Passive Core Cooling System

AP1000 Technology Chapter 4.0

Objectives

1. Describe how the passive core cooling system is designed to perform the following safety functions:

   a. Emergency core decay heat removal
   b. Reactor coolant system emergency makeup and boration
   c. Safety injection
   d. Containment pH control

Objectives (cont'd)

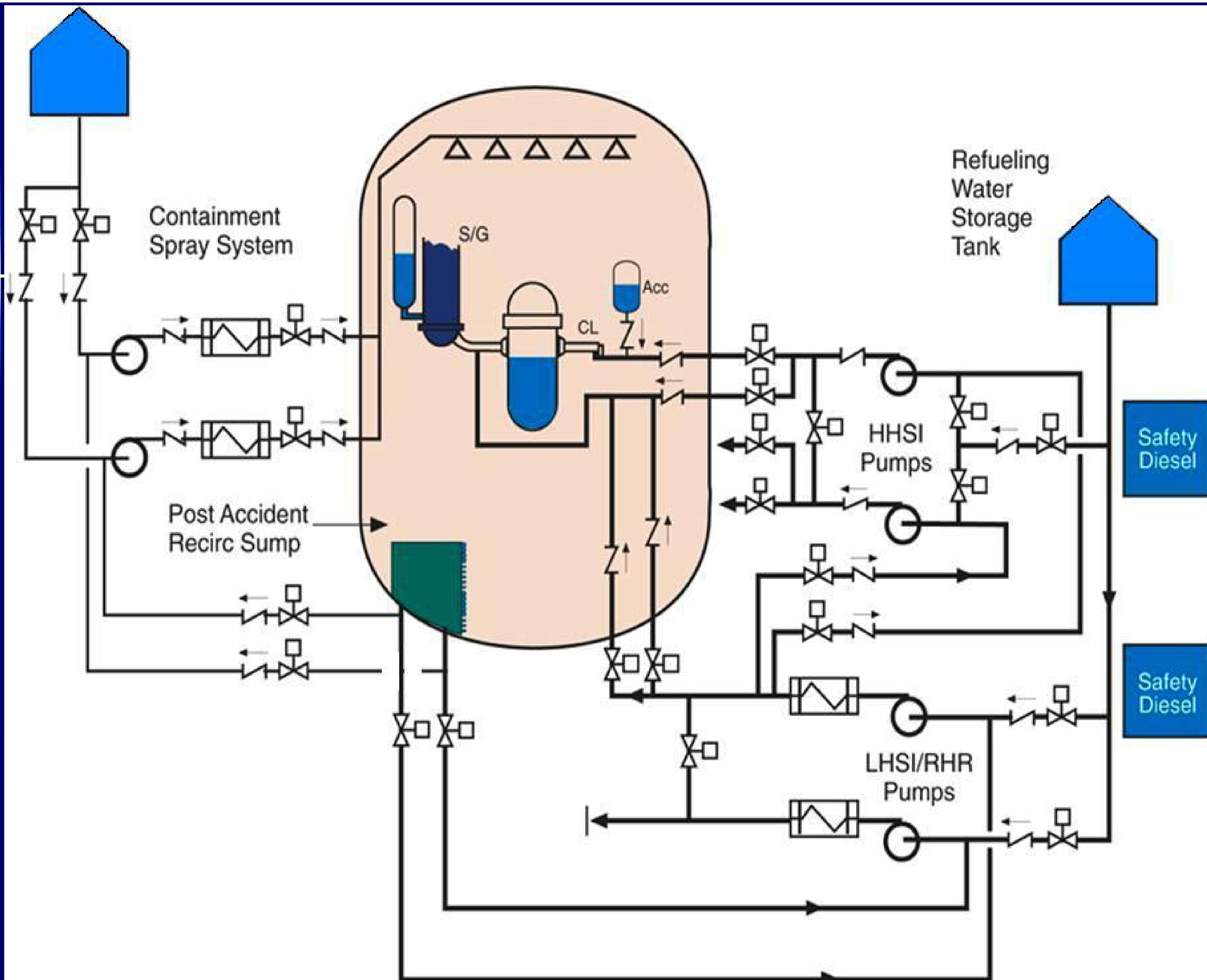
2. Describe how the following passive core cooling system components support performance of the safety functions listed above (Objective 1):
   a. Core makeup tanks
   b. Accumulators
   c. In-containment refueling water storage tank (IRWST)
   d. pH adjustment baskets
   e. Passive residual heat removal heat exchanger
   f. IRWST and containment recirculation screens
   g. Automatic depressurization valves

Objectives (cont'd)

3. Describe the passive core cooling system response to the following events:

   a. Steam system pipe failure
   b. Steam generator tube rupture
   c. Loss-of-coolant accident

Existing Plants



The passive core cooling system operates without pumps or power sources. Processes such as gravity injection and expansion of compressed gases are relied on. A one-time valve alignment (which does require electric power) is required upon actuation.

Objective 1: Safety Functions

1. Emergency core decay heat removal: Provide core decay heat removal when normal heat removal paths are lost.

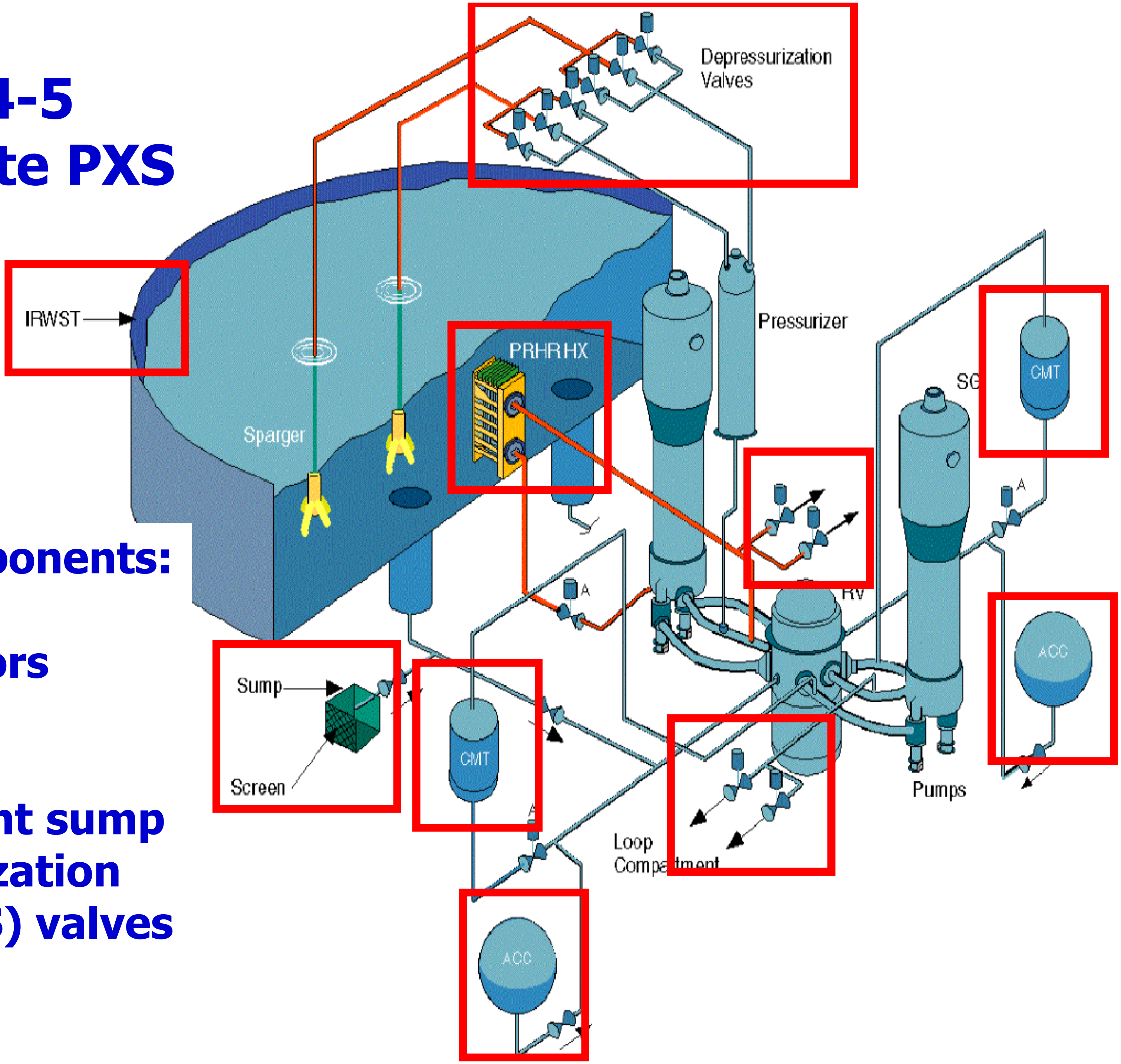
2. Reactor coolant system emergency makeup & boration: Provide makeup & boration when makeup from CVCS is unavailable or insufficient.

Objective 1: Safety Functions (cont'd)

3. Safety injection: Provide adequate core cooling for the complete range of LOCAs.

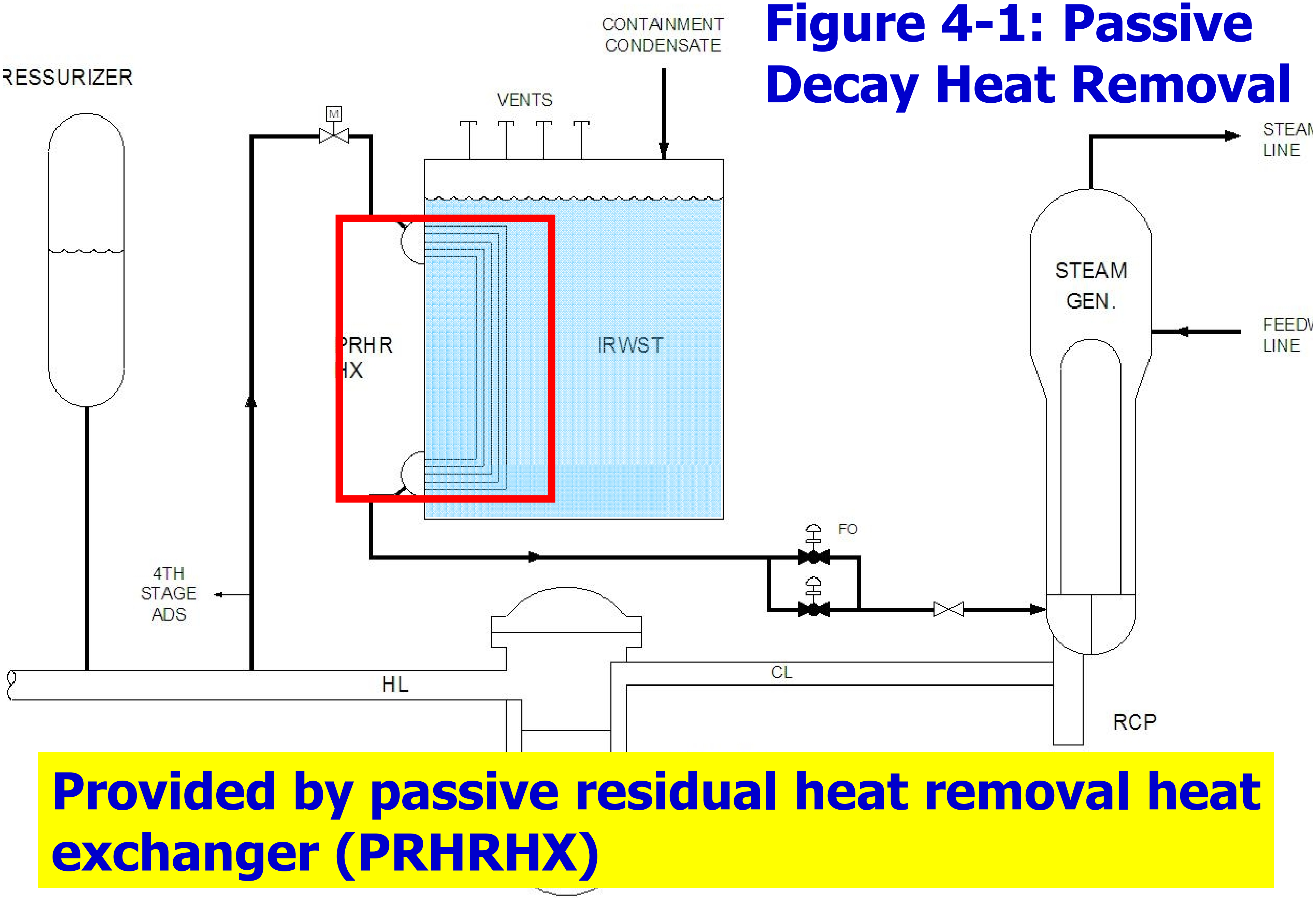
4. Containment pH control: Chemical addition to establish containment floodup conditions which support retention of radioactivity & prevent corrosion of equipment.

Figure 4-5
Composite PXS



Major components:
CMTs
Accumulators
IRWST
PRHRHX
Containment sump
Depressurization (ADS) valves

Figure 4-1: Passive Decay Heat Removal



Provided by passive residual heat removal heat exchanger (PRHRHX)

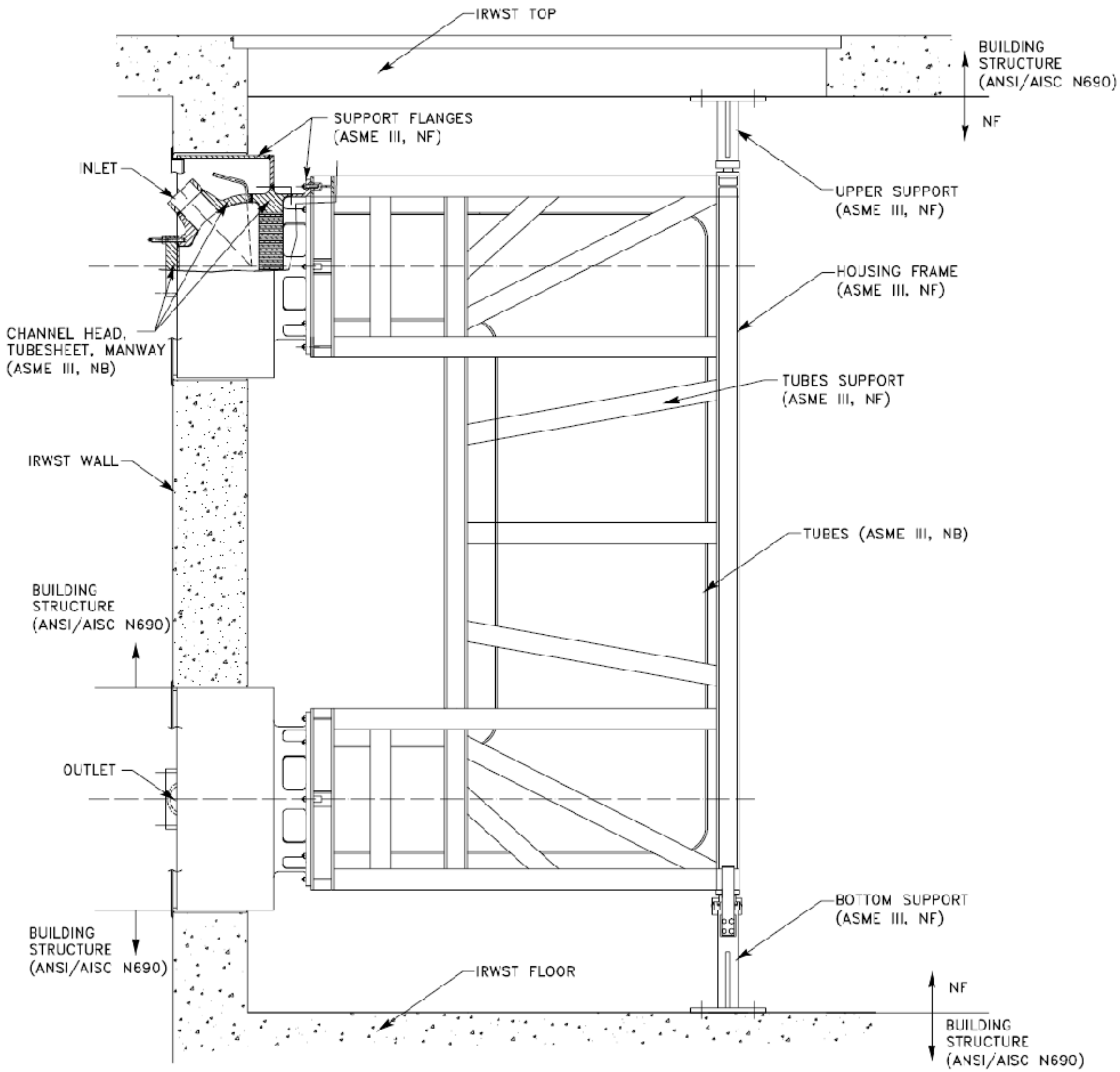


Figure 4-2: The PRHRHX is a bank of C-tubes mounted in the IRWST. HX is usually filled with coolant. Flow through the C-tubes from the RCS transfers heat to the IRWST contents.

Figure 4-3 Containment View

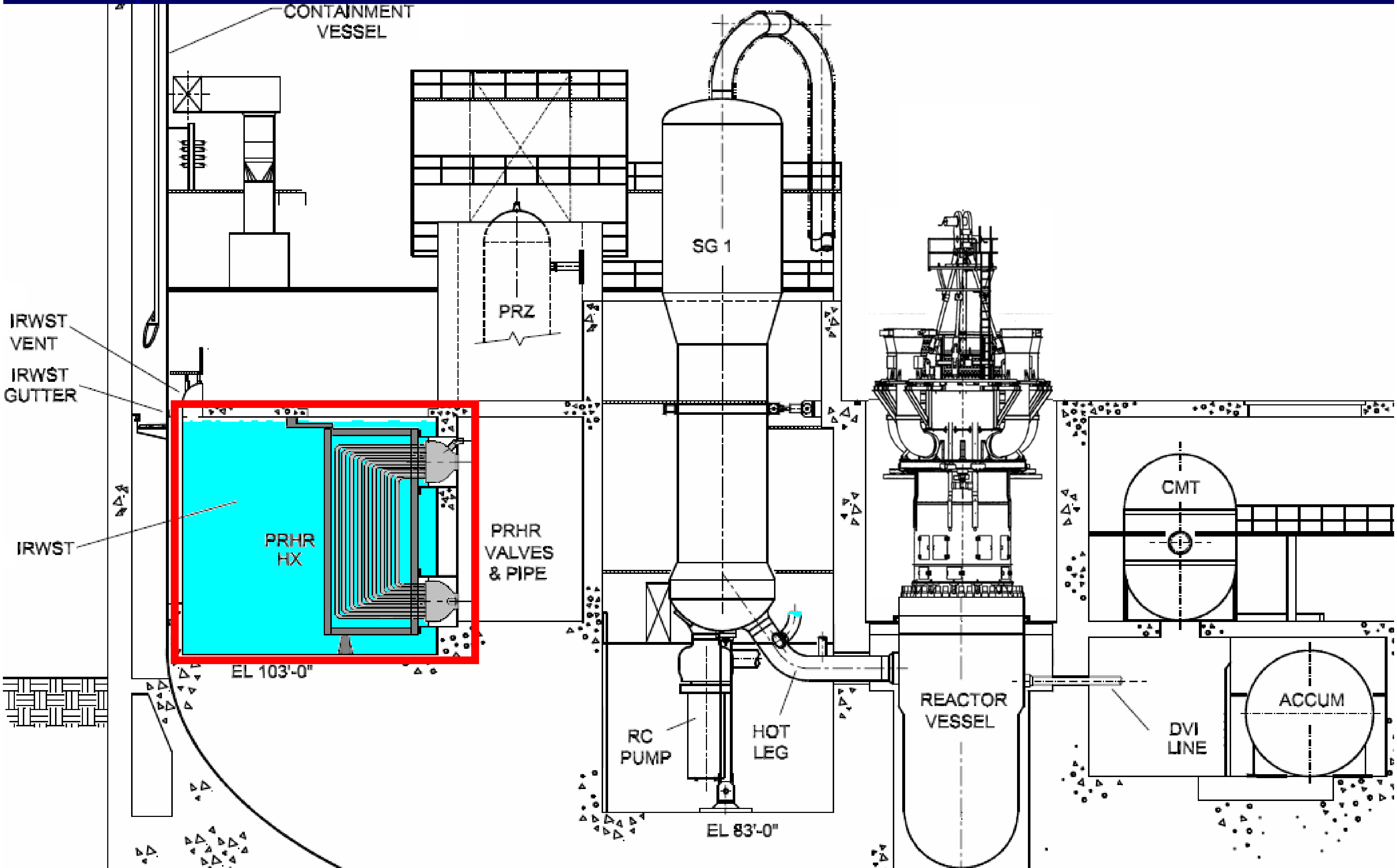
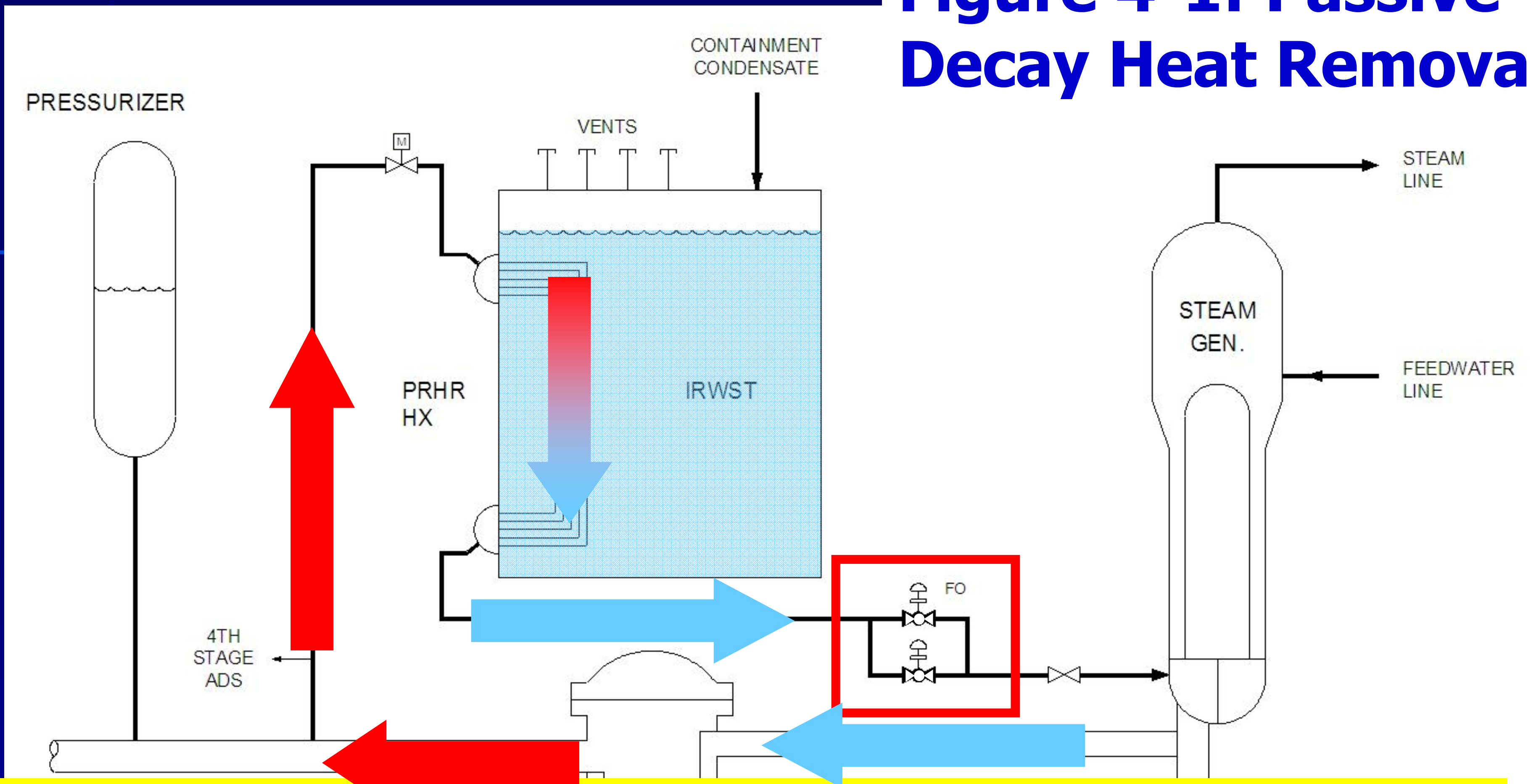
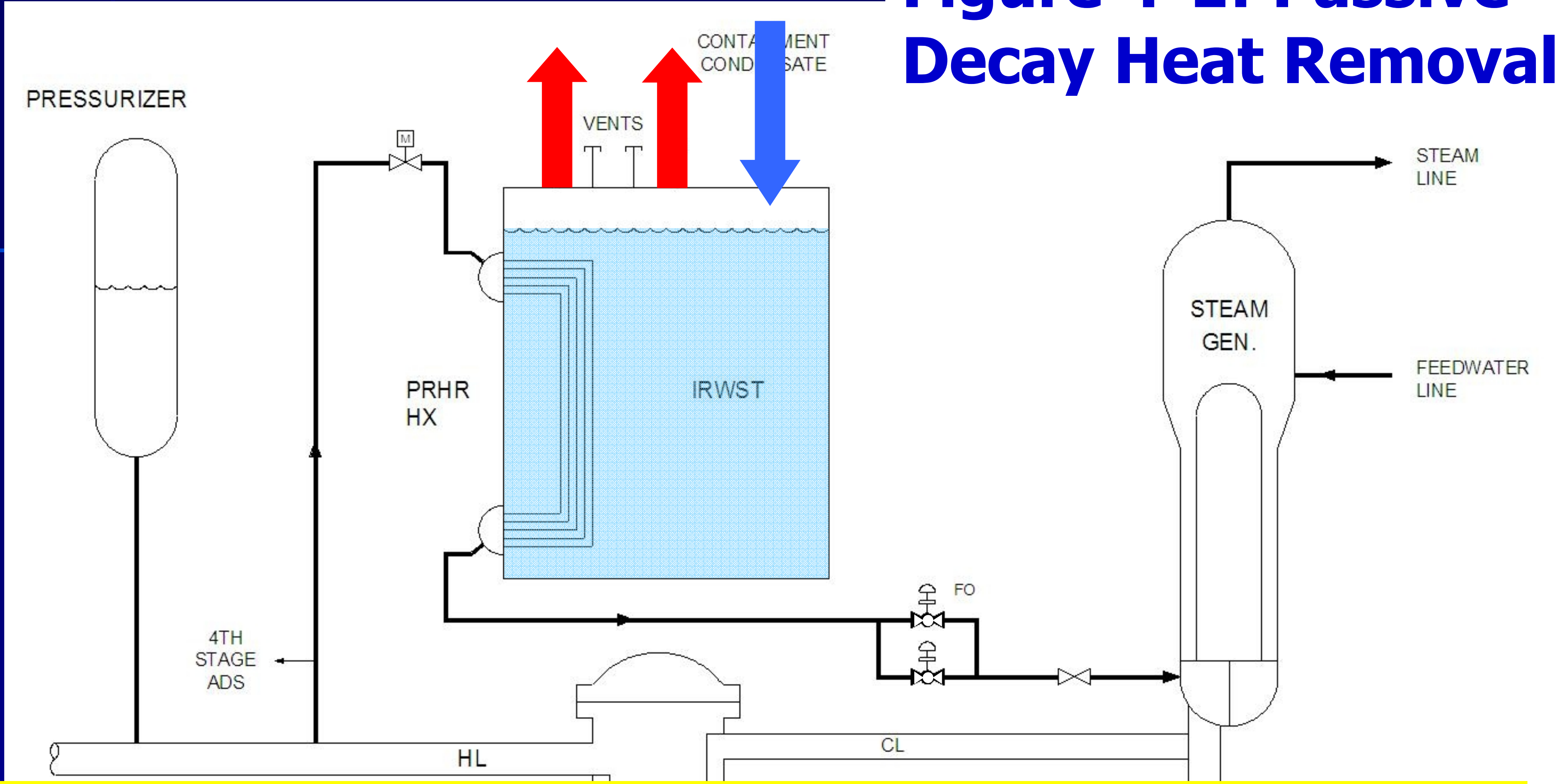


Figure 4-1: Passive Decay Heat Removal



When actuated:
AO isolation valves open.
Temp. & elevation of PRHRHX (IRWST conditions) provide thermal driving head.
NC or, if RCPs running, forced flow through the HX.

Figure 4-1: Passive Decay Heat Removal



If prolonged heat transfer is necessary:
Saturation is reached in IRWST (~2 hr).
IRWST steams to containment; steam condenses on steel containment vessel (cooled by PCS).
Condensate returns to IRWST via gutter arrangement.

PRHRHX Design Basis

- Automatically actuates to provide RCS cooling to prevent water relief through PZR safety valves.

- Can, in conjunction with PCS, remove decay heat indefinitely. Designed to cool RCS to 420°F in 36 hr, after which normal RHR system can be placed in service.

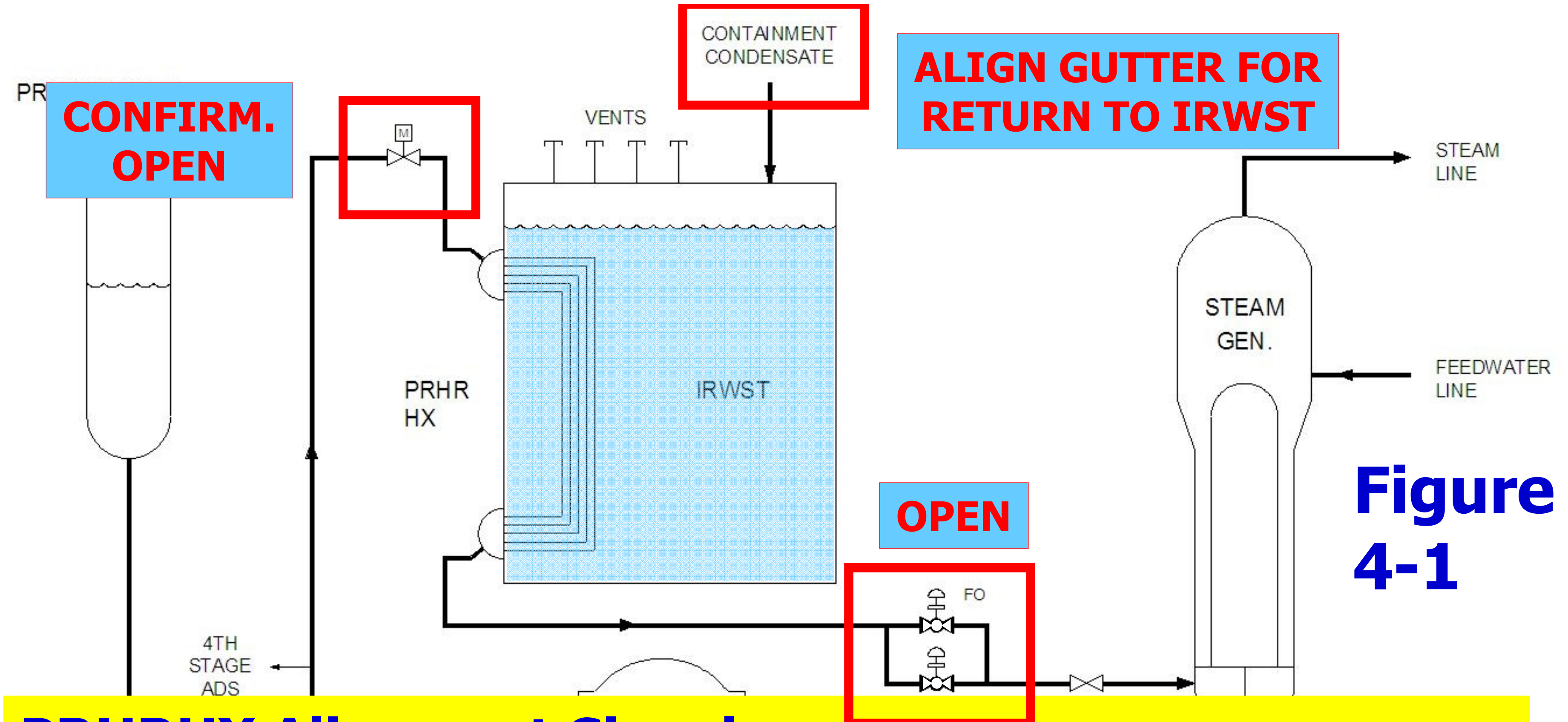


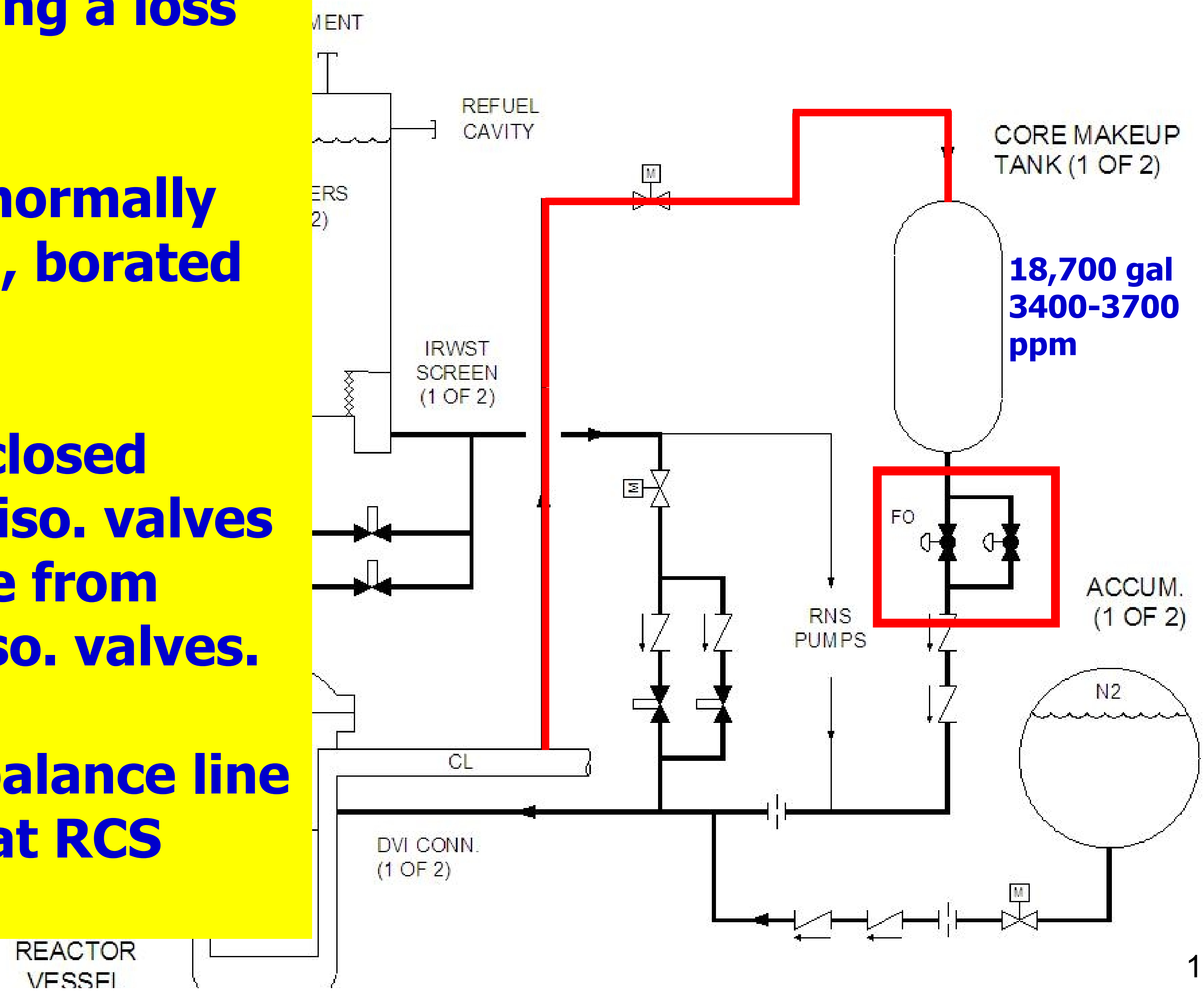
Figure 4-1

PRHRHX Alignment Signals:

1. **CMT injection alignment**
2. **1st-stage ADS actuation**
3. **Low WR SG level (55,000 lbm)**
4. **Low NR SG level (95,000 lbm) + low SU feed flow (200 gpm/SG)**
5. **High-3 PZR water level (71%)**
6. **Manual**

Figure 4-4: RCS Emerg. Makeup & Boration

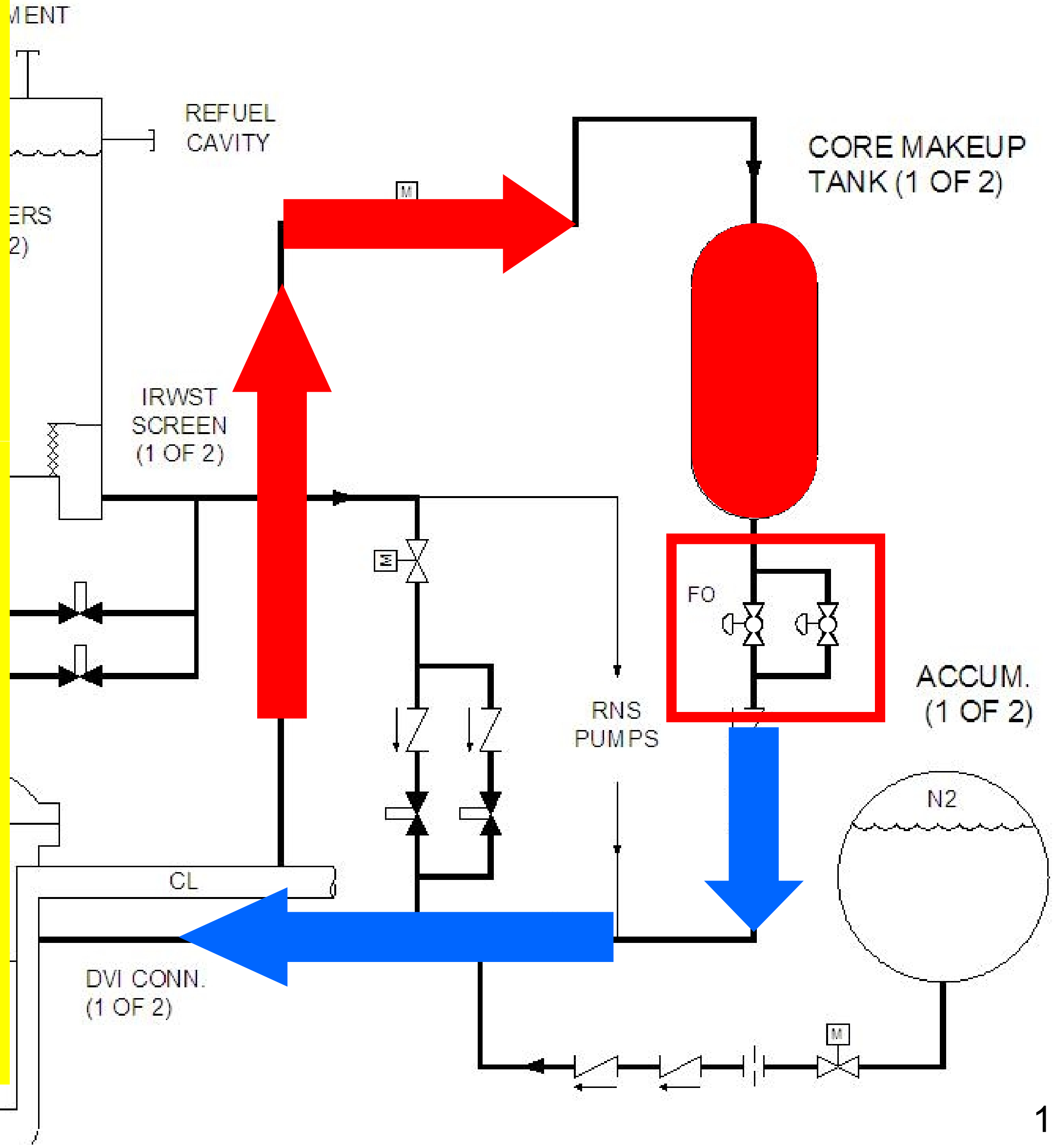
- **CMTs provide MU & boration for events not involving a loss of coolant.**
- **CMTs are normally full of cold, borated water.**
- **Normally closed discharge iso. valves are diverse from PRHRHX iso. valves.**
- **Pressure balance line is open & at RCS pressure.**



Upon actuation:

- **Discharge iso. valves open. PRHRHX uniso-lated also (not shown).**
- **Cold, borated water is discharged to vessel downcomer annulus via direct injection lines (2).**
- **Flow from the cold legs replaces the water discharged to the vessel.**
  - **Steam-compen-sated injection (cold leg[s] voided)**
  - **Water recirculation**

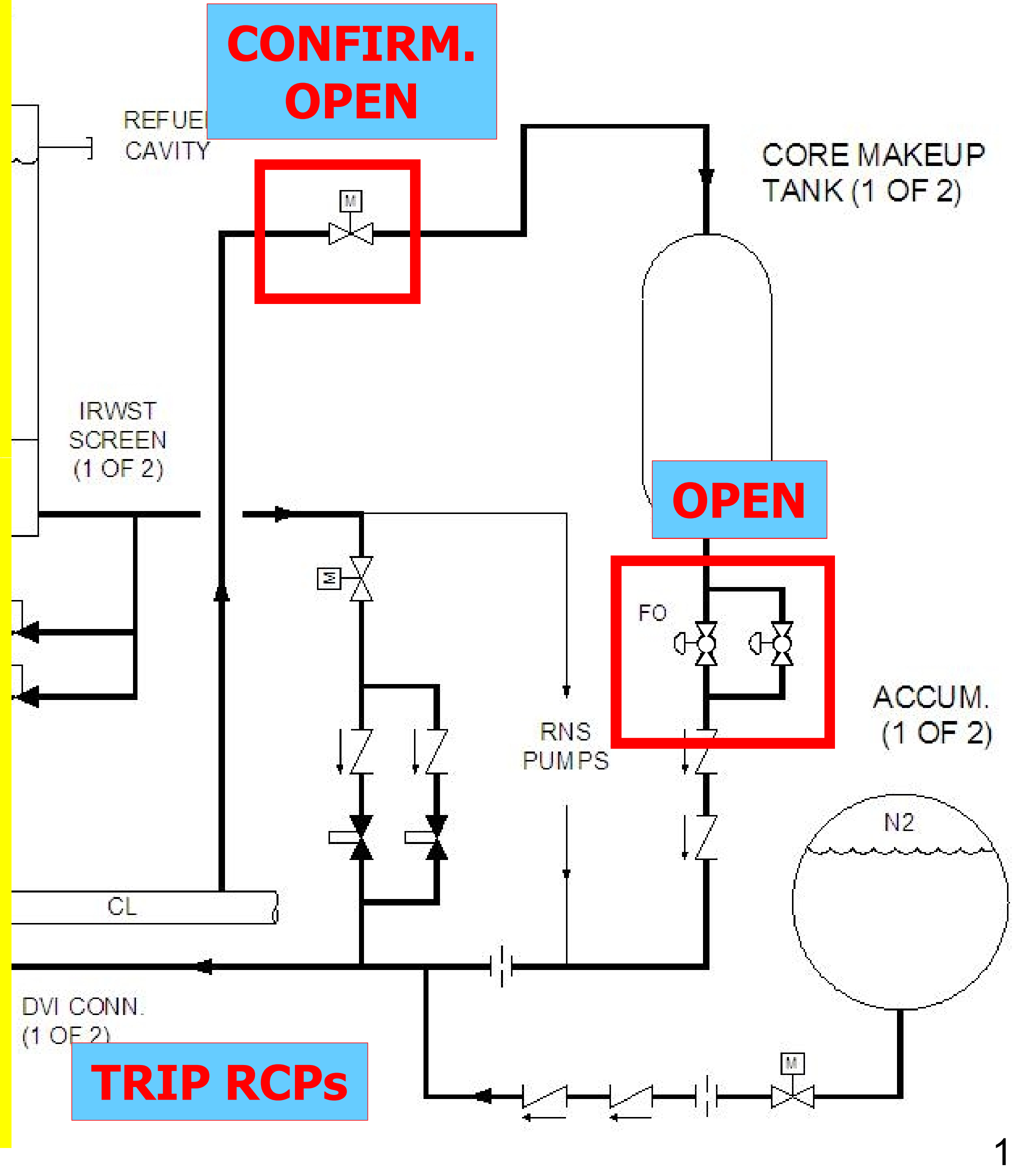
Figure 4-4: RCS Emerg. Makeup & Boration



CMT Injection Actuation signals:

- Safeguards actuation
  - Low PZR press. (1795 psig)
  - Low steam press. (560 psig)
  - Low T_c (505°F)
  - High-2 cont. press. (6.2 psig)
  - Manual
- 1st-stage ADS actuation
- Low-2 PZR level (10%)
- Low WR SG level + high T_H
- Manual

Figure 4-4: RCS Emerg. Makeup & Boration



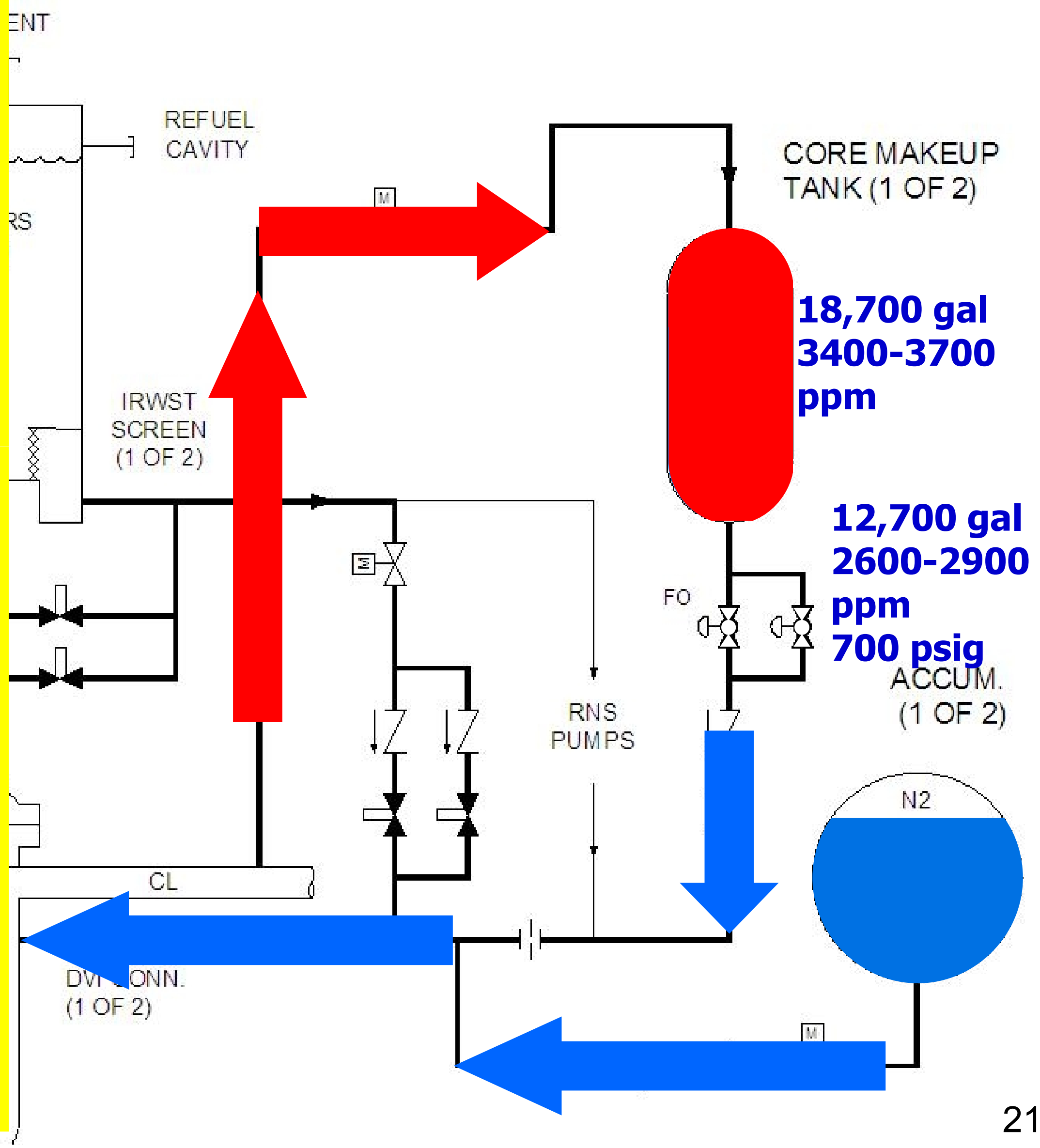
Emergency Makeup & Boration Design Basis

- For non-LOCA events, makeup water is automatically provided to cover core, remove decay heat.
- For an inadvertent RCS cooldown, coolant contraction is countered; any return to power is within acceptable limits.
- PXS supplies sufficient boron to meet T/S SDM req't for cold, depressurized conditions.

As RCS depressurizes:

- **CMTs provide high flow for relatively long duration. Water recirculation mode at start, then switch to steam-displacement mode as cold legs void.**
- **Accumulators provide high flow for several min. when RCS depressurizes below 700 psig. N_2 expands to displace tank contents.**
- **Both inject borated water directly to the vessel.**

Figure 4-4: Safety Injection for LOCAs



As RCS depressurizes from LOCA or ADS actuation:

- Squib valves in IRWST injection lines auto open on 4th-stage ADS actuation (20% CMT vol.).
- Borated water from IRWST, located above loop piping, gravity injects directly to the vessel.

Figure 4-4: Safety Injection for LOCAs

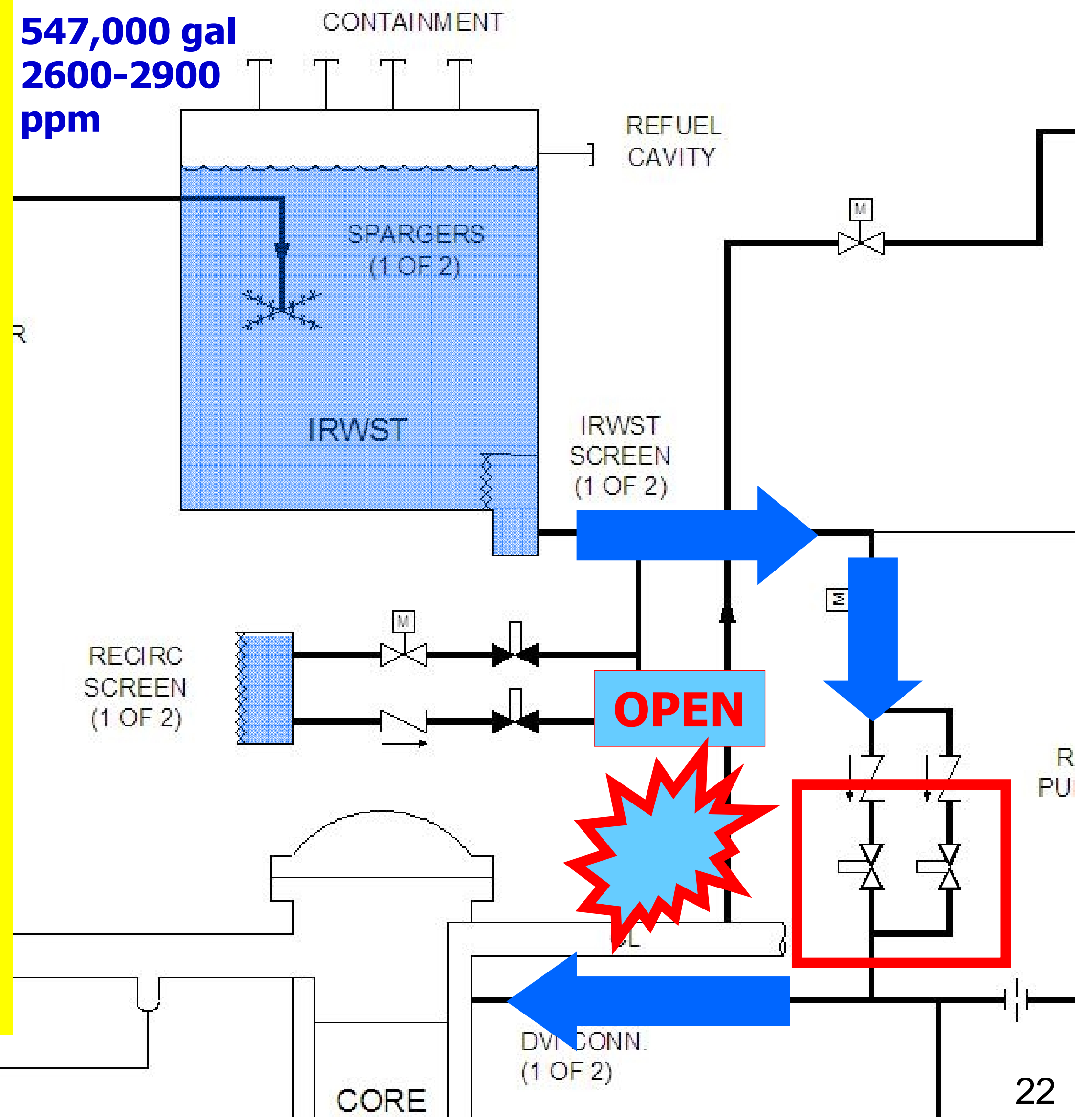


Figure 4-4: Safety Injection for LOCAs

After accumulators, CMTs, & IRWST have injected, containment is flooded sufficiently to provide recirc. flow:

- **Squib valves in containment recirc. lines auto open.**
  - **Low-3 IRWST level + 4th-stage ADS actuation**

- **At first, water from IRWST flows backward through recirc. screens, flushing away debris.**

- **Ultimately, containment sump gravity injects directly to the vessel.**

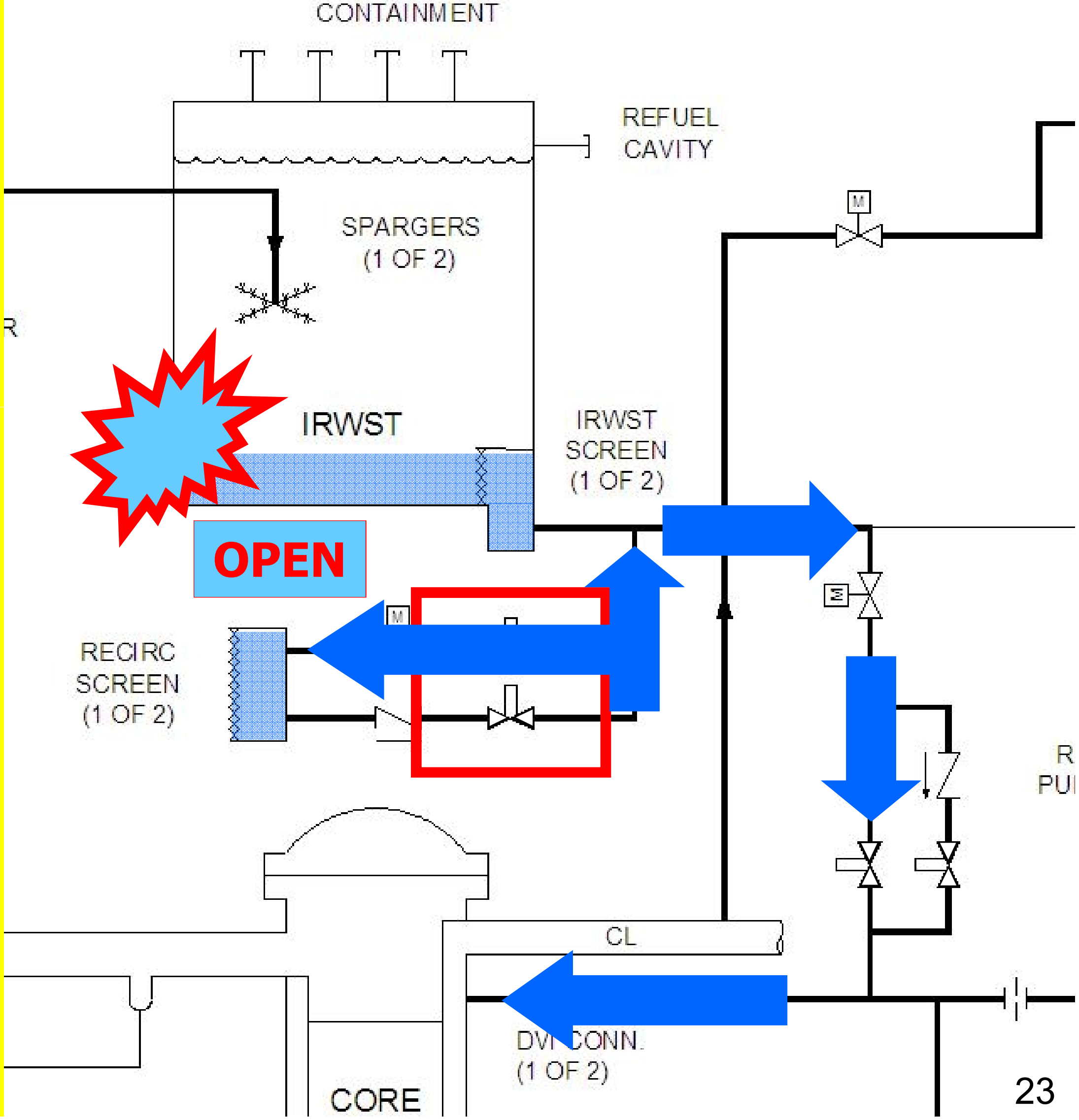
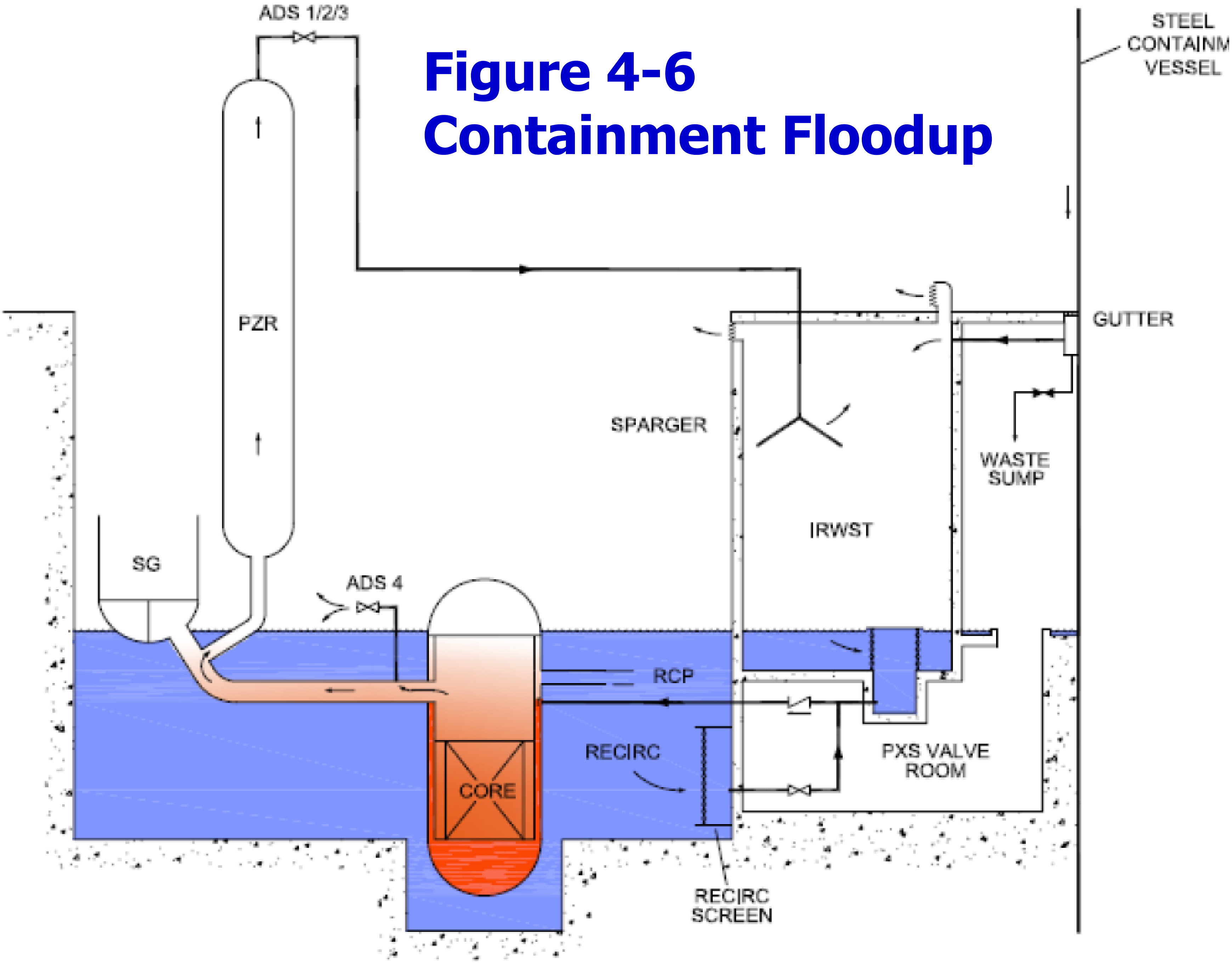


Figure 4-6
Containment Floodup



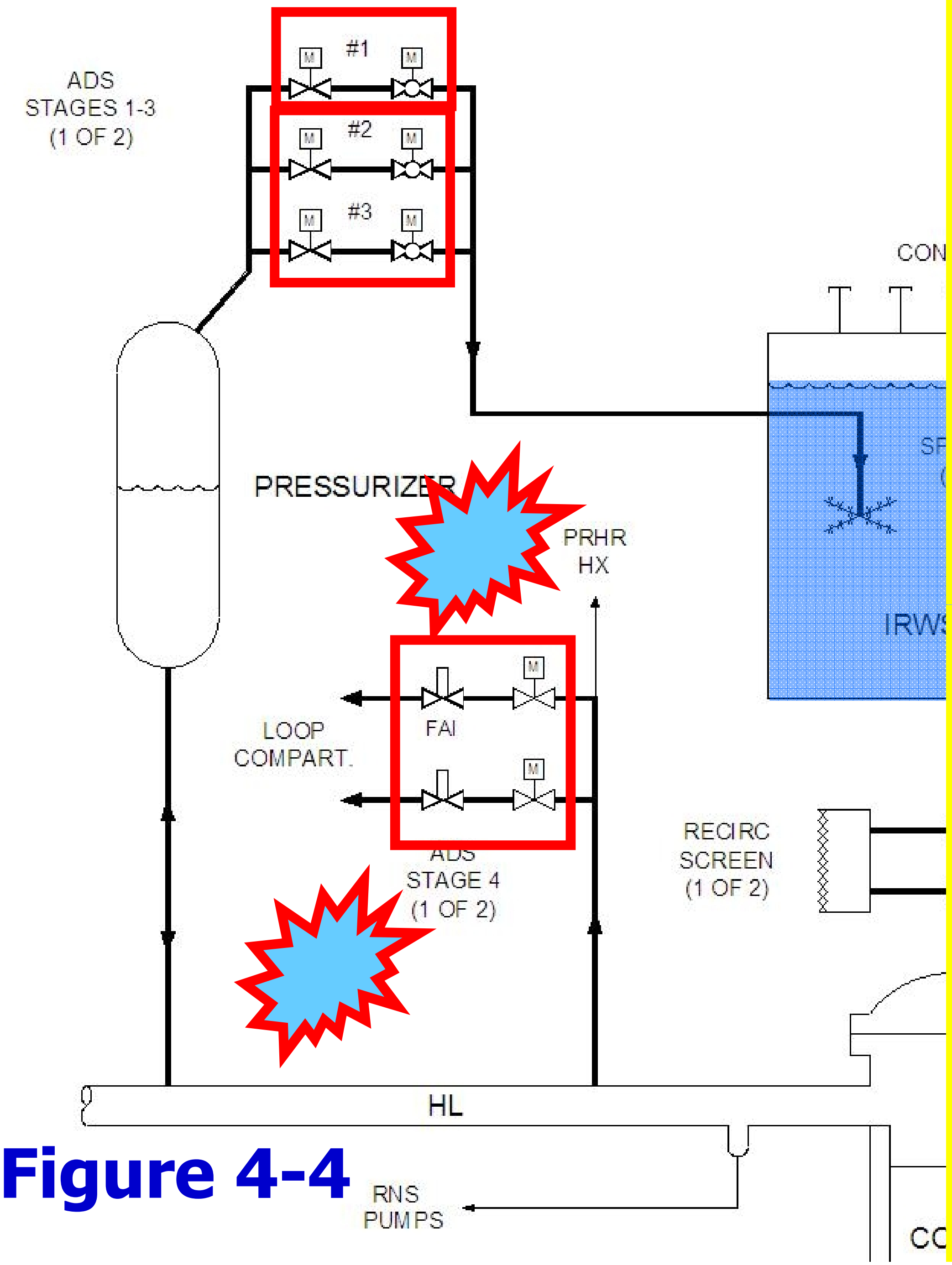
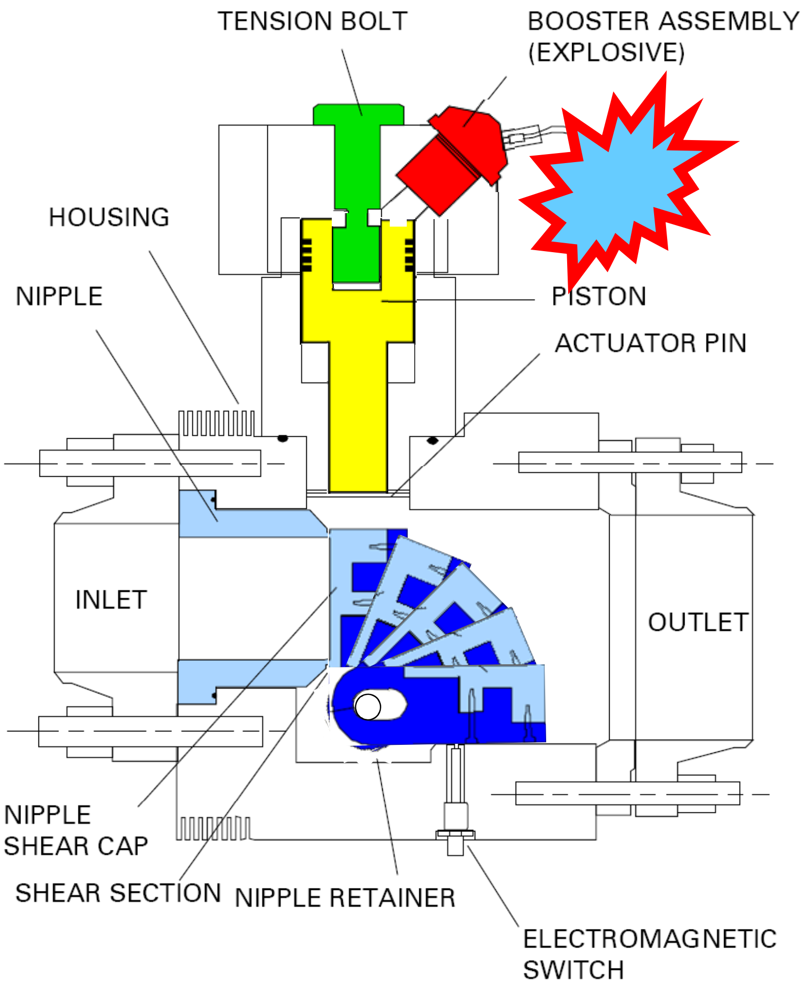


Figure 4-4

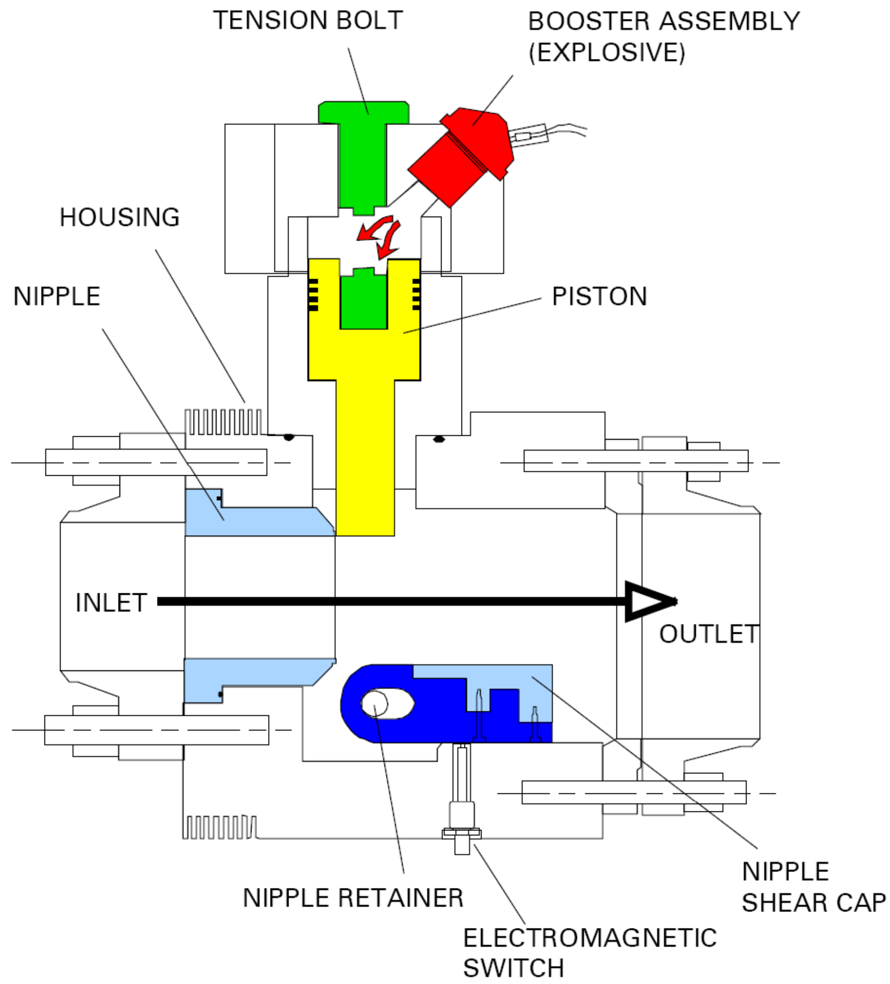
Automatic depressurization valves (RCS):

- 1st stage initiates with CMT intiation + CMT Low-1 level (67.5%).
- 2nd & 3rd stages initiate upon timed delay after actuation of preceding stage.
- 4th stage initiates with CMT Low-2 level (20%) + Low RCS pressure (1200 psig) following preset time delay after 3rd-stage depressurization valves have opened.

ADS Stage 4 Squib Valve



CLOSED



OPEN

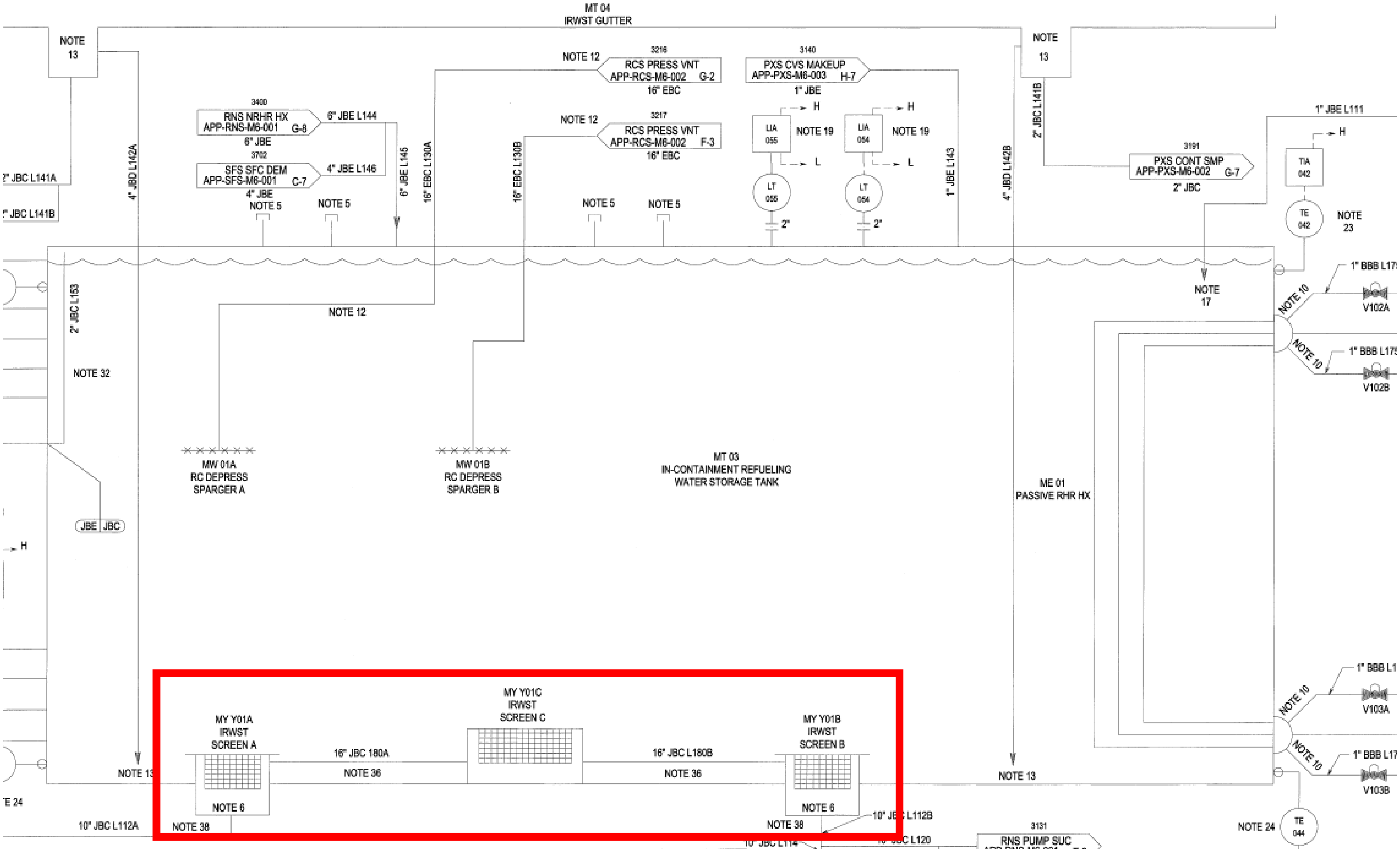
Safety Injection Design Basis

- PXS rapidly refills the reactor vessel, refloods the core, removes decay heat.
- ECCS performance criteria are satisfied.
- ADS + PXS satisfies SBLOCA performance req'ts.

Component Details: IRWST

- Large, stainless-steel-lined tank underneath operating deck
- Integral to containment internal structures, isolated from containment vessel
- 2 IRWST “sumps”; 3 vertical, large-area screens

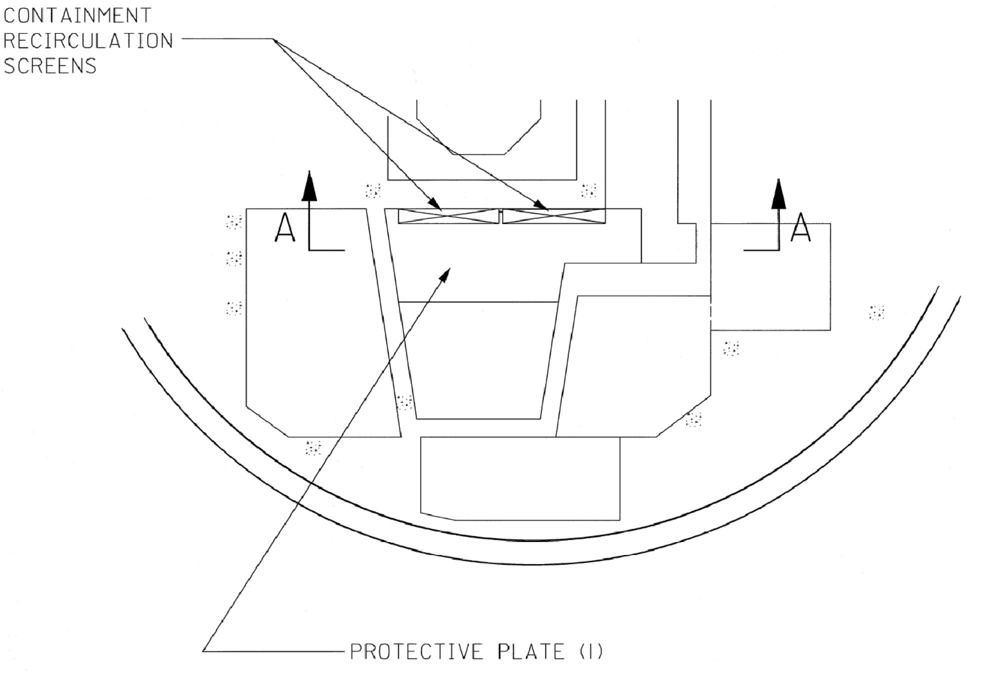
IRWST Screens

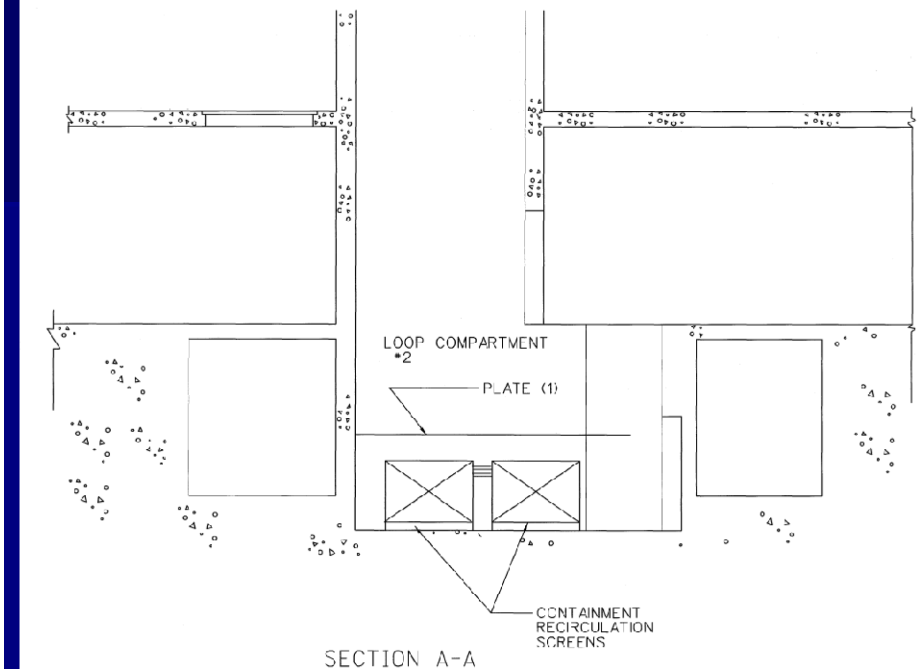


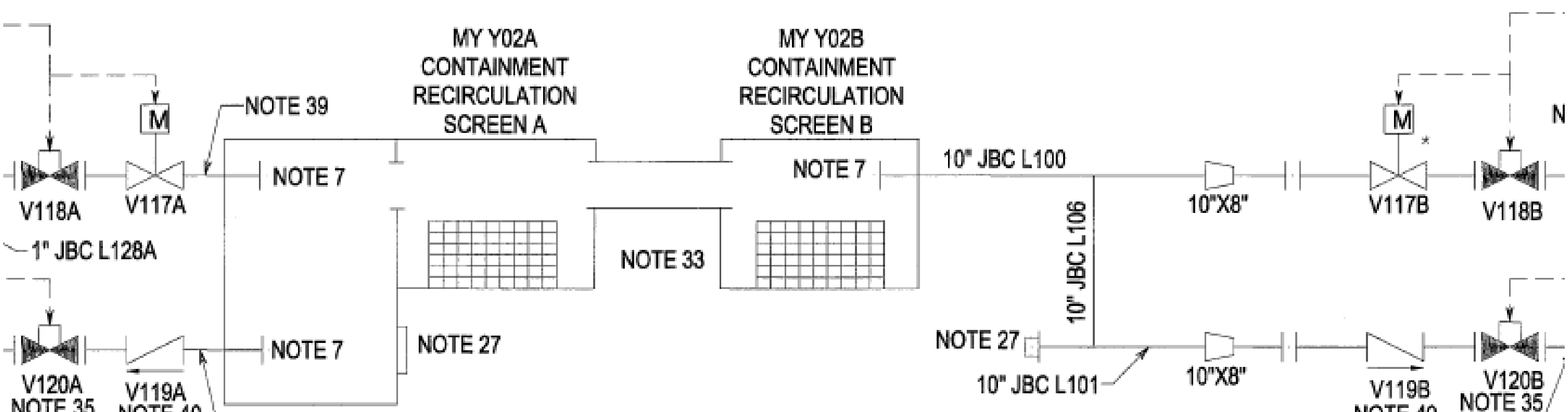
Component Details: IRWST & Containment Recirc. Screens

- Prevent debris from entering reactor & blocking core cooling passages
- Redundant sets
- Each screen functions as trash rack & fine screen
- 2-ft debris curb for containment recirc. screens
- Can withstand accident loads, missiles
- Solid top covers
- Corrosion-resistant
- Locations & orientations should limit potential for clogging
- Insulation & coatings inside containment designed not to clog screens

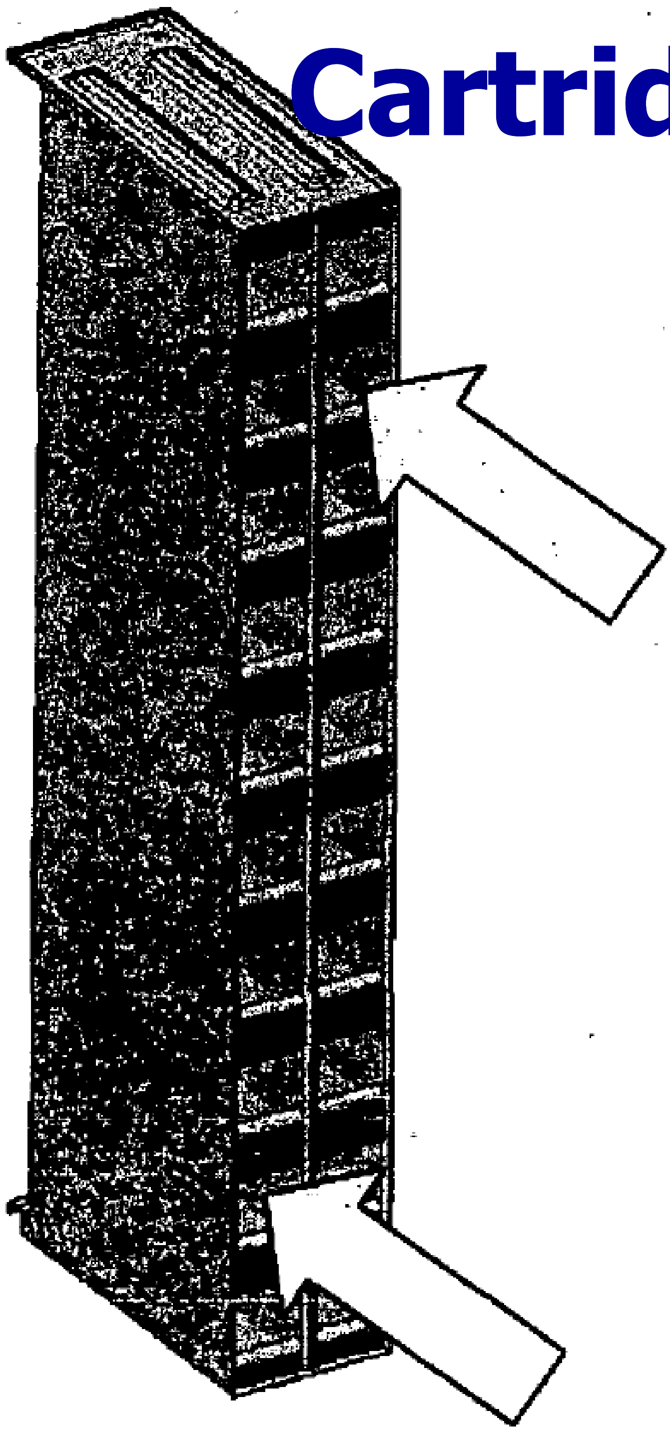
Fig. 4-7 Recirc. Sump Screens

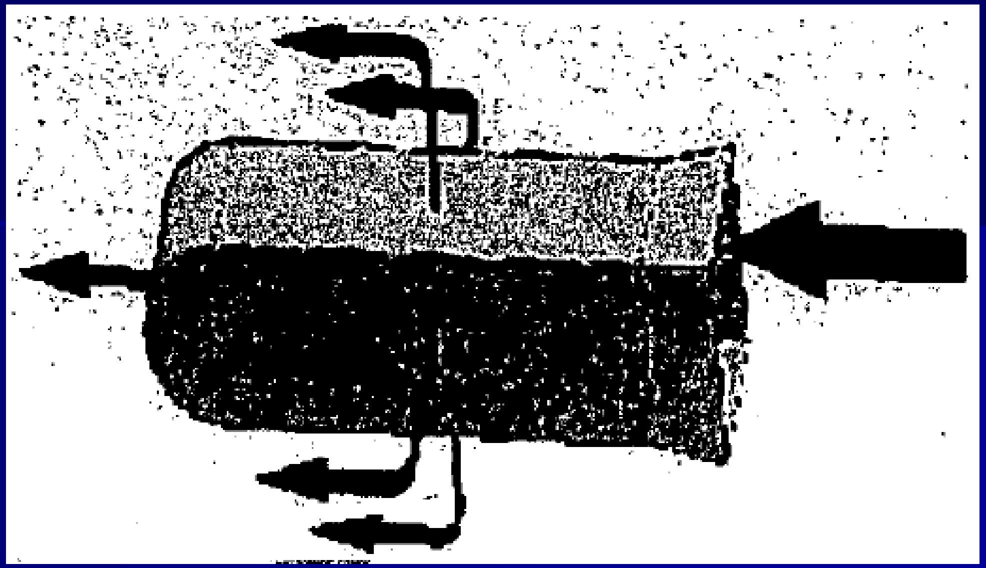


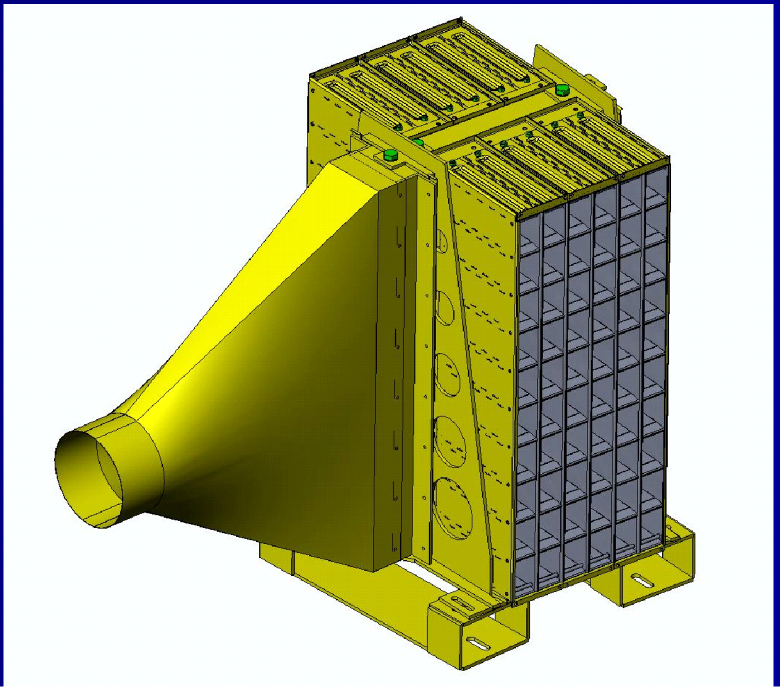




Cartridge Pocket Screens



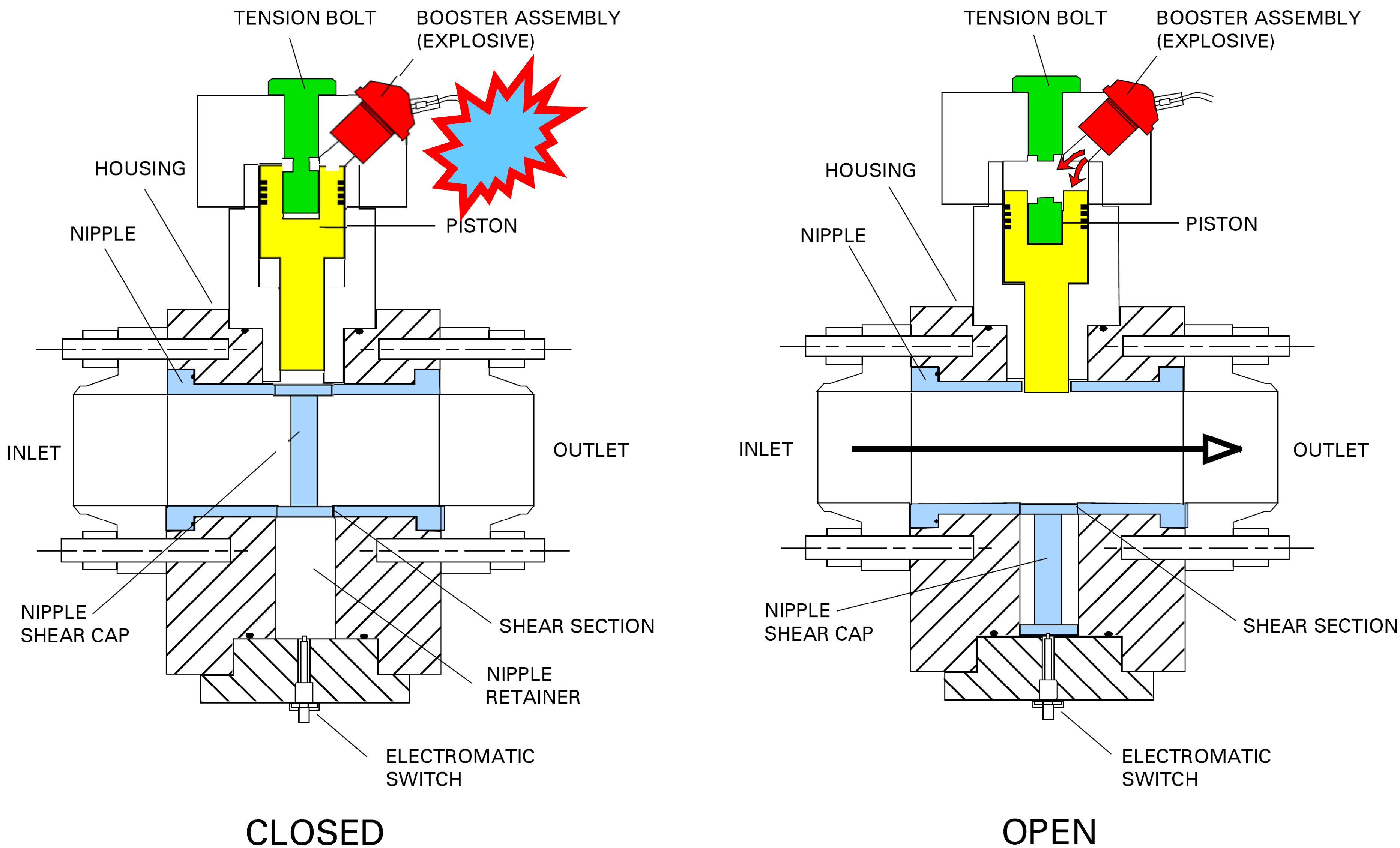




Component Details: Explosively Opening (Squib) Valves

- Used in IRWST injection lines, containment recirc. lines
- Zero leakage during normal ops
- Reliable opening during accident
- One set of containment recirc. squib valves is diverse from the others

Representative Squib Valve



Containment pH Control

- Accomplished passively via pH adjustment baskets in containment
- Baskets contain trisodium phosphate (Na_3PO_4)
- Placed at least 1 ft above containment floor, below post-accident floodup level
- Design basis: Maintain pH within 7.0 – 9.5 range, to enhance radionuclide (iodine) retention in containment and to reduce potential for stress corrosion cracking of stainless steel components due to chlorides leaching from concrete

PXS Event Response

- Steam system pipe failure (Objective 3.a)
- Loss of main feedwater
- SGTR (Objective 3.b)
- LOCA (Objective 3.c)

PXS Response to Steam System Pipe Failure

- Safeguards actuation signal
- RCPs trip, CMTs actuate, PRHRHX actuates.
- Main steam lines isolate.
- CMTs inject to vessel w/ water recirculation, making up for coolant contraction & positive reactivity addition. CMTs do not drain; ADS is not actuated.
- PRHRHX removes decay heat.

PXS Response to Steam System Pipe Failure (cont'd)

- Depending on break severity, accumulators may inject.

- Any return to power is within acceptable limits; the reactor is automatically made subcritical.

PXS Response to Loss of Main Feedwater

- PRHRHX is actuated, probably by decreasing SG levels.
- CMTs are actuated initially or after PRHRHX cooling has sufficiently reduced PZR level.
- RCPs are tripped; natural circulation through the PRHRHX.
- CMTs inject to vessel w/ water recirculation. CMTs do not drain; ADS is not actuated.
- Accumulators do not inject.

PXS Response to SGTR

- Analyzed event is complete severance of 1 tube.
- Nonsafety-related systems address this event: Makeup pumps restore inventory; SU FW throttles to limit SG overfill.
- Operators are expected to take actions similar to those for existing plants to cool down & depressurize the RCS to terminate break flow.

PXS Response to SGTR (cont'd)

- If operators don't take timely actions or nonsafety-related equipment fails, SG overfill protection isolates SU FW pumps & makeup pumps.
- CMTs then actuate on low PZR level. Actuation of CMTs automatically actuates PRHRHX.
- RCPs are tripped; natural circulation through the PRHRHX.
- CMTs inject to vessel w/ water recirculation.

PXS Response to SGTR (cont'd)

- PRHRHX & CMTs remove decay heat & reduce RCS temperature.

- RCS inventory contracts; PZR level & pressure decrease. RCS pressure is equalized w/ ruptured SG pressure; break flow is terminated.

PXS Response to LOCA

- Safeguards actuation signal actuates CMTs. If a SBLOCA, they initially operate in water recirculation mode. They operate in steam-compensated injection mode (with greater flow from CMTs) after RCS voids.
- The accumulators inject immediately, for a LBLOCA, or after ADS actuation, for a SBLOCA.
- ADS valves open sequentially as CMTs empty.

PXS Response to LOCA (cont'd)

- 4th-stage ADS actuation automatically opens IRWST squib valves. IRWST provides low pressure injection.
- The containment floods up.
- Low-3 IRWST level automatically opens the containment recirculation squib valves. Initially, some water drains from IRWST to containment until IRWST & containment levels equalize.

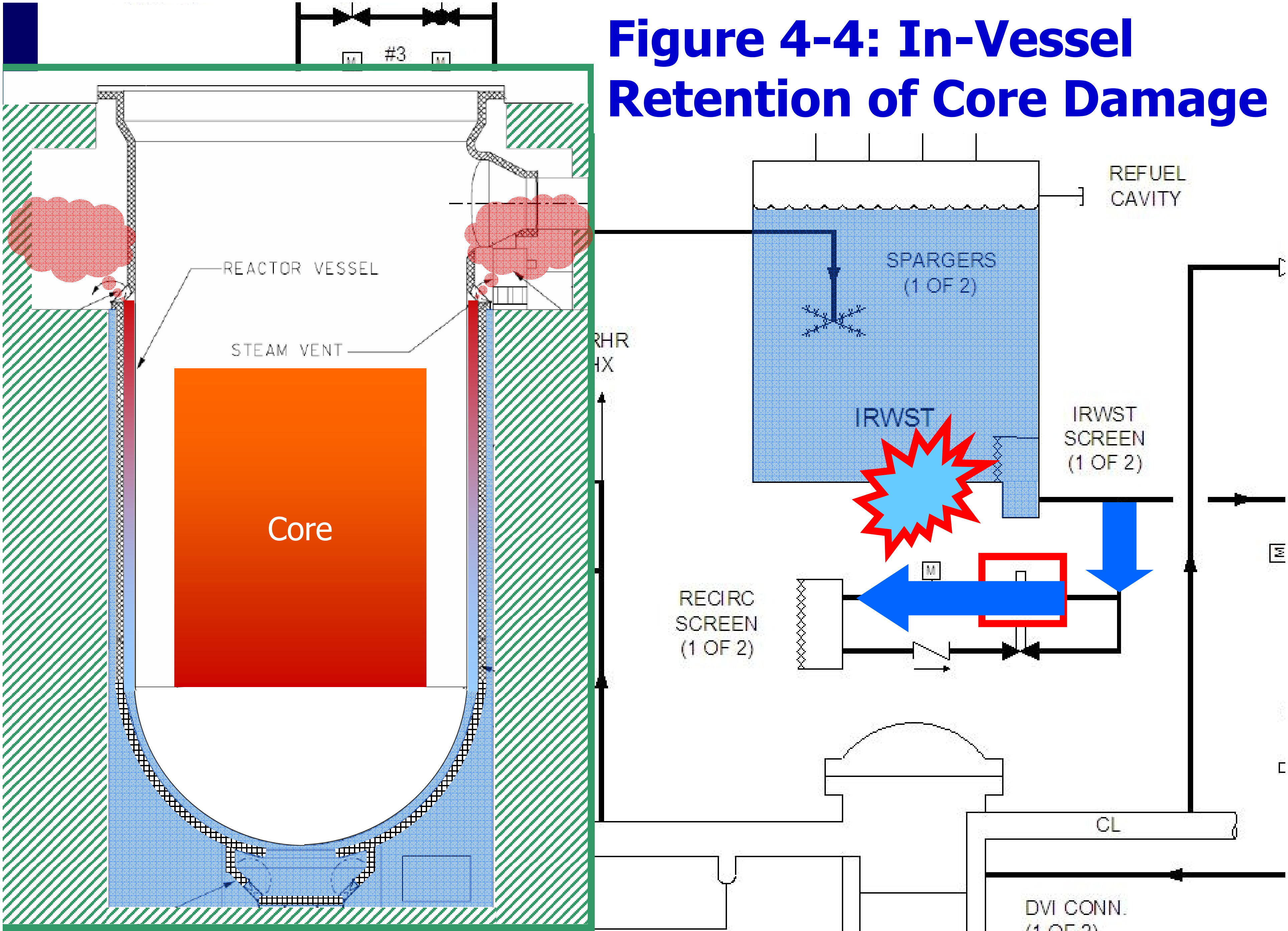
PXS Response to LOCA (cont'd)

- Recirculation of water from containment provides long-term cooling. Water in containment eventually reaches saturation, and heat transfer is ultimately through the containment vessel to the surrounding atmosphere.
- The RCS depressurizes to saturated conditions at about 250°F within 24 hr. The PXS maintains these conditions indefinitely.

Long-Term Considerations

- The PXS maintains safe shutdown conditions for 72 hr after an event without operator action or nonsafety-related power.
- Makeup to containment may be needed; with maximum allowable containment leak rate, makeup to containment not needed for 1 month.

Figure 4-4: In-Vessel Retention of Core Damage



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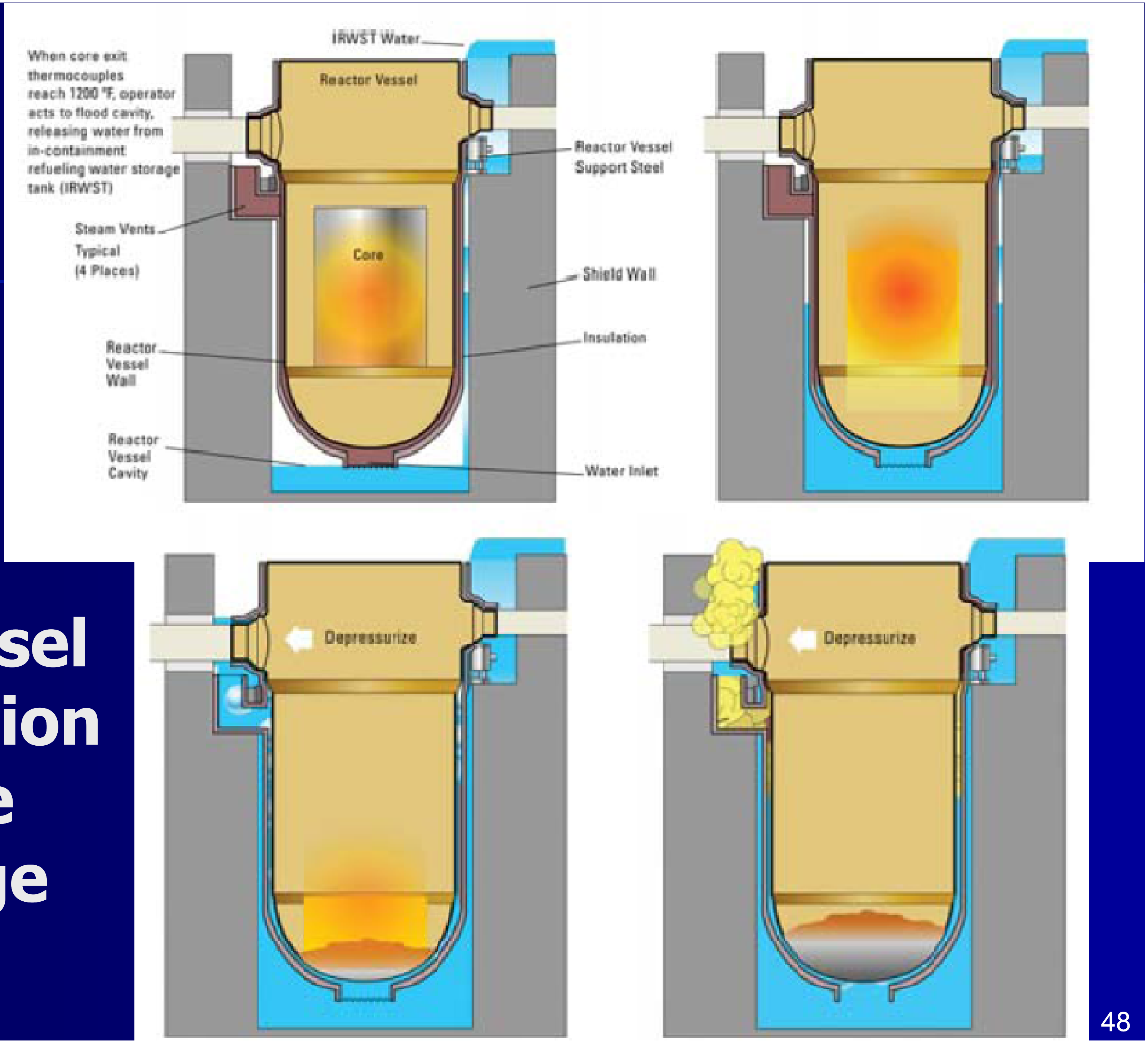

Review: The heat sink for the passive residual heat removal heat exchanger is…

a. Environmental water.
b. Component cooling water.
c. The contents of the in-containment refueling water storage tank.
d. Ambient air.

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Review: Retention of iodine in the containment sump after a LOCA is accomplished via…

a. The dissolving of Na_3PO_4 into the sump water during containment floodup.
b. Adding NaOH to containment spray water.
c. Containment floodup without an additive.
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Review: Mitigation of a steam line break is expected to involve…

a. Injection from the both the accumulators and the IRWST.
b. Recirculation of containment sump water.
c. Complete emptying of the core makeup tanks (CMTs).
d. Makeup from the CMTs and heat removal in the passive residual heat removal heat exchanger.

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Review: During an SBLOCA, injection from the IRWST would be expected…

a. Immediately.
b. As the accumulators discharge.
c. After depressurization of the RCS by the automatic depressurization system.
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Review: Which of the following is NOT a driving force for PXS flow?

a. Gravity.
b. Spring force after removal of hydraulic pressure.
c. Temperature (density) difference between water masses.
d. Compressed gas.

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