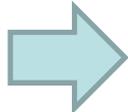# HTGR Technology Course for the Nuclear Regulatory Commission

May 24 – 27, 2010

Module 10d

Reactor Cavity Cooling System

Outline

- **RCCS functions and requirements**
- **Passive heat removal in modular HTGRs**
- **RCCS configuration**
- **RCCS design concepts**
- **RCCS performance**

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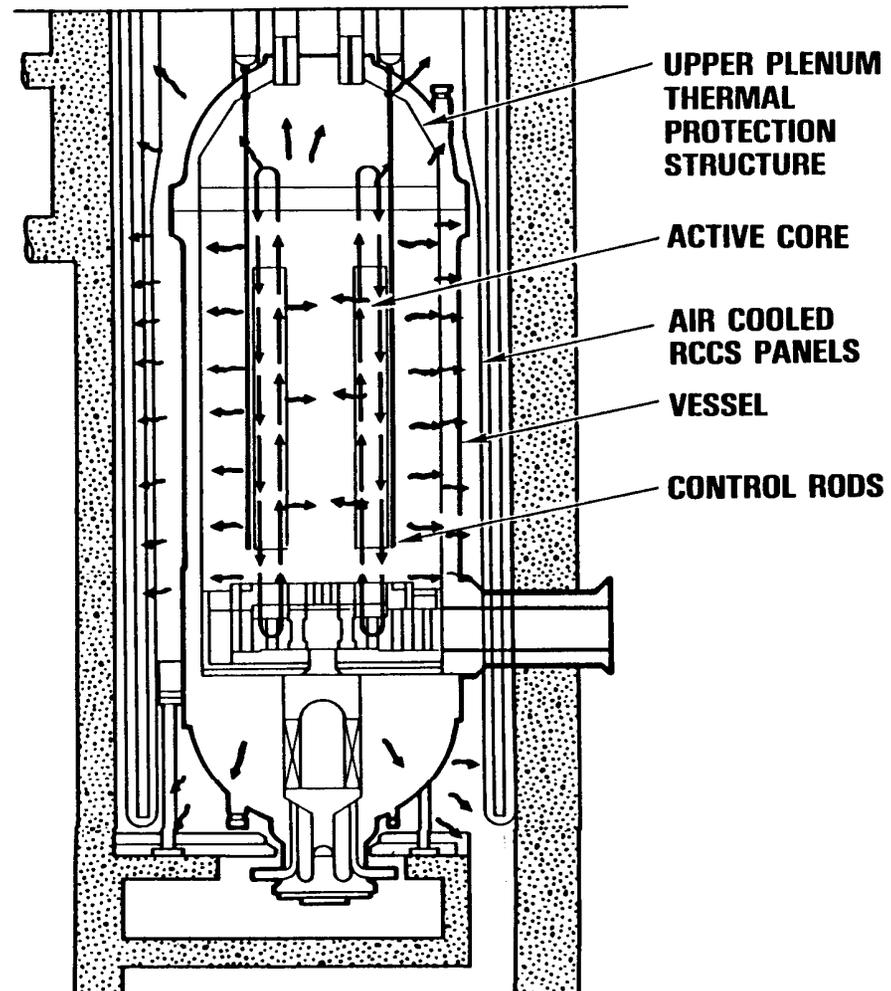
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RCCS System Functions and Requirements

- **Normal operation**
  - Control cavity concrete temperatures
  - Cool reactor vessel (for some concepts)
- **Accident conditions**
  - Control cavity concrete temperatures
  - Control reactor vessel temperatures
  - Residual heat removal
- **Passive operation during accidents (typical)**
- **Safety-related heat removal system (typical)**
- **Redundant loops (typical)**

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- **In reactor vessel**
  - Conduction
  - Radiation
  - Convection (pressurized)
  - Heat capacity
- **In reactor cavity**
  - Radiation
  - Convection
- **In RCCS**
  - Conduction
  - Convection
  - Evaporation

UPPER PLENUM THERMAL PROTECTION STRUCTURE

ACTIVE CORE

AIR COOLED RCCS PANELS

VESSEL

CONTROL RODS

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General RCCS Configuration Considerations

- **RCCS heat absorber structures shield cavity wall surrounding reactor vessel active core height**
  - Air ducts
  - Panels
  - Stand pipes
- **RCCS fluid circulates through heat absorber structures to remove heat from cavity**
- **RCCS fluid**
  - Air
  - Water
- **RCCS isolation from atmosphere**
  - Open to atmosphere
  - Separated by HX
- **Passive and/or active operation**

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Outline

- **RCCS functions and requirements**
- **Passive heat removal in modular HTGRs**
- **RCCS configuration**
- **RCCS design concepts**
  - MHTGR
  - NP-MHTGR
  - PBMR-DPP
  - AREVA
- **RCCS performance**

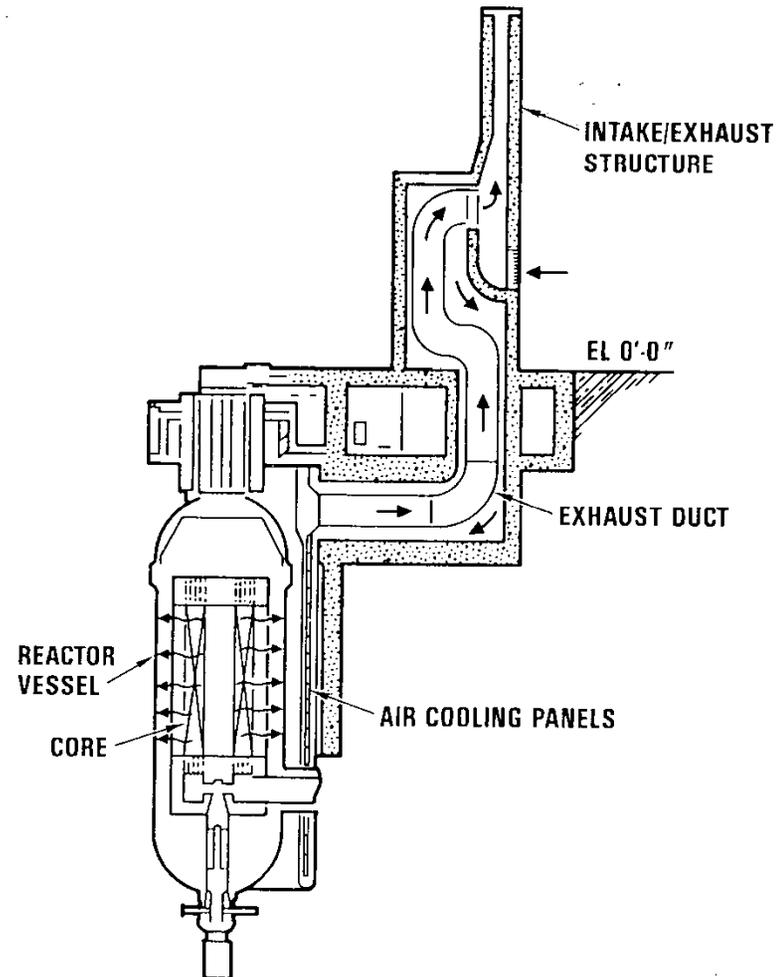Idaho National Laboratory

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RCCS Concepts

- **A large variety of possible RCCS concepts**

- **Current vendor approaches provide examples**

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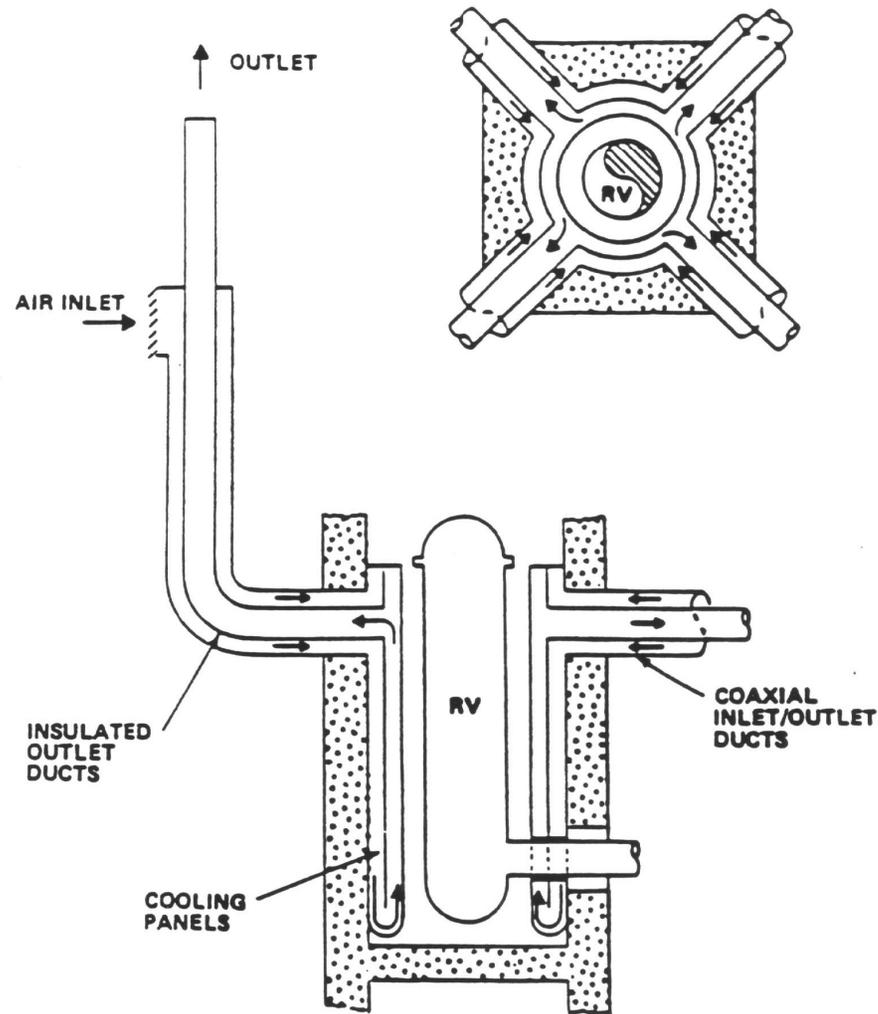
MHTGR RCCS Concept

- **Air-cooled**
- **Natural circulation**
- **Multiple flow paths**
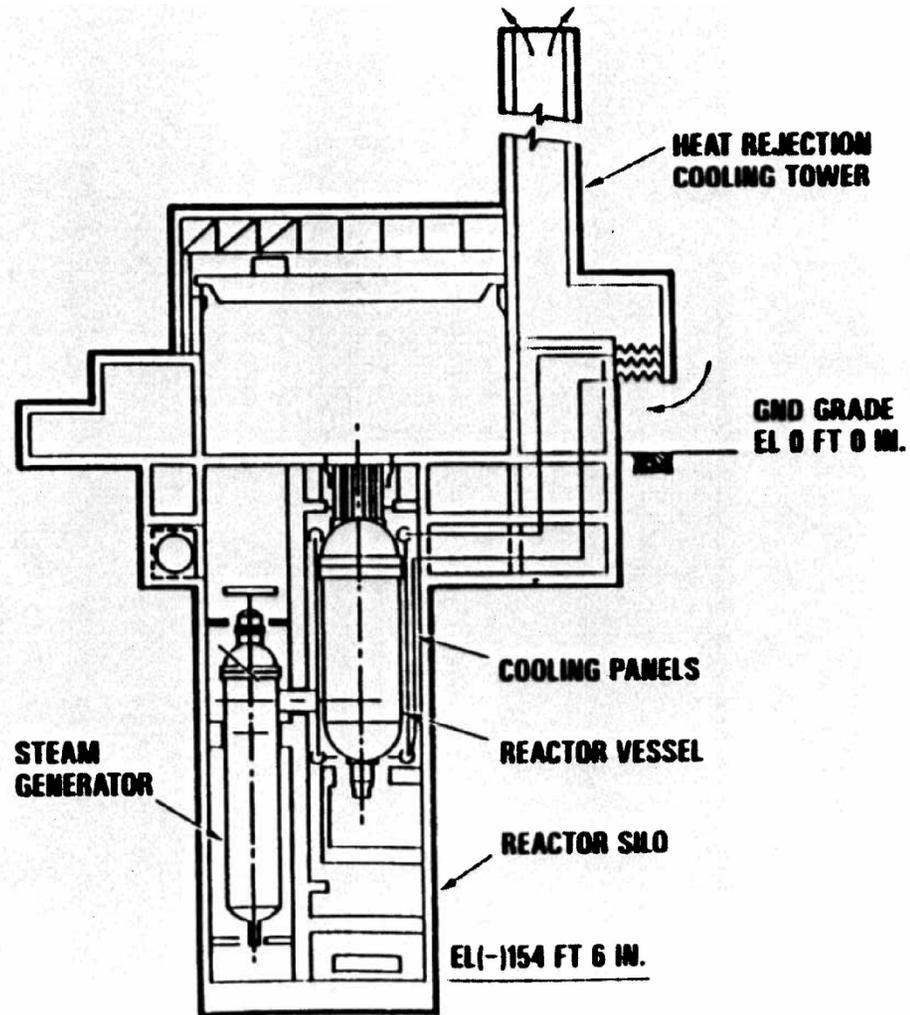- **Intake/exhaust structure to mitigate external effects**

- **Staggered riser channels create "black" surface**

- **Riser channels form part of cavity boundary**

- **Leaks provide escape path**

- **No loss of coolant**

- **Activation of air impurities considered during design**

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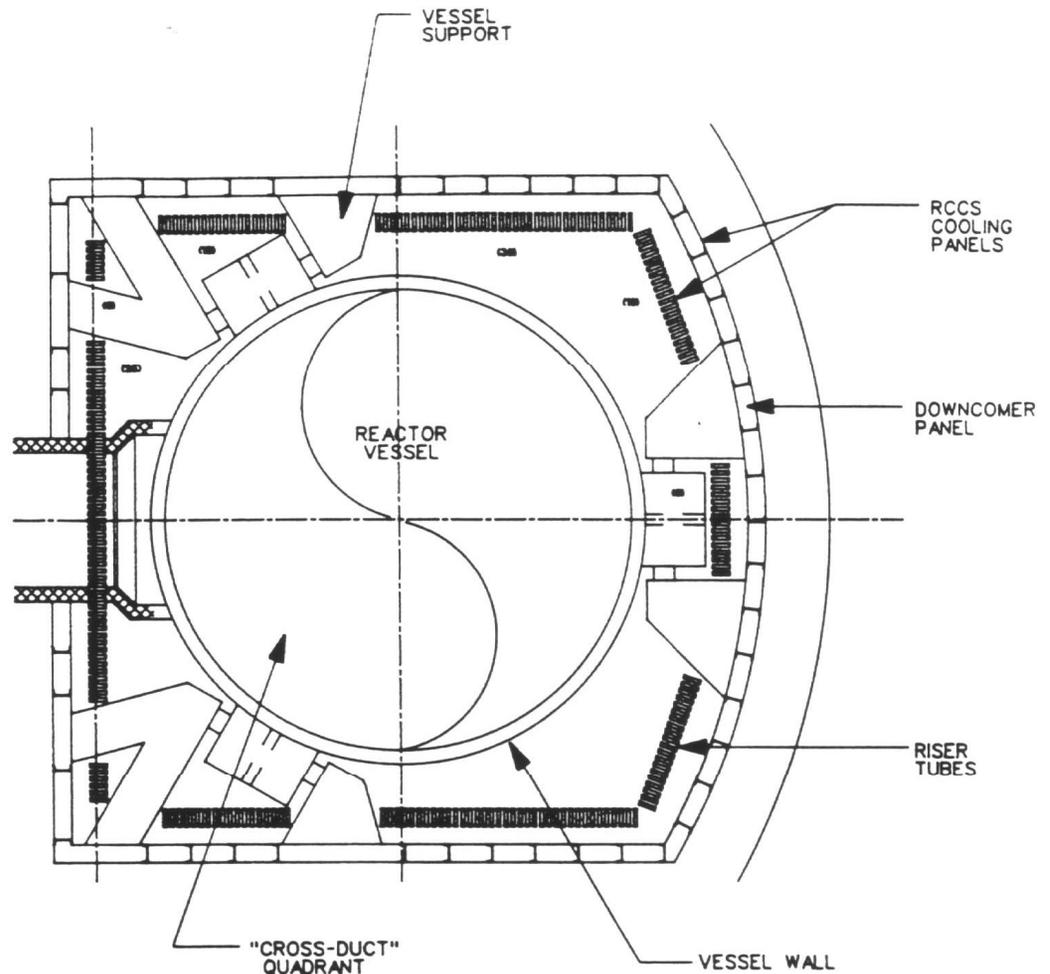
- **Water loop in cavity**

- **Heat pipes transfer heat to air in chimney**

- **Redundant loops**

- **All natural circulation**

- **Head requirements for water and air loops leads to tall structure**

HEAT REJECTION COOLING TOWER

GND GRADE EL 0 FT 0 IN.

COOLING PANELS

STEAM GENERATOR

REACTOR VESSEL
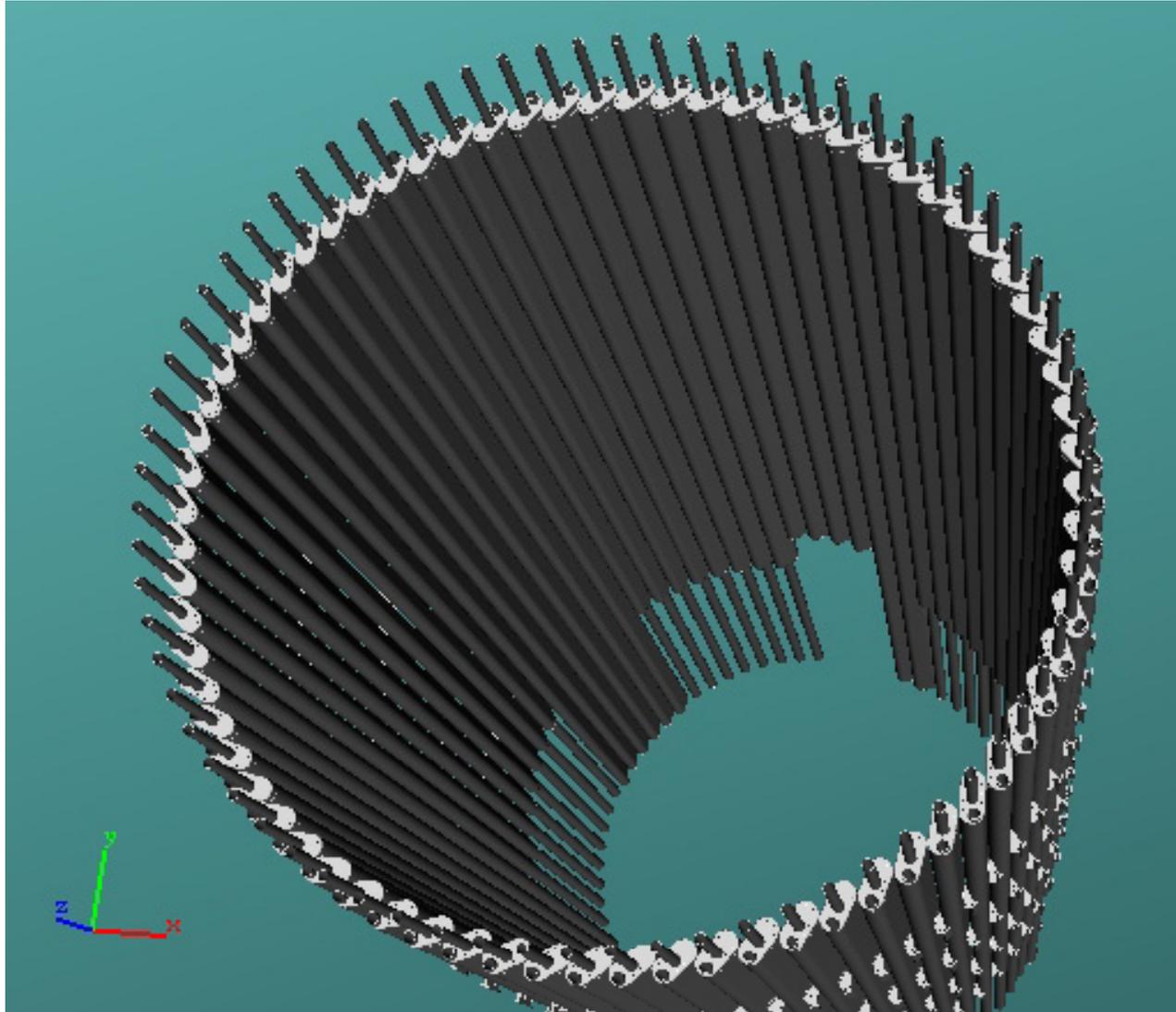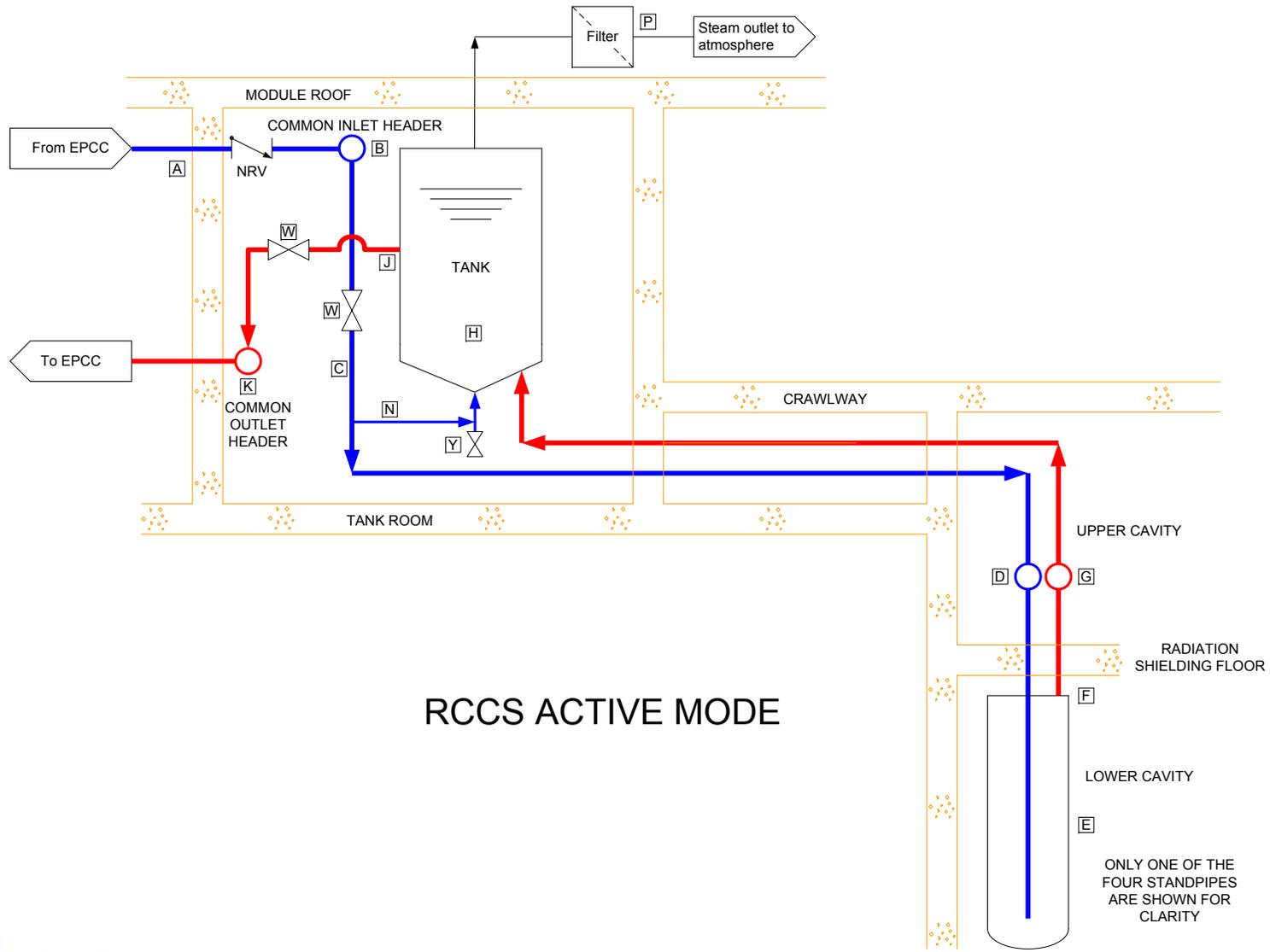
REACTOR SILO

EL(−)154 FT 6 IN.

PBMR-DPP RCCS Concept

- **Water-cooled**
- **Standpipes surround vessel**
- **18 independent circuits**
  - 1 tank
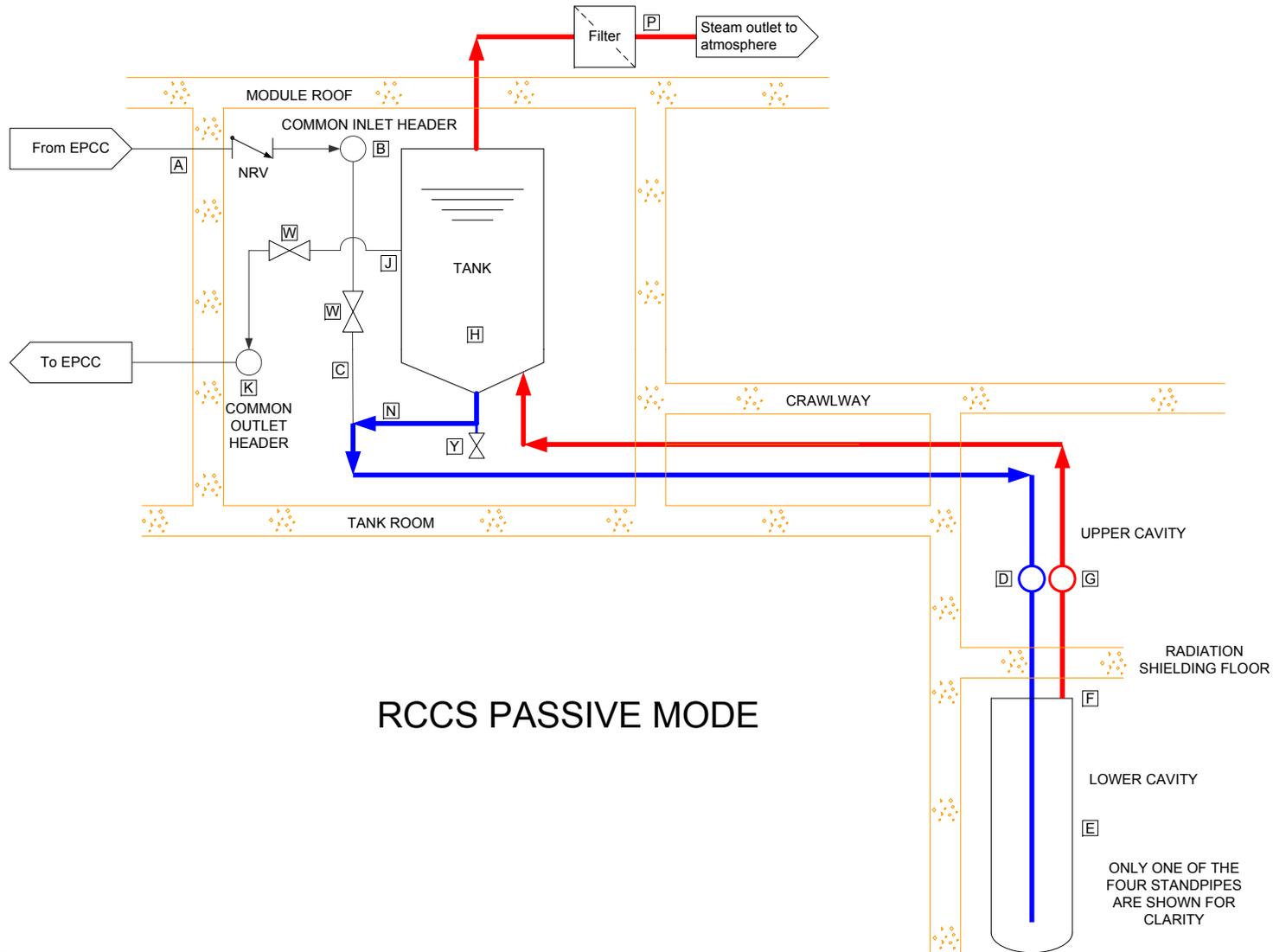 - 4 standpipes
- **Active and passive modes**

Boil-off tanks

Stand Pipes

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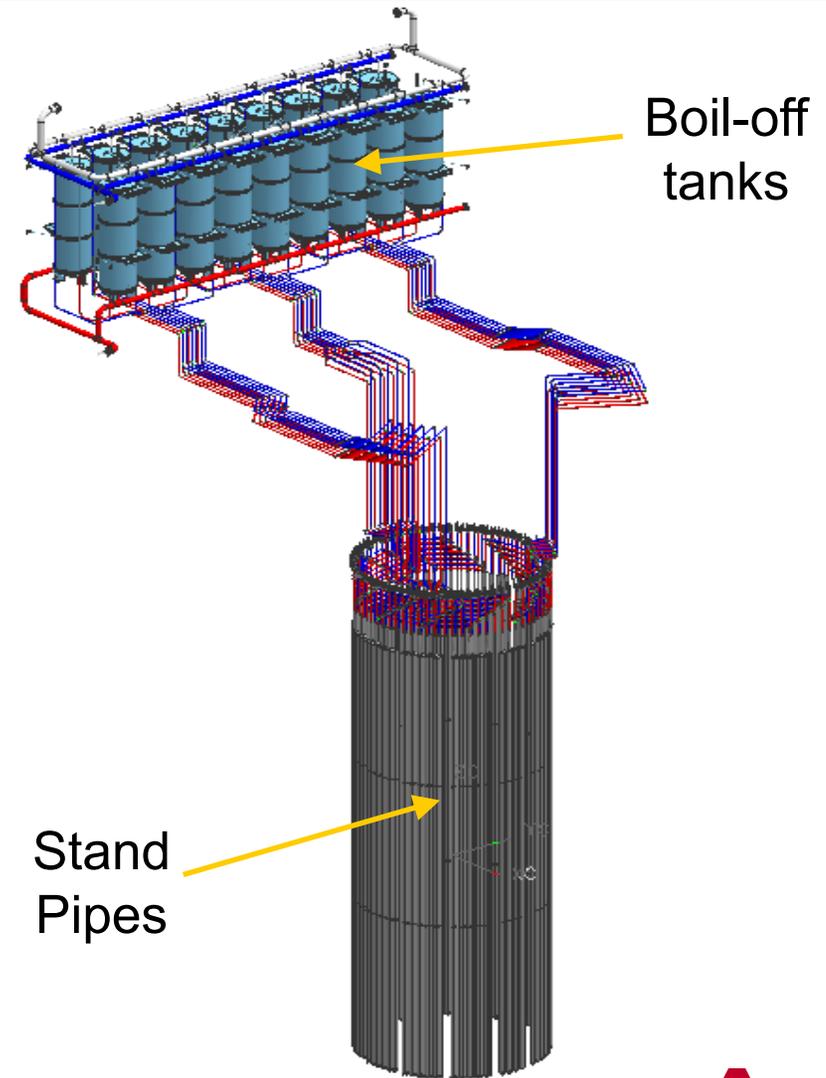
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PBMR-DPP RCCS Active Mode

RCCS ACTIVE MODE

PBMR-DPP RCCS Passive Mode

RCCS PASSIVE MODE

AREVA RCCS Concept

Water Storage and Heat Exchanger

Outlet Headers

Natural Convection Flow

Reactor Vessel

Panel wall Cavity Cooler

Inlet Headers

Forced flow
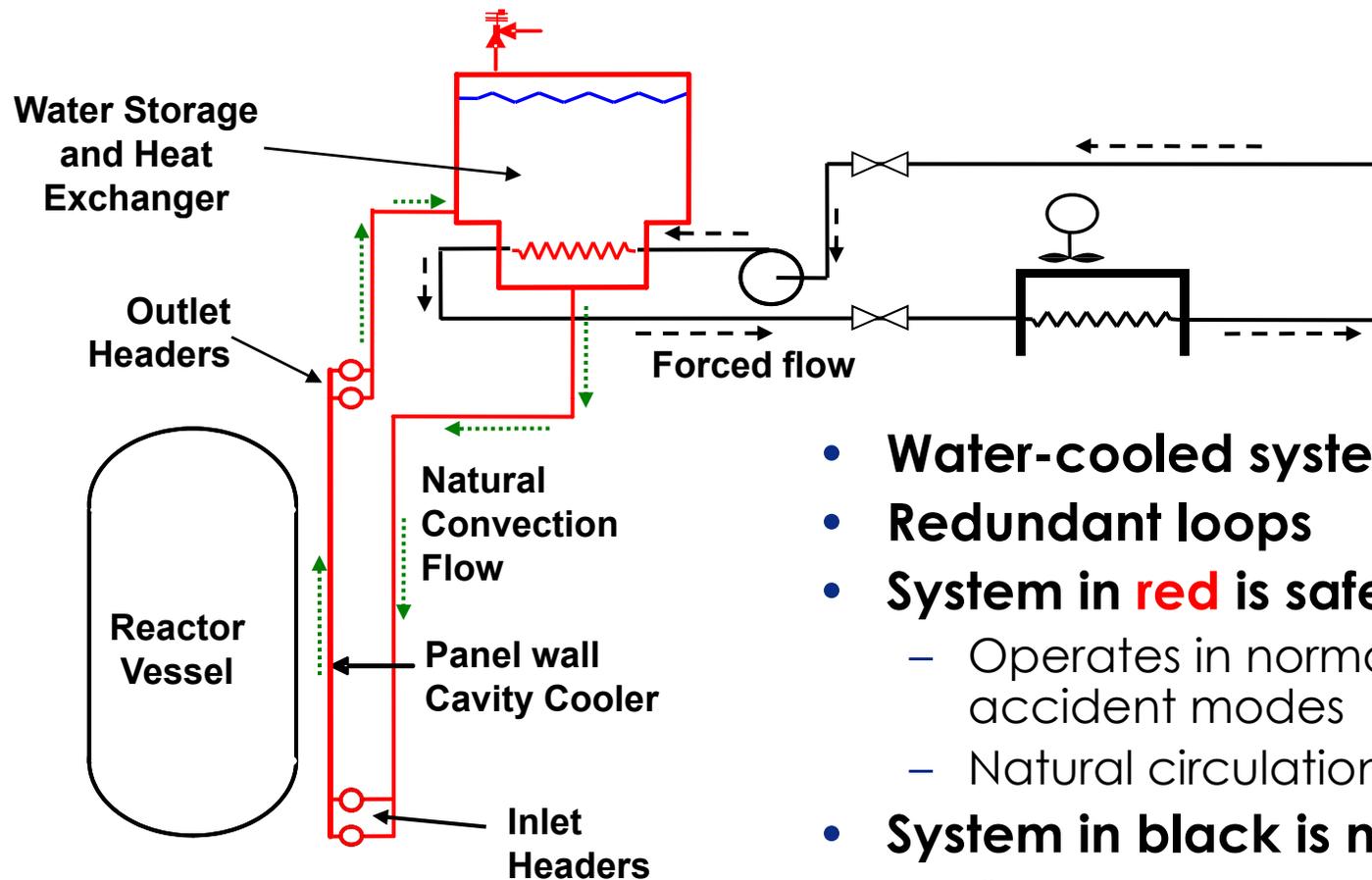
- **Water-cooled system**
- **Redundant loops**
- **System in red is safety-related**
  - Operates in normal and accident modes
  - Natural circulation driven
- **System in black is non-safety**
  - Operates during normal operation
  - Forced circulation

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AREVA RCCS Panel Wall Concept

- **Cavity lined with panels of welded "finned" tubes**
- **Comparable to panels for HTR-Modul and NP-MHTGR**
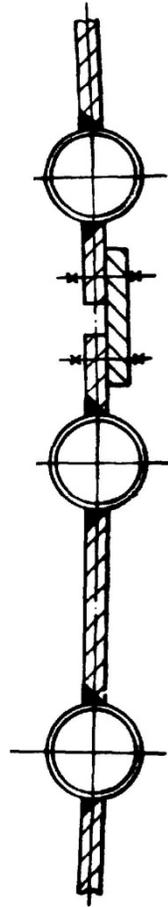
Panel tube cross section
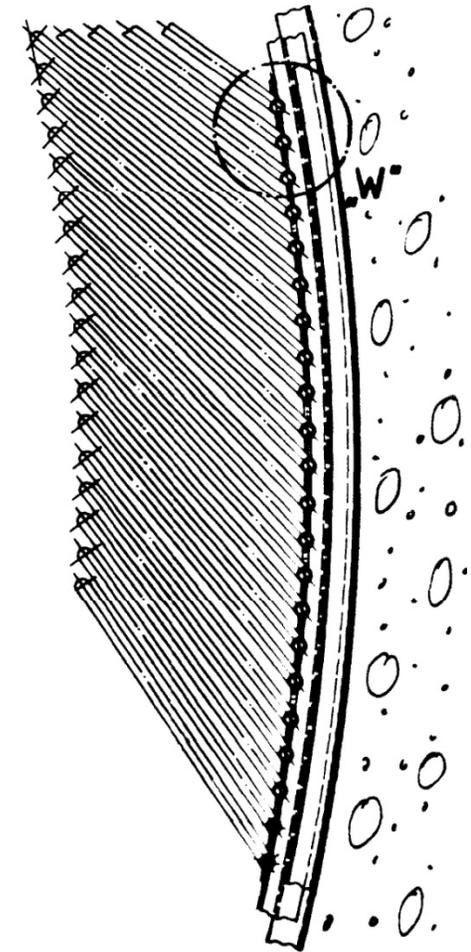
Wall panel section

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Overall RCCS Performance Factors

- **Performance for each function**
  - Vessel heat removal
  - Cavity "cooling"
  - Concrete surface protection
- **Heat removal mechanisms**
  - Thermal radiation (~80%)
  - Convection (~20%)
- **Overall reactor heat removal**
  - Depends on reactor size and operating temperature
  - Typically 1-2 MWt during normal operation
  - Typically 1-3 MWt at accident peak
- **Local effects**
  - Local reactor effects
  - RCCS discontinuities

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RCCS Operating Modes

- **Normal operation**
- **Accident conditions**
- **Single loop operation**
- **Active cooling**
- **Passive cooling**
- **Dryout (and refill)**
  - Typically BDBE
- **Failed RCCS**
  - Typically BDBE

Performance Sensitivity

- **RCCS heat removal rate is similar during normal operation and accidents**
  - On-line monitoring of RCCS performance confirms system status

- **Accident fuel temperatures are insensitive to RCCS performance**

- **Vessel temperatures are more sensitive to RCCS performance but still not a strong function**

- **Reactor cavity concrete temperatures are a strong function of RCCS performance**

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Other Considerations

- **Failure modes**
  - Leaks
  - Blockage
  - Dryout
- **Environmental effects**
  - Emissivity
  - Cavity atmosphere
- **Performance monitoring**
  - Overall heat removal
  - Local temperatures

Summary

- RCCS maintains cavity wall and reactor vessel temperatures
- RCCS is a simple system
- A wide variety of potential RCCS configurations is possible
- Fuel temperatures are insensitive to RCCS performance
- Concrete temperatures are a strong function of RCCS performance
- Normal operation provides confirmation of system status