Idaho National Laboratory

INL

Pressurization Accidents in ARIES-CS

Brad Merrill, Richard Moore
Fusion Safety Program

ARIES Meeting
General Atomics, February 25th, 2005

Presentation Outline

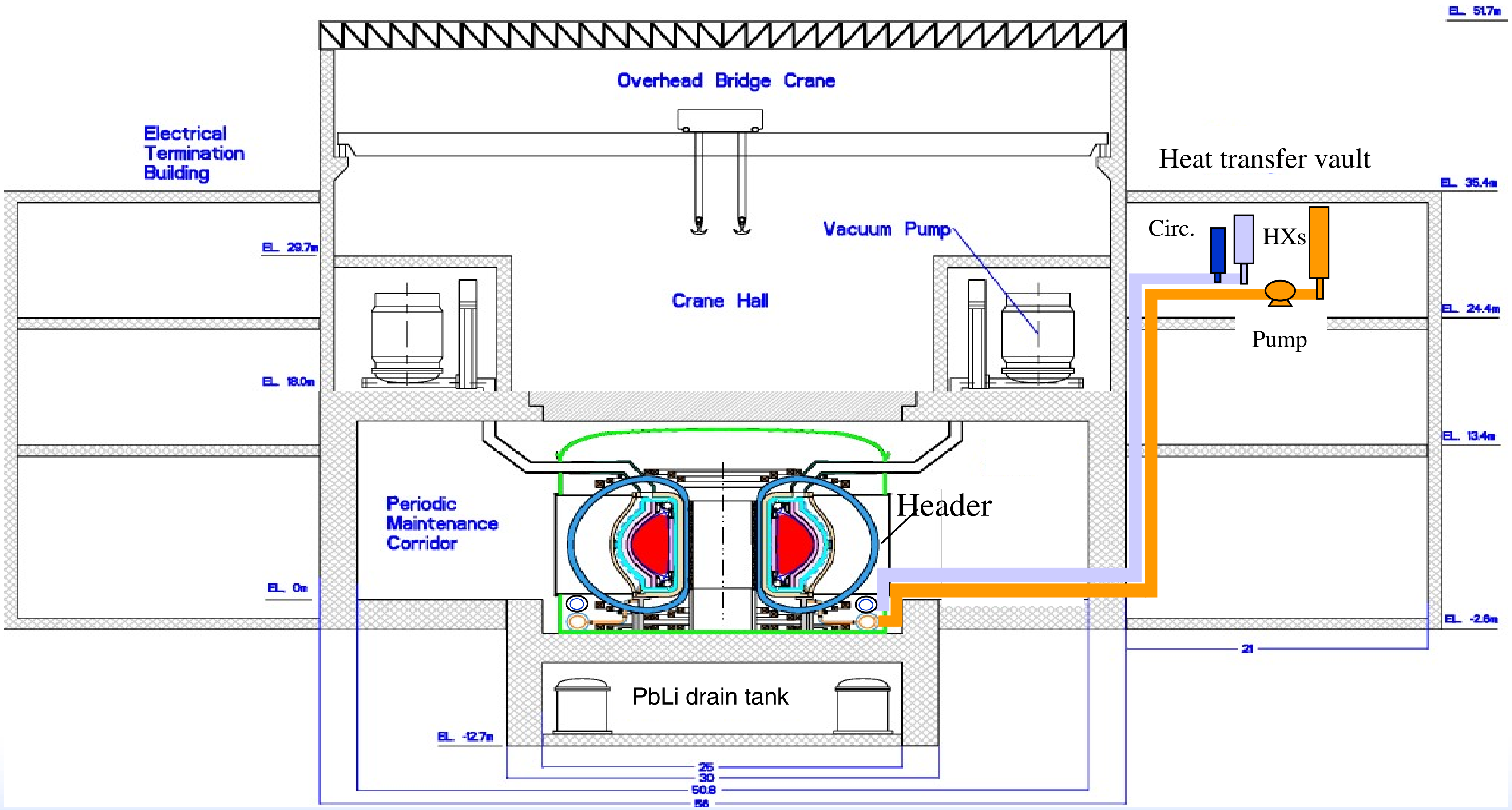
- Describe the details of a MELCOR model under development for the ARIES-CS dual coolant blanket concept
- Present MELCOR results for reactor startup
- Present the results of a decay heat removal analysis for a complete loss-of-flow-accident (CLOFA) as a benchmarking exercise for our MELCOR model
- Discuss possible accident scenarios that must be considered in assessing the safety of ARIES-CS
- Present results for two vacuum vessel (VV) pressurization accidents with the use of the ARIES-CS MELCOR model
- Conclude by discussing future modeling requirements and analyses

Modeling Assumptions and Parameters

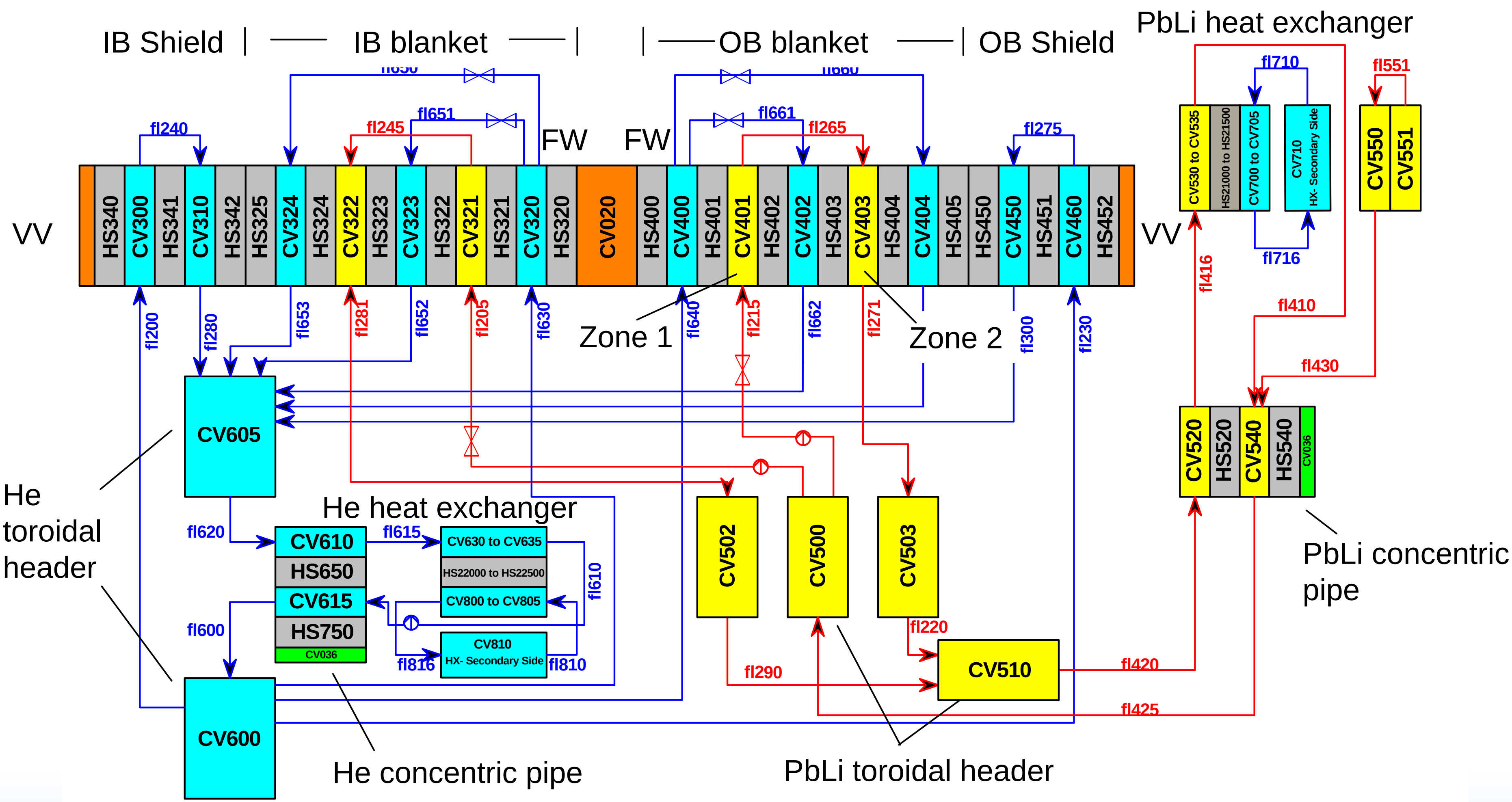
- Modeled one-half a field period segment (1/6th of three field period reactor)
  - First wall surface area 1/6 of plasma surface area ~ 135 m^2
  - Applied first wall heat flux of 0.5 MW/m^2
  - Total operating thermal power for model ~ 372 MW
  - Decay heat (obtained from “Initial Activation Assessment for ARIES Compact Stellarator Power Plant” paper ~ 10 MW at shutdown and 3 MW at 60 s)
  - Radial build based on Laila’s Nov. 11th radial compositions and an ARIES-ST unit blanket cell
- Helium Loop (~115 m^3)
  - Pressure 8 MPa and inlet /outlet temperature 300/480 °C
  - Mass ratio (external /in-vessel) ~ 7 to maintain He velocities below 40 m/s in piping
- PbLi Loop (~255 m^3)
  - Pressure 4 MPa and inlet /outlet temperature 460/700 °C
  - Mass ratio (external /in-vessel) ~ 4 (assumed from previous studies)
- Loop configurations based on ARIES-AT confinement building

MELCOR Model Elevations Based on ARIES-AT
(Need similar information for ARIES-CS)

North-South Cross Section View of ARIES-AT Power Core Building

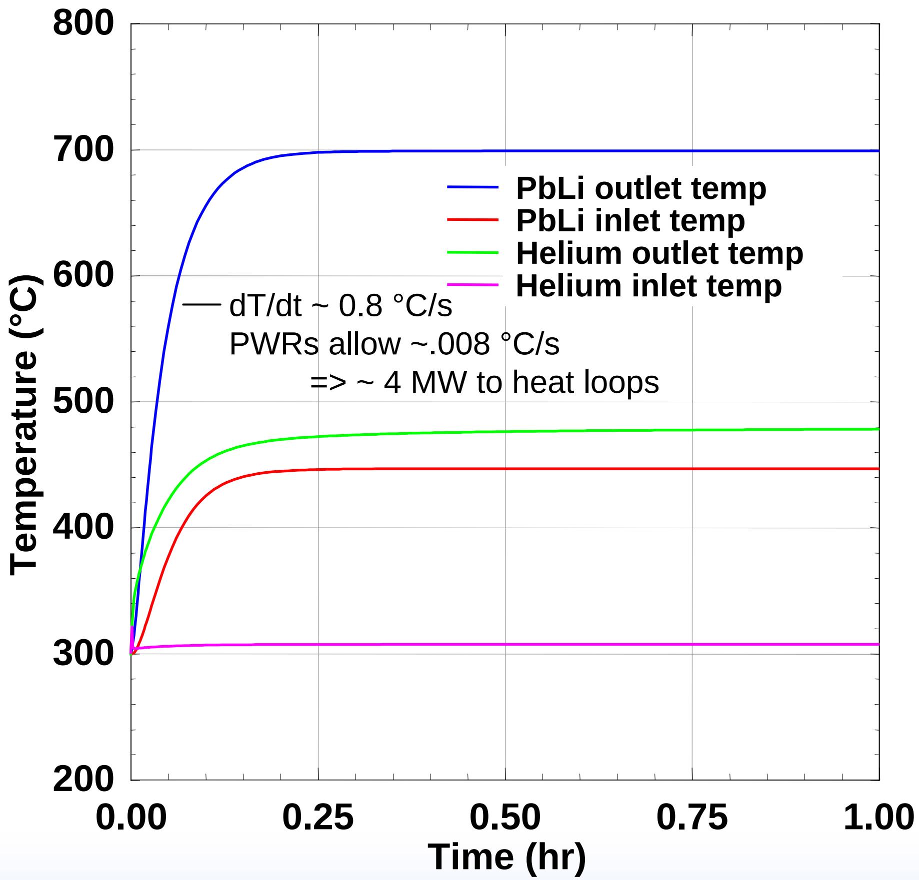


MELCOR ARIES-CS Model Schematic

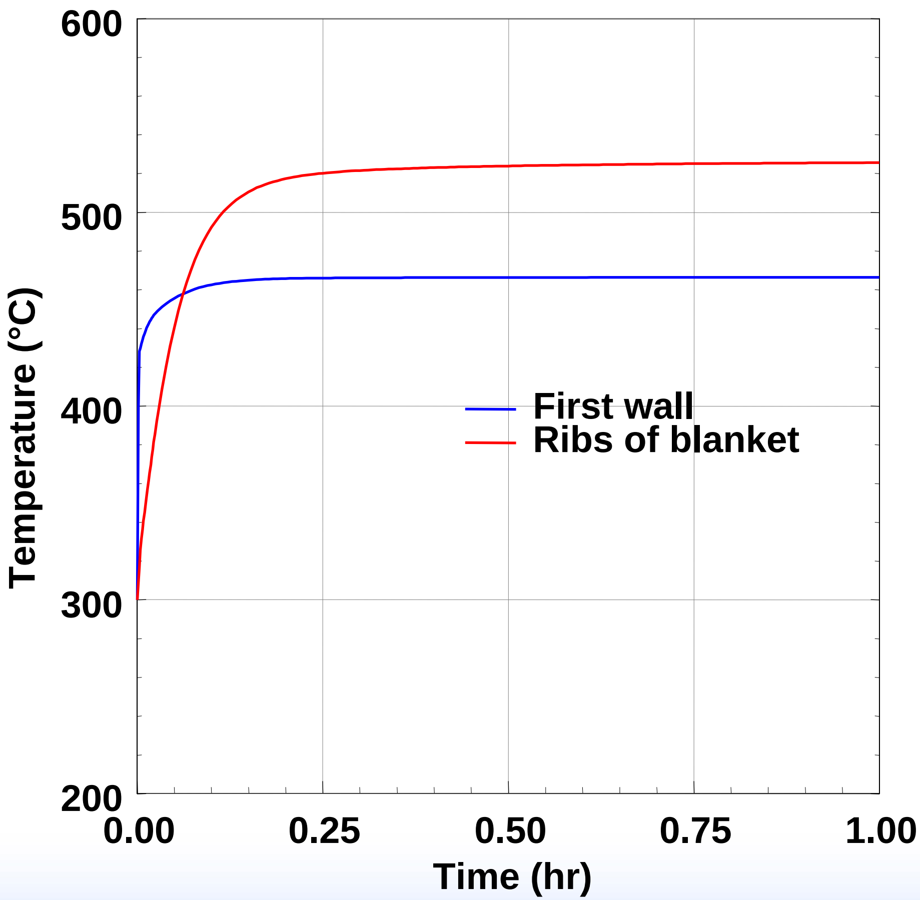


Startup Transient Predictions

Fluid temperatures



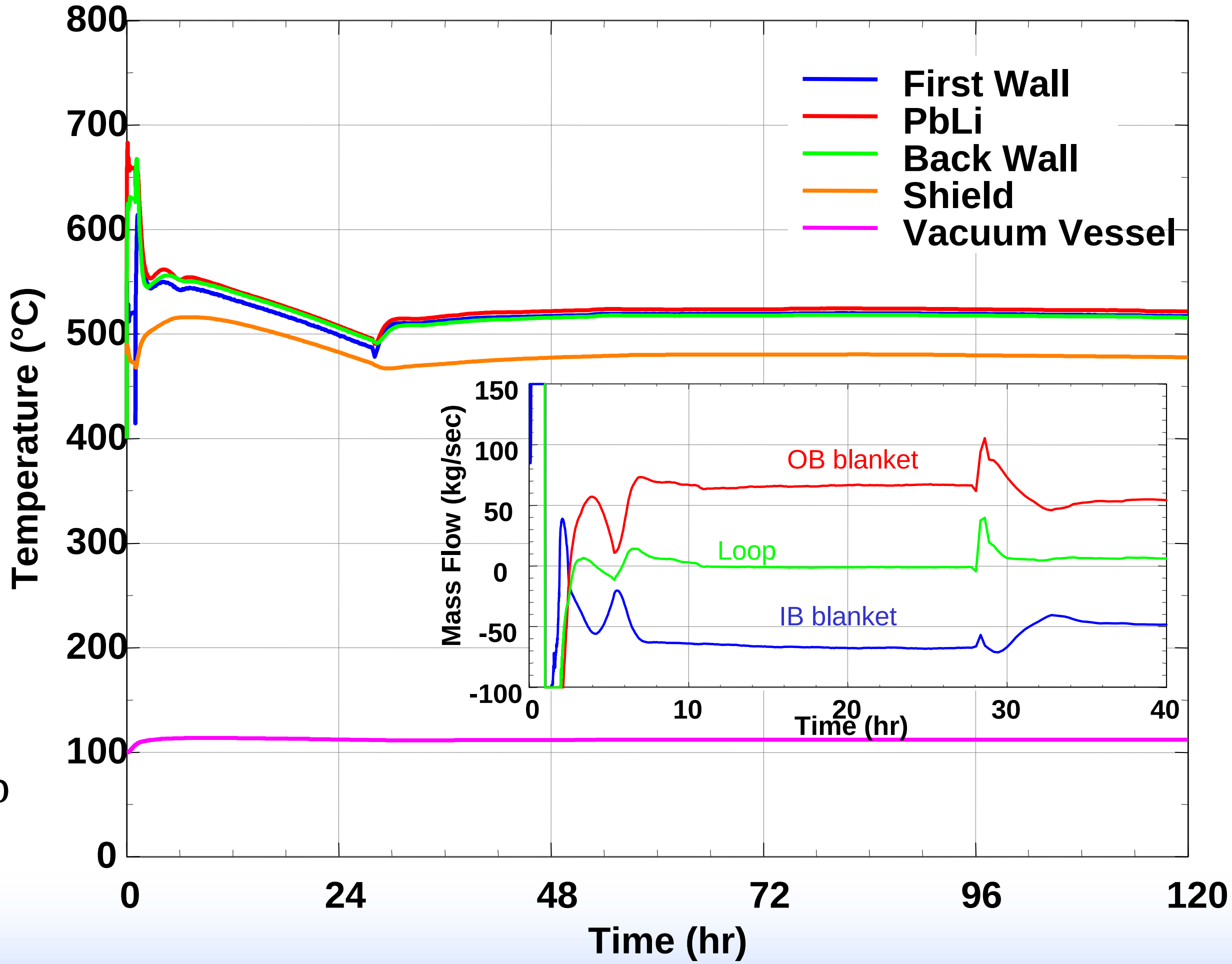
Structure temperatures



Idaho National Laboratory

CLOFA Decay Heat Removal

- Shutdown and complete loss of active cooling flow occurs, with the VV cooling system entering a natural convection mode
- Latent heat re-distribution results in FW temperature of ~ 630 °C (lower than 730°C predicted by Carl, perhaps due to flow coast down)
- By 3 hours the temperatures start to decay
- At ~26 hours the PbLi loop natural convection increases



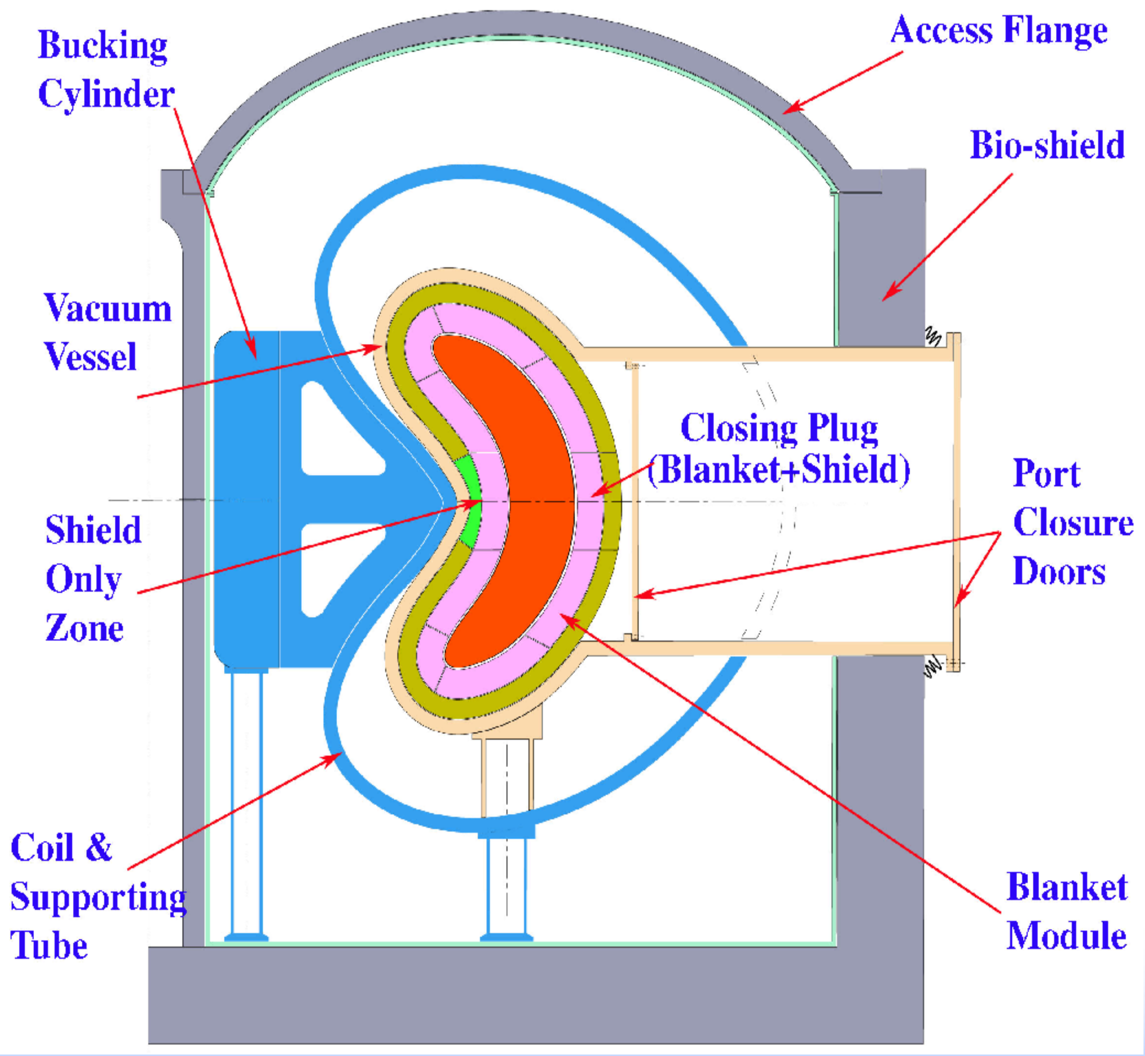
Idaho National Laboratory

Possible Reference Accidents

- In-vessel helium or water loss-of-coolant accident (LOCA) analysis to demonstrate:
  - Pressurization does not fail first confinement barrier (i.e., ARIES-CS vacuum vessel)
  - Limited chemical reactions and hydrogen formation (exclude water or limit PbLi)
- In-blanket (breeder zone) helium LOCA analysis to assess:
  - Blanket and tritium purge gas system pressurization
  - Subsequent in-vessel leakage
- Ex-vessel helium and PbLi LOCA analysis to determine:
  - Pressurization of reactor or HTS vault is tolerable
  - Behavior of FW/blanket without active plasma shutdown
- These accidents are the most likely confinement bypass event initiators because of confinement barrier over-pressurization; it must be demonstrated that for all three events the dose at the site boundary does not exceed 10 mSv for all radioactive sources combined (dust, FW oxidation, Po-210, and tritium)

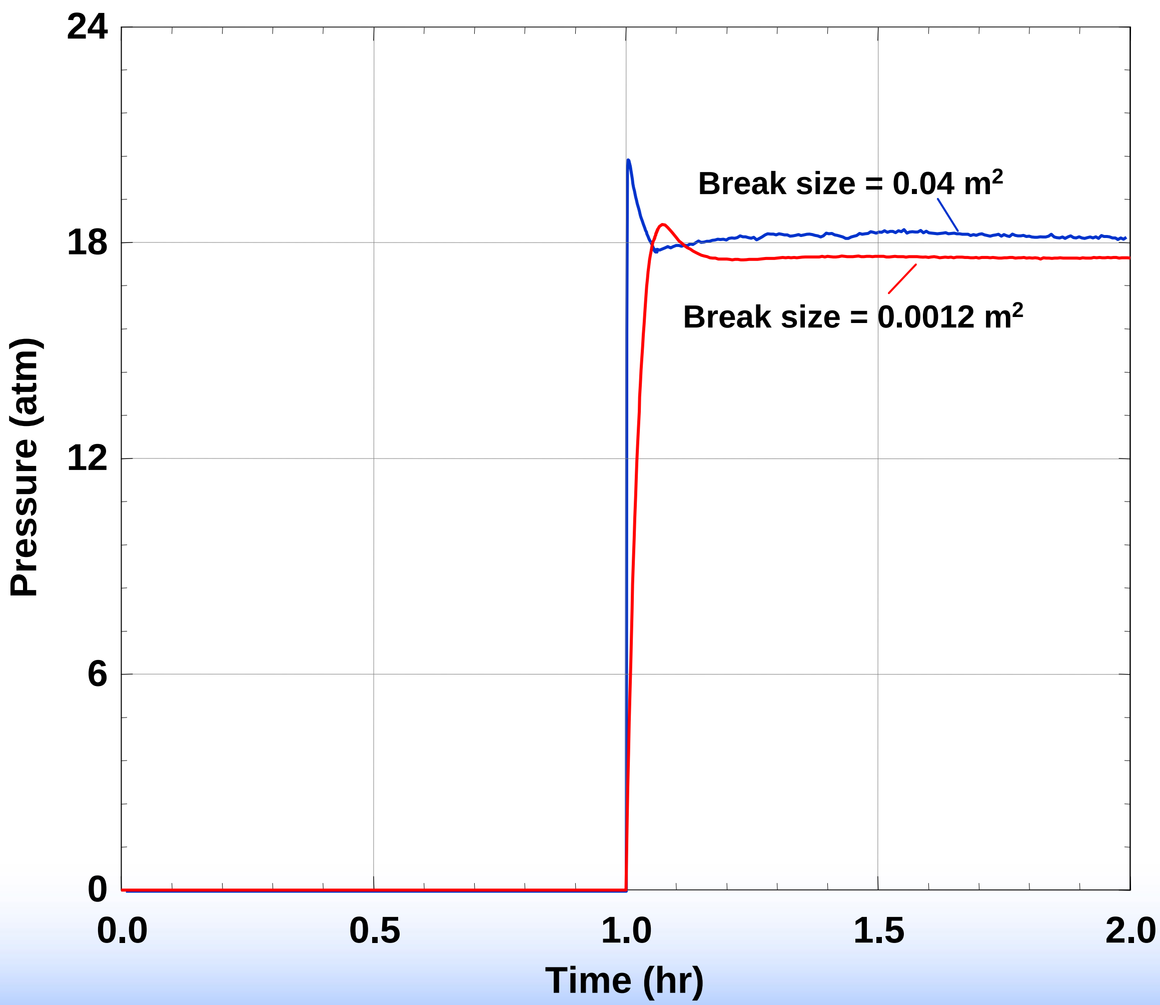
Pressurization of Module Maintenance Vacuum Vessel

- Two pressurization accidents were considered
  - A single FW channel rupture (0.0012 m^2)
  - Helium inlet header (0.04 m^2)
- Design basis events with probabilities in the ~ $1x10^{-3}$/year range
- Free volume within the vacuum vessel (VV) was set at plasma volume of ~535 m^3
- Immediate plasma shutdown occurs, but radiant collapse was not included



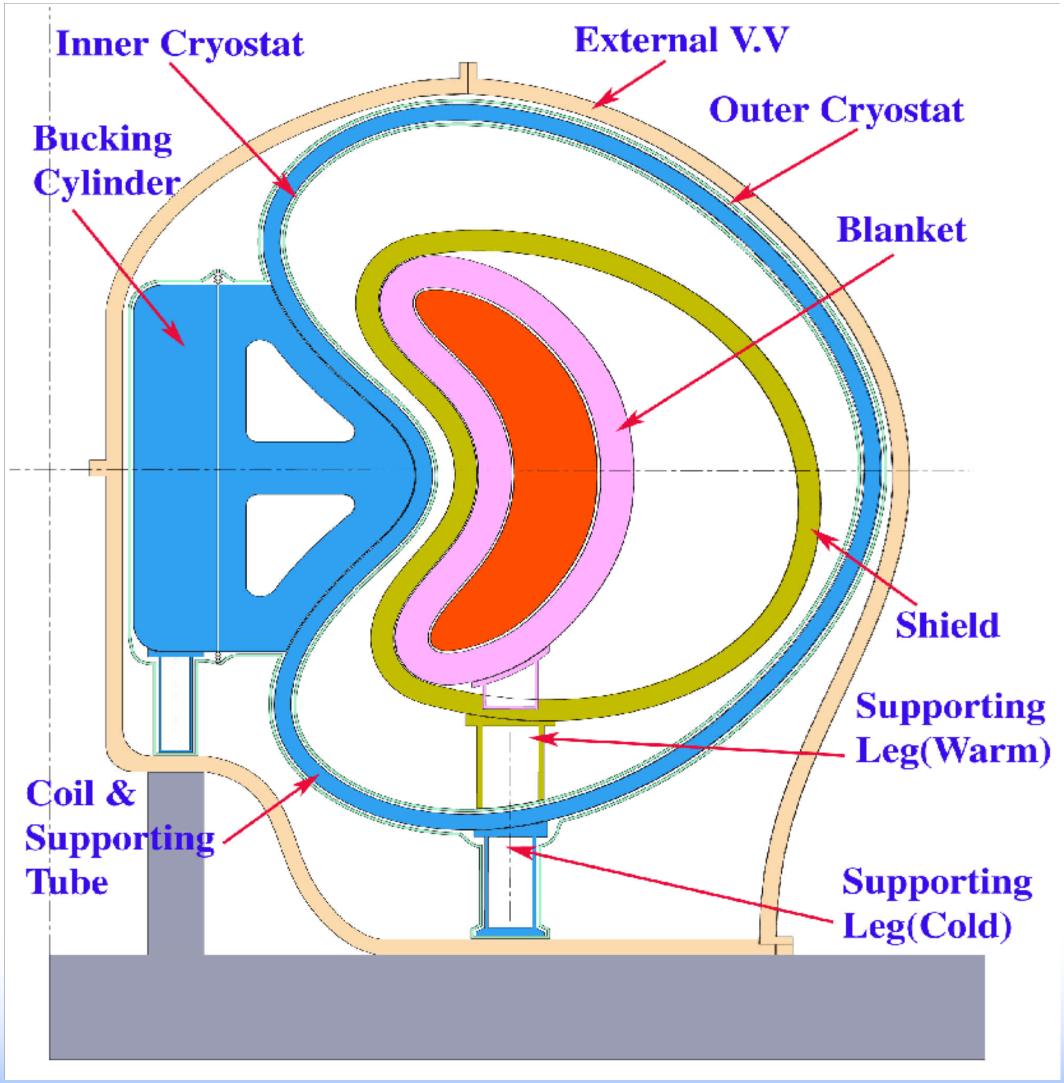
Pressurization of Module Maintenance Vacuum Vessel

- Shutdown and loss-of-coolant occurs after 1 hour, and VV cooling enters natural convection mode
- Pressures reach > 18 atmospheres within seconds after the large break while the small break takes ~ 5 minutes to reach 18 atmospheres
- A pressure relief system will be required for this VV option



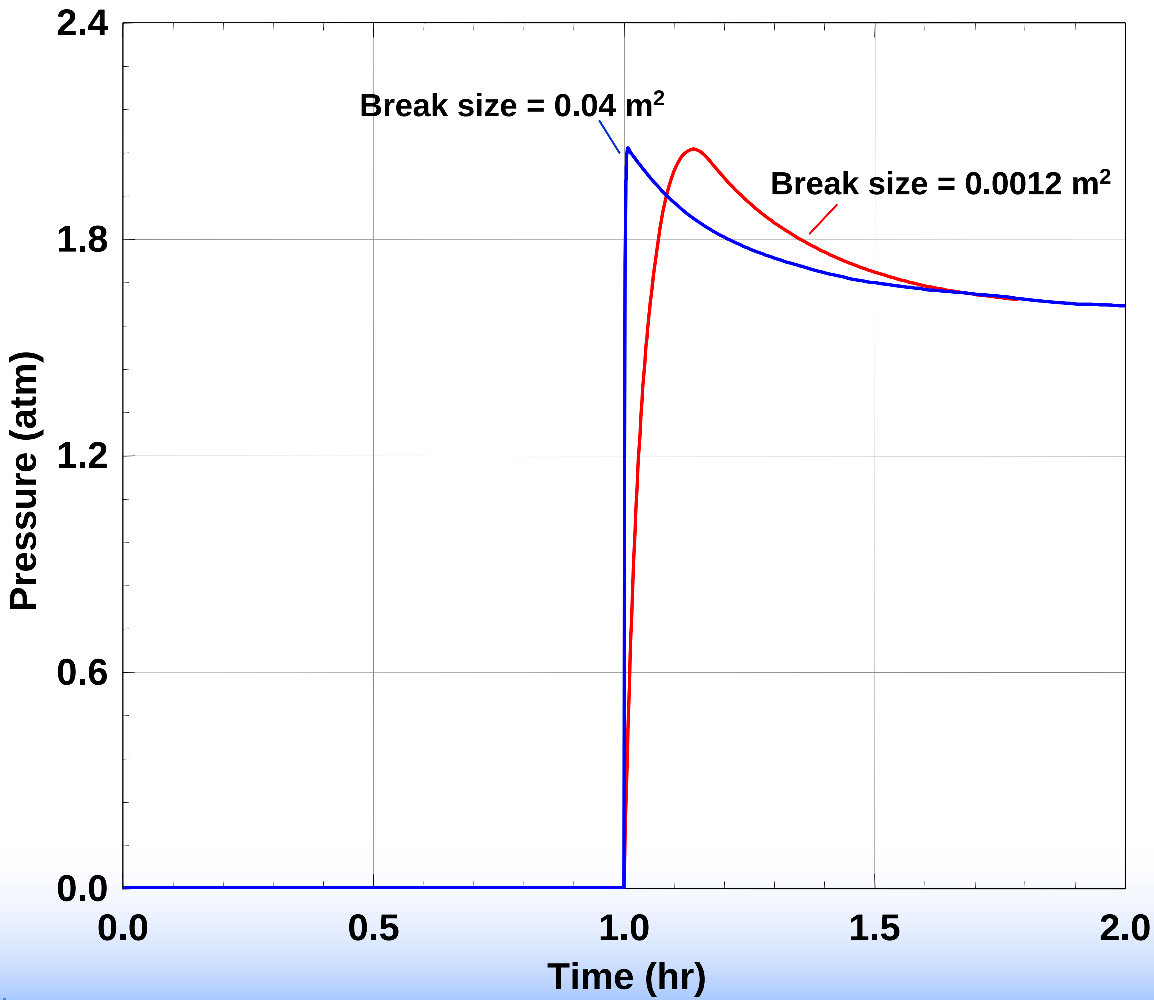
Pressurization of Period Maintenance Vacuum Vessel

- Two pressurization accidents were considered
  - A single FW channel rupture (0.0012 m^2)
  - Helium inlet header (0.04 m^2)
- Design basis events with probabilities in the $1x10^{-3}$/year range
- Free volume within the vacuum vessel (VV) was set at plasma volume of ~7000 m^3
- Immediate plasma shutdown occurs, but radiant collapse was not included



Pressurization of Period Maintenance Vacuum Vessel

- Shutdown and loss-of-coolant occurs after 1 hour, and VV cooling enters natural convection mode
- Pressures reach ~ 2.0 atmospheres within seconds for the large break while the small break takes ~ 10 minutes to reach 2.0 atmospheres
- A pressure relief system may not be required for this VV option
- However, decay heat removal may be an issue



Results Summary

- A decision must be made on which accidents will be selected as Reference Accident Scenarios (pressurization, decay heat removal, and hydrogen generation are concerns)
- Models are being developed to analyze releases during adopted Reference Accident Scenarios, but more design information and benchmarking is required
- Decay heat removal analysis suggests temperatures somewhat less than Carl's analyses, and this difference must be investigated further
- The VV is the primary confinement barrier and design basis pressurization events must not fail this boundary
  - The small VV for the module maintenance scheme will not work without an expansion volume available (will also be part of primary confinement boundary)
  - The large VV for the sector maintenance scheme is very attractive as a primary confinement barrier, if the decay heat removal problem can be addressed

Future Analysis Requirements

- MELCOR in-blanket (LOCA) model may have to be developed based on choice of tritium and Po-210 (or Bi-208) extraction systems (low or high pressure extraction systems)
- Tritium inventory, permeation, and accident releases
  - Annual release limit (0.1 g-T as HTO/a – ITER to 8 g-T as HTO/a – FIRE) translates into an in-building permeation limit of between ~10 to 800 g-T/a, assuming a 99% efficient tritium cleanup system
  - To meet this limit the tritium extraction method proposed by Siegfried Malang, which is a vacuum permeator (Nb tubes), is proposed for the PbLi to lower the T_2 concentration to levels (produce pressures above PbLi < 0.2 Pa) where losses to the building are below the annual release limit
  - Will need tritium production rates
- A TMAP model should be developed to examine tritium permeation in the blanket and from the cooling systems, and to estimate tritium accident mobilization rates
- Need estimates of VV PFC erosion dust and FW activation product inventories
- ARIES-AT PFC dust and Po-210 inventories will be used for accident source terms
- This information will feed into MELCOR LOCA and LOVA predictions for radioactive release estimates and site boundary dose predictions