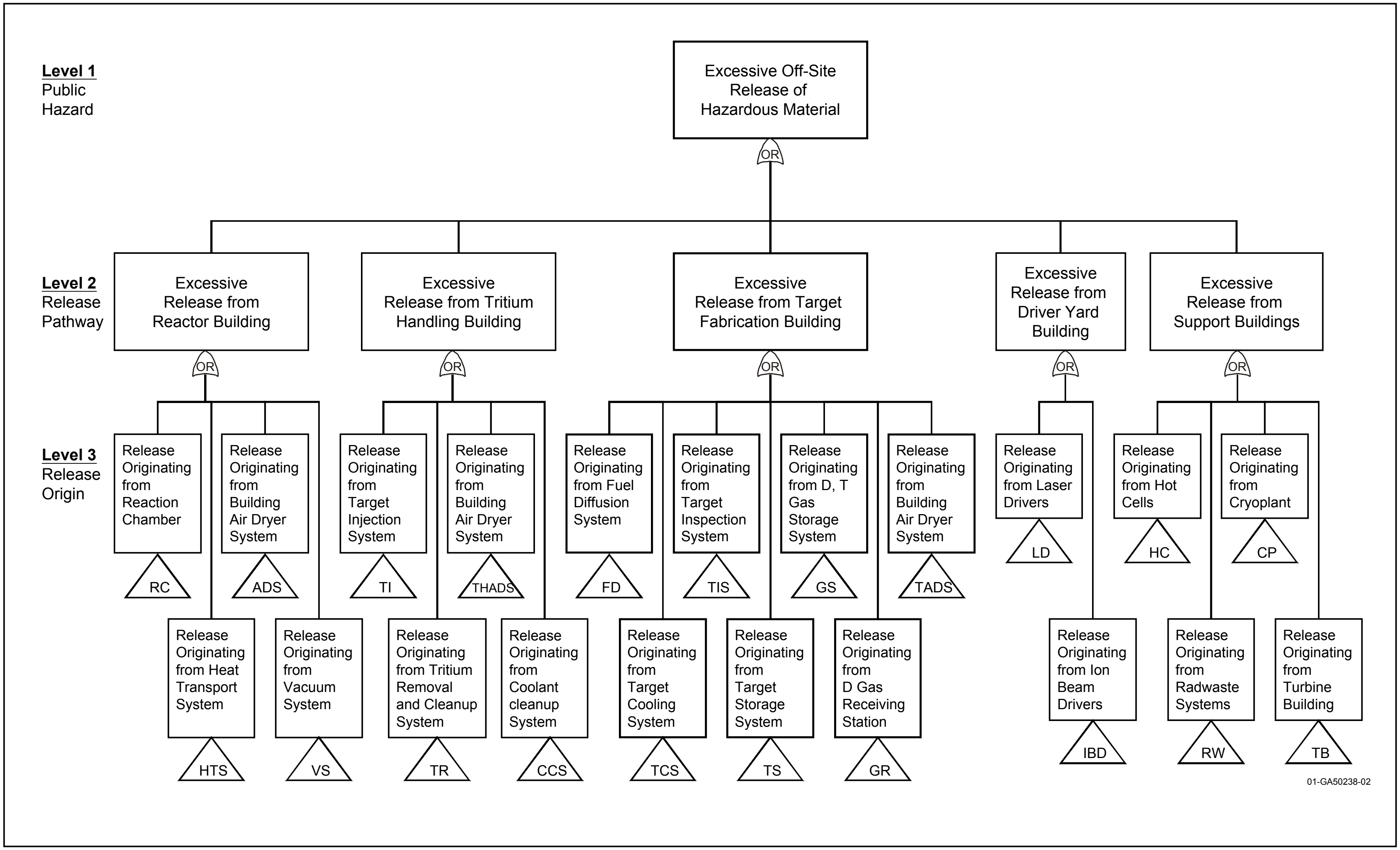
# ARIES-IFE IE Study

- We are using PHA, historical document review that includes safety analyses of past IFE designs, DOE occurrence reports from existing facilities, and NIF safety work; and a Master Logic Diagram. The initial results will be reviewed by IFE safety researchers.
- A PHA is currently under revision.
- The document review is in progress, and results are being recorded.
- A Master Logic Diagram is basically a large fault tree constructed at the plant level. It has the advantages of being a graphical technique, while FMEA results are tabular. A person can easily scan a dozen MLD pages to identify accidents of interest and assess completeness; binders of FMEA results require more time and effort to review.
  - A layout or schematic diagram of major plant systems is needed as the basis for constructing an MLD.
  - The initial work is presented here. The MLD branches are still under construction.

# IFE Power Plant Layout



# Preliminary Upper Tier for MLD



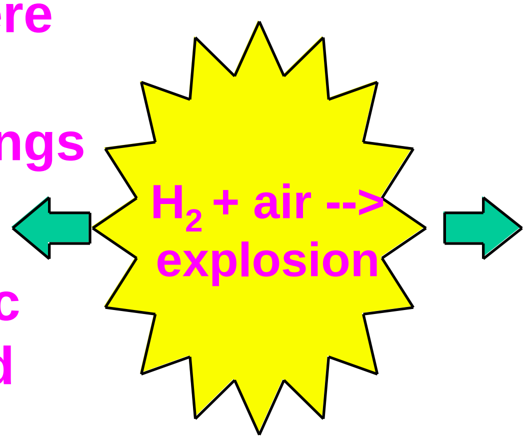
# Another Concern is Hydrogen Gas Safety

- Filling targets with D and T involves operating chambers and pumps at very high gas pressures and modestly high temperatures.
- Gases are known to have varying flammability in air as ambient conditions change.  Hydrogen and deuterium are under investigation to determine how flammability varies with pressure and temperature.
- The very preliminary findings are that there have not been any combustion experiments with tritium, and only a few with deuterium.  There have been many hydrogen combustion experiments since Three Mile Island.

# Hydrogen Deflagration/Detonation Risk

## Deflagration

- Most common mode of explosion, can be severe (break glass, cause shrapnel, topple buildings
- Combustion wave propagates at subsonic velocity, between 1 and 1000 m/s
- Pressures from mbar to 8 bar
- Low ignition energy, mJ




## Detonation

- Most severe form of explosion (collapse strong buildings, denude trees)
- Combustion wave propagates at supersonic velocity, between 1500 and 2000 m/s
- Pressures 15 bar and higher are possible
- High ignition energy, kJ

# Lower Flammability Limit is the Primary Concern

- The Lower Flammable Limit (LFL) is important to safety. The most likely leaks to occur are small, hard-to-detect leaks that could accumulate gas up to the LFL. For $H_2$ in air at STP, the LFL is 4%, and the upper limit is 75%.
- A gas with a narrow flammable concentration band and a high ignition energy needs less rigor for assuring safety.
- Unfortunately, all gases have low ignition energies (mJ range) for deflagrations. Hydrogen is particularly susceptible to ignition by static discharge, where static has been generated by the motion of pressurized hydrogen escaping confinement.

# Combustion Conditions Affect Flammability

- Increasing the gas temperature will decrease the LFL and increase the UFL for almost all gases. Widening the flammable zone means that extra precautions must be taken to prevent explosions.
- Increasing pressure generally does not affect the LFL very much, but can increase the UFL.
- Some early Bureau of Mines work with hydrogen at elevated pressure and temperature (50 and 100 psig, at 300 °F) showed a several percent increase in the UFL, and about 1% increase in the LFL (see WAPD-SC-545, 09/57).

# Combustion Test Findings are Favorable thus far

- Our initial findings from literature reviews of combustion tests are that the deuterium LFL is about 1.5% higher than that of hydrogen in air at STP, due to deuterium having lower diffusivity in air than hydrogen. Tritium is calculated to be perhaps another 1% higher than deuterium.
- At high pressures, the hydrogen LFL may also increase. Review continues to learn if the deuterium LFL would increase.
- Considering safety, these initial findings suggest that slightly larger leaks may be tolerated; D and T detection requirements may be slightly relaxed; and air in-leakage concerns into D-T confinement may be relaxed slightly.

# Operational Issues for Consideration

- IFE power plant startup. The plant must ramp up its target supply to operating levels without violating the target holding time limit. If hold times are long, this is not a difficult issue. If hold times are short, then this needs to be clarified.
- The plant has a potential vulnerability in forced outages; the fuel has a hold time. If a long outage forces the plant to recycle some targets, then the costs per target increase. Other power plant energy sources (fossil fuels, uranium, etc.) are not as sensitive to wait times.
  - Loss of Offsite Power (due to electrical equipment fault, lightning strike, etc.) is in the 0.1 to 0.01 per year range, depending on the site location.
  - Loss of heat sink is typically ~ 0.1/year, loss of feedwater flow is also ~0.1/year. Turbine and generator trip are within "general transients" that has an overall frequency of 1/year. (from NUREG/CR-5750, 02/99)
  - Outage durations are important for an IFE plant. LOSP events are usually less than 1 hour. Other transient events vary in time duration from 0.5 to several hours.

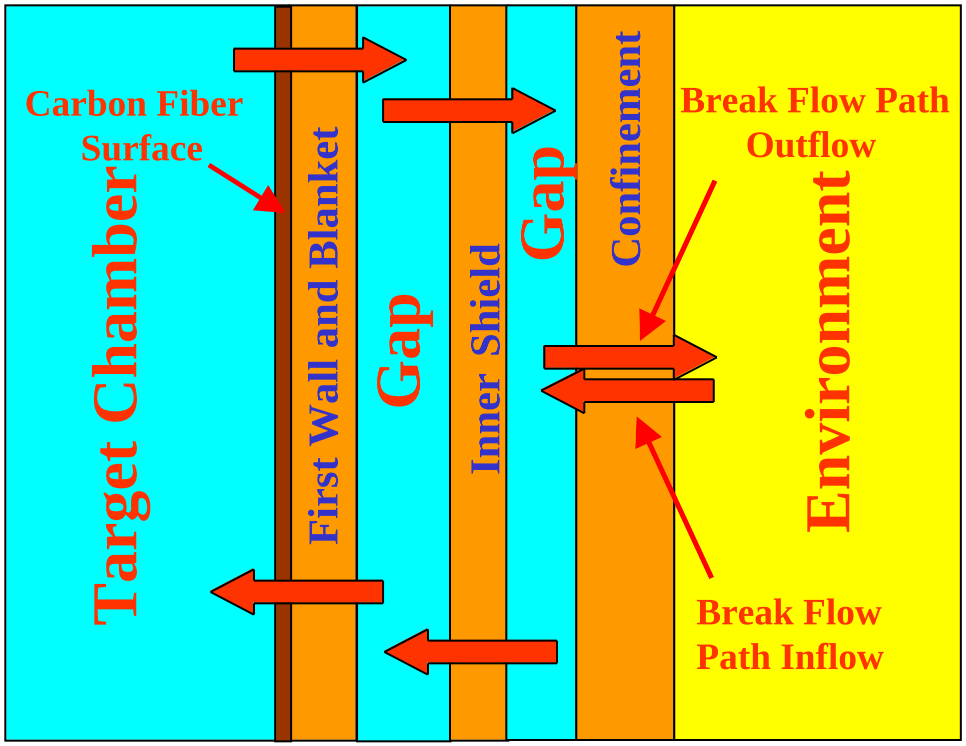
# Economics may Force Coupling

- For an IFE power plant, the target fabrication factory may need to be closely coupled to plant operation. Transients that cause plant outages economically force the target fabrication factory to throttle back production until a good estimate of the outage time is known.
- It is very difficult to judge the outage duration at the onset of a forced outage. Data from existing plants can be used for the balance of plant. Fusion equipment-specific outages would need to occur for the staff to accumulate expertise in judging outage duration.

# Preliminary Initiator Frequency for IFE Rogue Shots

- We need to improve our overall understanding of mass production of large quantities of “widgets” to better understand the quality and reliability issues associated with target production
- What technologies are available to sort out “bad widgets” for production systems with large throughputs? What is the rate at which “bad widgets” get through the system?
- We recommend a trip to a computer chip technology company like Micron Technologies in Boise ID, to see what they do, how they do it and what we could learn from that.
- Anybody interested?

# Accident Analysis: What is the influence of the Carbon Whisker material with a large amount of surface area?




ARIES-IFE MELCOR Model With a Carbon Fiber Surface

MELCOR model obtained from LLNL

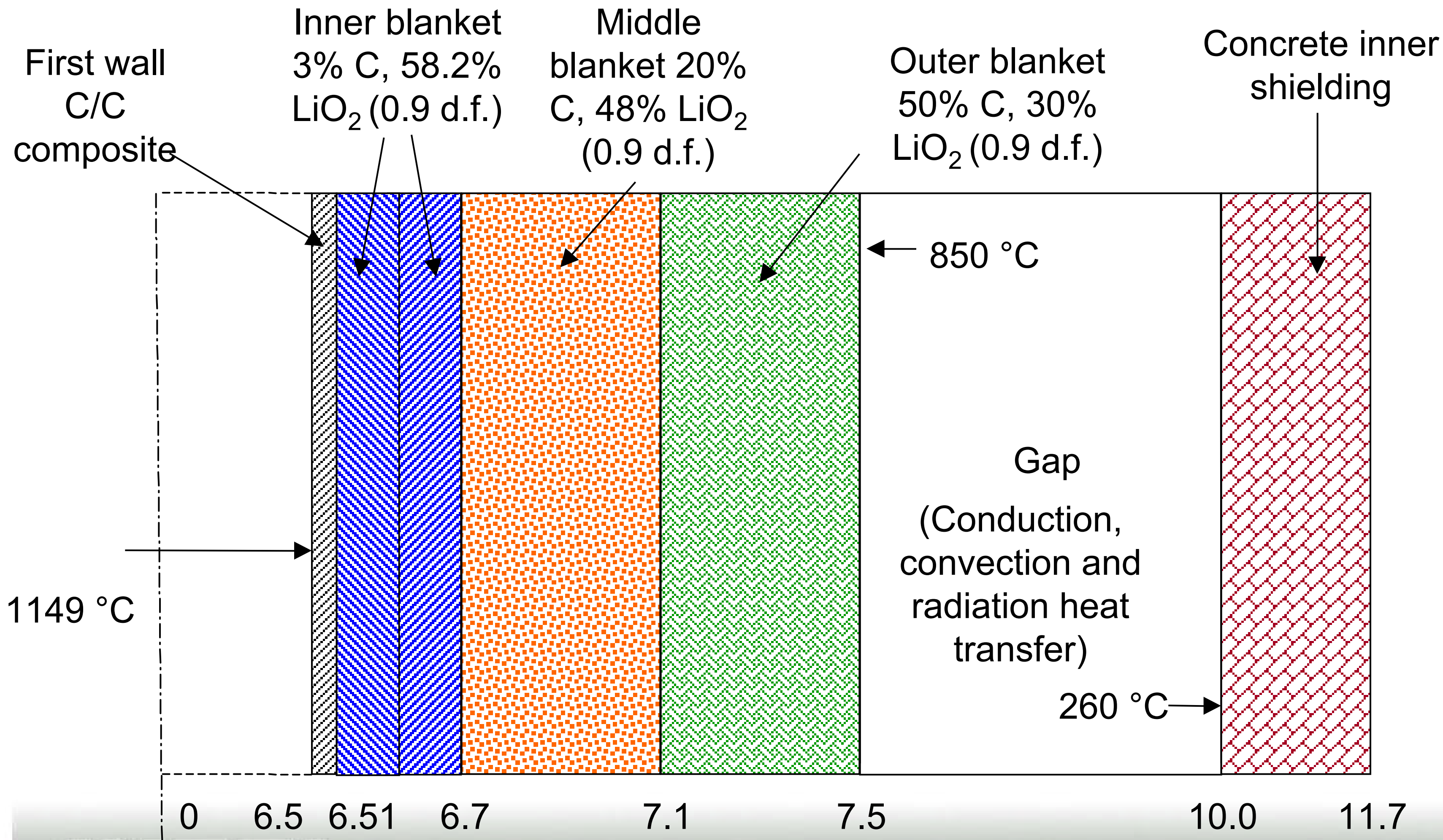
Some modifications were made in order to model carbon fiber surface

Carbon fiber surface is assumed to be 90% dense. The length of the fibers are assumed to be 2.5 mm.

Break area in confinement wall was assumed to be 1 $m^2$

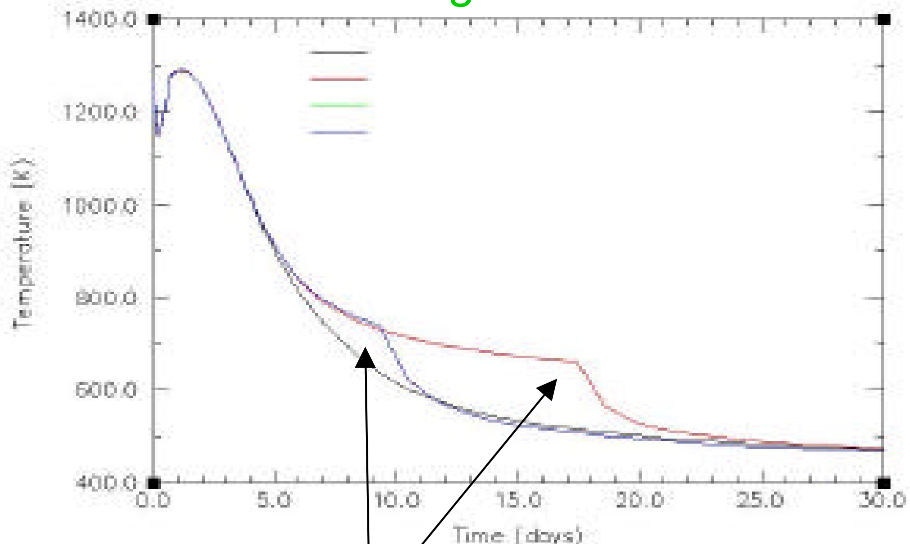
Although the back wall of the outer blanket is calculated to fails at ~14 hrs the $LiO_2$ pellets are assumed to remain in the blanket

# First Wall and Blanket Radial Build



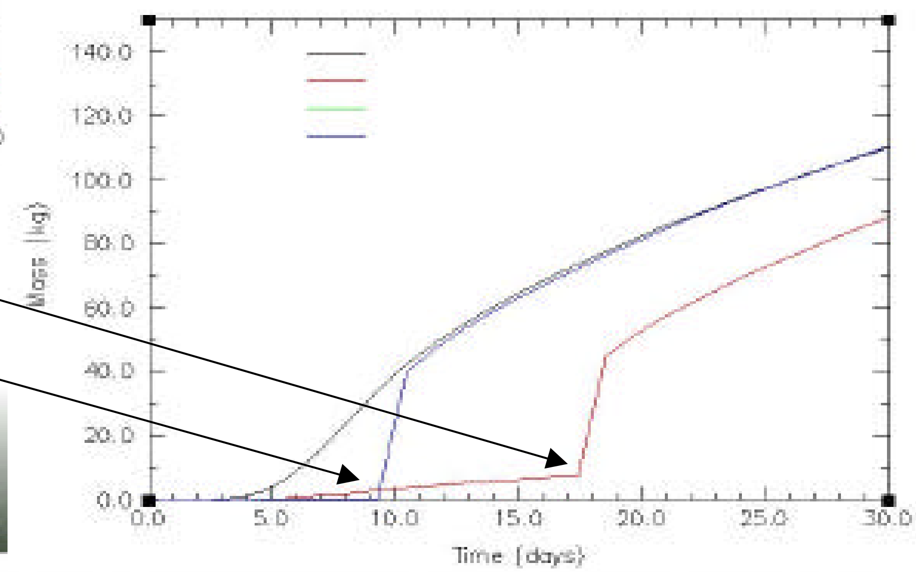
# Peak temperature is not affected by surface area of carbon material because reaction is limited by air availability.

Surface Temperature of Plasma Facing First Wall




Base
Carbon surface area 10 x
Carbon surface area 100 x
Carbon surface area 1000 x

Mass of Oxygen in Plasma Chamber




All fibers have been oxidized

# Future Activities

- Continue MLD to determine important initiators and accident scenarios
- Continue tritium target factory safety examination
- Continue studying confinement implementation study
- Specific safety analysis as needed for ARIES-IFE