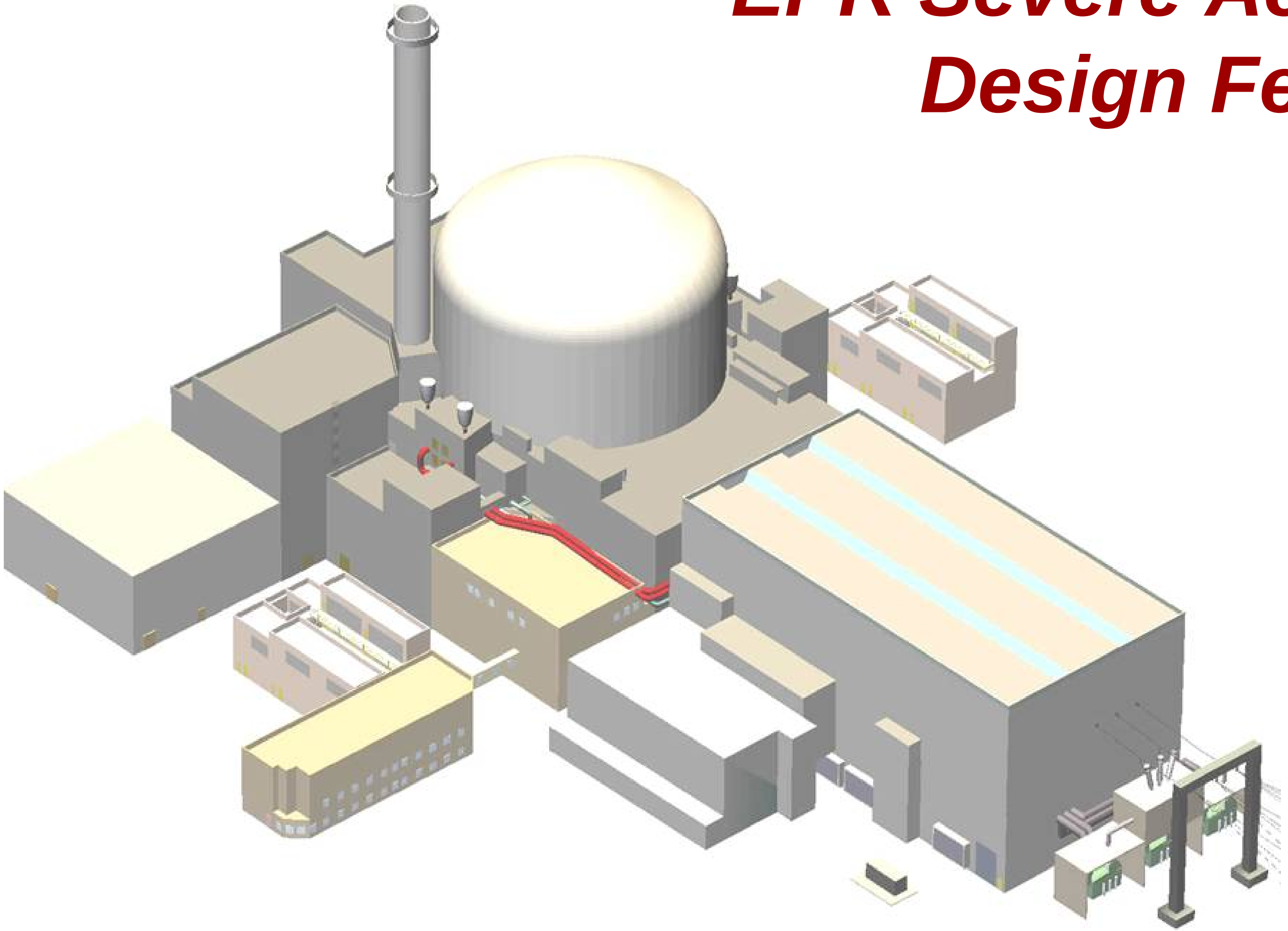
EPR Severe Accident Design Features



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NRC Severe Accident Guidance

- **Following 1979 accident at Three Mile Island-2, NRC recognized that severe accidents needed further attention.**

- **NRC developed guidance for resolving safety issues for reactor accidents more severe than DBAs:**
  - Severe accidents are events in which substantial core damage occurs
  - Severe accidents represent the major risk remaining for nuclear plant operation

- **For existing plants, NRC determined that severe accidents do not pose an undue risk to the public.**

- **For new plants, NRC determined that enhanced features should be provided to mitigate consequences of severe accidents. Per SECY-90-016 & 93-087, following issues require consideration:**
  - Hydrogen Generation and Control
  - Core Concrete Interaction
  - High Pressure Core Melt Ejection
  - Containment Performance

Severe Accident Licensing Basis in U.S.

- **Consideration of severe accidents is integral part of NRC licensing review for new plant, but it is <u>not</u> part of plant “design basis”.**

- **NRC guidance for severe accident mitigation features for new plants reflects this position:**
  - Non-safety related systems
  - Not seismically qualified
  - Equipment survivability; not environmental qualification (10 CFR 50.49)
  - Consideration of single failure not required

U.S. EPR Safety Philosophy

- **EPR safety philosophy is hierarchical:**
  - Prevent deviations from normal operation
  - Detect deviations and prevent escalation to DBA conditions
  - Control DBAs and prevent escalation to severe accidents
  - <u>Mitigate consequences of severe accidents</u>

- **EPR design features aimed at limiting radiological consequences**
  - Design objective to minimize need for countermeasures (e.g., evacuation)

Robust U.S. EPR design features for severe accidents

U.S. EPR Severe Accident Philosophy

- **U.S. EPR designed for broad spectrum of severe accident phenomena and issues:**
  - Hydrogen Generation and Control
  - Core Concrete Interaction
  - High Pressure Core Melt Ejection
  - Containment Performance

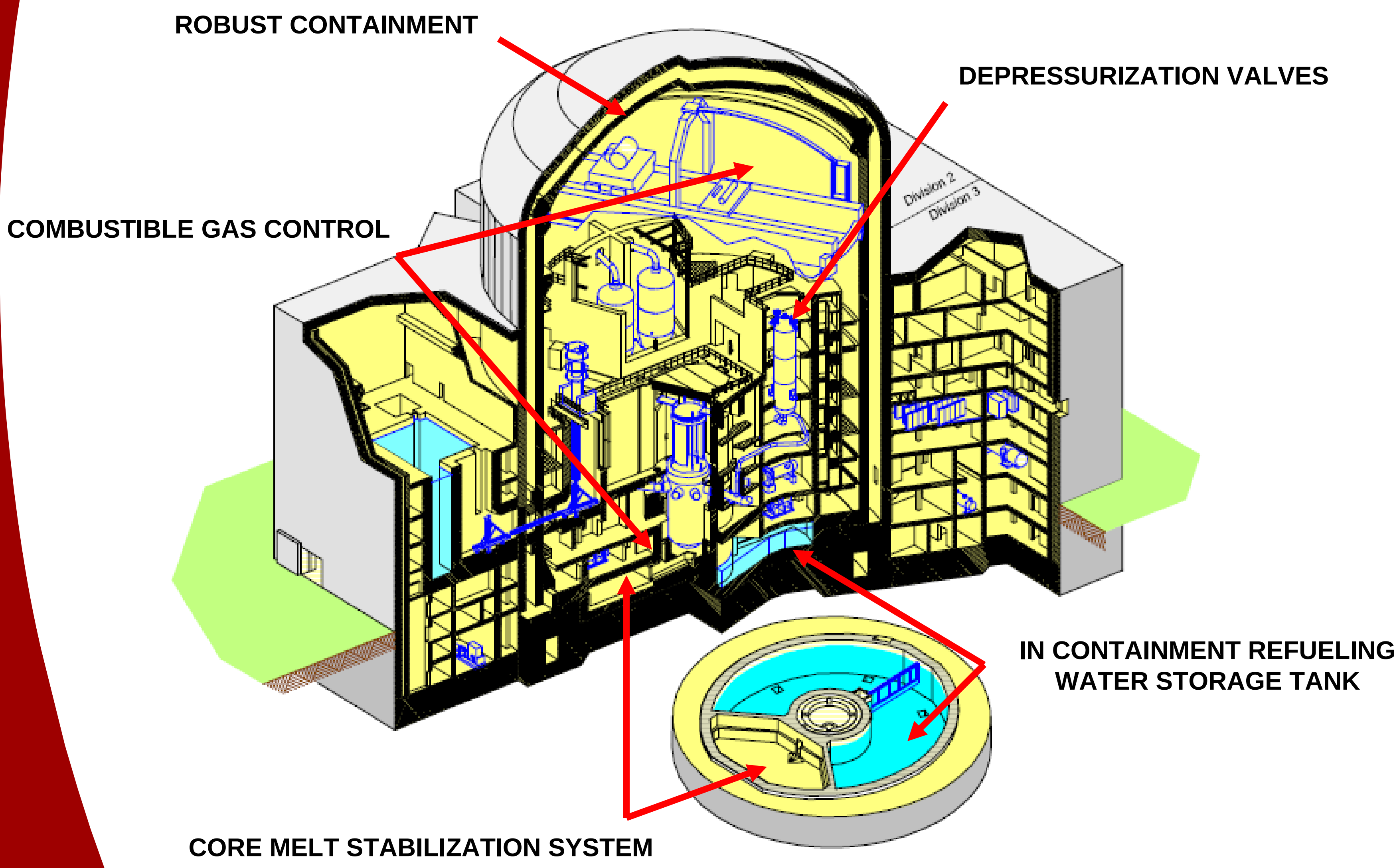
- **Robust design of severe accident mitigative features demonstrated through evaluation of bounding sequences.**

Severe accident mitigation philosophy is focused on maintaining containment integrity

R&D Basis for Severe Accident Features

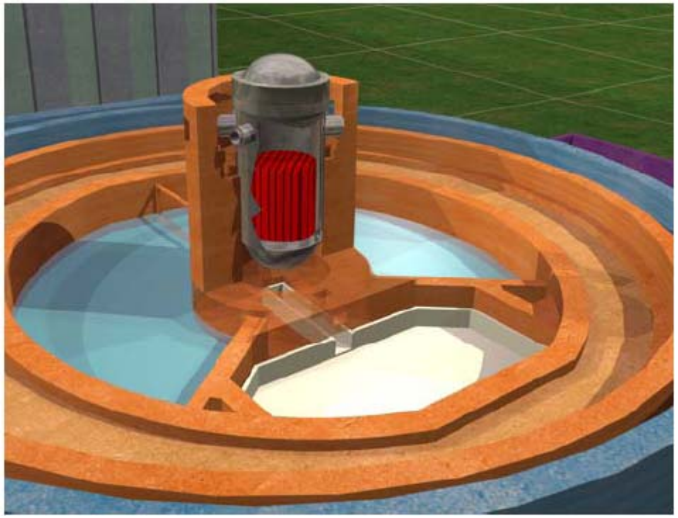
- **U.S. EPR features built upon results of testing programs, for example:**
    - ACE, MACE, OECD-MCCI programs at Argonne National Labs
    - CORESA, KALI, H2PAR, KATS programs in Europe
    - Internal testing programs in AREVA
- **R&D basis supports deterministic design conclusions <u>and</u> validation of analytical codes (e.g., MAAP).**

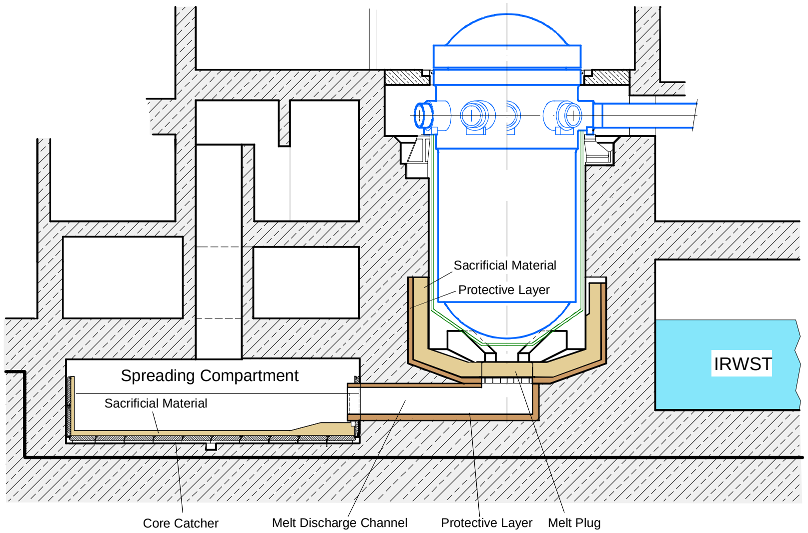
Severe Accident Design Features



Core Melt Stabilization System (CMSS)

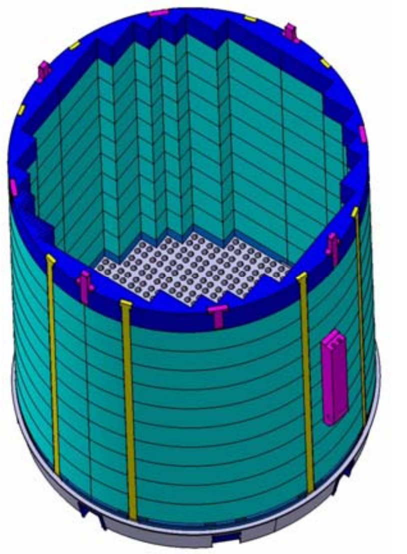
- **CMSS protects integrity of containment basemat**
- **CMSS designed to passively spread and stabilize molten core debris**
- **CMSS features accomplish staged melt progression**
  - **In-vessel melt progression**
  - **Controlled RPV failure**
  - **Melt retention and conditioning**
  - **Melt relocation and quenching**
  - **Long-term melt stabilization**

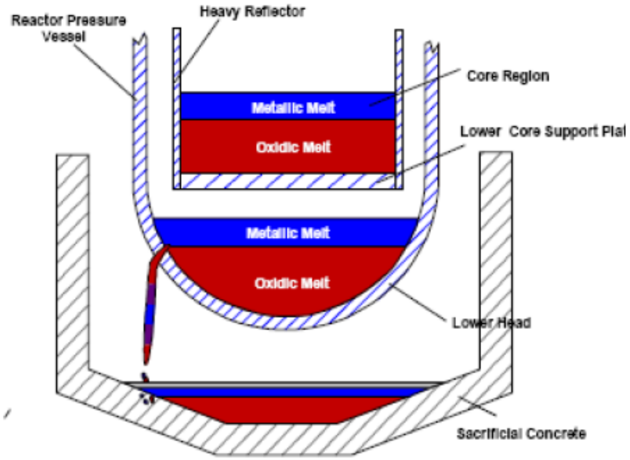




In-Vessel Melt Progression

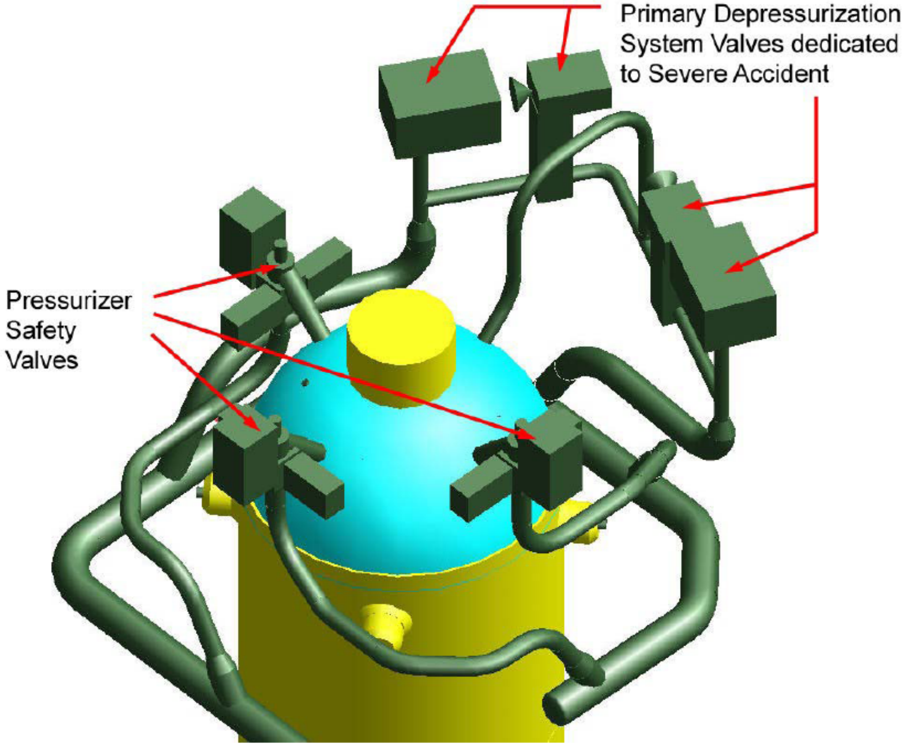
- In-vessel melt progression is dependent on RPV internals
- Corium will accumulate in lower RPV head as melt progresses
- Accumulation in lower head can lead to RPV failure and relocation into reactor cavity





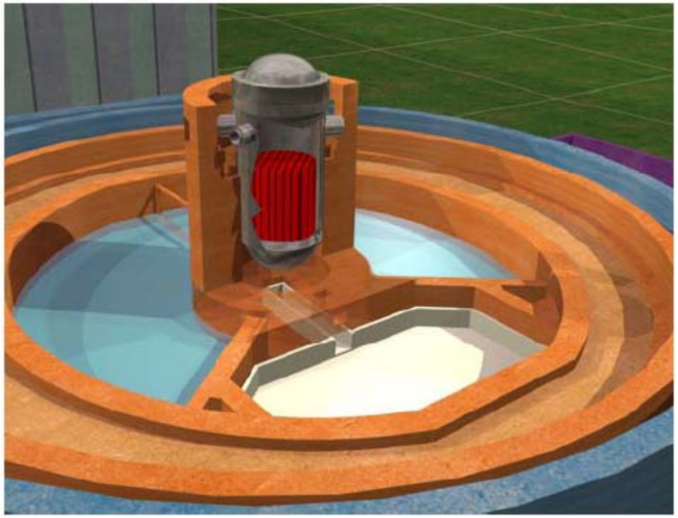
Severe Accident Depressurization Valves

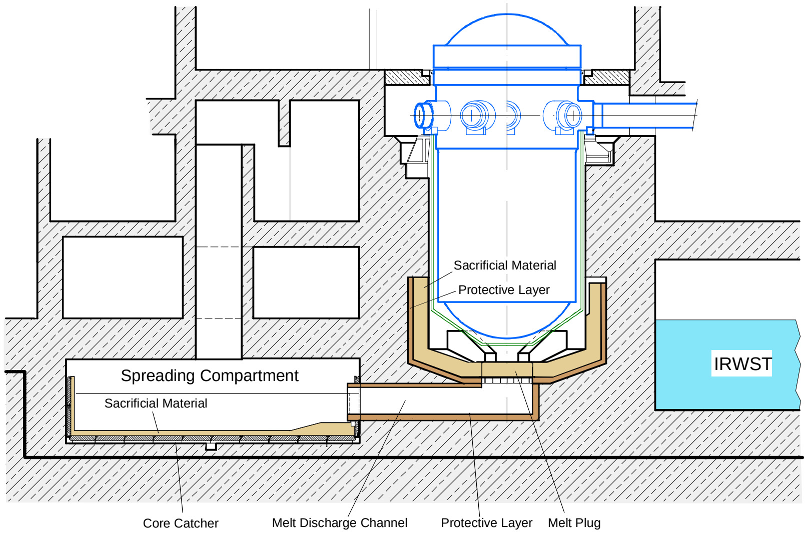
- Dedicated valves preclude high RC pressure core melt ejection concerns
- Valve sizing ensures rapid depressurization of RCS
- EPR reactor cavity design limits Direct Containment Heating in case of RPV failure at elevated pressure



Melt Retention and Conditioning

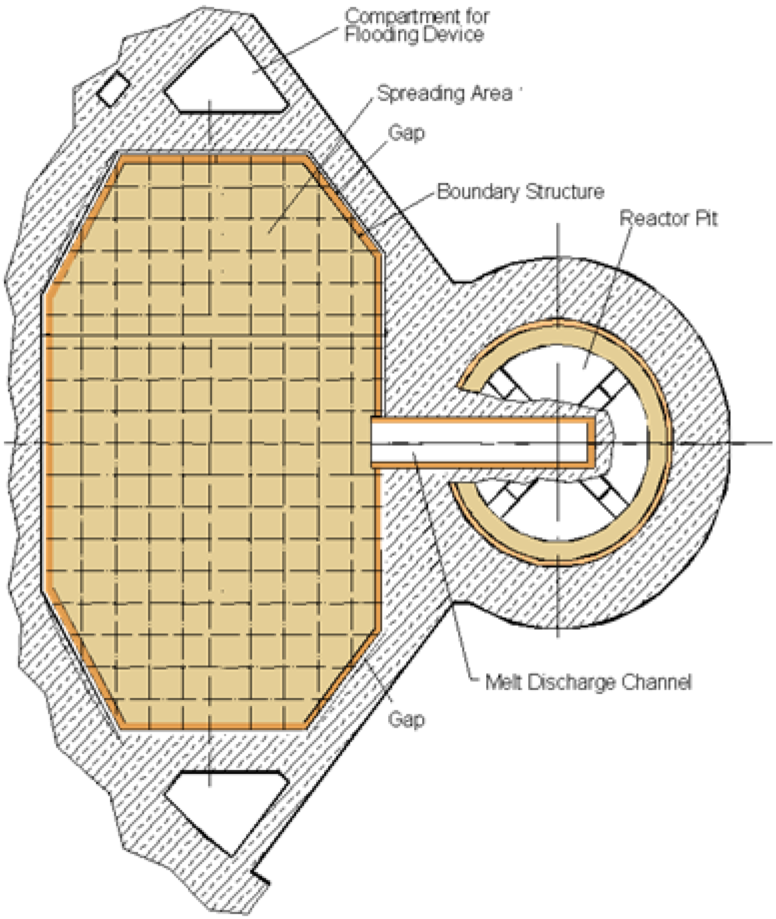
- **Reactor cavity is designed to temporarily retain molten core debris prior to spreading and stabilization processes**
- **Melt retention and conditioning is integral part of melt stabilization strategy**
  - Limits uncertainties associated with RPV release states
  - Core concrete interaction within reactor cavity lowers melting temperature of corium and promotes spreading





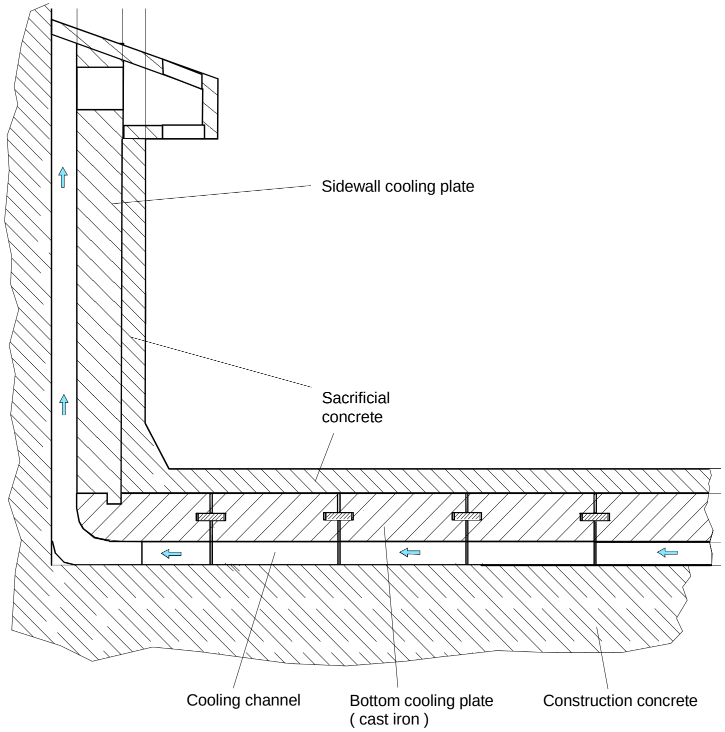
Melt Spreading and Relocation

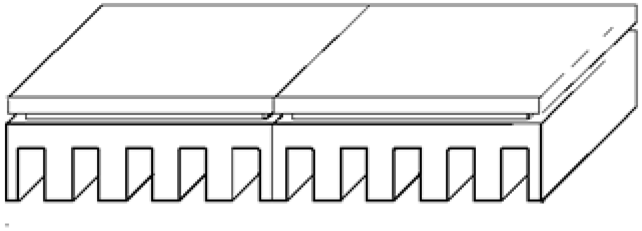
- After melt plug failure, conditioned melt will relocate into spreading area (shallow crucible)
- Large mass and low viscosity of conditioned melt promotes spreading
- Large melt spreading area promotes cooling, and aids in subsequent stabilization processes
- Spreading area is dry at time of melt relocation to preclude ex-vessel steam explosion



Spreading Area and Cooling Structure

- Core melt is retained within spreading area and is passively cooled on all sides
- Cooling structure consists of finned iron elements that are protected from corium with sacrificial concrete
- Flooding of spreading area is initiated by thermally sensitive spring-loaded valves (passive)
- Water from IRWST gravity fills cooling channels and overflows onto melt surface
- Melt quenching is performed at low flow rates to minimize fuel coolant interactions



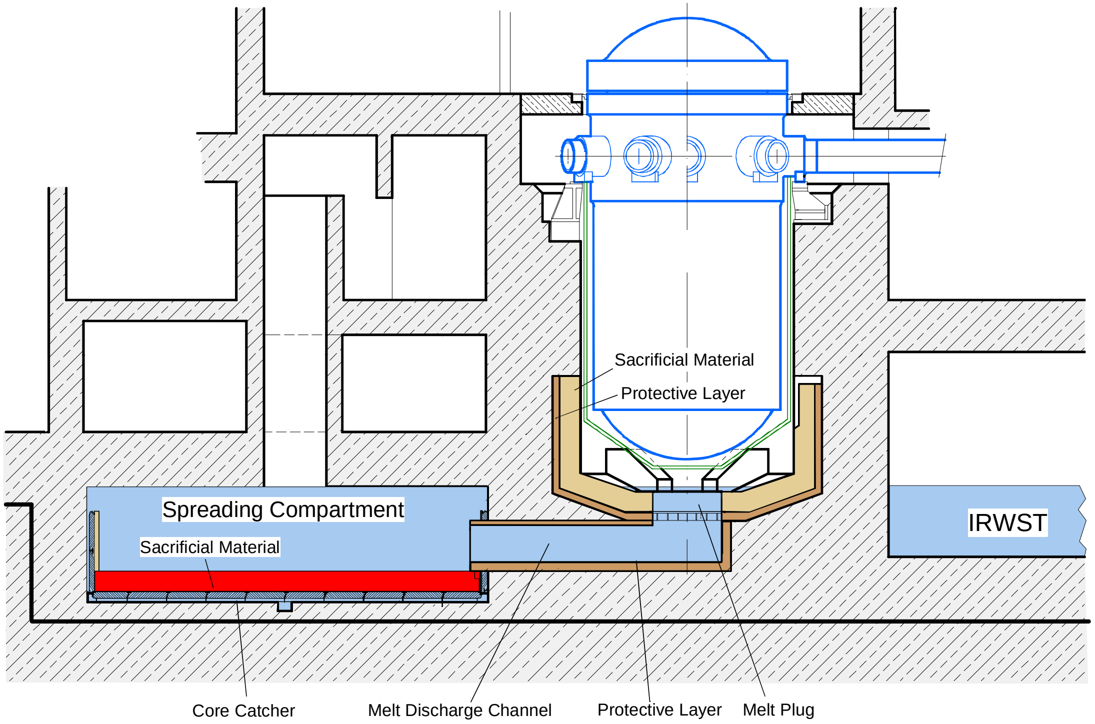


Short –Term Melt Stabilization and Cooling

<u>Passive Melt Cooling:</u>

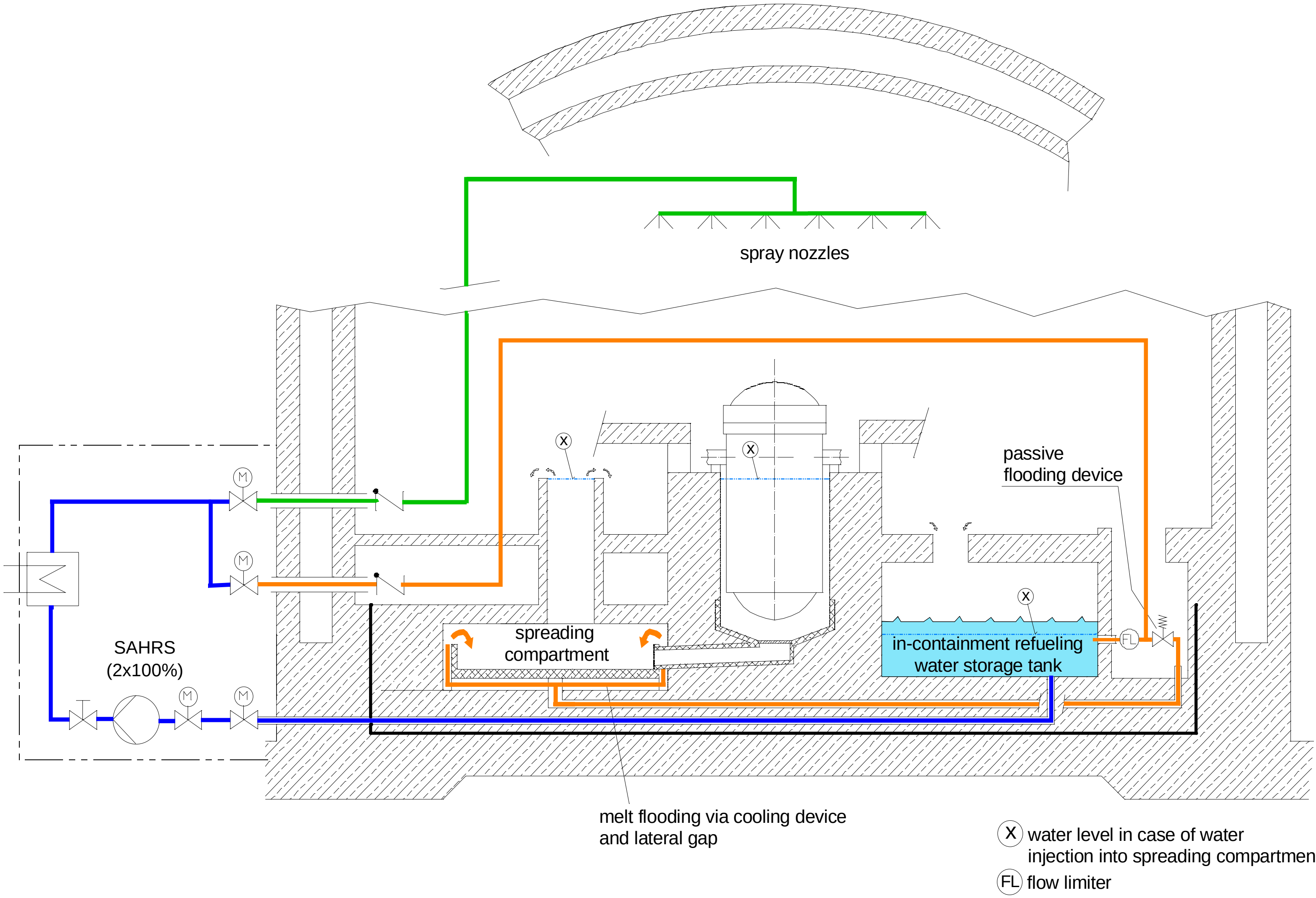
Gravity-driven flow of water from IRWST

At equilibrium water level, cooling is also established for debris remaining within transfer channel and lower reactor cavity pit



Active cooling is <u>not</u> required for ~12 hours to maintain containment pressure within design limits

Severe Accident Heat Removal System

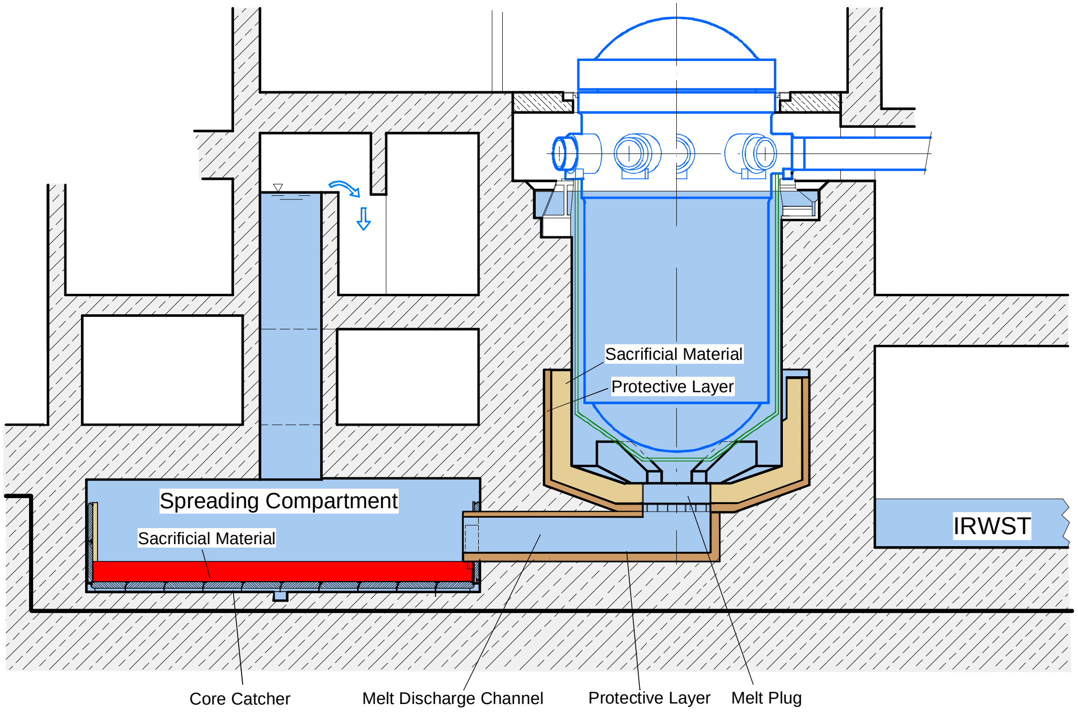


Long-Term Melt Stabilization and Cooling

Active Melt Cooling:

Water injection by SAHRS into spreading area with overflow into IRWST

Elevated water level establishes long-term cooling for all debris that potentially remains in either transfer channel, reactor cavity pit, or RPV



Formation of sub-cooled water pool above melt precludes need for further containment spraying (atmospheric pressure)

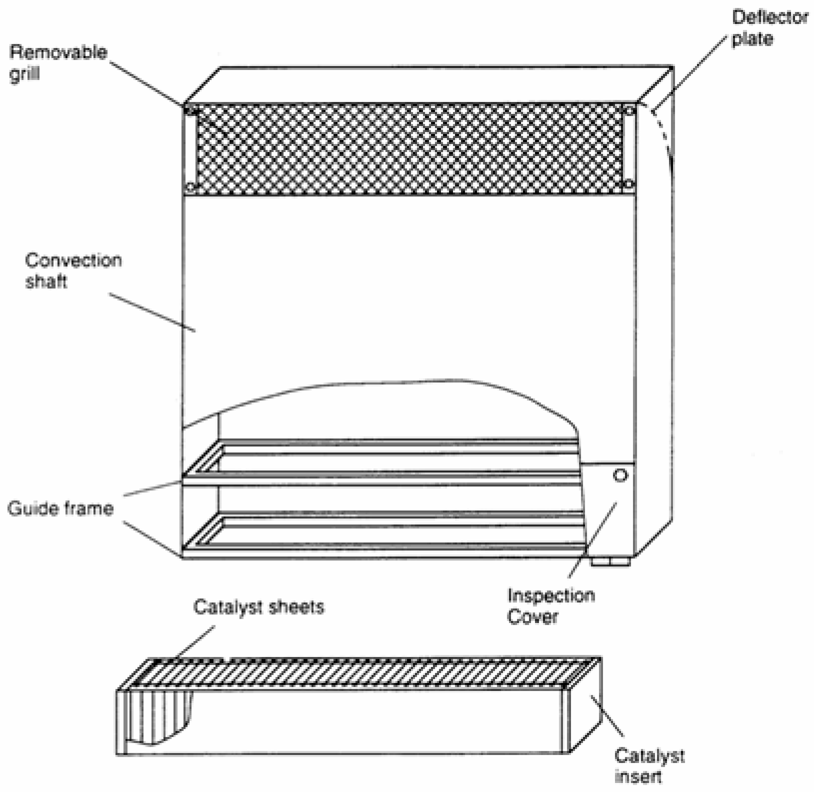
Combustible Gas Control System (CGCS)

- **CGCS manages hydrogen risk inside containment following severe accidents and design basis LOCAs, and accomplishes following functions:**
  - **Maintains local atmospheric concentration of hydrogen below 10% (by volume)**
  - **Reduces global atmospheric concentration of hydrogen below 4% (by volume) ignition limit prior to containment spray actuation**
  - **Maintains adiabatic isochoric complete combustion (AICC) pressure from global hydrogen combustion below containment design pressure for representative severe accident sequences**

- **U.S. EPR CGCS is comprised of:**
  - **Passive Autocatalytic Recombiners**
  - **Rupture panels (passively actuated on differential pressure) located at top of SG compartments**
  - **Mixing dampers (passively actuated on differential pressure) located in lower portions of containment**

Passive Autocatalytic Recombiners (PARs)

- PARs use catalyst to chemically recombine hydrogen and oxygen
- 47 PARs distributed throughout containment
- PARs used in EPR have high efficiency, even in steam saturated atmosphere
- Efficiency of PARs demonstrated through testing programs
- PARs currently used in KONVOI plants



Summary – Severe Accident Features

- **U.S. EPR includes design features to manage broad spectrum of severe accidents issues:**
  - Hydrogen Generation and Control
  - Core Concrete Interaction
  - High Pressure Core Melt Ejection
  - Containment Performance

- **Severe accident management strategy of U.S. EPR is based on domestic and international research**

- **Severe accident design features of U.S. EPR aimed at limiting radiological consequences and minimizing need for countermeasures (e.g., evacuation)**