Containment Thermal Hydraulics

Matt Krause
Containment Response Section
Fuel & Fuel Channel Safety Branch
Presentation to NRC, 2004 July 20-22

AECL TECHNOLOGIES INC.

Outline

- ACR Containment Design Features
- Overview of Containment Thermal Hydraulics R&D at AECL
  - Experimental programs
  - Code Development and Validation
  - Interfaces to other Codes and Disciplines
- GOTHIC Containment Analysis Code
  - Code capabilities
  - Validation
- GOTHIC model for ACR Containment

ACR Containment Dimensions

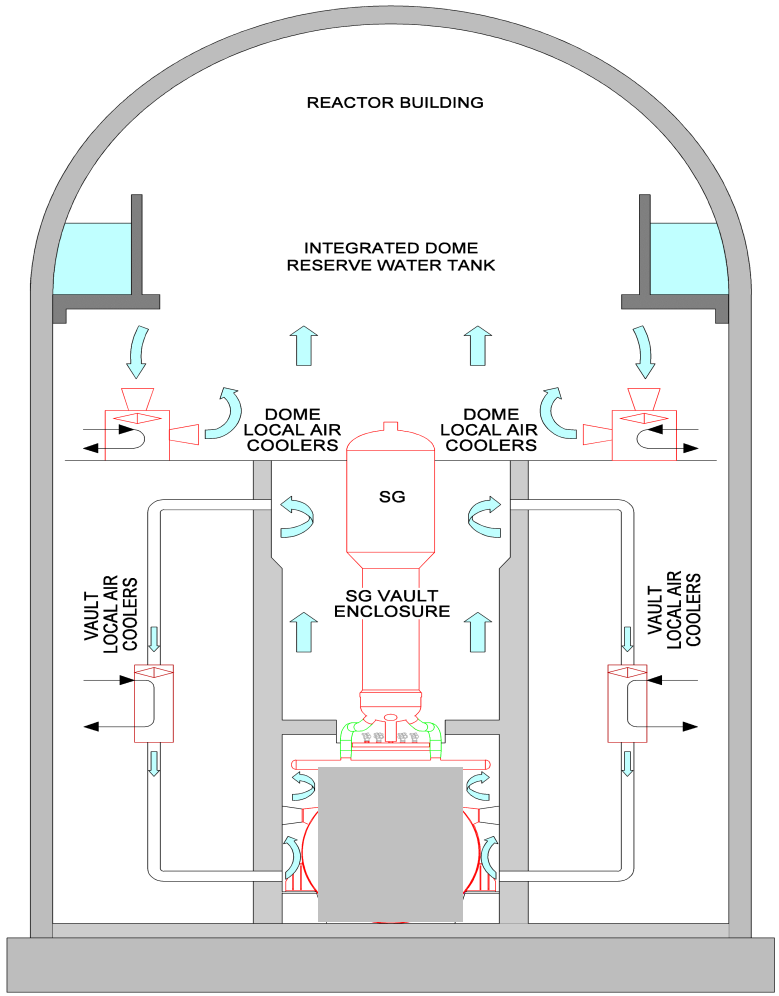
Comparison of CANDU 6 and ACR-700 Containment Dimensions

	CANDU6	ACR-700
Inside Diameter	42 m	39.5 m
Cylinder Height	42 m	38.25 m
Total Height	48 m	58 m
Concrete Walls	1.07 m	1.2 m
Steel Liner	n/a	6.4 mm
Free (air) Volume (estimated)	48,477 m^3	47,628 m^3

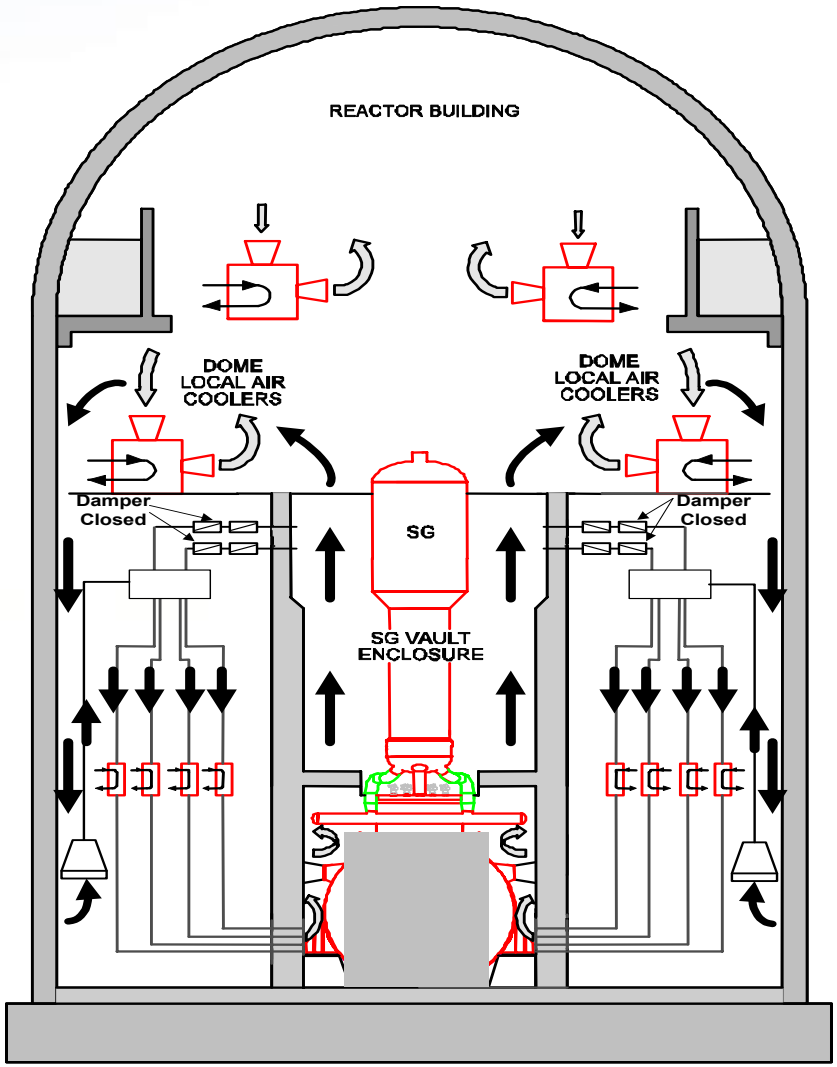
ACR Containment

- Same volume as CANDU 6 containment
- Very similar phenomenology, with only slightly different emphasis in containment cooling and hydrogen mitigation systems
- Extensive past experience at AECL with CANDU 6 containment design and R&D applies to ACR as well

ACR Containment Cooling System



Hydrogen Control System – LACs Accident Mode Operation



Containment Thermal Hydraulics R&D

- Large-Scale Containment Facility (LSCF)
  - Largest operational containment thermal hydraulics facility in the world (~1700 m^3), completed in early 2004
  - Used for CANDU containment T/H and Aerosol studies, also supports ACR
  - Its main purpose is to study hydrogen behavior (mixing, stratification, using helium as simulant), Passive Containment Cooling, and Aerosol removal mechanisms from a flashing jet at a representative scale
  - Data used for Code Validation (GOTHIC-IST and SMART-IST)
- Large-Scale Gas Mixing Facility (LSGMF)
  - Decommissioned facility (WL), used to provide existing data base for hydrogen mixing phenomena
- Large-Scale Vented Combustion Test Facility (LSVC)
  - Located at WL, addresses vented combustion issues and PAR qualification

Experimental Programs in LSCF

1. Gas Mixing in Containment
   - determine the transient distribution of helium and steam for given injection location and rate, facility geometry, and initial temperature
   - use either or both rooms of the facility
2. Passive Containment Performance
   - determine the transient distribution of helium and steam over a period of up to three days for various tube bank configuration and temperature to assess the effectiveness of the Passive Emergency Water System (PEWS)
3. Wet Aerosol Behavior in Containment (after 2004)
   - study the behavior of water aerosols during agglomeration, gravitational settling, impingement and thermophoresis within the facility
   - measure aerosol size and velocity distributions within containment, produced by a high-pressure, high-temperature flashing jet
   - use large room only

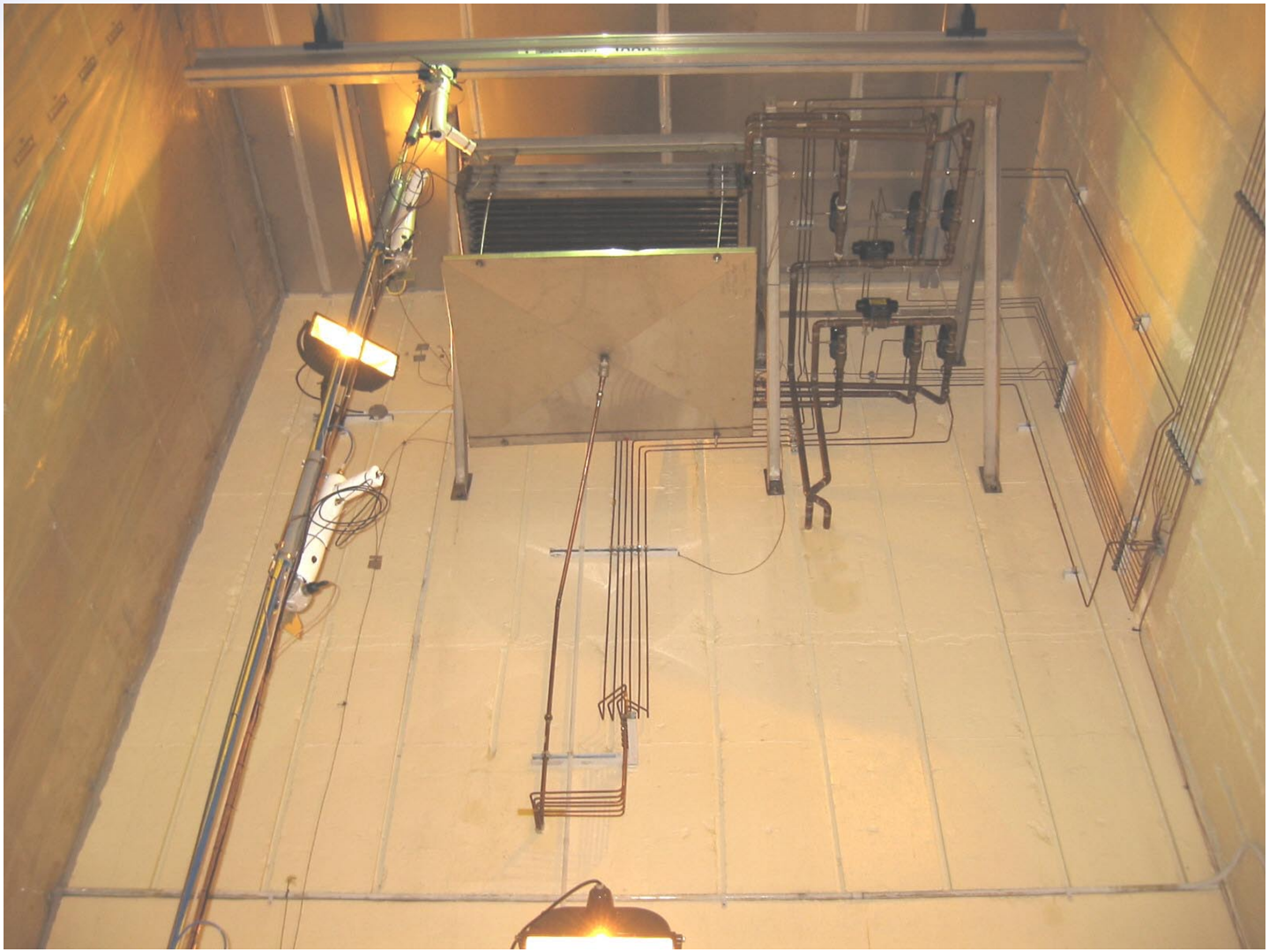
Major Systems in the LSCF

- Low-pressure steam supply system, including continuous feed 500kW steam boiler, used for gas mixing and passive containment tests
- Helium supply system (max. inventory 32 bottles), used for gas mixing and passive containment tests
- PEWS closed-loop cooling system (non-pressurized), used for gas mixing and passive containment tests
- High-pressure high-temperature water supply system, including 18-MPa water boiler and electrical trace heating, used for aerosol tests
- The facility heating, ventilation and exhaust system, used for pre-conditioning

LSCF

High-Temperature Room in LSCF

Containment Tube Bank in LSCF



Containment Codes for ACR

- GOTHIC Thermal-Hydraulics Analysis Code
- DDTIndex Flame Acceleration and DDT Code
  - Post-processing software to GOTHIC, developed at AECL
  - Calculates “likelihood” Index for DDT or Flame Acceleration
- SMART Aerosol Transport and Release Code
  - Includes IMOD2 Iodine Model for Containment

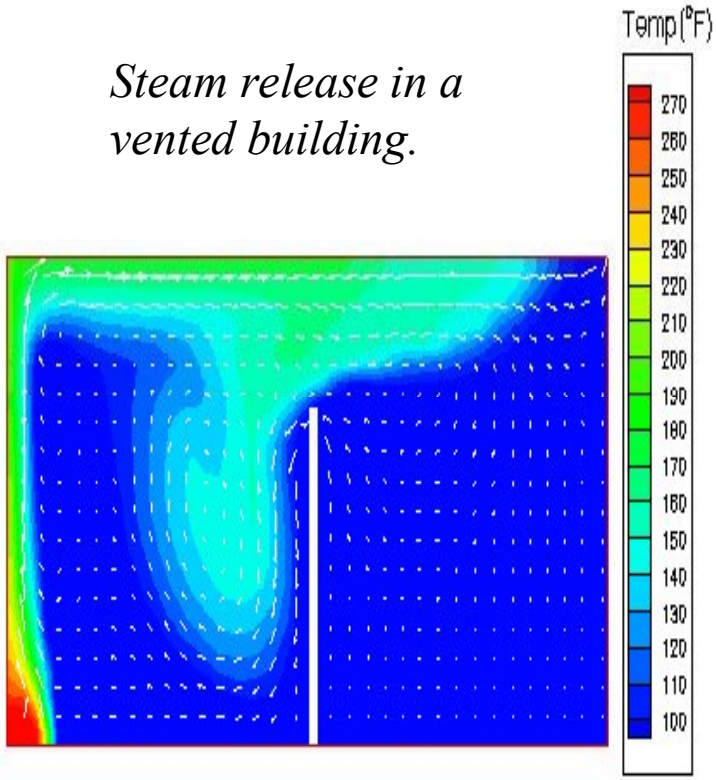
GOTHIC
Containment Thermal-Hydraulics Analysis Program

- Developed by NAI (Numerical Applications Inc), used under licenses held by AECL
  - Owned by EPRI
  - Quality Assured to US Nuclear Standards
- general purpose T/H code for design, licensing, safety and operating analysis of containment and other confinement buildings
- used by over 30 US and international utilities and labs
- CANDU industry standard tool ("IST") for containment analysis
- No code changes required for ACR application

GOTHIC

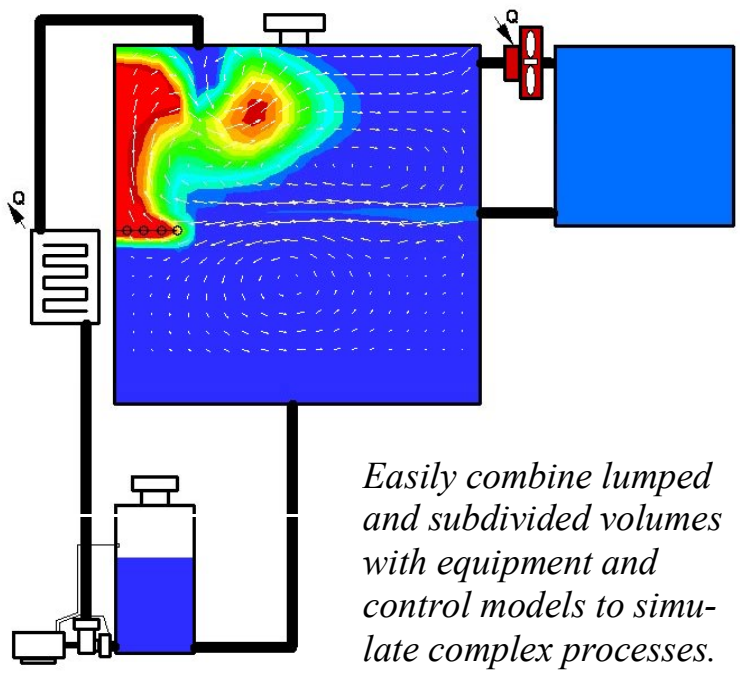
- graphical, menu-driven pre- and post-processor
- Multiphase Flow and Heat Trans
  - Steam/Gas Mixtures
  - Drops/Mist
  - Liquid
- Condensation/Evaporation
- Boiling/Flashing
- Gas Mixing, k-e Turbulence
- H_2 Combustion

Steam release in a vented building.



GOTHIC

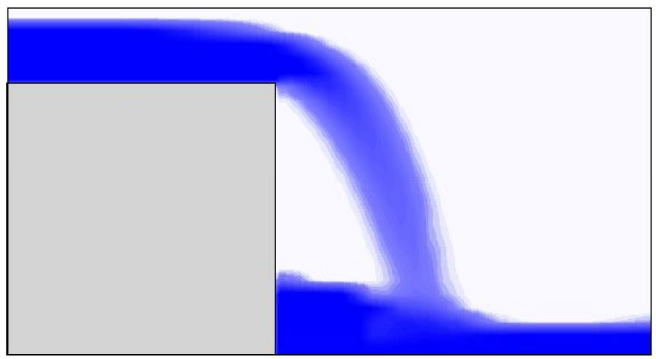
- Multi-zone Grids
- Combined Lumped and Multidimensional CFD Analysis
- Equipment Models
  - Igniters
  - Recombiners
  - Heat Exchangers
  - Pumps/Fans
  - Valves/Doors



Easily combine lumped and subdivided volumes with equipment and control models to simulate complex processes.

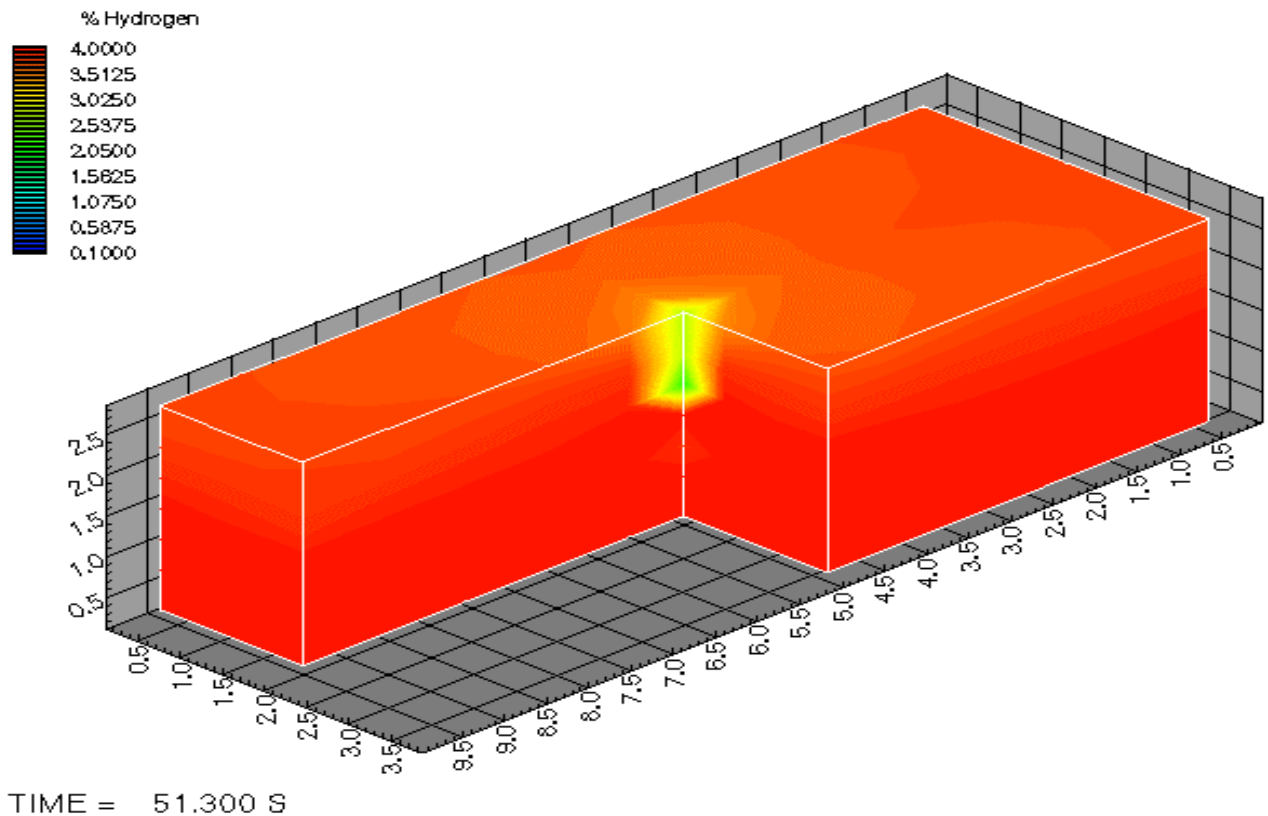
GOTHIC

- Applications, including NRC licensing applications
  - Compartment Pressurization and Heat up
  - Fluid Loads on Structures - Static, Dynamic
  - H_2 Deflagration, not including DDT
  - Jet Induced Mixing
  - Buoyant Flows
  - Spray Heat and Mass Transfer
  - Gas Dispersion
  - Others



GOTHIC simulation of water flowing over a step.

GOTHIC Simulation of AECL Recombiner – 3D Hydrogen Distribution and Stratification

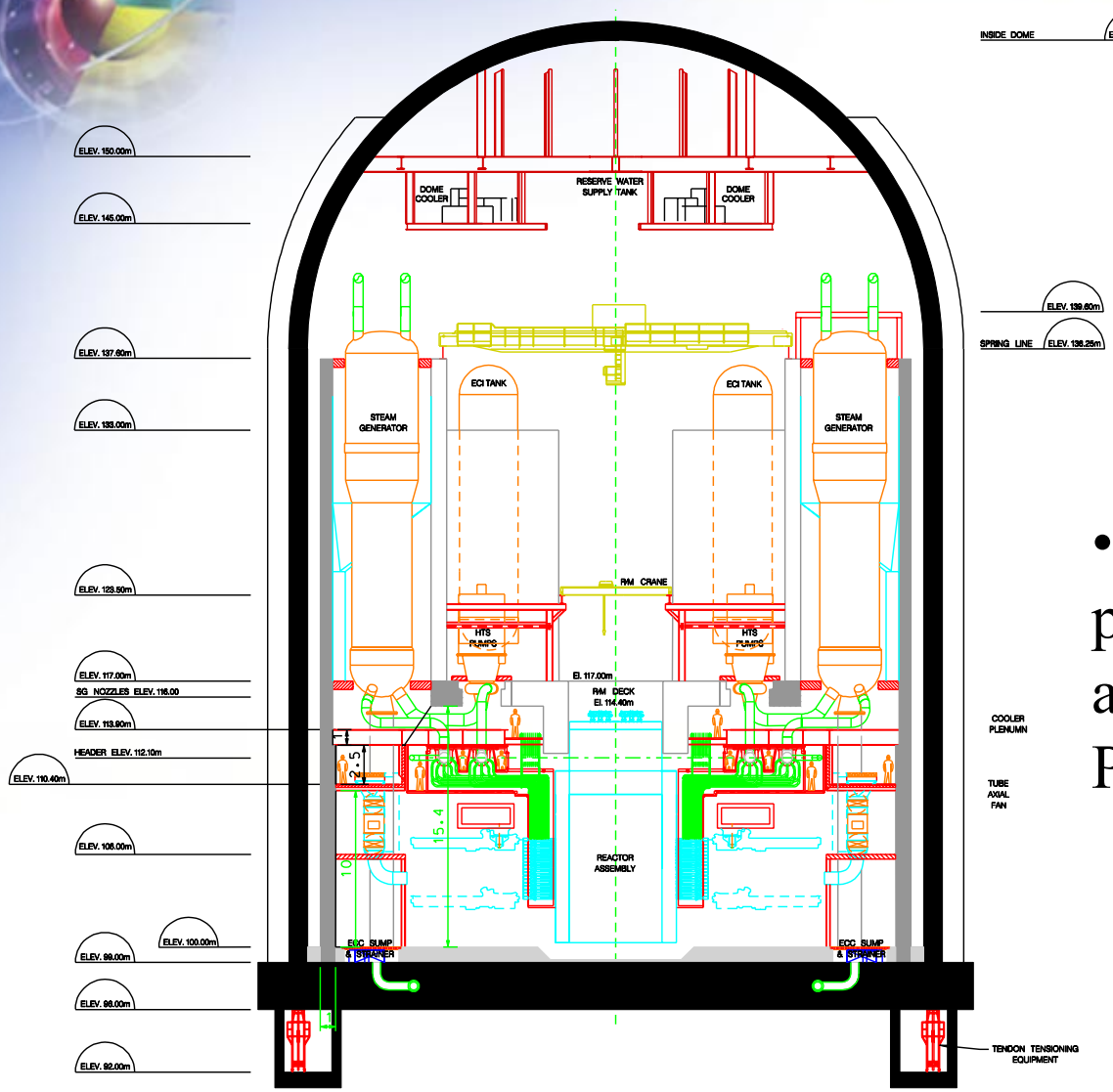


Validation

- **Existing Database**
  - **NAI qualification for T/H phenomena mostly in LP models and more recently also for 3D applications**
  - **Extensive validation program at AECL and Canadian Utilities completed in 2002 and submitted to CNSC, including models important to CANDU analysis (dousing, LACs, leakage, recombiner)**
  - **Recent GOTHIC participation in ISP-47 by AECL (IST) and NAI (V7.1), very good results so far**

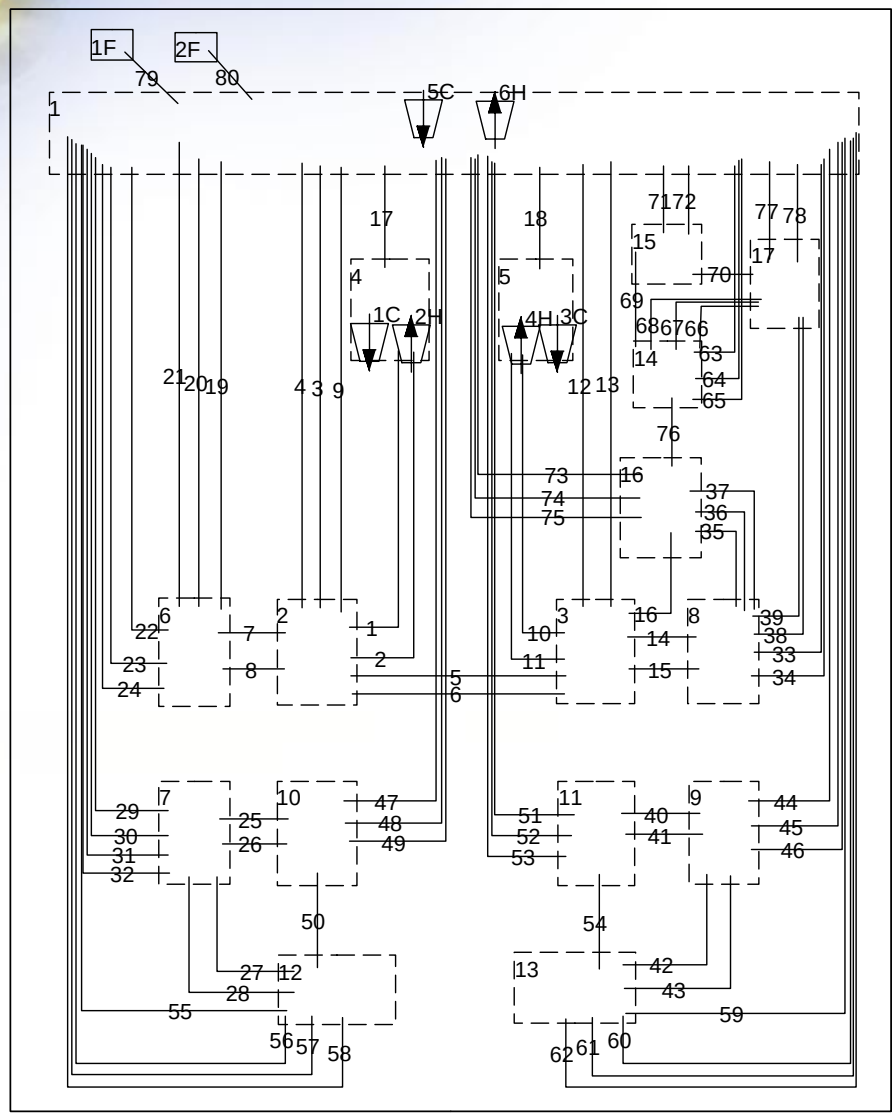
Validation Results

- Validation was completed for all important containment thermal hydraulics phenomena
- No major limitations for using GOTHIC to model important phenomena in CANDU containment safety analysis
- Current IST Version (6.1bp2) requires "workarounds" for modeling CANDU LACs and PARs
  - these code deficiencies have been eliminated in Version 7.2, which will be the future IST version (after 2005)



Section through ACR Containment

- similar application as previous typical GOTHIC applications (CANDU 6, PWR)



Basic GOTHIC Model of ACR Containment

- lumped-parameter model currently used for dose calculations (18 nodes, ~80 links)
- will be refined to 3D model for hydrogen distribution analysis

Summary

- Existing database (experiments) applies to ACR
- Existing code validation results apply to ACR
- Containment Thermal Hydraulics R&D in progress at AECL addresses issues generic to CANDU and ACR

AECL

TECHNOLOGIES INC.