Idaho National Engineering and Environmental Laboratory

Future US ITER Safety Tasks

David Petti
Brad Merrill

16th TOFE
September 13, 2004
Madison, Wisconsin

Future US Safety Tasks

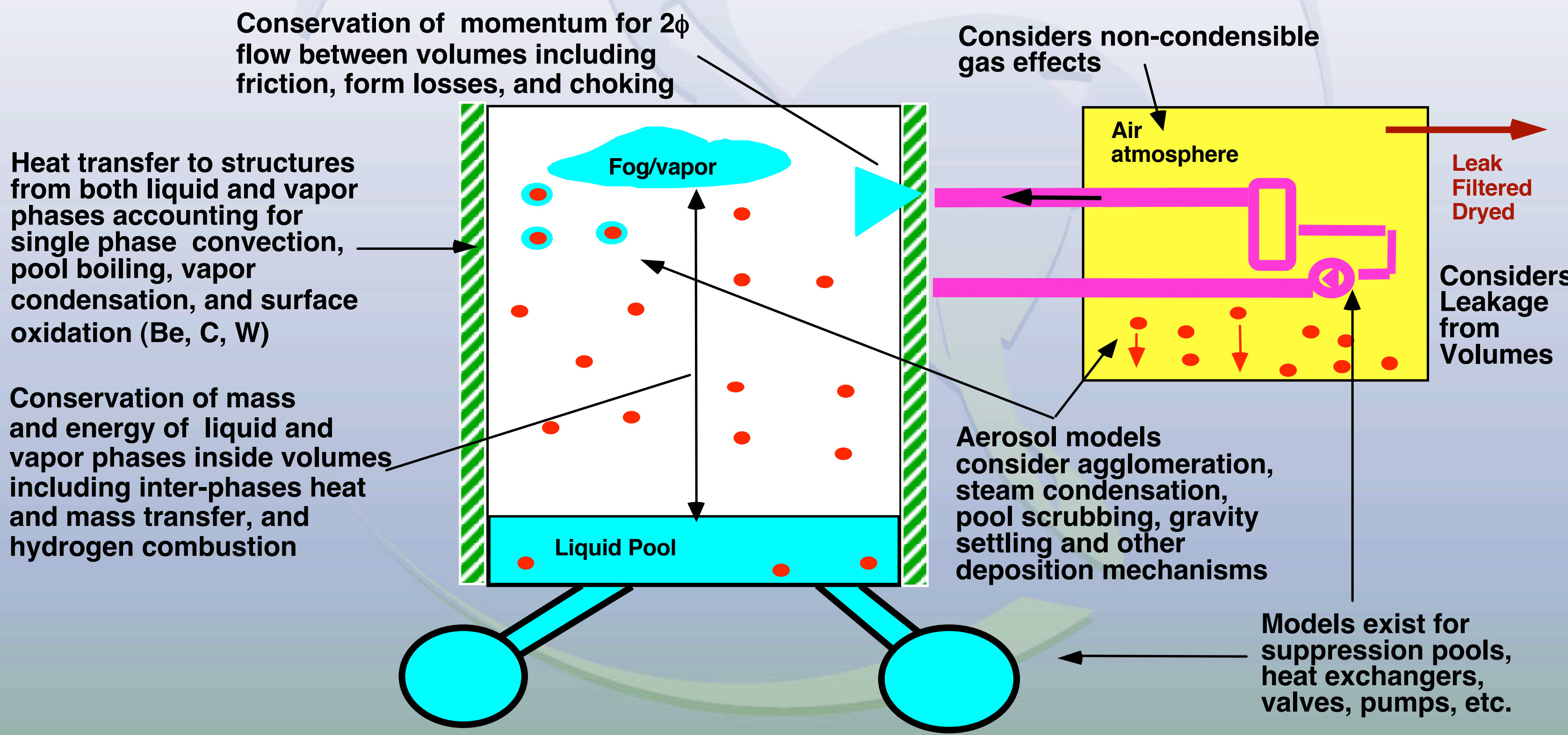
- Validate US safety analysis tools (calculations with quantified uncertainties with the level of detail to depend on regulatory requirements of the actual site) that underpin the ITER safety analysis
- Validate magnet safety codes against medium scale magnet and busbar arcing experiments to demonstrate that ITER can tolerate large internal and external arcs in the magnet systems without violating the integrity of the radioactive confinement barriers.
- Validate dust inventory estimates in ITER and develop a dust removal strategy that will demonstrate compliance against dust safety limits in ITER and not hamper operational flexibility of the machine
- Validate tritium inventory estimates in ITER mixed material (Be, W, C) PFCs and demonstrate that removal strategies are effective at the ITER scale to comply with safety limits

ITER IT has requested Continued US Code Development, Application, and Validation & Verification

- Our work during the ITER Engineering Design Activity (EDA) focused on developing fusion specific safety models for use in ITER safety studies (e.g., chemical reaction rates for fusion materials, condensation of air and water on cryogenic surfaces, ice formation on cryogenic surfaces, and dust transport behavior)
- State-of-the-art fission safety codes were adapted to develop the first self-consistent systems level safety models of a DT fusion facility (ITER) to show that ITER could meet the no-evacuation objective (Non-Site Specific Safety Report - NSSR)
- Three US fusion safety computer codes were prominently employed in analyzing accident scenarios of the NSSR: MELCOR, ATHENA, and MAGARC
- Since the EDA, the ITER International Team (IT) has used these codes to produce the ITER-FEAT Generic Site Safety Report (GSSR). Now that the US has reentered the ITER project, the US Safety Program has been tasked to provide the ITER IT with the latest fusion versions of the MELCOR, and ATHENA codes, to update the MAGARC code, to apply these codes to specific GSSR accident scenarios, and to contribute to validation studies for safety codes

MELCOR Analysis Capabilities

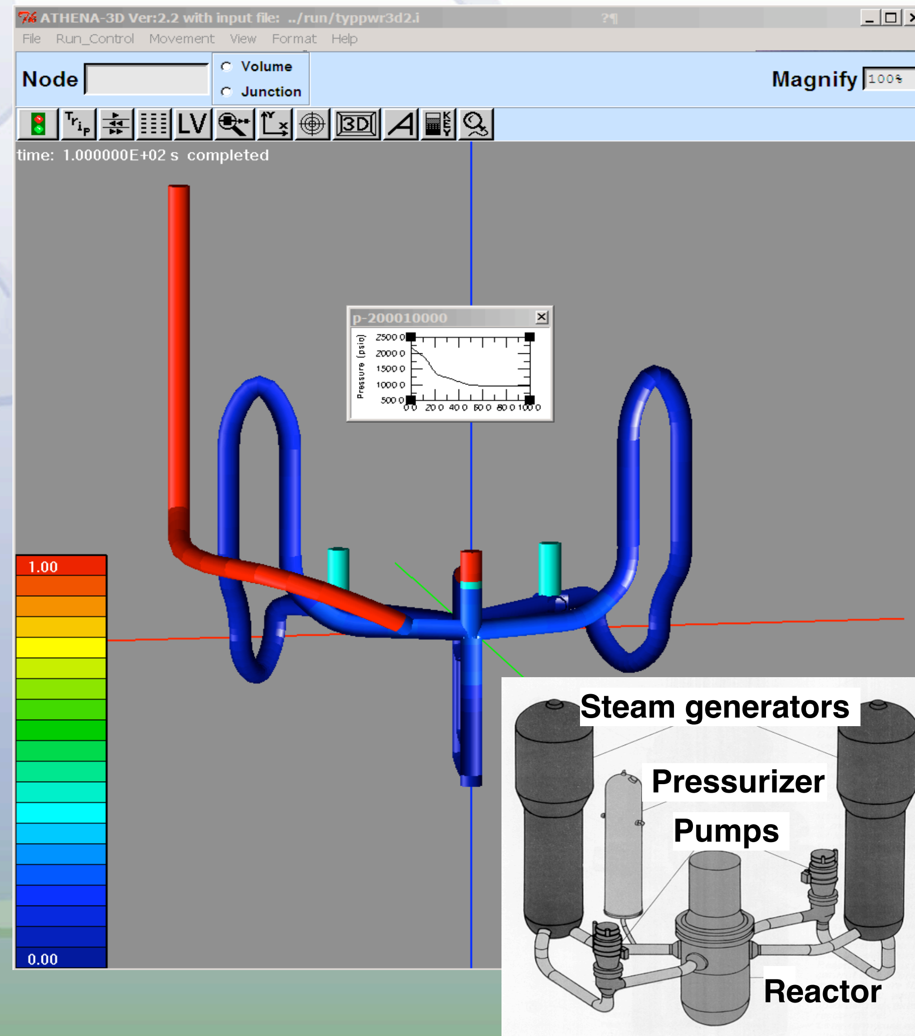
MELCOR is a engineering-level computer code that models the progression of severe accidents in light water reactor (LWR) nuclear power plants, including reactor cooling system and containment fluid flow, heat transfer, and aerosol transport. (Developed by SNLA, fusion modifications by INEEL)



ATHENA Analysis Capabilities

- Advanced Thermal-Hydraulic Energy Network Analyzer (ATHENA) is an extension to the RELAP5 code developed at the INEEL for the NRC to analyze fission reactor accidents
- Models transient fluid two-phase non-equilibrium fluid flow in user-defined thermal-hydraulic networks
- Fifteen working fluids available, including water, helium (gas & liquid state), nitrogen, lithium, lead lithium, flibe
- Detailed models for
  - Single or two-phase flow pressure drop in 1-, 2-, or 3- dimensional flow networks
  - Conduction, convection, radiation
  - Pumps, valves, separators, accumulators, jet-mixers, pressurizers, and turbines
  - Critical flow, abrupt area change, form loss, phase separation at tees

New capability: Graphical User Interface (GUI)
Model of typical PWR simulating cold leg break

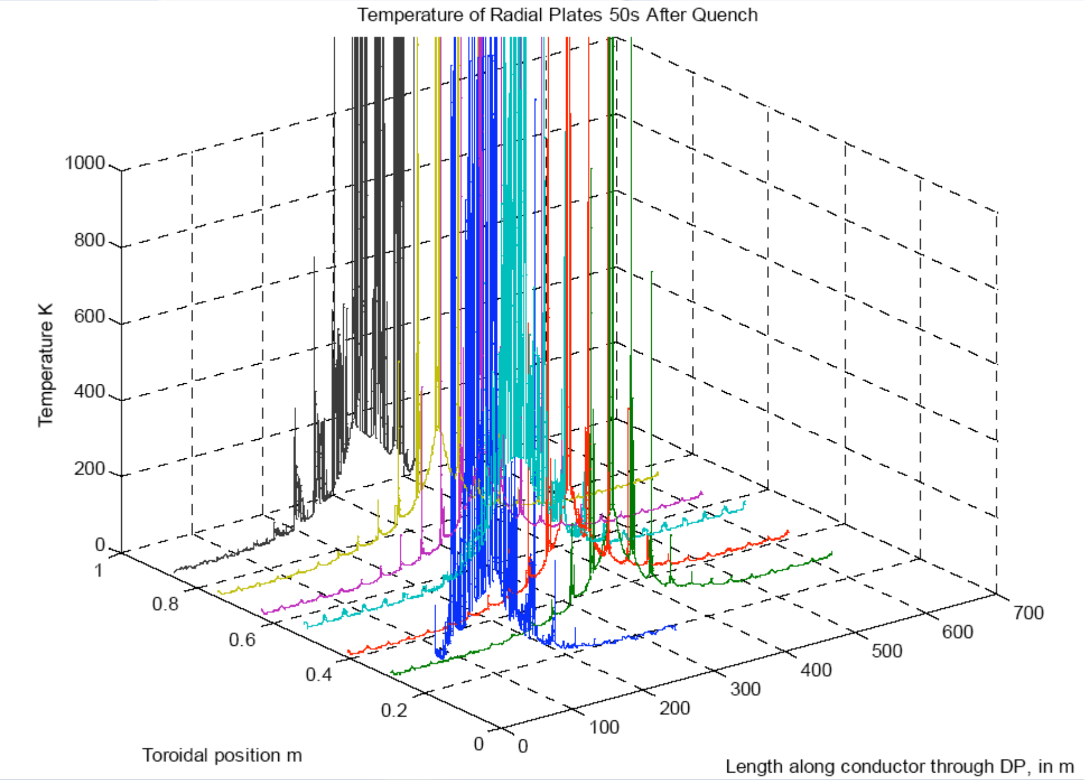


MAGARC Analysis Capabilities

MAGARC Capabilities

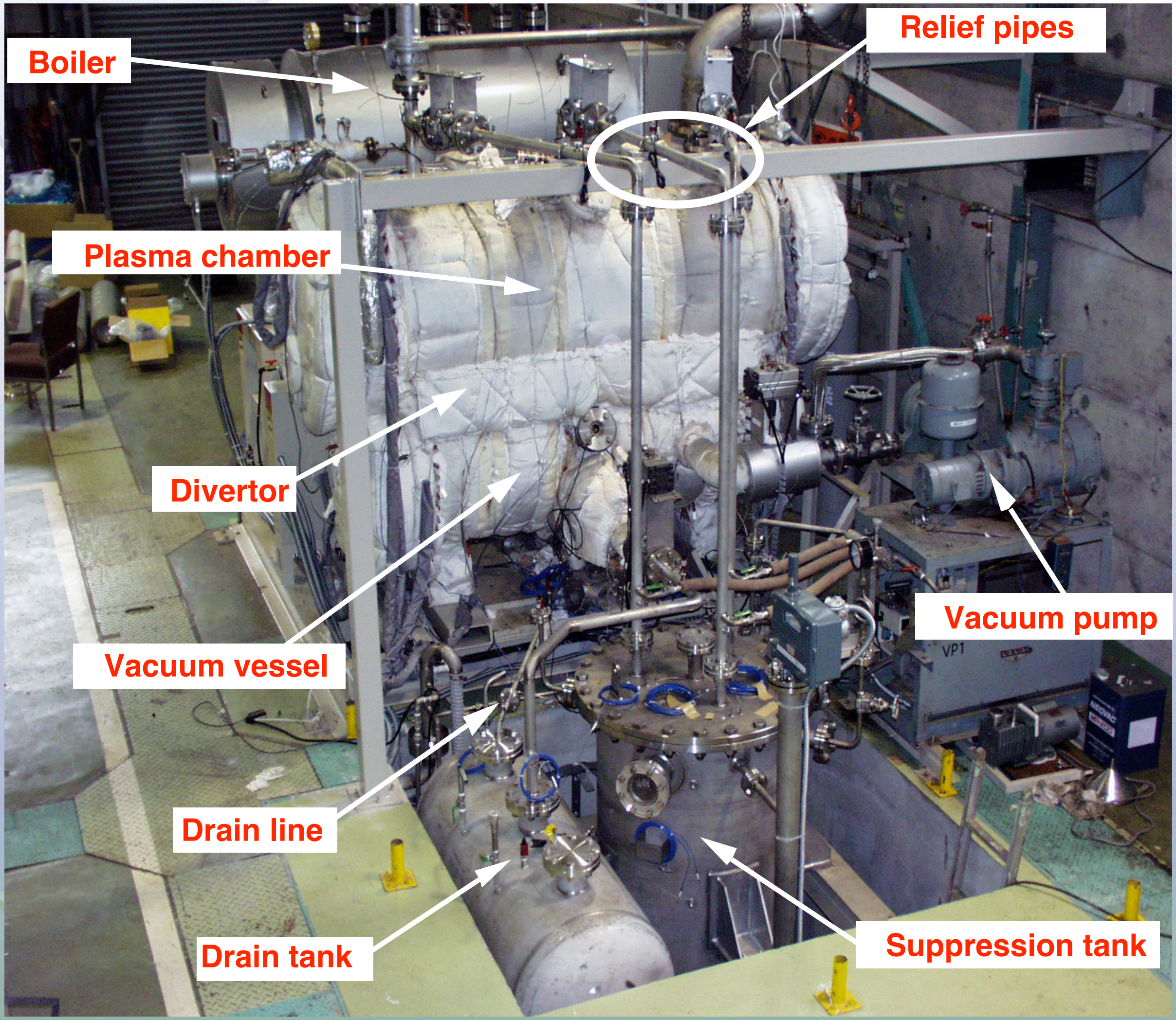
- MAGARC predicts the thermal and electrical response of a toroidal field (TF) magnet during an unmitigated thermal quench by solving three-dimensional heat conduction equations to determine magnet temperatures and a three-dimensional resistive circuit model to determine magnet currents and internal arcing behavior.
- Conduction - copper stabilizer, glass epoxy insulation, radial plates, and coil case
- Arc models, displaced currents, resistive heating, and material melting
- One-dimensional helium fluid flow and convection

MAGARC Application in GSSR

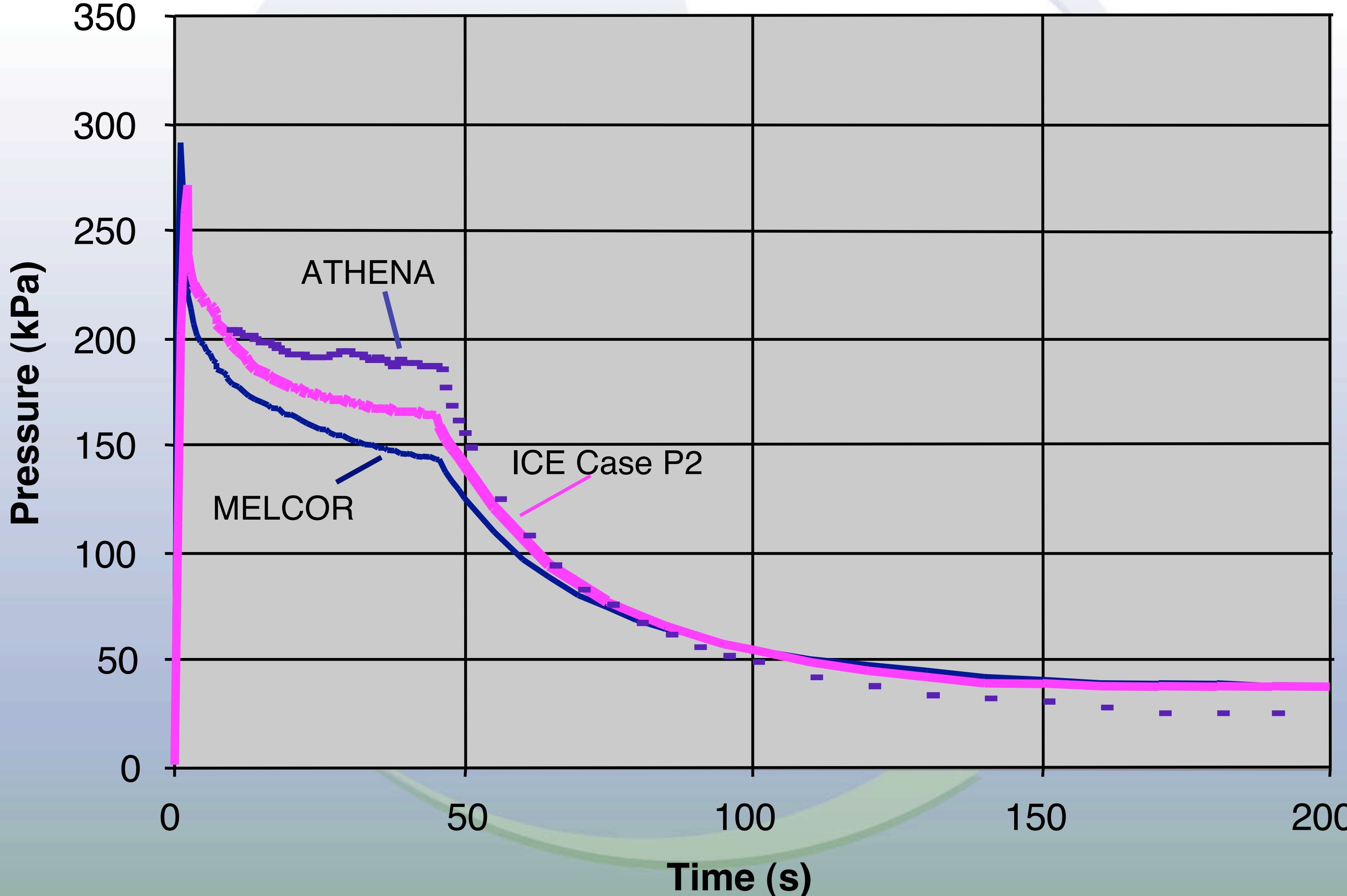


Ingress of Coolant Event (ICE) Facility at Naka, Japan

- The ICE facility is used to validate computer codes and to demonstrate that the adopted ITER-FEAT vacuum vessel (VV) pressure relief strategy would be successful
- The suppression tank (ST) is connected to the plasma chamber through three relief lines containing relief valves which open at 150 kPa
- Tests were conducted that injected high pressure steam or water into the VV, with the walls either heated or at room temperature. A typical test was ICE Case P2 which injected 5.6 kg/s of 150 °C water for ~45 seconds with the PC walls heated to 230 °C

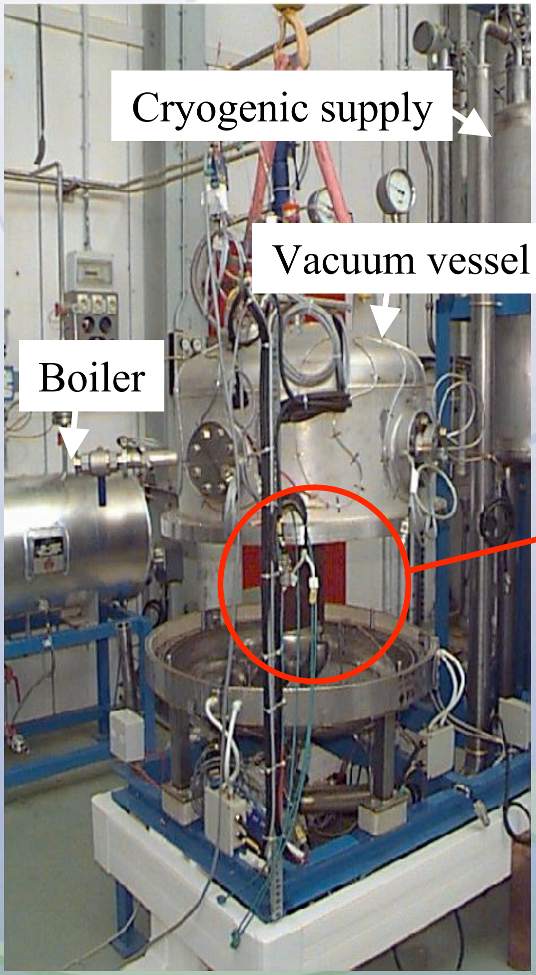


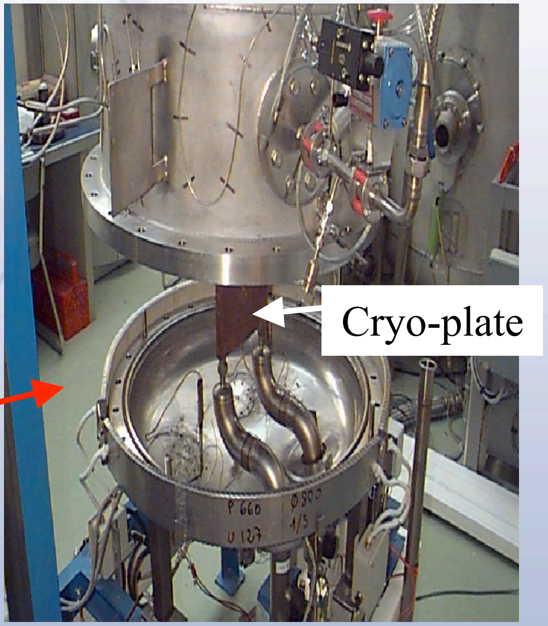
MELCOR and ATHENA Comparison with ICE Vacuum Vessel Pressure (Case P2)



Experimental Vacuum Ingress Testing Apparatus (EVITA) at Cadarache, France

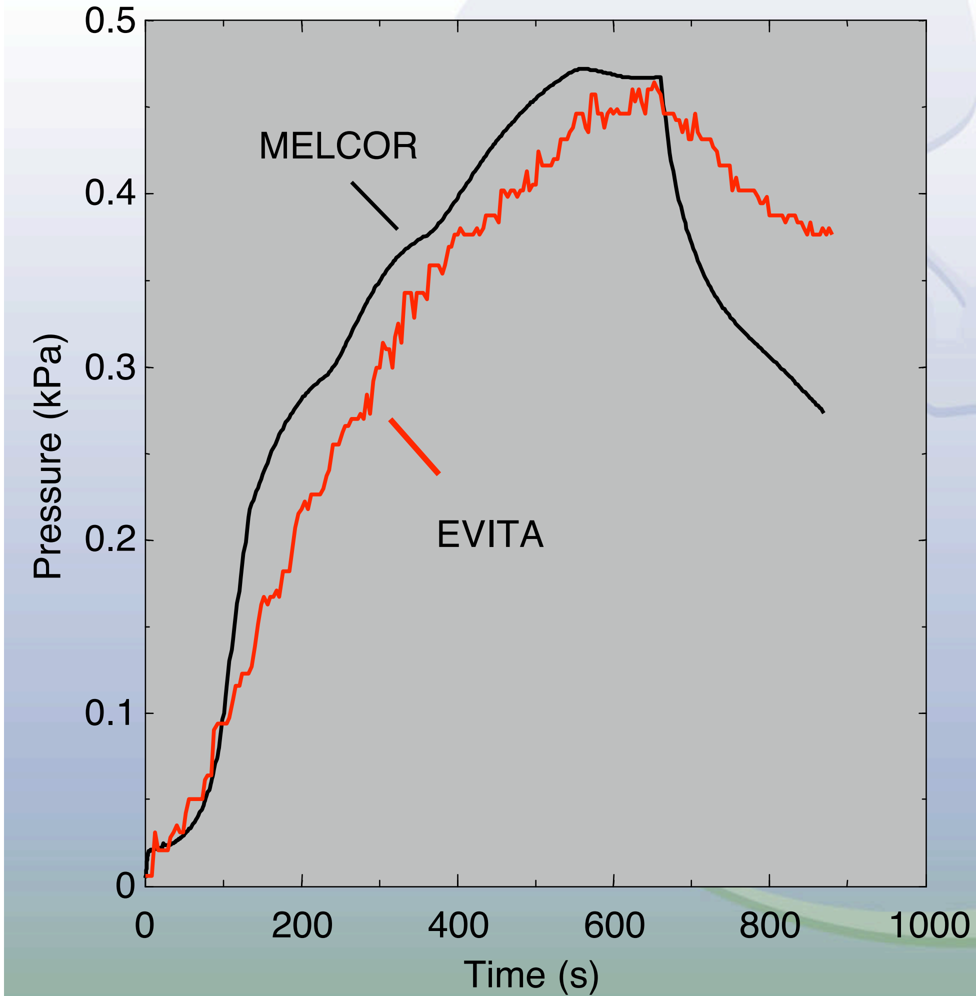
- EVITA is an experiment designed to study the thermal hydraulic phenomena associated with a water pipe break in a cryostat containing structures at temperatures less than 80 K
- A key safety issue regarding the event is the possible failure of the cryostat by pressurization because the cryostat is a radioactive confinement barrier for ITER
- Tests have been conducted in EVITA that inject steam or water into the VV heated to 165 °C with the copper cryoplate internally cooled to 80 K, such as EVITA Test 5.3 that injected 165 °C water at a flow rate of 0.7 g/s for ~650 seconds



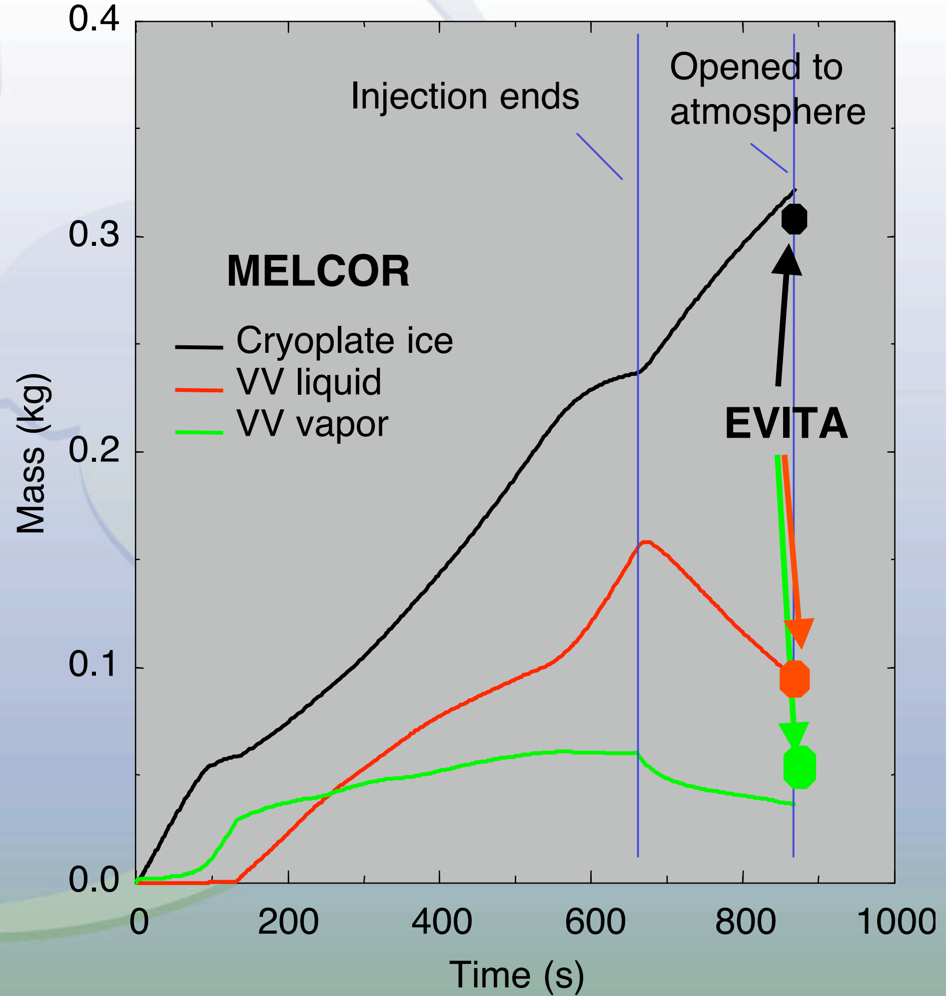


MELCOR Comparison with EVITA Test 5.3

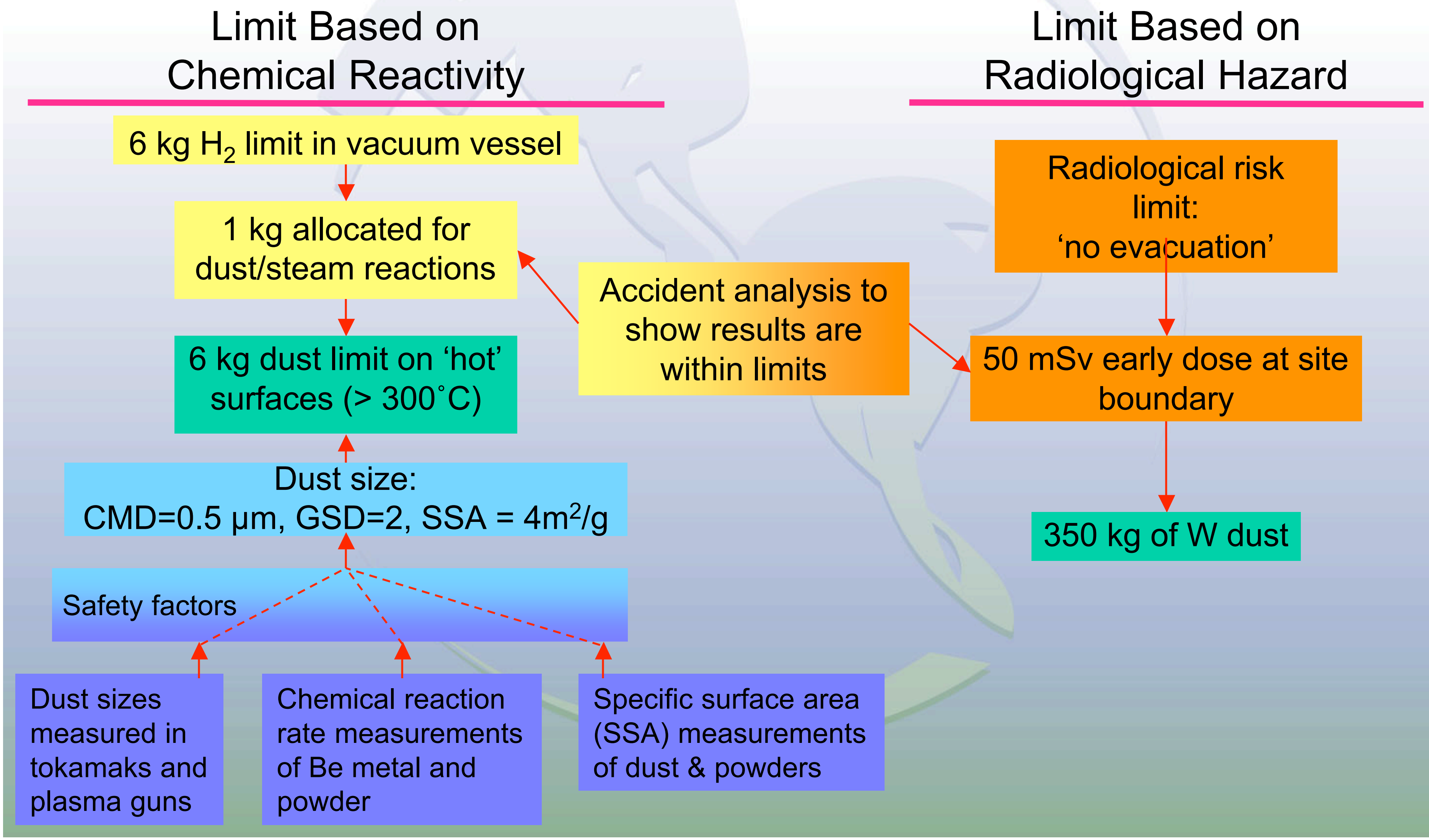
VV Pressure



VV Mass Balance

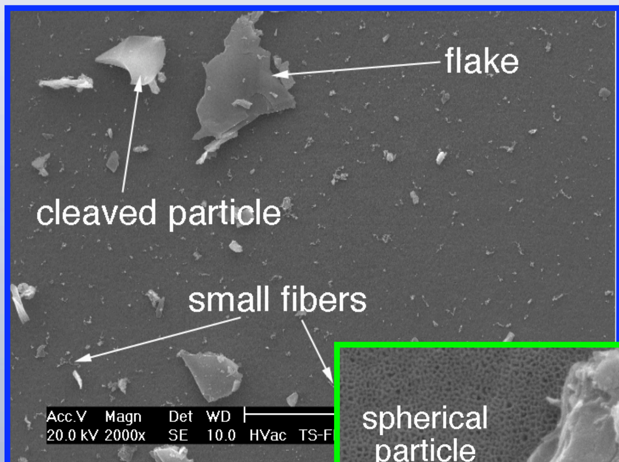


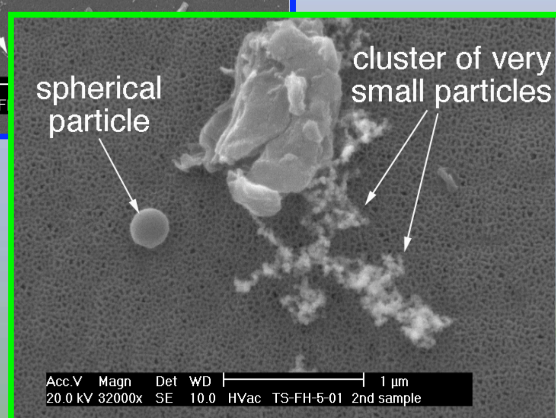
Dust Safety Limits in ITER are based on the total quantity of dust, its size, surface area and location in the vessel



Dust Behavior

- Characterization (size, surface coverage, specific surface area)
- Apply self-consistent analysis protocol
- Demonstrate effective monitoring and removal techniques



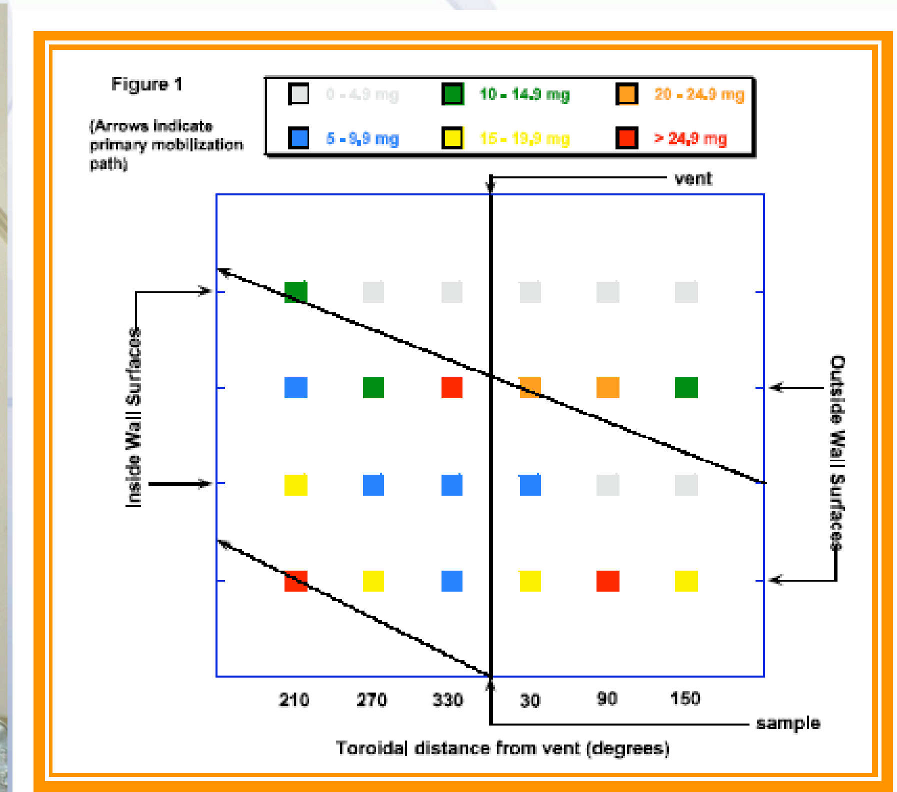


	CMD (µm) ± GSD		
Machine	Lower Regions	Middle Regions	Upper Regions
DIII-D	0.66 ± 2.82	0.60 ± 2.35	0.89 ± 2.92
TFTR	0.88 ± 2.63	1.60 ± 2.33	-
Alcator-Cmod	1.58 ± 2.80	1.53 ± 2.80	1.22 ± 2.03
JET	27 ± (-)	-	-
TEXTOR	5-20 ± (-)	-	-
Tore Supra	2.68 ± 2.89	2.98 ± 2.94	3.32 ± 2.94
ASDEX-Upgrade	2.21 ± 2.93	3.69 ± 2.81	3.59 ± 3.08

	Surface Mass Density, mg/m^2		
Machine	Lower Regions	Middle Regions	Upper Regions
DIII-D	23.5	896.	8.40
TFTR	-	-	-
Alcator-Cmod	5,470	87.0	66.5
JET	1,300	-	-
TEXTOR	-	-	-
Tore Supra	595.	31.9	5.33
ASDEX-Upgrade	1,300	55.7	28.3

Dust Mobilization and Chemical Reactivity

- Mobilization behavior in the vacuum vessel (toroidal geometry) needs to be understood, accounting for presence of obstacles
- Chemical reactivity of dust in grooves must be characterized (mass transport limitations?)



In-vessel Tritium Behavior

- The lack of an accurate quantifiable estimate of in-vessel tritium retention and accumulation in ITER could hamper the licensing of ITER and, if unresolved, could severely limit its operational flexibility.
- Further refinement of tritium inventory estimates in ITER mixed material plasma facing components (PFCs) and demonstration that removal strategies are effective at the ITER scale are needed to demonstrate compliance with safety limits.
- Large uncertainties exist in the underlying plasma material interaction behavior that directly impacts the tritium retention in the vacuum vessel
  - Rates of co-deposition of tritium with eroded material from the plasma-facing components.
  - Rate of erosion of material from the first wall and transport via the scrape-off layer to the divertor region and subsequent interaction with the plasma and with the surfaces in the divertor.
- Experiments are planned in the Tritium Plasma Experiment at the Safety and Tritium Applied Research (STAR) facility at the INEEL
- Analysis with the V&Ved code TMAP4

Summary

- As ITER heads toward site selection and regulatory approval, a few areas in the safety case still remain incomplete related to verification and validation of safety codes used to demonstrate public safety under off-normal conditions and validation of the in-vessel dust and tritium inventory safety limits that have been used as part of the overall safety strategy in ITER.
- The results of the R&D described here are anticipated to help ease regulatory approval of ITER. However, only ITER operation will yield answers to dust generation and tritium uptake definitive enough to convince regulators.
- Regulators will likely use a graduated approach to operation whereby the regulator can gain confidence in the behavior of the facility and the operating experience results from the previous stage will provide data that can benchmark the safety limits and assumptions for the subsequent stage.