AP1000 Passive Safety Systems

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AP1000 Approach to Safety

- **Passive Safety-Related Systems**
  - Use “passive” process only, no active pumps, diesels, ….
    - One time alignment of valves
    - No support systems required after actuation
      - **No AC power, cooling water, HVAC, I&C necessary for mitigation**
  - Greatly reduced dependency on operator actions
  - Mitigate design basis accidents without nonsafety systems

- **Active Non-safety Related Systems**
  - Reliably support normal operation
    - Redundant equipment powered by onsite diesels
  - Minimize challenges to passive safety systems
  - Not required to mitigate design basis accidents

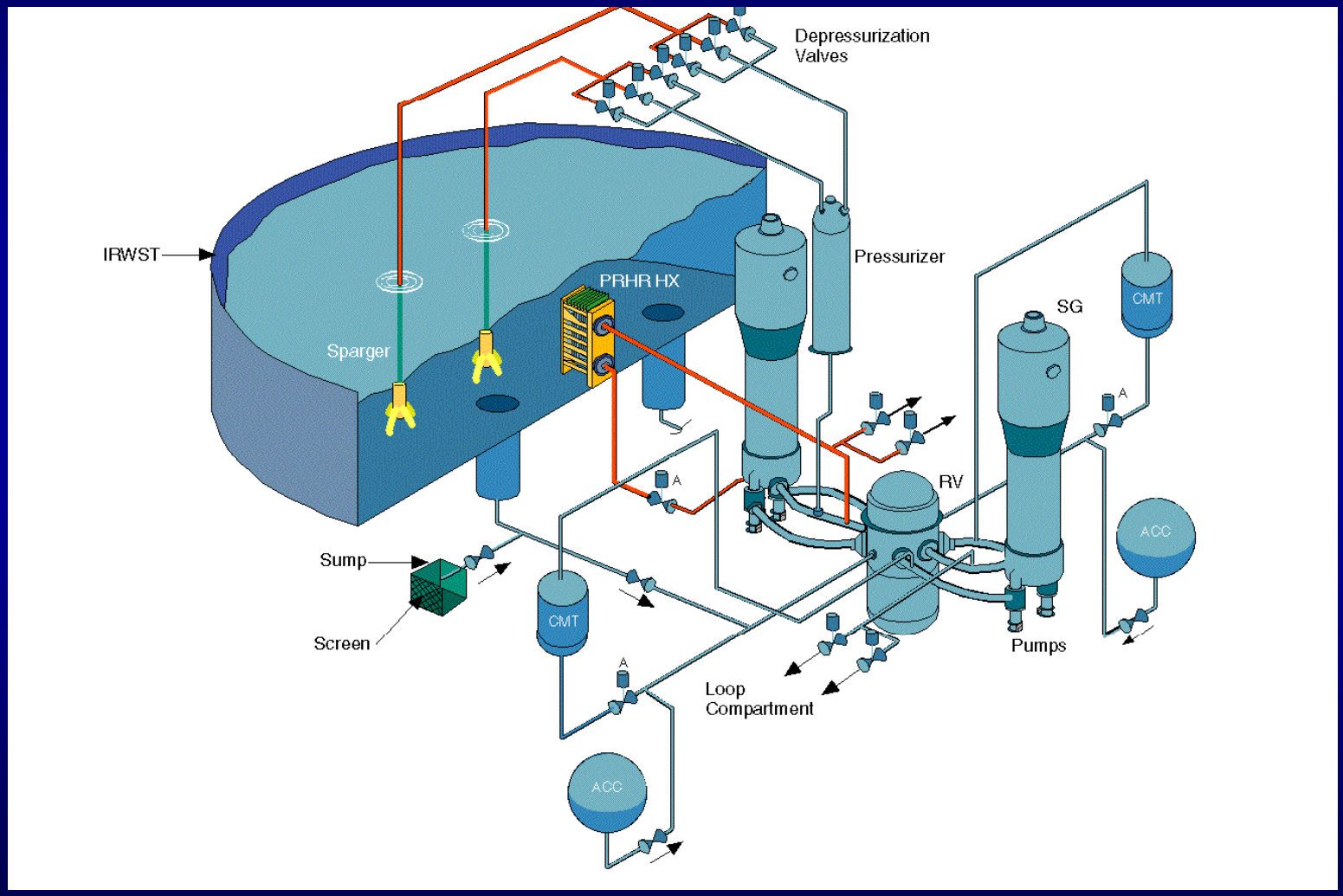
Passive Safety Features

- **Passive Decay Heat Removal**
  - Natural circulation HX connected to RCS
- **Passive Safety Injection**
  - Natural circulation / gravity drain core makeup tanks (RCS pres)
  - N2 pressurized accumulators; Initial pressure = 700 psig (4.9 MPa)
  - Gravity drain refueling water storage tank (containment pres)
  - Automatic depressurization valves, Pzr & HL
- **Passive Containment Cooling**
  - Natural circulation of air / evaporation of water on outside surface of steel containment vessel
- **Passive Radiation Removal from Containment Atm.**
  - Natural circulation / removal mechanisms

Passive Safety Features

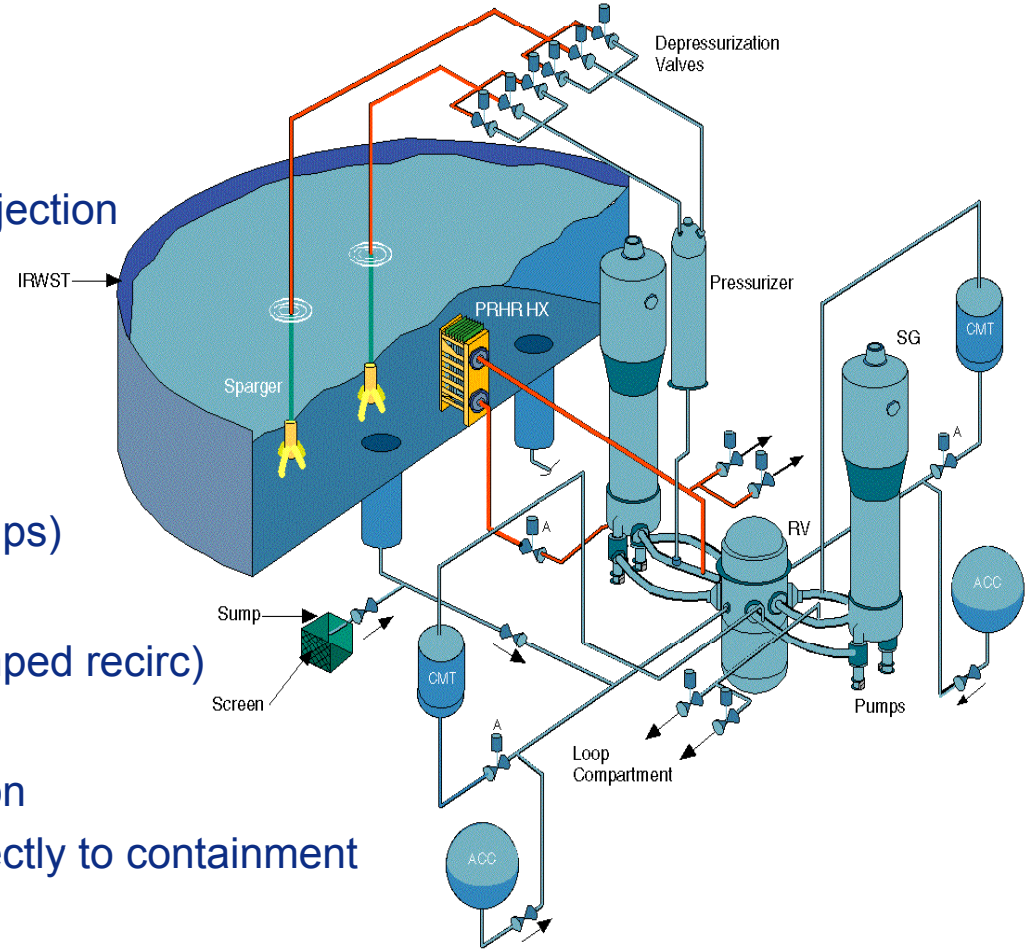
- **Passive Main Control Room (MCR) Habitability**
  - Compressed air pressurization of MCR
- **Passive MCR / I&C Room Cooling**
  - Natural circulation to concrete walls / ceiling
- **Passive Containment Hydrogen Control**
  - Autocatalytic recombiners
- **Passive Containment pH Control**
  - Baskets of TriSodium Phosphate flooded by accident

AP1000 Passive Core Cooling System



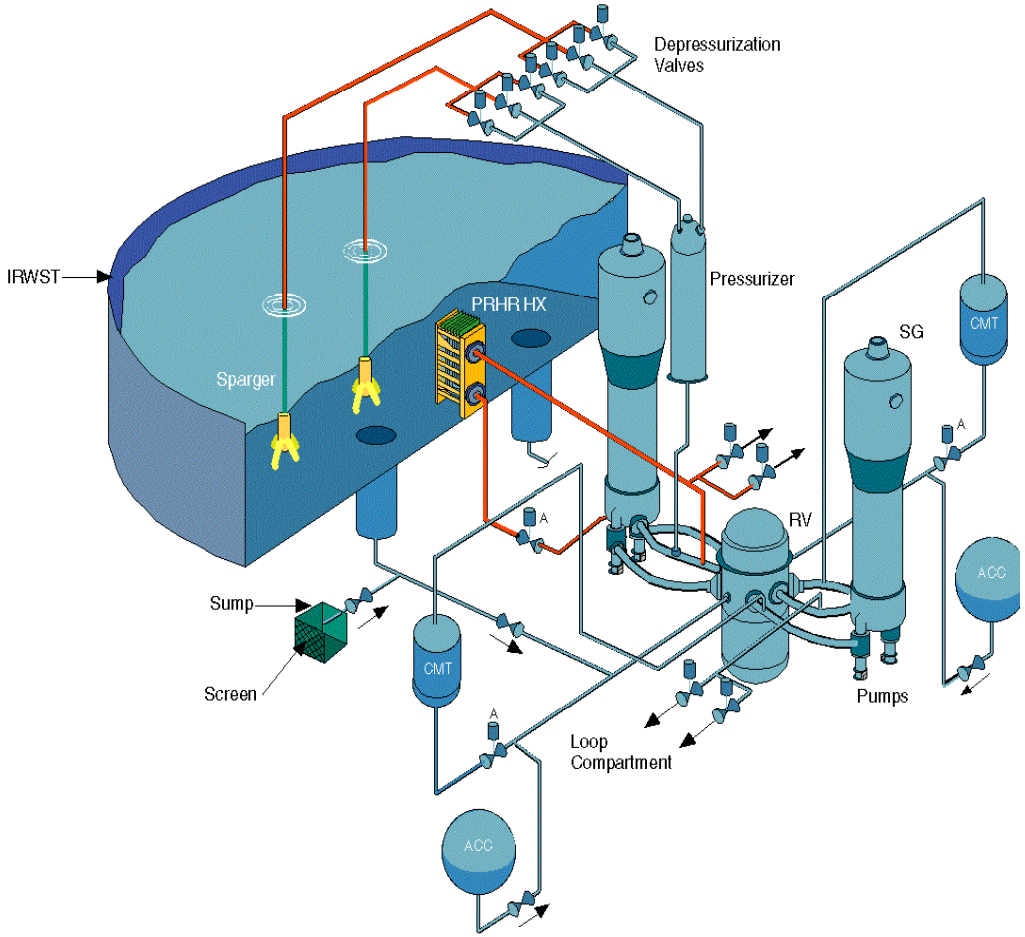
AP1000 Passive Core Cooling System

- **PRHR Heat Exchanger**
  - Natural circulation heat removal
- **Passive Safety Injection**
  - Core Makeup Tanks (CMT)
    - Full RCS pressure, natural circ. injection
    - Replace HHSI pumps
  - Accumulators
    - Similar to current plants
  - IRWST Injection
    - Low pressure (replaces LHSI pumps)
  - Containment Recirculation
    - Gravity recirculation replaces pumped recirc)
  - Automatic RCS Depressurization
    - Staged, controlled depressurization
    - Stages 1-3 to IRWST, stage 4 directly to containment



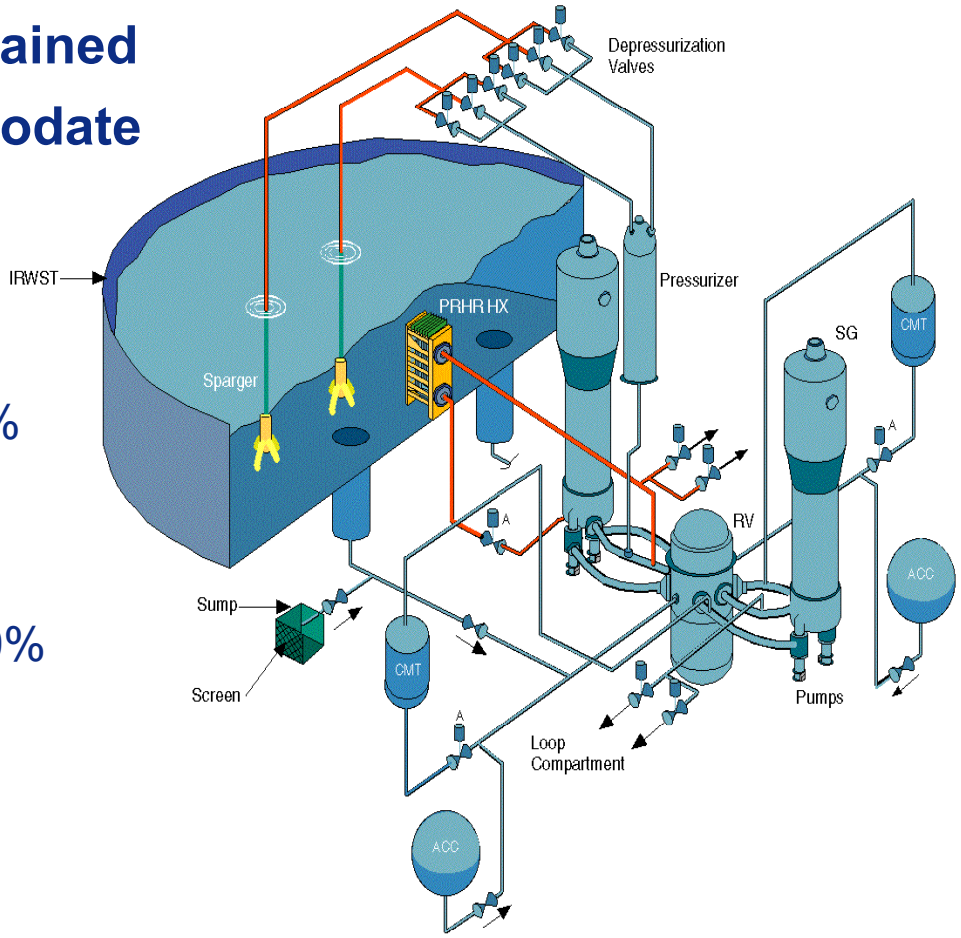
AP1000 Passive Core Cooling System

- **Based on AP600 Systems**
  - Extensive testing and analysis
  - Reviewed by US NRC
  - No active pumps, DGs, chillers
  - One time valve alignment
    - Most are fail safe
- **AP1000 Capacities Increased to Accommodate Higher Power**
  - System Performance Maintained
    - Transient DNBR margin > 15%
    - No core uncovery for SBLOCA
      - ≤ DVI line break
      - Large margin to PCT limit
    - No operator actions for SGTR

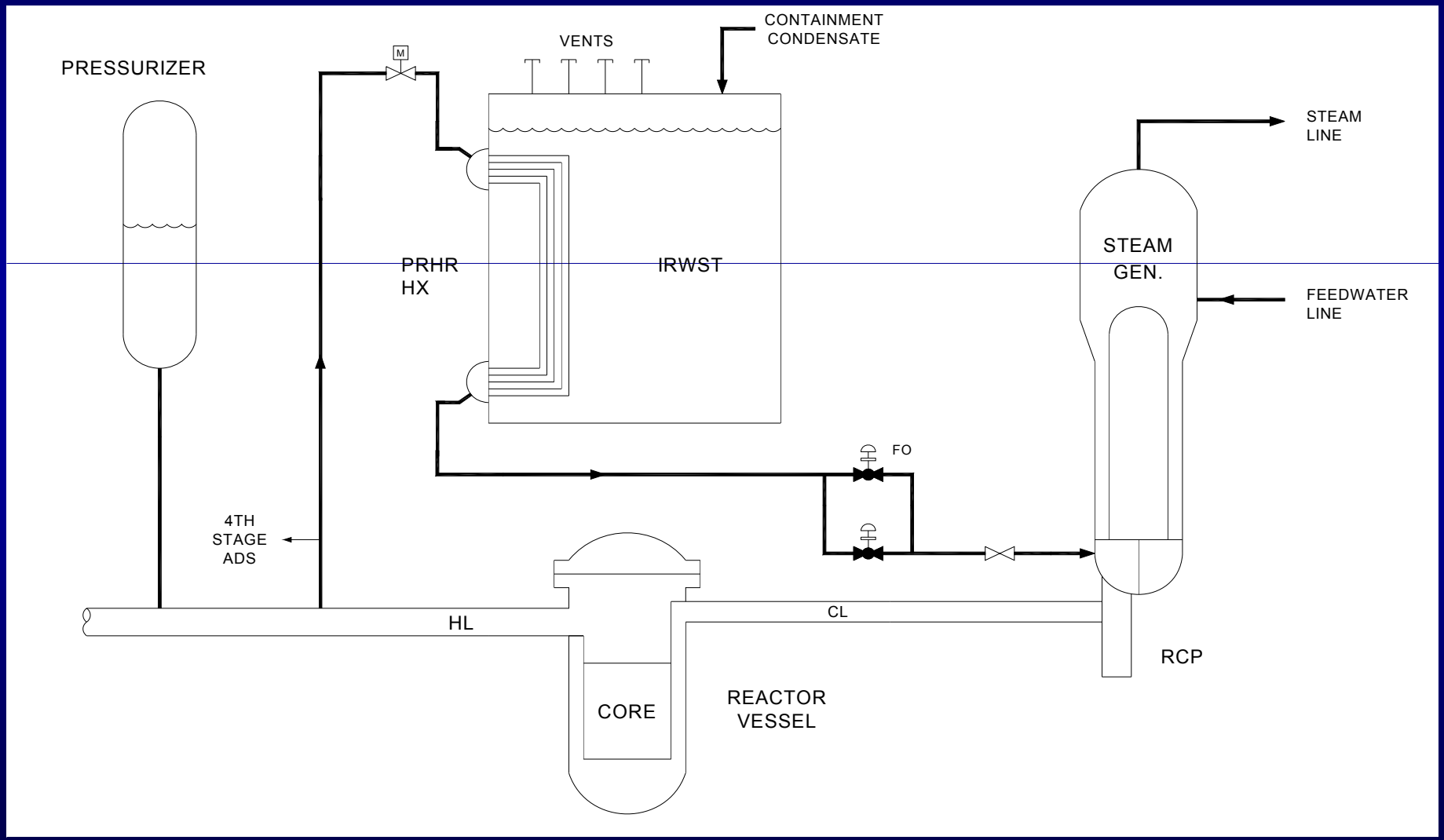


AP1000 Passive Core Cooling System

- **AP600 System Configuration Retained**
- **Capacities Increased to Accommodate Higher Power**
  - Core 1933 MW > 3400 MW or 76%
  - PRHR HX Capacity Increased 72%
  - CMT Volume & Flow Increased 25%
  - ADS-4 Flow Increased 93%
  - IRWST Injection Increased 89%
  - Containment Recirc. Increased 139%
- **System Performance Maintained**
  - No core uncovery for SBLOCA
    - ≤ DVI line break
    - Large margin to PCT limit
  - No operator actions required for SGTR



Passive Decay Heat Removal

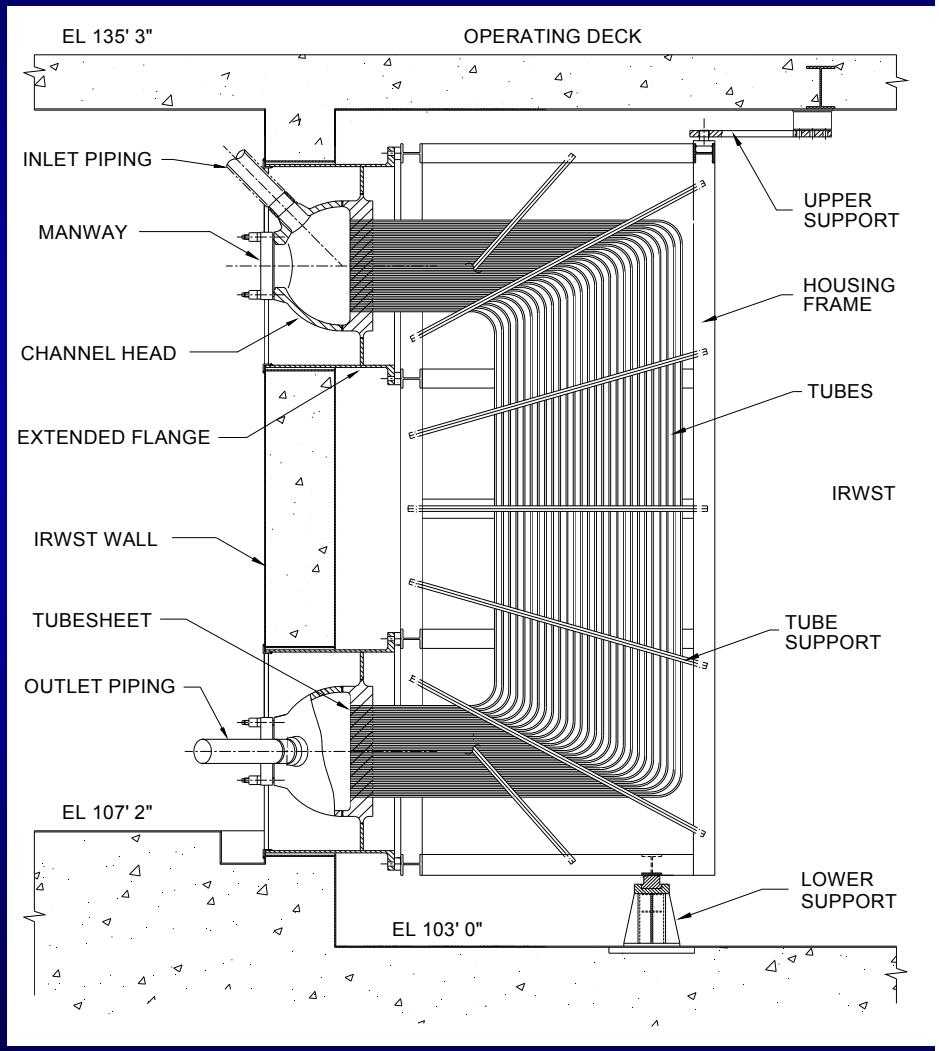


Passive Decay Heat Removal

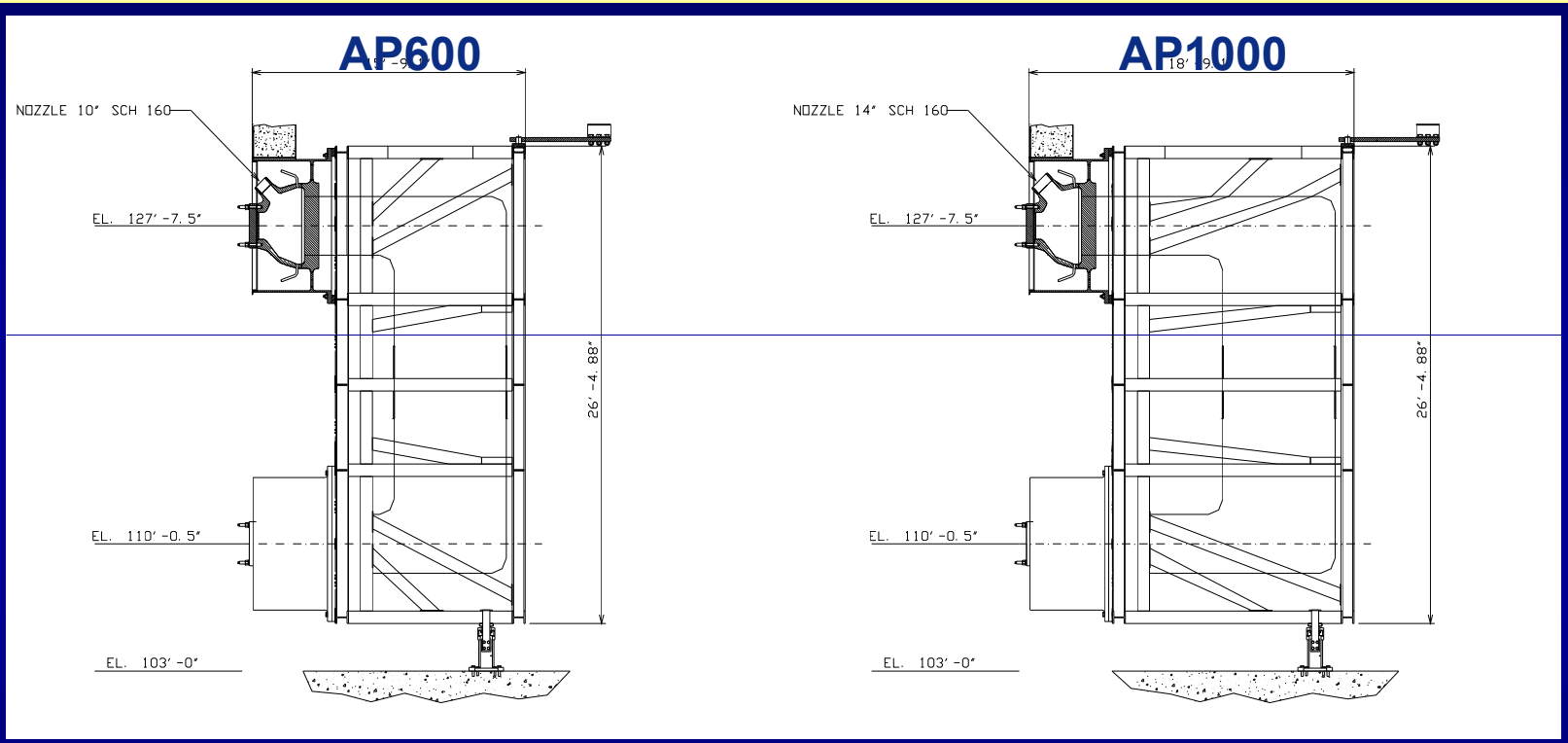
- The passive residual heat removal (PRHR) system is designed for 100% decay heat removal.
- Protects plant from upsets in normal steam generator feedwater and steam system.
- IRWST provides heat sink for PRHR HX
- PRHR HX with passive containment cooling system provides infinite decay heat removal capability without operator action.

AP1000 PRHR HX

- **Size Based on AP600 Tests**
  - Full size tubes
  - Full pressure / temperature
- **Connected to IRWST Wall**
  - “C” tubes provide flexibility
  - No pipes in IRWST
    - No pipe break induced dynamic effects
  - Access from outside IRWST
    - Easy tube inspection
- **Uses Proven SG Technology**
  - Flat tube sheet
  - Tube / tube sheet connection
  - 3/4” Inconel 690 TT tubes
  - SG tube inspection methods

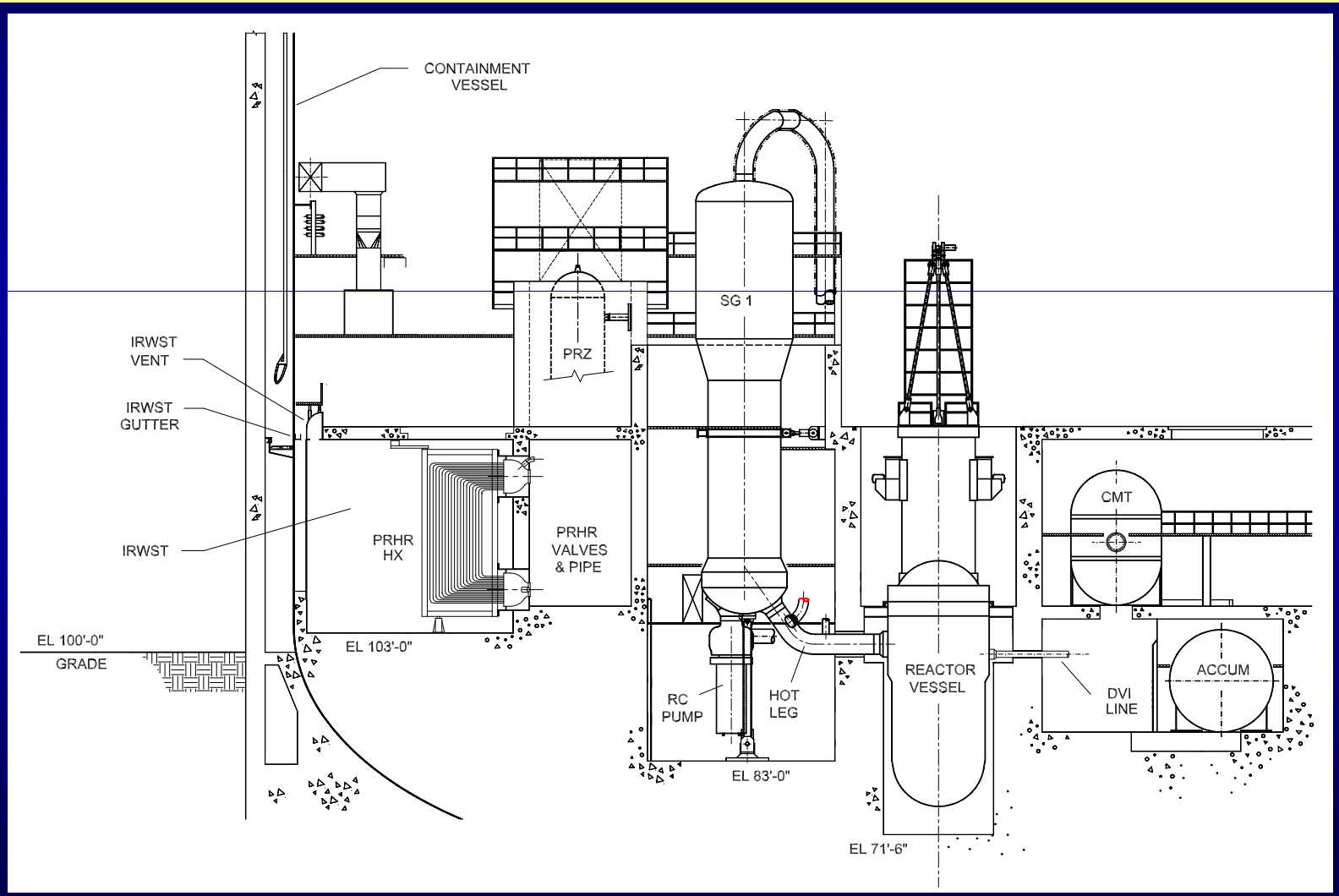


Passive RHR Heat Exchanger

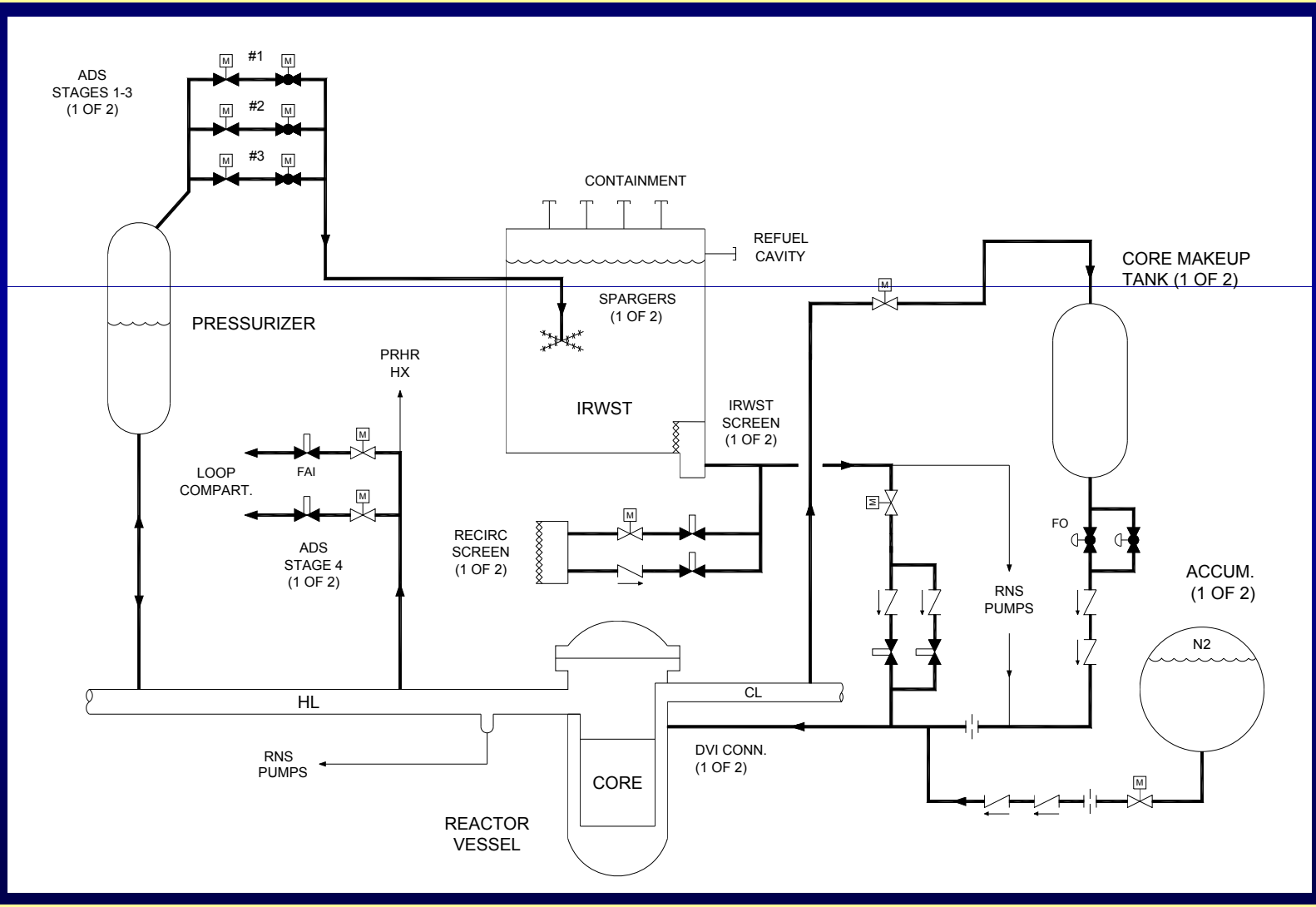


- **AP1000 PRHR Heat Transfer Capacity Increased 72% Above AP600**
  - Pipe / valves increased to 14" (AP600 10")
  - 9 more tubes, 3 ft. (1 m) longer horizontal tube length
- **Safe Shutdown Capability Maintained** ; 420 F (488 K) in 36 hours

PRHR Equipment Layout



AP1000 Passive Safety Injection

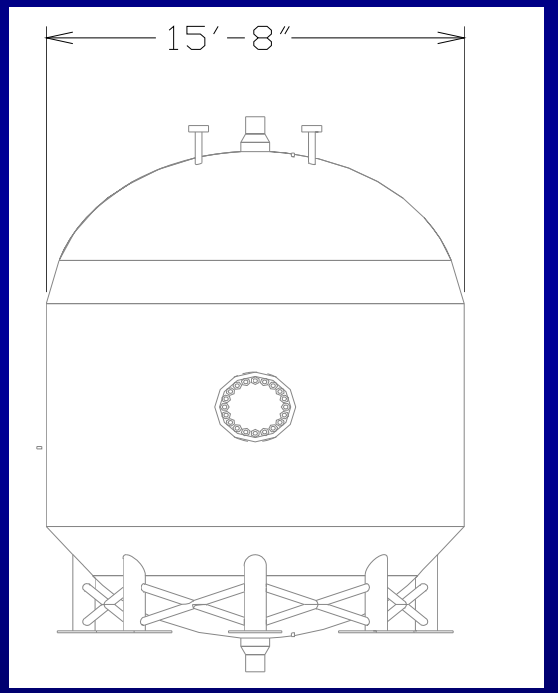


AP1000 Passive Safety Injection

- The AP1000 passive safety injection system uses three sources of water for RCS make-up.
- CMTs (Core Make-up Tanks) provide coolant at full system pressure to downcomer through DVI (direct vessel injection) line.
- Two accumulators provide coolant at high flow rates once RCS pressure is < 700 psig (4.9 MPa).
- IRWST supplies borated water to RCS once the primary system has depressurized to low pressure.

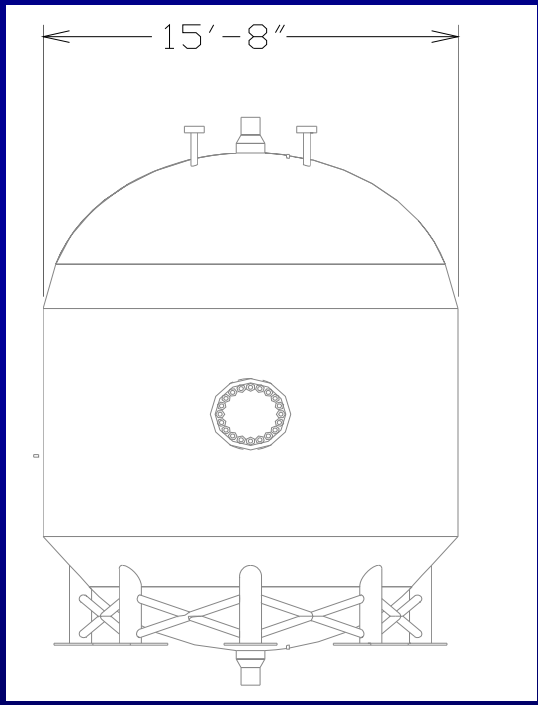
AP1000 Core Makeup Tanks

- **Core Makeup Tanks (CMTs) provide coolant at full RCS pressure and eliminate the need for HPSI pumps.**
- **AP1000 CMTs have capacity to mitigate most small LOCAs.**
  - Maintains time available for ADS to depressurize RCS to IRWST cut-in
  - No core uncovery for design basis small LOCAs up to DVI line break.
  - Required to meet PRA success criteria (for multiple failure scenarios w/o accumulators).



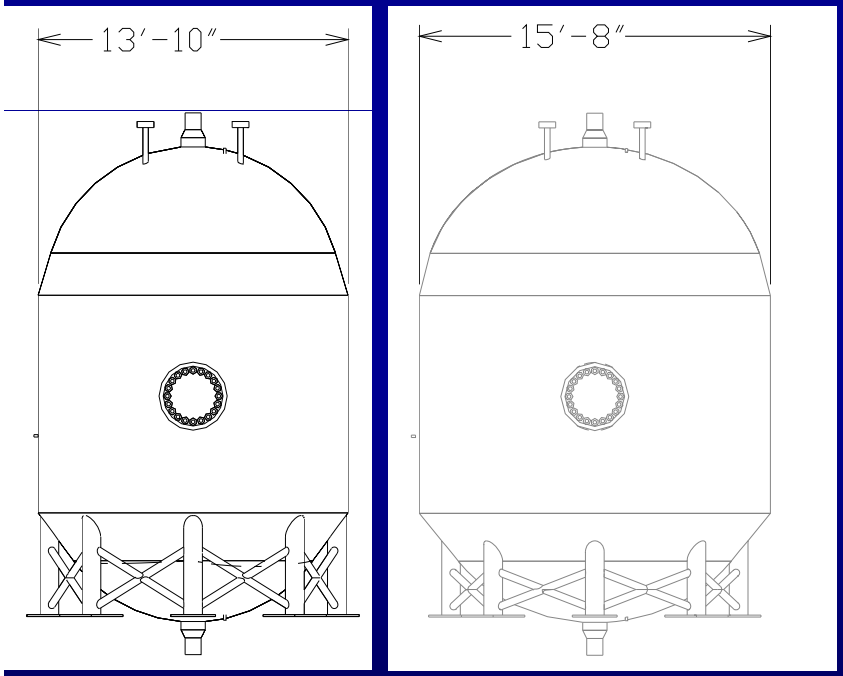
AP1000 Core Makeup Tanks

- **CMTs Operate in Two Modes:**
  - Hot water recirc mode
    - When Cold Leg (CL) is filled
    - For non-LOCAs and initial small LOCAs
    - Initial flow is ~ 29 lbm/s (13.2 kg/s) each to RCS
    - Duration is ~ 100 min.
  - Steam displacement drain mode
    - When CL voids during LOCA
    - Initial flow is ~ 135 lbm/s (61.2 kg/s) each
    - Final flow is ~ 71 lbm/s (32.2 kg/s) each
    - Duration is ~ 25 minutes
  - Sized for DVI LOCA
    - Remove decay heat after accumulators empty
  - Controls ADS actuation
    - Low1 starts ADS 1 (67% vol)
    - Low2 starts ADS 4 (20% vol)



AP1000 Core Makeup Tanks

AP600 AP1000



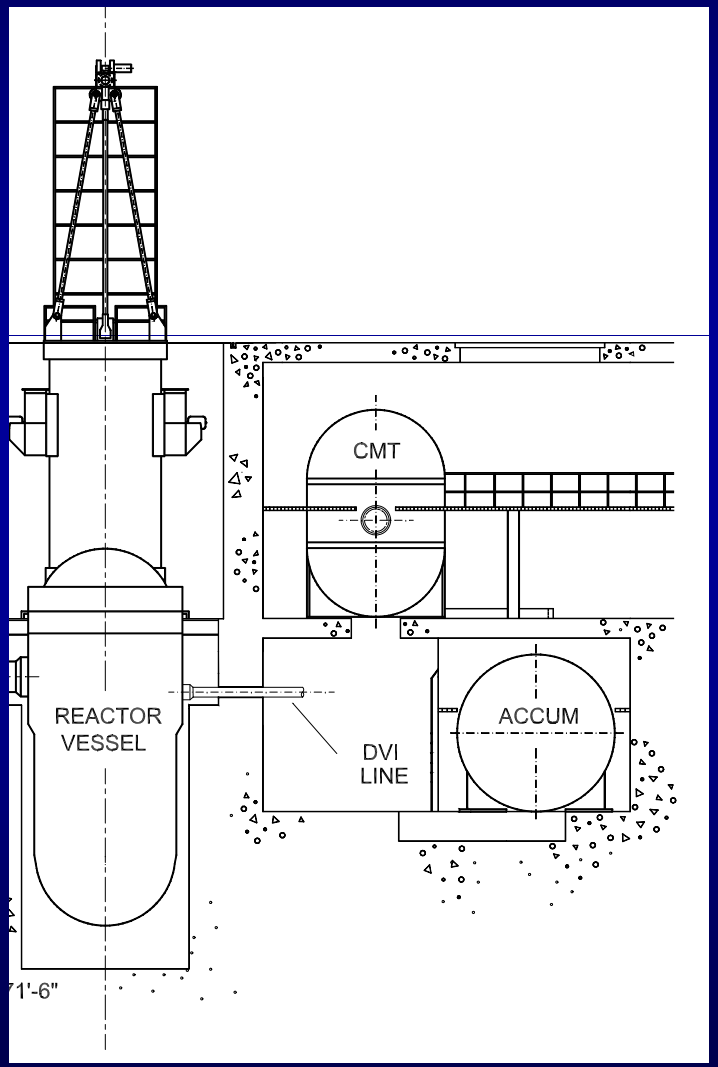
- **Compared to AP600, the AP1000 CMT volume and flow capacity was increased by 25%.**
  - AP1000 volume is 2500 ft^3 (70.8 m^3)
  - AP600 volume is 2000 ft^3 (56.6 m^3)
  - Re-tuned flow control orifice with same pipe size
    - Maintains duration of CMT injection same as AP600
    - Maintains time available for ADS to depressurize RCS to IRWST cut-in

AP1000 Accumulator

- Accumulators are spherical tanks containing borated water and pressurized to approximately 700 psig (4.9 MPa) with nitrogen cover gas.

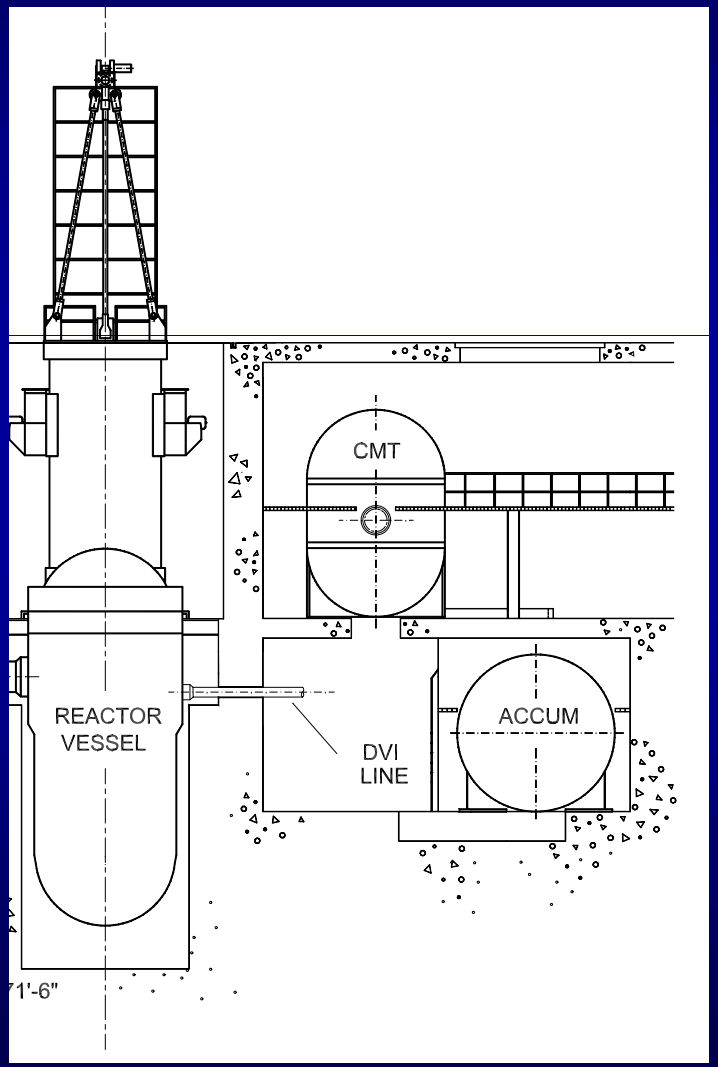
- Are designed to provide high rate of coolant flow for several minutes to mitigate large LOCAs.

AP1000 Accumulator



- **Compared to AP600, Accumulator Volume / Flow Not Changed**
  - Controlling accident is LBLOCA.
  - Increasing Accum volume is difficult
    - Would impact containment layout
- **AP1000 Large Break LOCA**
  - Margin to 2200 F (1478 K) fuel acceptance limit remains for DBA LBLOCA.
  - For PRA, change success criteria
    - Require 2 of 2 accum (same as DBA) for large RCS pipe breaks
    - Require 1 of 2 accum for spurious ADS stage 4 events

AP1000 Accumulator



- **Compressed N2 Provides High Flows**
  - Forces open check valves when RCS pressure decreases < 700 psig (4.9 MPa)
  - Sized to refill RV rapidly in large LOCA
    - Supports small LOCA during ADS
  - Peak flow ~ 1200 lbm/s (544 kg/s) per accumulator with RCS at atmospheric pressure.
  - Injection duration during large LOCA is about 5.5 min
  - When injects rapidly – CMT flow is reduced / stopped due to increased back pressure on CMT

AP1000 IRWST Injection

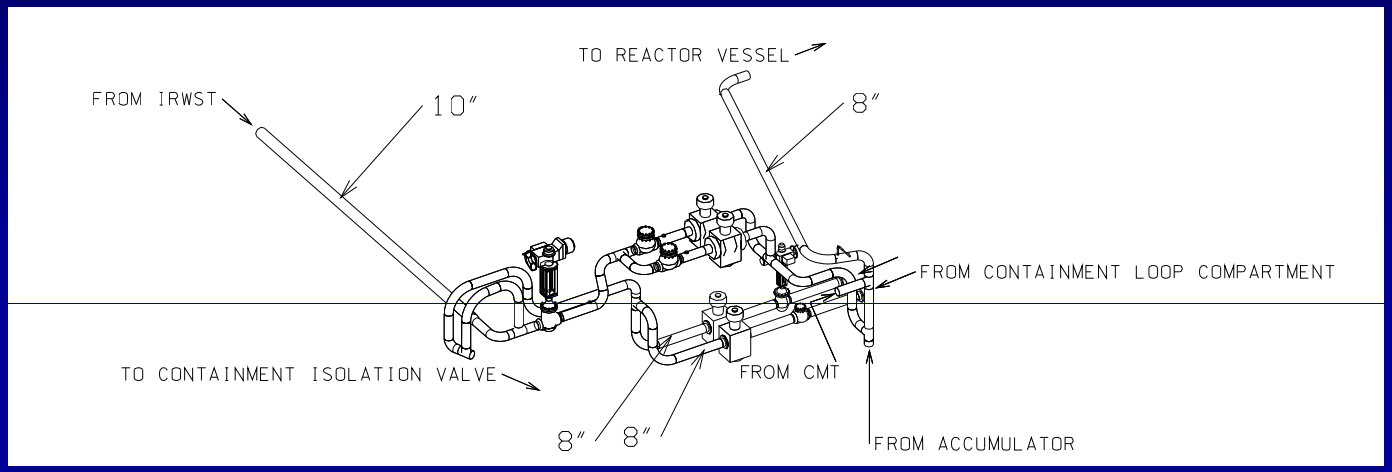
- The in-containment refueling water storage tank (IRWST) is a large, un-pressurized stainless steel tank below the operating deck.
- Approximately 590,000 gallons (2233 m^3) of borated water serve as low-pressure makeup source and heat sink for PRHR HX.
- Connects to both DVI lines.

AP1000 IRWST Injection

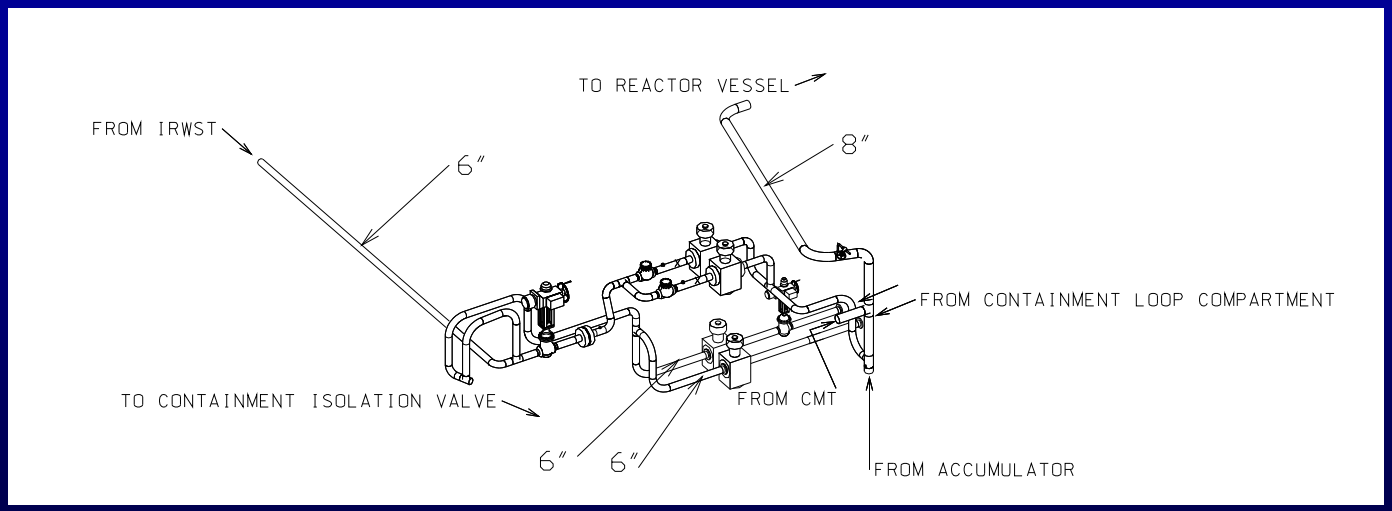
- **Compared to AP600, AP1000 IRWST volume and injection capacity increased:**
  - Pipe and valves increased to 8/10” (AP600 6/8”)
    - Eliminated flow tuning balancing orifices
      - Simplifies piping, helps apply larger piping size
      - System can tolerate flow variation without orifice
  - Initial water level increased
    - Added narrow range level sensors to reduce error
  - Flow capacity increased 89%
  - IRWST is enclosed, which limits debris to screens.

IRWST Injection & Cont. Recirc. Piping

AP1000



AP600



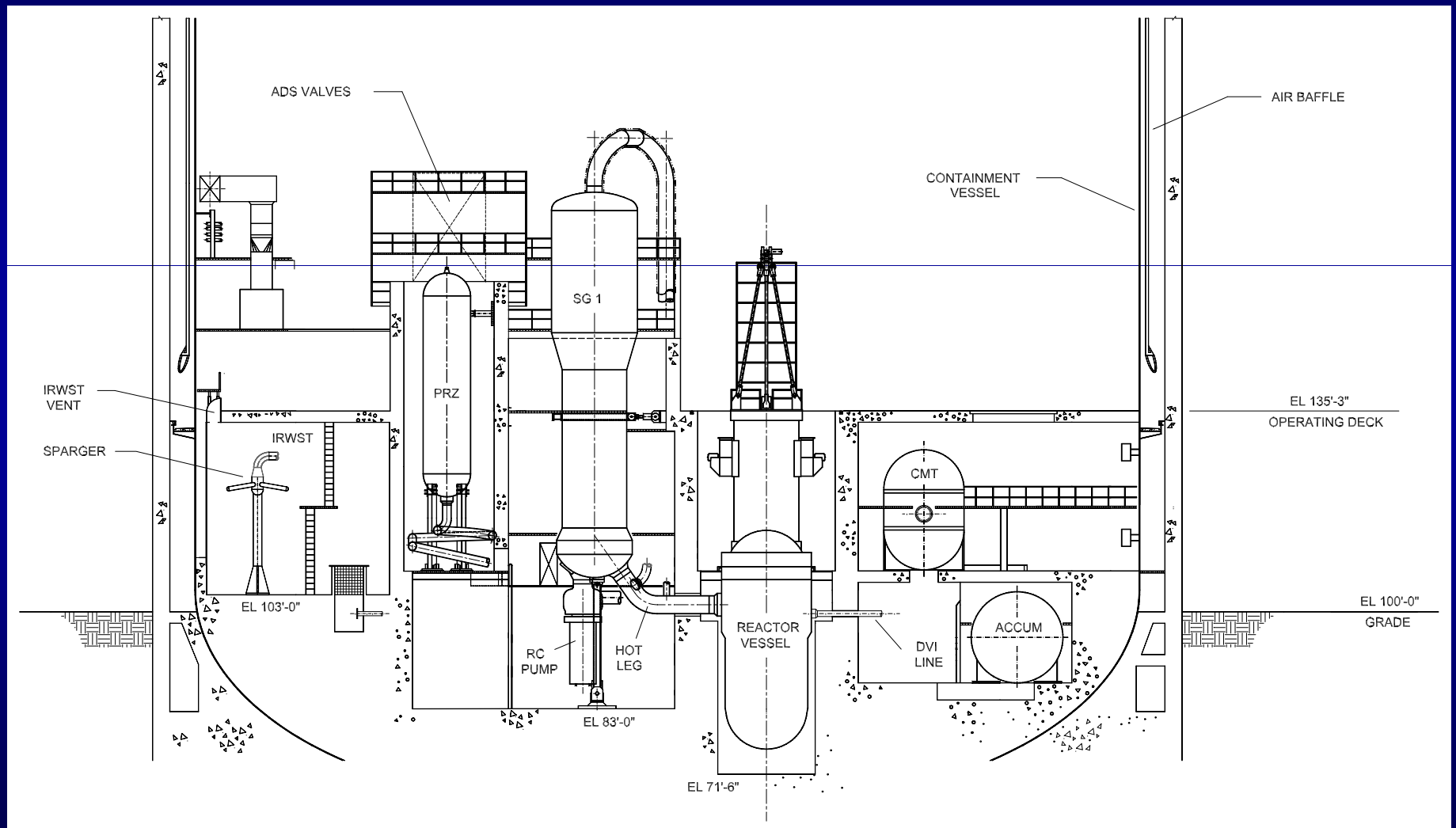
AP1000 Containment Recirculation

- **AP1000 Containment Recirc. Capacity Increased**
  - Pipe and valves increased to 8” (AP600 6/8”)
  - Containment post ADS water elevation increased
    - DVI LOCA min flood elevation is 108.05’ (AP600 106.2’)
      - PXS curbs raised to 110.17’ (AP600 108.17’)
    - Initial IRWST level increased
    - Initial flooding of refueling cavity prevented
      - Check valves added to drain line
    - RNS suction from outside containment
      - Injection suction from Spent Fuel cask loading pit
      - Prevents RNS operation from reducing time for recirc start
        - » By pumping down IRWST during DVI LOCA
  - Flow capacity increased 139%

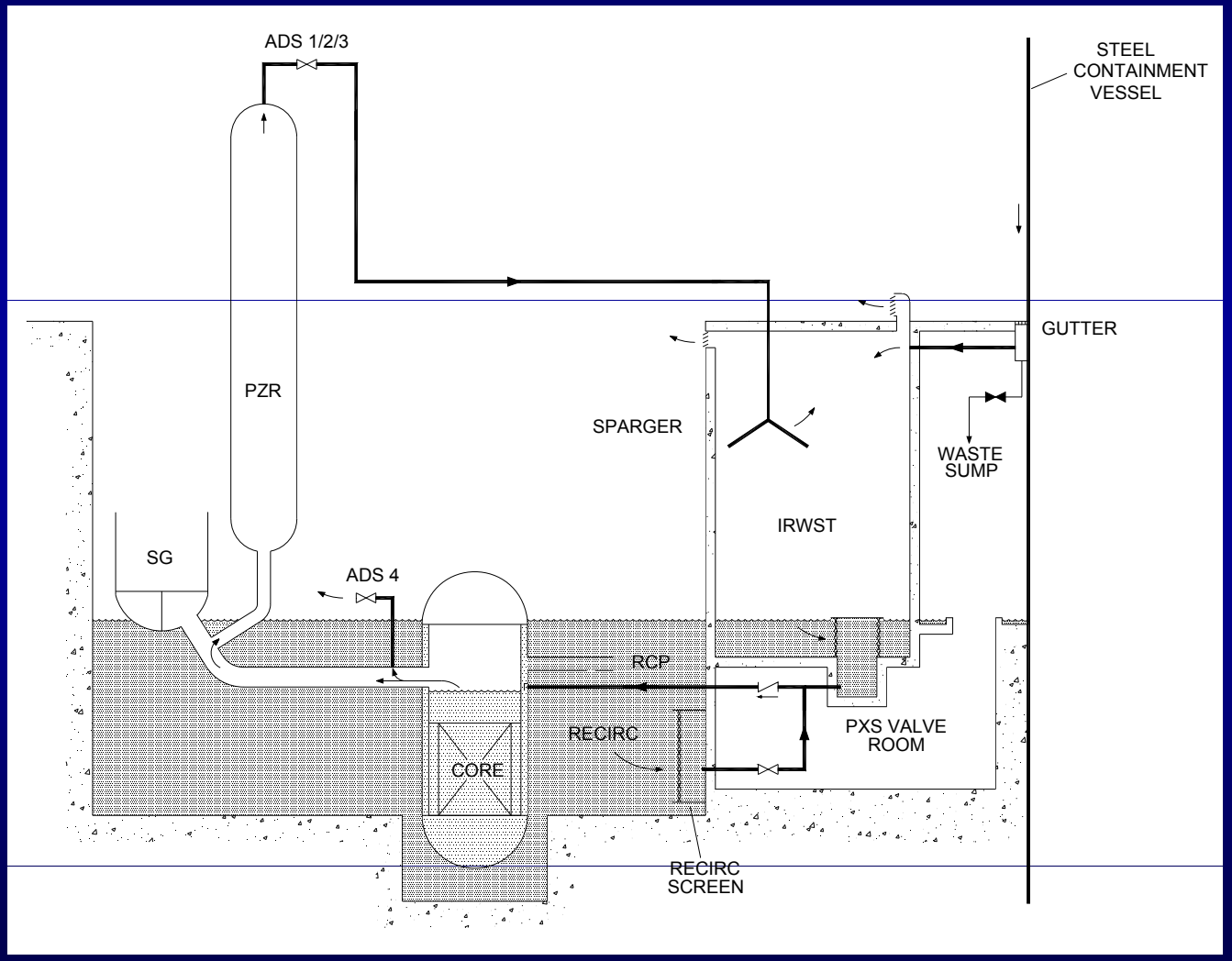
AP1000 Containment Recirculation

- **PRA Based Changes**
  - Recirc MOVs made normally open
    - Improves opening reliability
      - Fewer valves need to open
      - Squib valves are more reliable than MOVs
  - Containment Recirc squib diversity
    - AP1000 applies diversity between Cont Recirc paths
      - Recirc paths with MOVs use low pres squib (150 psig)
      - Recirc paths with check valves use high pres squib (2500 psig)
        - » Same squib valve used in IRWST injection lines
      - Improves reliability of Cont. Recirc. and drain for IVR support

Passive Safety Injection Equipment Layout



LOCA Long Term Cooling



Automatic Depressurization System

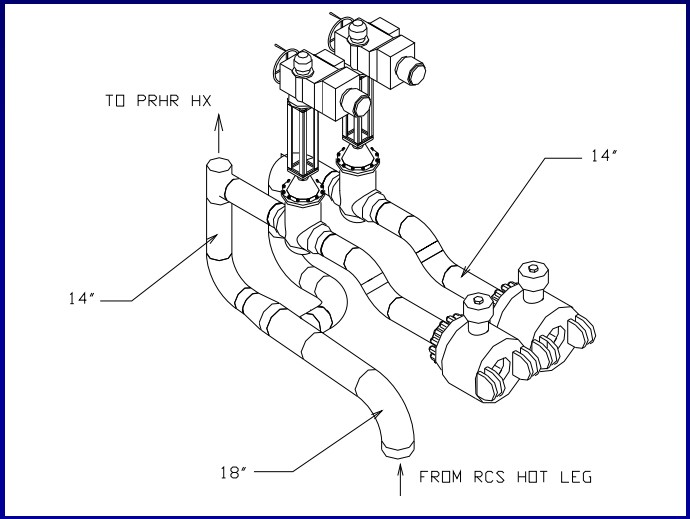
- Purpose of the Automatic Depressurization System (ADS) is to progressively decrease RCS pressure to allow passive systems to inject.
- ADS actuates when CMT level decreases below 67.5%. ADS-1/2/3 opens and begins depressurization, discharging from top of pressurizer through spargers into IRWST.
- ADS-4 actuates at 20% CMT level and vents directly to containment. ADS-4 connect to RCS at top of HLs.

Automatic Depressurization System

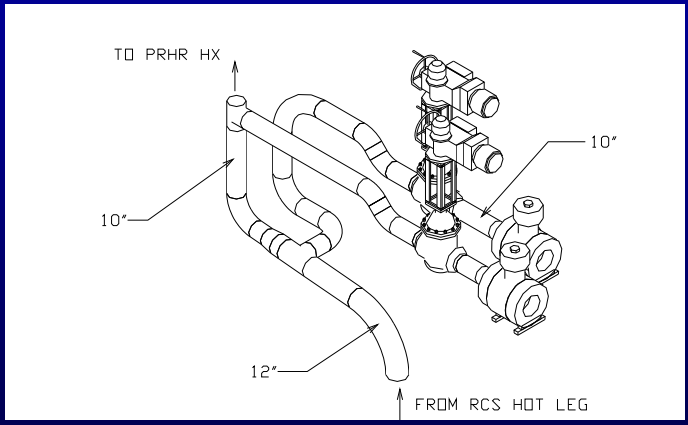
- **ADS Stages 1,2,3 Not Changed**
  - Not important for final RCS depressurization to IRWST Injection and Containment Recirc
  - Maintains ADS 1,2,3 piping layout / design, sparger design and IRWST T&H loads
- **ADS Stage 4 Capacity Increased**
  - Very important for final RCS depressurization to IRWST / Cont Recirc
  - ADS 4 valves / pipe increased to 14” (AP600 10”)
    - Common pipe increased to 18” (AP600 12”)
  - Critical flow area increases 76%
  - Subcritical flow increases 93%

Comparison of 4th Stage ADS

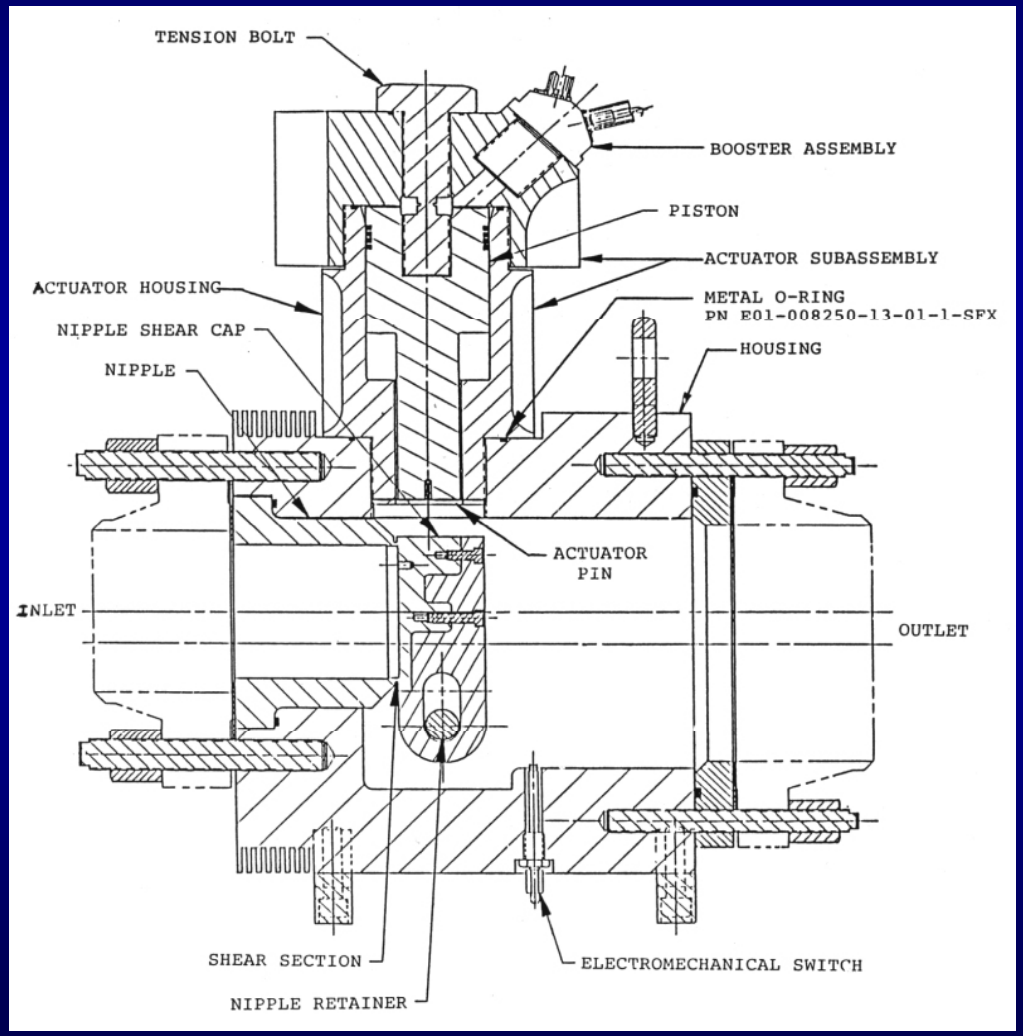
AP1000



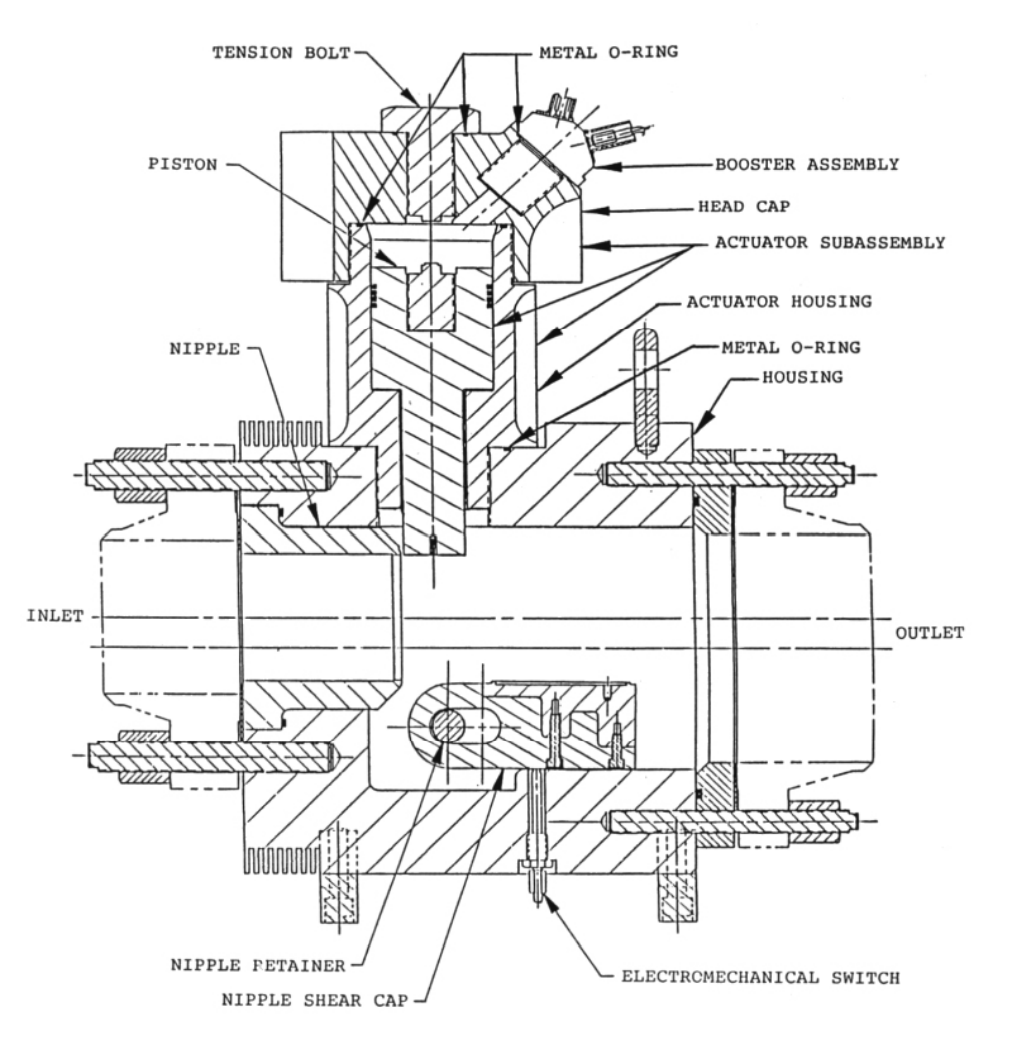
AP600



AP1000 ADS 4 Squib Valve (Closed)



AP1000 ADS 4 Squib Valve (Open)

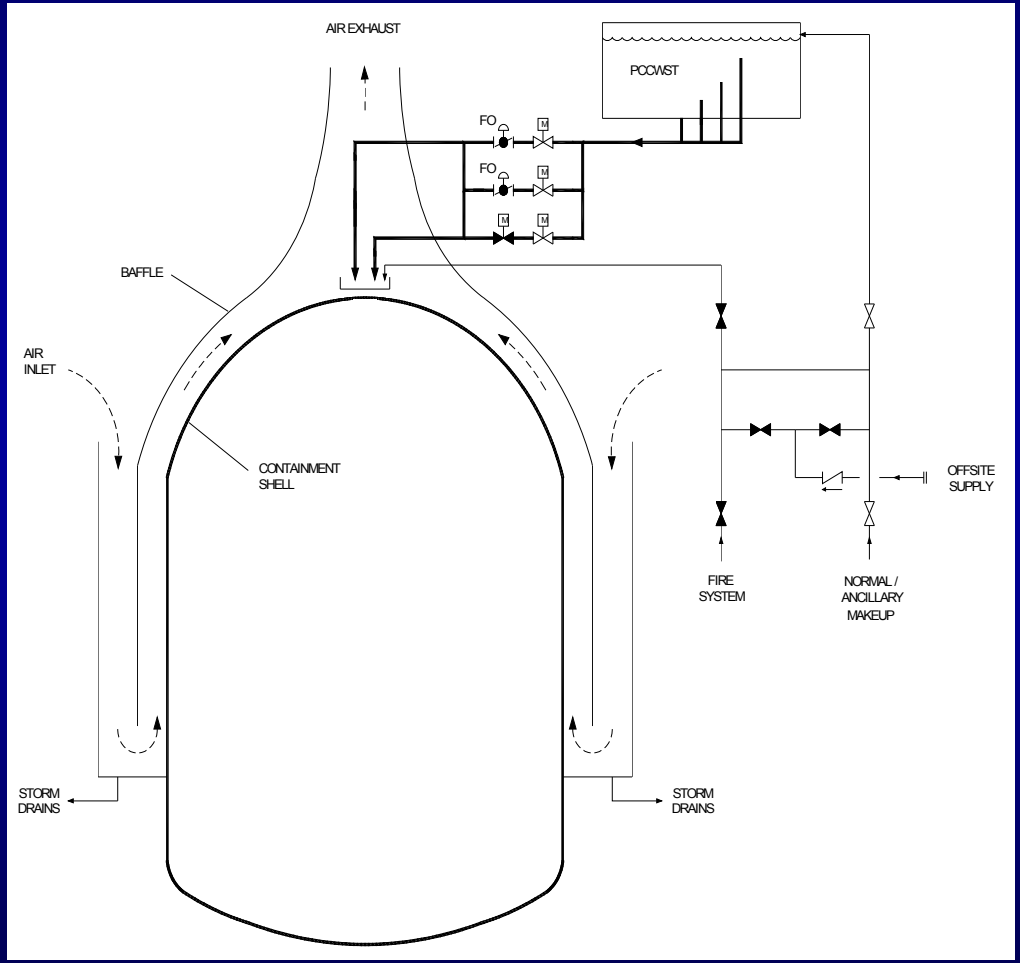


Passive Containment Cooling System

- The passive containment cooling system (PCS) provides the safety-related ultimate heat sink.
- Steel containment shell provides heat transfer surface area to remove heat by continuous natural circulation.
- Air cooling is supplemented by evaporation of water on external surface.

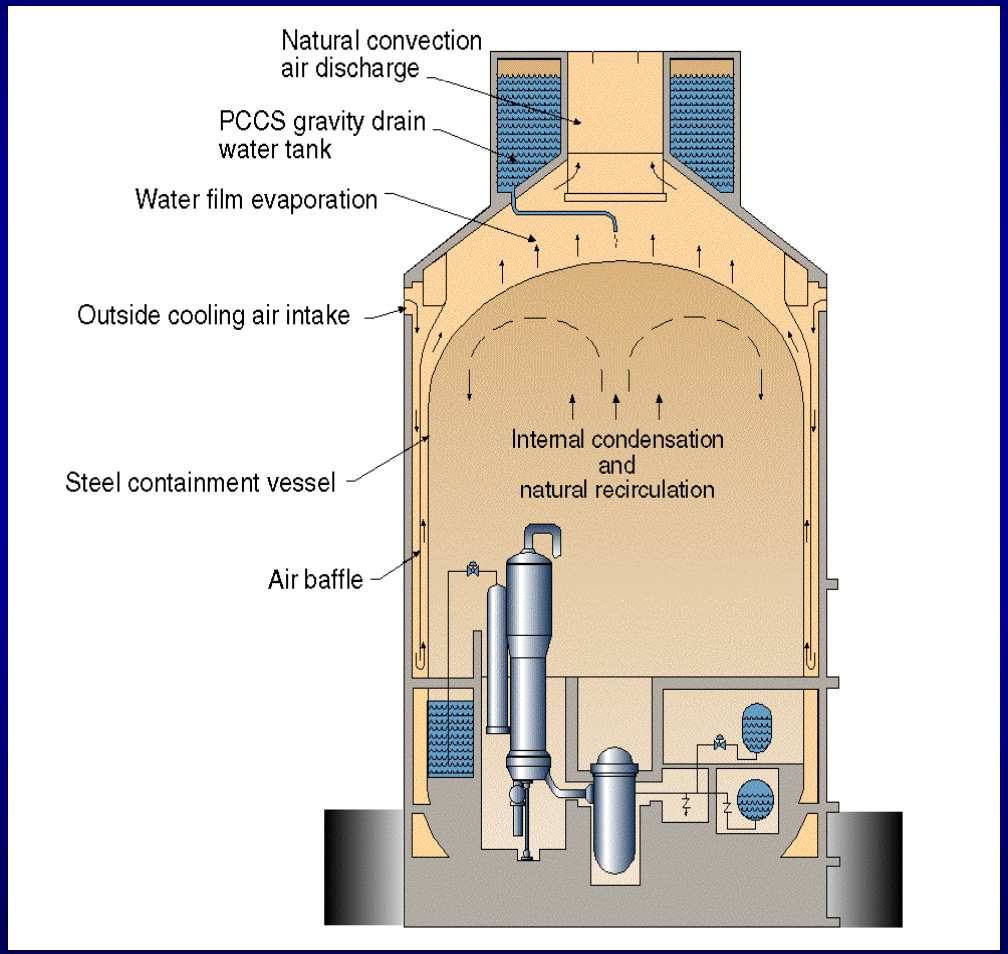
Passive Containment Cooling System

- **PCS Water Storage Tank**
  - Provides 72 hr drain
    - Afterwards use on/offsite water
    - Air only cooling prevents failure
  - Flow decreases with time
    - Uses 4 standpipes
- **PCS Flow Rates**
  - High initial flow
    - Rapidly forms water film
    - Effectively reduces containment pressure
  - Later flows match decay heat cooling



Passive Containment Cooling System

- **Same configuration as AP600**
- **Heat removal capacity increased to accommodate higher power:**
  - Larger, higher pressure containment
  - Larger water storage tank
  - Added 3rd, diverse, drain valve



AP1000 Containment Hydrogen Mitigation

- **Design Basis Accidents**
  - Slow long term buildup of H2
  - Uses 2 full size Passive Autocatalytic Recombiners (nonsafety)
    - **No power or actuation required**
  - Equipment is non-safety based on NRC / industry activities on risk-informed changes to 10 CFR 50.44 (Combustible Gas Control)
- **Severe Accidents**
  - Rapid buildup of H2
  - Uses non-safety igniters distributed in pairs around containment
  - Release paths from RCS ensure standing H2 flames located away from containment walls
    - **IRWST vents designed to discharge H2 away from containment wall**

AP1000 Containment Recirculation

- **No Fibrous Debris Generated by LOCA**
  - Fibrous debris could create safety challenge
    - Transported to screens, forms mat and filters out smaller particles (crud, dirt)
    - Increases differential pressure, could challenge core cooling
  - Avoided in AP1000; all insulation in LOCA jet zone is reflective metal
- **Enhanced Debris Settling**
  - Deep floodup levels with low flows / velocities
  - Long delay to initiation of recirculation
- **Protective Plates Above Screens**
  - Prevents particles (coating debris) from being transported to screens
- **Coatings Inside Containment**
  - Non-safety related - if detached, will settle before reaching screens
  - Reduced use of coatings inside containment (stairs, cabinets, etc)

Summary

- AP1000 defense in depth uses passive safety systems, to enhance safety and simplify design.
- Redundancy and overcapacity in AP600 safety systems used to achieve increase in power for AP1000.