Idaho National Engineering and Environmental Laboratory

Safety Issues Related to Flibe/Ferritic Steel Blanket and Vacuum Vessel Placement

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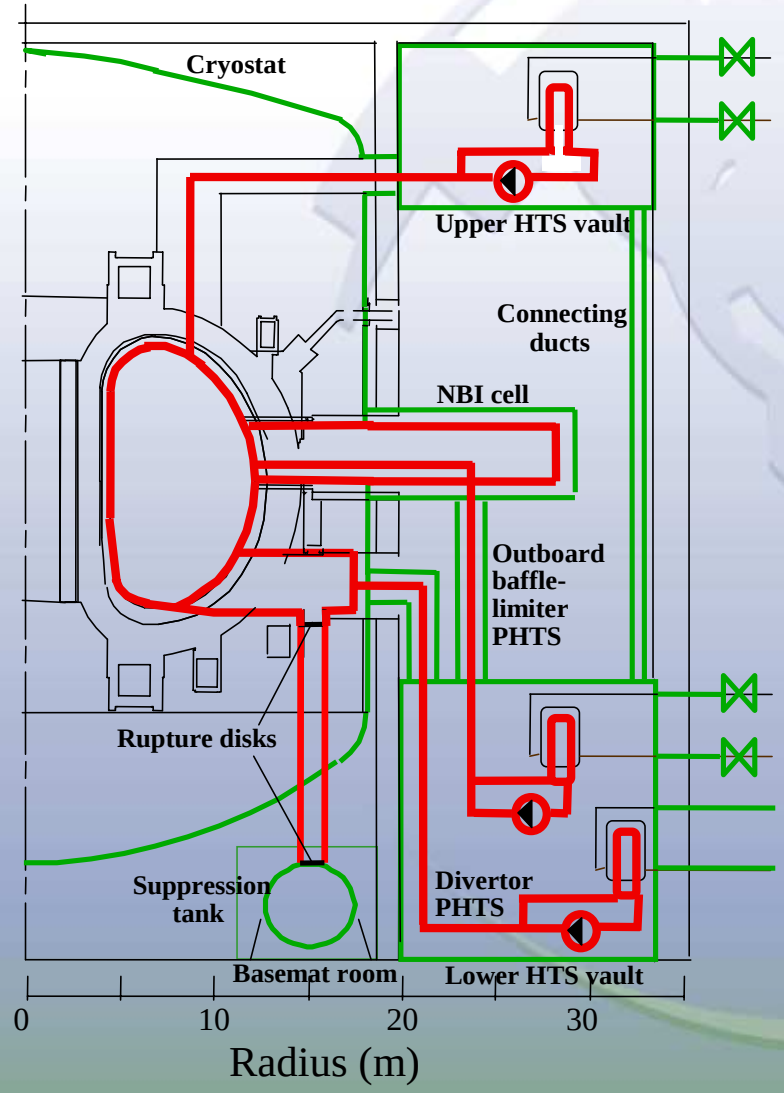
Presentation Outline

- Safety requirements
- ITER Confinement strategies
- ITER Confinement bypass accident scenarios
- ARIES Compact Stellarator Bypass Accident Initiators
- APEX radioactive inventories
- APEX releases during a bypass accident and resulting site boundary doses
- APEX waste disposal ratings
- Summary

Safety Requirements

- The DOE Fusion Safety Standard enumerates the safety requirements for magnetic fusion facilities, two primary requirements
  - The need for an off-site evacuation plan shall be avoided, which translates into a dose limit of 10 mSv at the site boundary during worst-case accident scenarios (frequency < 10^{-6} per year)
  - Wastes, especially high-level radioactive wastes, shall be minimized, implying that all radioactive waste should meet Class C, or low level, radioactive waste burial requirements
- To demonstrate that the no-evacuation requirement has been met, accidents that challenge the radiological confinement boundaries (e.g., confinement bypass accidents) must be examined.

Schematic of ITER Confinement Barriers



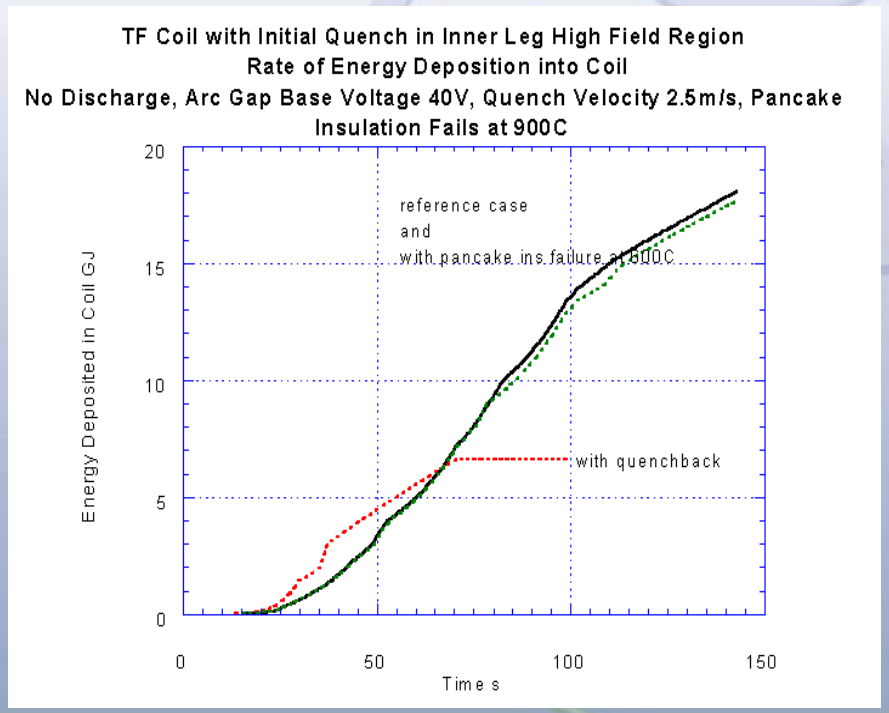
- Confinement of radioactive inventories by multiple barriers (defense in depth), *primary boundary, secondary boundary*
- Vacuum vessel (VV) is part of primary confinement boundary

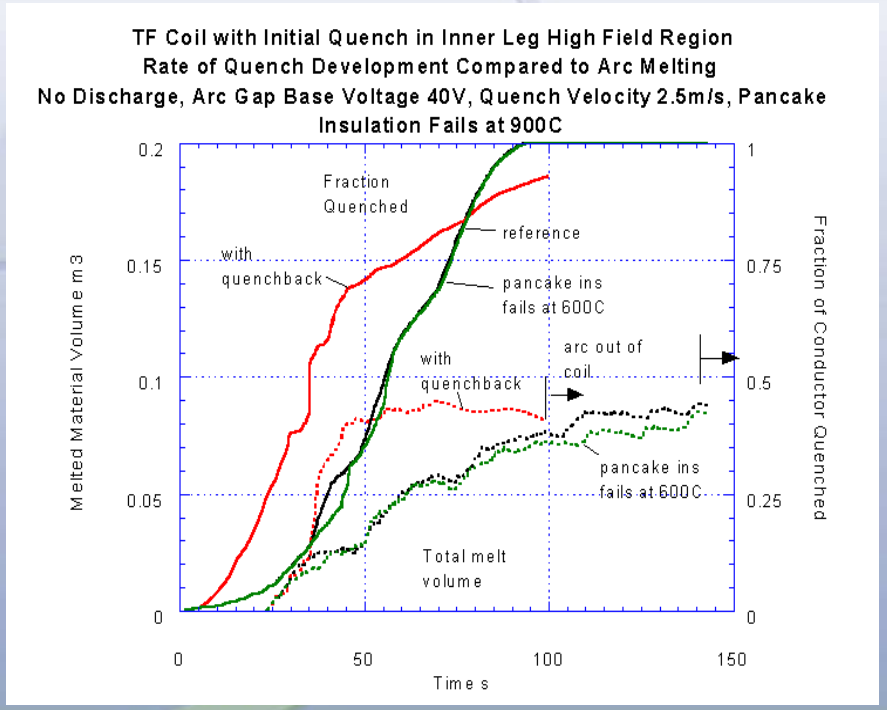
Bypass accident initiators considered by ITER

- Plasma Disruption
  - Disruption forces on VV fail a diagnostic duct that leads to a non-nuclear room, plus runaway electrons fail FW
- Ex-vessel loss-of-cooling accident (LOCA)
  - Plasma continues to burn and FW fails by melting
- Unmitigated Toroidal Field Coil Quench
  - Sensors fail to activate dump resistors
  - Quenched conductor melts by 20 s
  - Internal arcs form depositing ~10 MW per arc
  - 10's of GJ of energy associated with magnetic field (44 GJ available) resistively dissipates in failed coil before arc leaves the magnet by way of magnet busbars
  - Arc travels along busbars and fails cryostat (hole > 2 m^2)
  - Magnet melt is at high pressure(~120 bar)
  - Molten metal jet from the arcs create a hole in VV (~ 1 m^2)

Bypass accident initiators considered by ITER (cont.)

- Unmitigated toroidal field coil quench (cont)
  (ITER FEAT calculations by N. Mitchell)





ARIES Compact Stellarator Bypass Accident Initiators

- For ITER, the plasma disruption initiated bypass scenario produced the largest off-site dose
- ARIES-CS could potentially experience all three scenarios, with plasma disruption replaced by a rapid plasma bootstrap current quench possibly caused by FW failure and Flibe injection into plasma
- If field coils are placed inside of the VV, then the unmitigated quench bypass accident will probably become the more severe accident because of multiple barrier failures
  - Magnet arcing/molten melt could fail blankets producing an in-vessel Flibe LOCA
  - Arc traveling along busbars could fail VV where busbars penetrate VV, releasing VV cooling water into plasma chamber and into cryostat
  - Water/Flibe interactions could result in steam vapor explosions and the mobilization of Flibe activation products
  - Busbar arc will eventually fail cryostat leading to a pathway for VV inventories to be released into the magnet power supply room (a non-nuclear room)

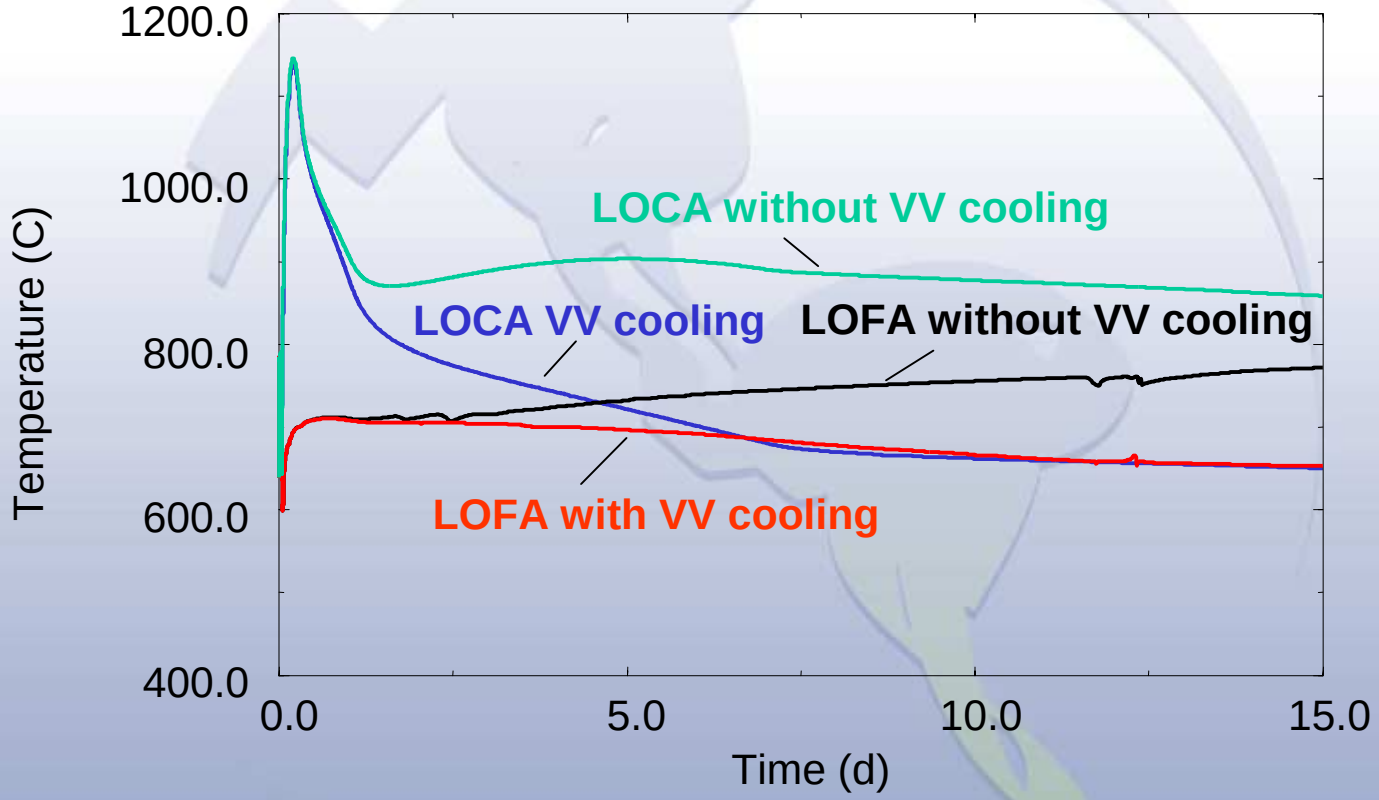
APEX AFS/Flibe Blanket Radioactive Inventories

- Inventories of concern
  - Advanced ferritic steel (AFS) activation products
    Specific dose varies with time, maximum of 10.6 mSv/kg with Mn-54 at 26 %, Ca-45 at 15%, and at Ti-45 14%
  - Tritium
    HTO specific dose is 77 mSv/kg
  - Flibe activation products
    Specific dose - 0.32 mSv/kg with 99% F-18
- Mechanisms that can mobilize these inventories
  - AFS activation products by oxidation
    FW high temperatures in air or water environment
  - Tritium by permeation into vacuum vessel
  - Evaporation of Flibe after a LOCA

APEX Tritium Inventory & Permeation Issues

- Problem is that tritium solubility & diffusivity are low in Flibe and high in AFS
- Tritium Inventory
  - AFS primary loop ~ 82 g, with 62 g in blankets.
  - Flibe & helium ~ 1.1 g and 5.5 g, respectively
  - Neutron reactions with beryllium multiplier produces up to 2.1 kg over blanket lifetime
- Tritium control & recovery
  - Helium purification systems
  - Cool pipe and pressure boundary walls
  - Aluminum pipes in Brayton cycle coolers
  - Beryllium tritium inventory reduced by bake-out, however tritium release temperature is initially ~850 C but will decrease to ~700 C after a fluence of 1.0 $x10^{26}$ n/m^2

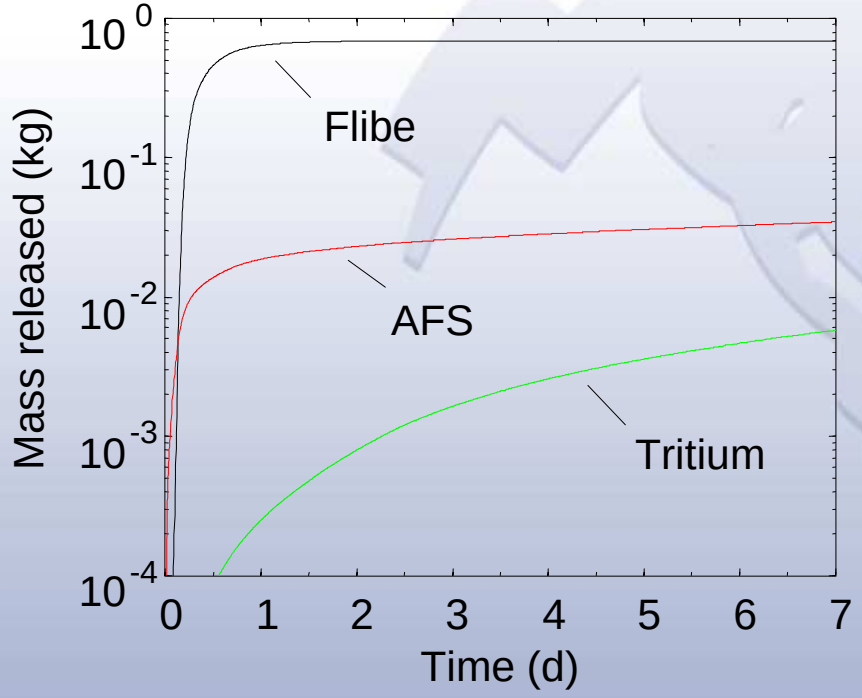
MELCOR FW Temperature during LOCA and LOFA



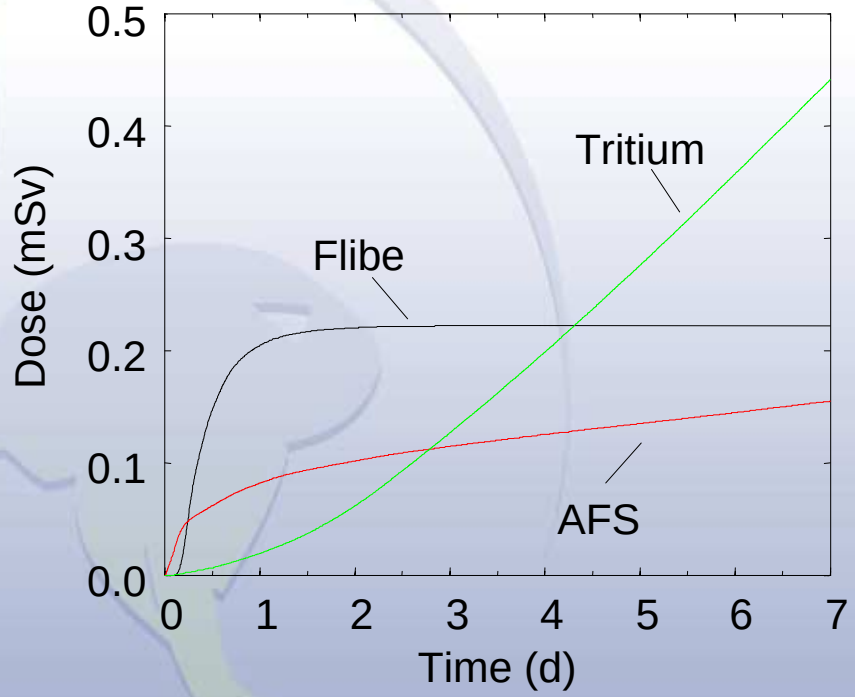
Flibe provides thermal inertia during LOFA and VV natural convection appears to be able to remove decay heat (~3.6 MW max load), and low FW temperatures reduce oxidation

Dose at Site Boundary from Bypass Accident

Mass released to environment



Site boundary dose



- Total dose after one week is 0.93 mSv (< 10 mSv no-evacuation plan limit) if release is stacked, must isolate within one week for a ground release
- If Be bakeouts are successful, the blanket tritium inventory is 660 g. When this tritium is included with AFS inventories, the dose exceeds 10 mSv in six days for a stacked release, two days for a ground release

APEX Waste Disposal Ratings

- AFS can meet Class C limit
  - AFS structure WDR is 0.33-1.97 with Fetter limits, dominated by Tc-99 produced from Mo; reduce Mo content from 0.02% to <0.01%
  - Flibe WDR is 0.042 with 10CFR61 limits, major contributor is C-14 from neutron reactions with F

Summary

- Placing the field coils inside of the VV could lead to a severe bypass accident
- APEX worst case bypass accident analysis shows that this low vapor pressure molten salt/low oxidation ferritic steel design has many safety advantages
  - Dose at site boundary is only 0.93 mSv after one week (< 10 mSv limit) for stacked release, facility must be isolated by one week for ground release
  - Ample time to manually operate plant remediation and isolation systems
  - Blanket and coolant will likely meet low level waste burial criterion