ACR Technology Base: Containment

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Introduction

- The containment of a CANDU reactor is designed to mitigate the consequences of an accident
- During an accident the containment building could be subjected to a harsh environment of hot vapor, fission products from failed fuel, and hydrogen released from oxidation reactions
- Research is performed to ensure that we understand:
  - The time dependent nature of the environment
  - The behavior of fission products
  - Any threats posed by released hydrogen (primarily a concern for severe accidents)

Containment Performance

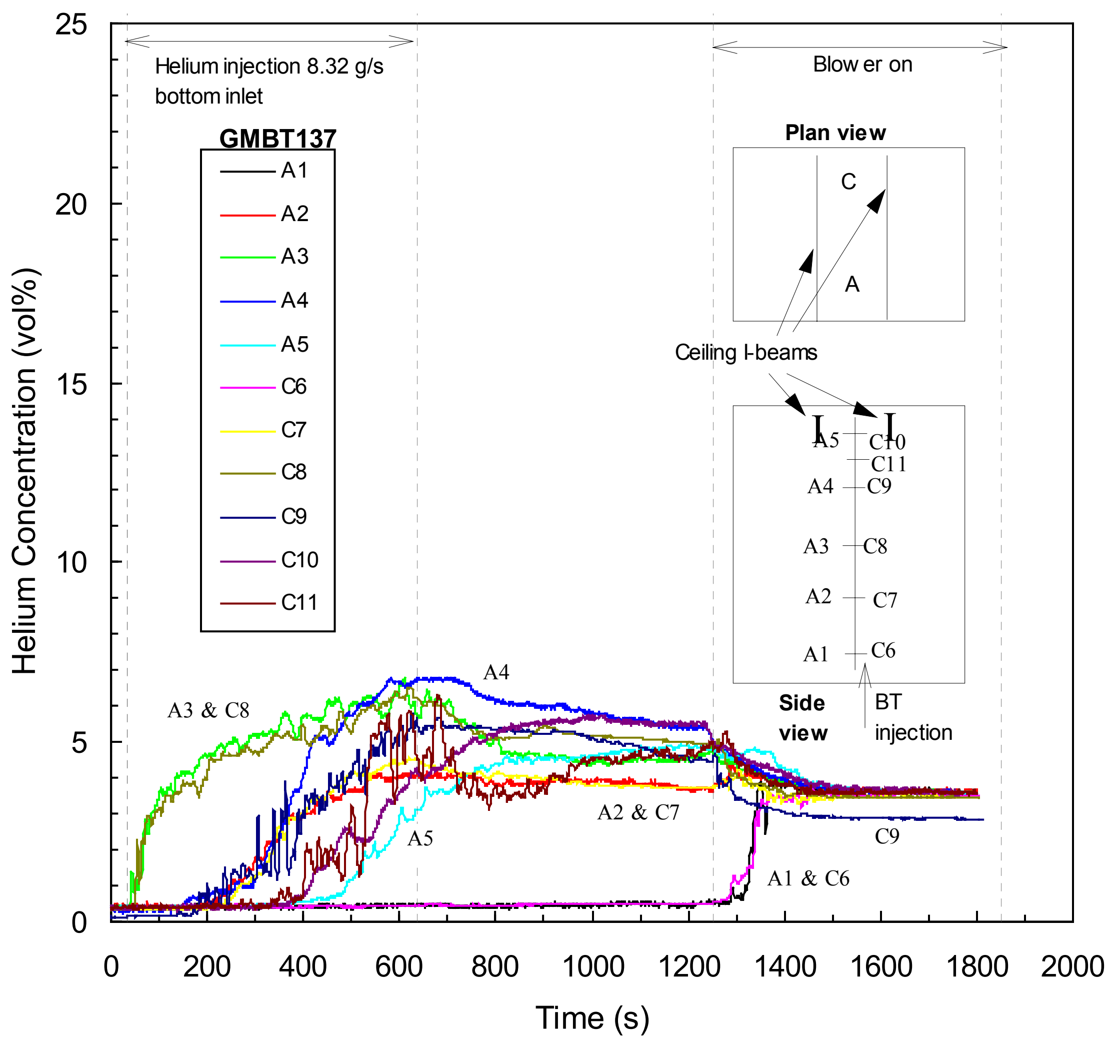
- R&D focused on determining behavior of effluent from the reactor coolant system in containment
- Experimental:
  - Large-scale gas mixing facility
  - Used to study mixing, buoyancy-induced flows, stratification, condensation, effects of containment partitions
  - Data used to validate GOTHIC
- Modeling:
  - GOTHIC, with addition of CANDU-specific models for hydrogen behavior, used to model containment thermalhydraulics and hydrogen transport

Large Scale Gas Mixing Facility

Large-Scale Gas Mixing Facility

- Volume: 1000 m^3 (35000 ft^3)
- Atmosphere: air, steam and helium
- Internal partitions simulate sub-compartments

Example of a Gas-Mixing Experiment



- **Steam injected and formed a stratified layer**
- **Helium injected, breaks through stratified layer after ~200 seconds, and rises**
- **After 1200 seconds, blowers create uniform mix**

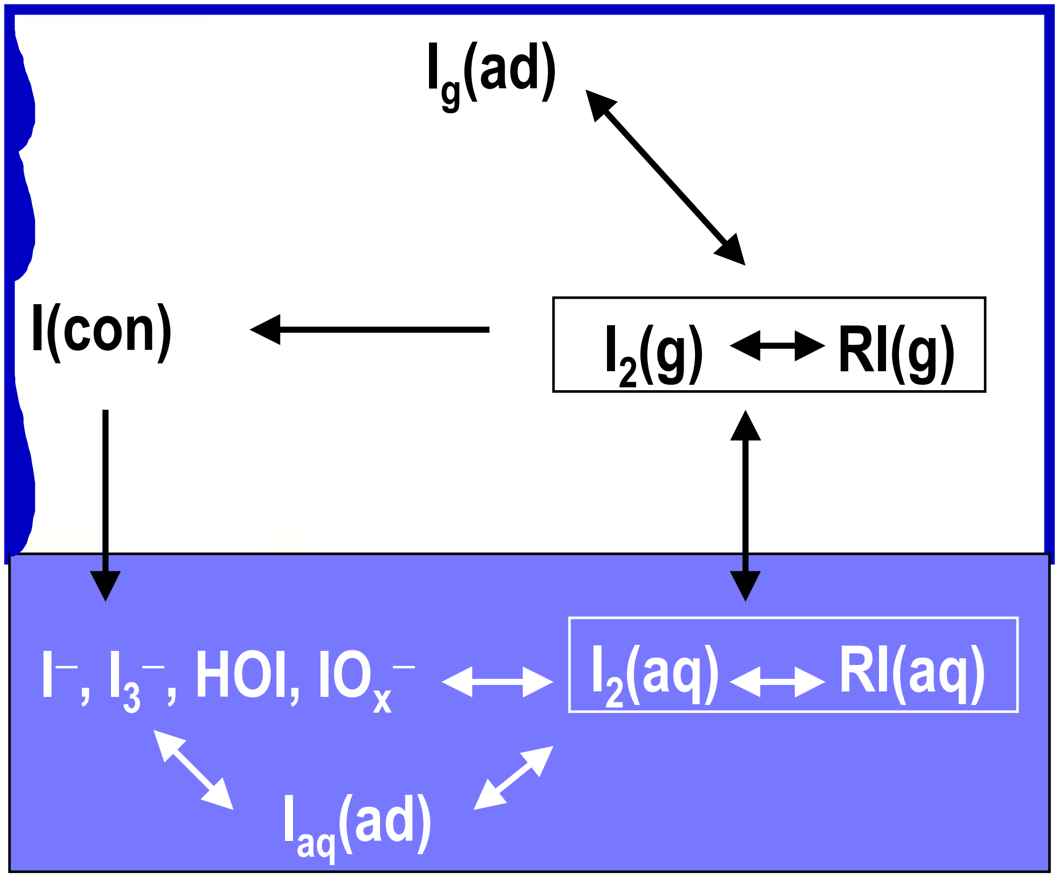
Fission Product Behavior

- In the event of a LOCA, fission products from failed fuel are discharged from the break
- Fission products that remain in the vapor phase are more subject to release from containment than those that partition to water
- Iodine has been a focus because of its relative abundance, high biological activity and gaseous forms

Iodine Behavior in Containment

- Primary concern is the time dependent concentration of gaseous iodine
- Released from fuel into containment mainly as CsI, which dissolves as non-volatile iodide in water
- Under the oxidizing and high radiation environment following an accident, non-volatile iodide would react and become volatile and partition into the gas phase

Iodine Reactions and Transport



Factors affecting Iodine Behavior

- Iodine exists in various chemical states
- Post-accident containment is under irradiation and not in chemical equilibrium
- Iodine chemistry is driven by water radiolysis
- Many reactions and processes are inter-dependent
- Iodine behavior can not be easily scaled from correlations based on integrated tests
- Requires a correct representation of aqueous chemistry (which can be scaled)

AECL Iodine Program Components

- Intermediate-scale integrated-effects tests in the Radioiodine Test Facility (RTF)
- Supporting bench-scale tests to separate and quantify individual effects
- Development and validation of containment iodine behavior models, LIRIC & IMOD, for safety analysis
- International collaboration
  - EPRI ACEX
  - PHEBUS
  - International Standard Problem code comparison exercise

Radioiodine Test Facility

50 RTF Tests

- Type of Vessel Surface
  - Stainless Steel (electropolished, untreated)
  - Organic Coatings on carbon steel or concrete (Vinyl, Epoxy, Polyurethane)
  - Inorganic Coatings (zinc primer)
- Radiation on, Radiation off
- pH controlled, pH uncontrolled: range 4.5 – 10.5
- Temperature
  - constant throughout experiment: 25, 60, 90^{o}C (80, 140, 190^{o}F)
  - steps from 25 to 80^{o}C (80 to 170^{o}F)
- Condensing, Non-condensing
- Organic and Inorganic Additives

Bench-Scale R&D Areas

- Aqueous Phase Chemistry
  - Inorganic Iodine Reactions
  - Water Radiolysis
  - Effects of Organic Impurities
    - Sources of organic compounds dissolved in water
    - Radiolytic decomposition of organic impurities
    - Organic iodide formation & decomposition
- Aqueous-Gas Phase Partitioning of Volatile Species
- Iodine – Surface Interaction

Model Development & Validation

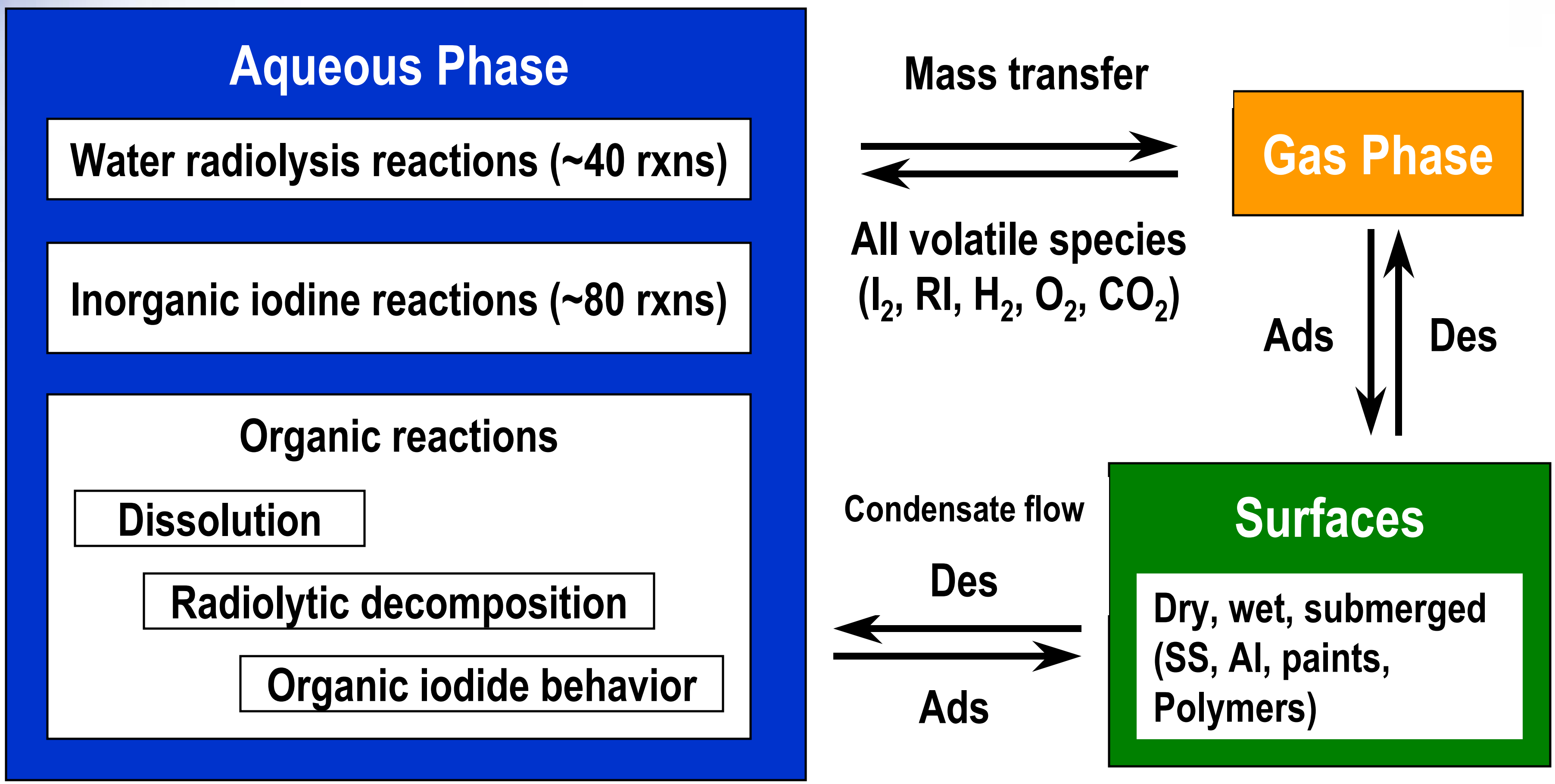
LIRIC

- A comprehensive mechanistic model, based on our extensive knowledge of relevant chemical reactions and mass transport
- Performs well when tested against bench-scale and RTF tests carried out over a wide range of conditions
- Due to its complexity and size, integration of LIRIC into a safety analysis code is considered to be impractical

IMOD

- Reduced reaction set based on extensive LIRIC analysis and simulations of various RTF tests
- A smaller and simpler model, but maintains many of the capabilities of LIRIC

LIRIC


Aqueous Phase
Water radiolysis reactions (~40 rxns)
Inorganic iodine reactions (~80 rxns)
Organic reactions
Dissolution
Radiolytic decomposition
Organic iodide behavior
Mass transfer
All volatile species
(I_2, RI, H_2, O_2, CO_2)
Gas Phase
Ads
Des
Condensate flow
Des
Ads
Surfaces
Dry, wet, submerged
(SS, Al, paints,
Polymers)

IMOD

Aqueous Phase

NONVOLI(aq) $\longleftrightarrow$ I_2(aq)
I_2(aq) $\longrightarrow$ HVRI(aq), LVRI(aq)
HVRI(aq), LVRI(aq) $\rightarrow$ NONVOLI(aq)

Dissolution
Radiolytic decomposition
Acid-Base Equilibria

Total 16 reactions

Mass transfer $\rightleftarrows$

Volatile Iodines
(I_2, HVRI, LVRI)

Gas Phase

Ads $\downarrow$ $\uparrow$ Des

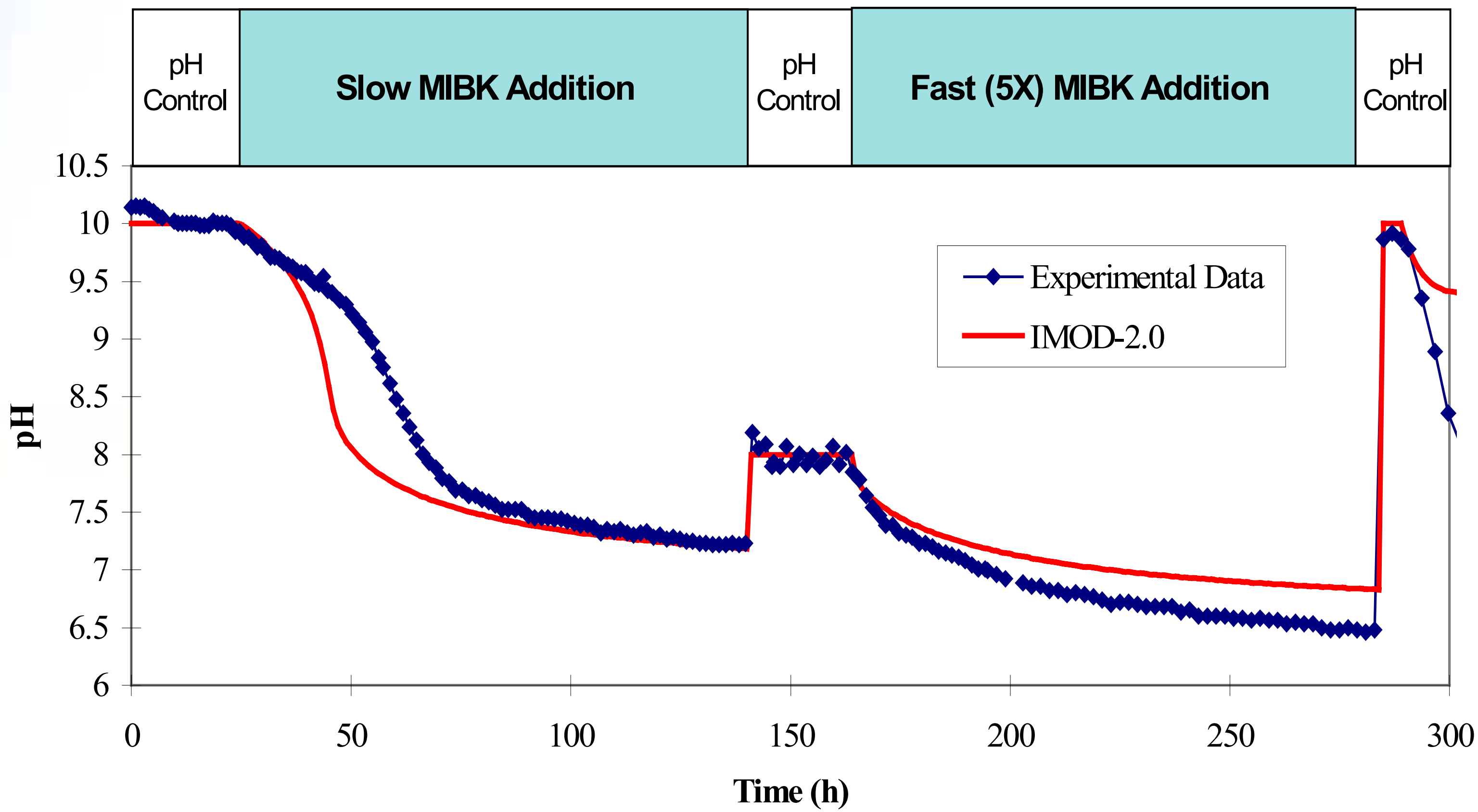
Condensate Flow

Des $\leftarrow$
$\rightarrow$ Ads

Surfaces

Dry, wet, submerged
(SS, Al, paints,
Polymers)

IMOD Simulation of an RTF Test (organic addition in a stainless steel vessel)



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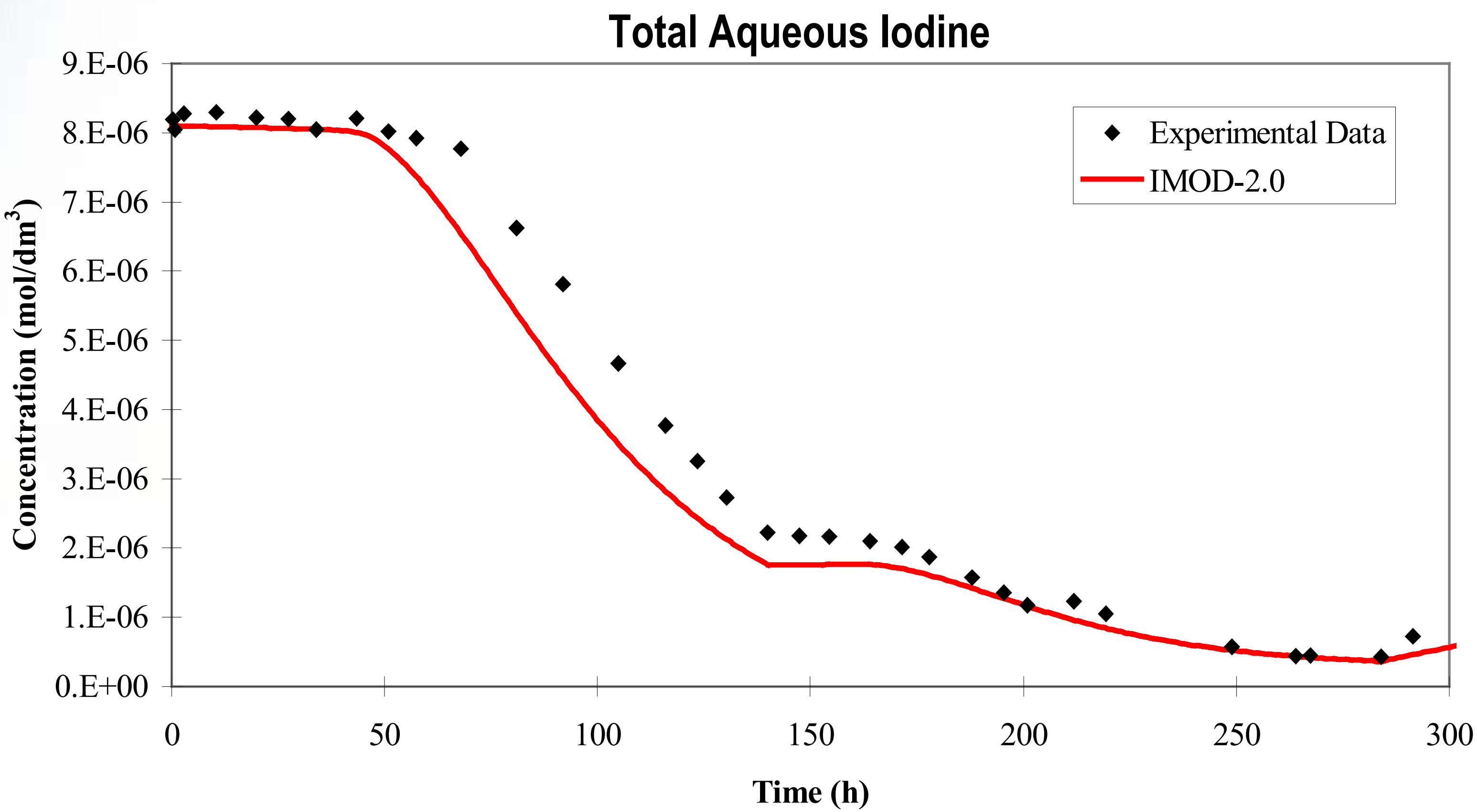

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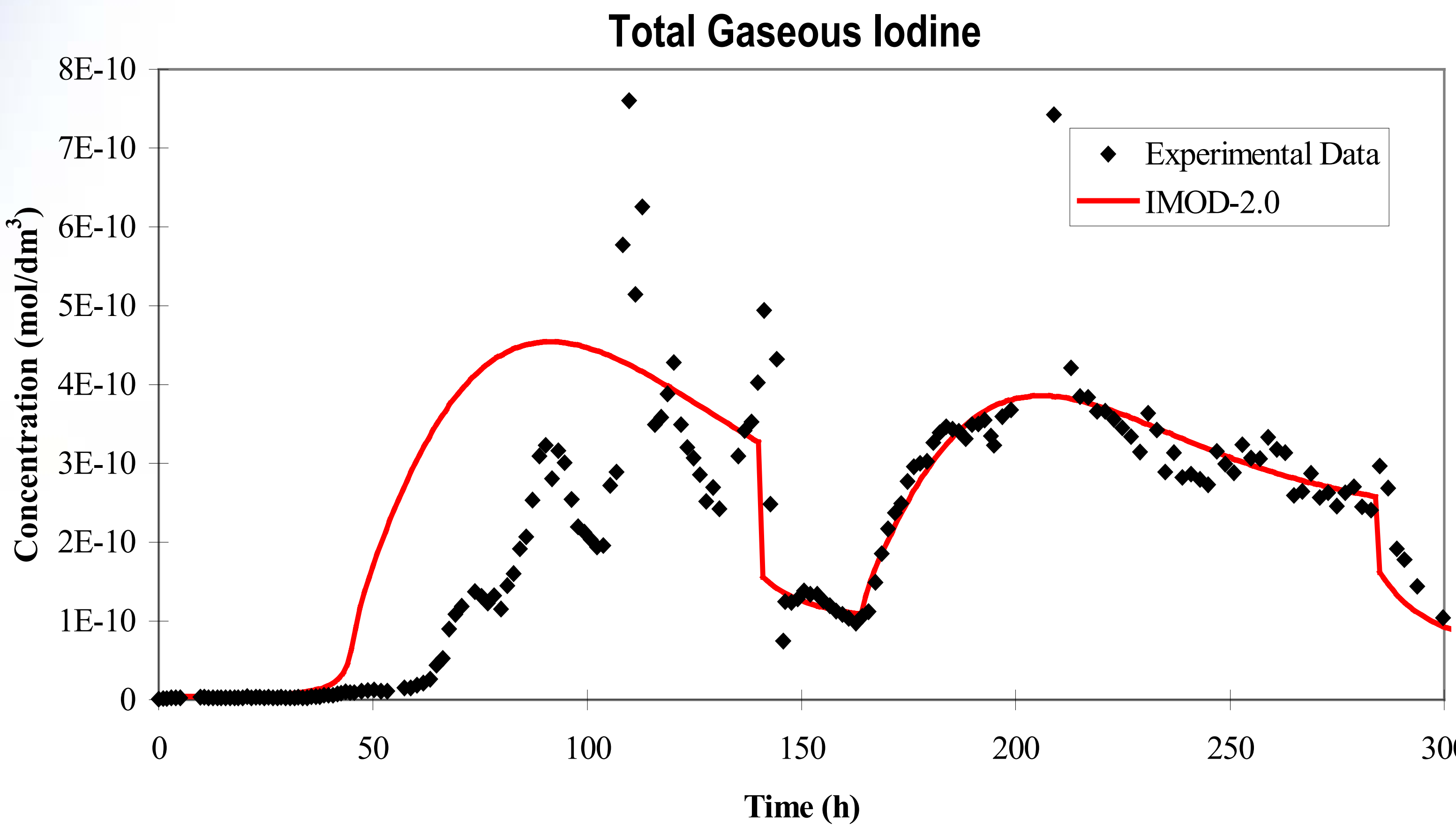


International Collaboration

- EPRI ACE (Advanced Containment Experiments) & ACEX
  - RTF tests, critical review of the current understanding of iodine chemistry and model developmental work were performed in support of ACE & ACEX (extension) projects
- PHEBUS-FP
  - RTF & Bench Scale experiments investigating LWR severe accident phenomena
- International Standard Problem (ISP) 41 and 41F Phase 1 & 2
  - Iodine code comparison exercises endorsed by NEA (Nuclear Energy Agency) CSNI (Committee on the Safety of Nuclear Installations)
  - AECL has lead the very successful exercises
  - AECL's iodine codes, LIRIC and IMOD are participating

AECL Iodine Program Status

- We have a good understanding of iodine behavior in containment
- Models have been developed and shown to predict iodine behavior well

Hydrogen Behavior In Containment

Sources of Hydrogen

- **Short-term: reactions between hot fuel and RCS components and steam**
- **Long-term: water/steam radiolysis and metal corrosion in containment**

Areas of Investigation

- **Transition from deflagration to detonation (DDT)**
- **Effects of deflagration and standing flames on containment structures**
- **Development and evaluation of Passive Auto-catalytic Recombiners**

Results of Hydrogen R&D

- Acquired fundamental understanding of key combustion phenomena:
  - the mechanisms for flame acceleration and transition to detonation
  - the dynamics of flame jet ignition
  - the mechanisms and dynamics of standing flames
  - the mechanisms and dynamics of vented combustion
- Developed computer models for implementation in GOTHIC to predict gas distribution and combustion pressure
- Program based on a variety of facilities

Containment Test Facility (CTF)

- 6-m^3 (200 ft^3) sphere and a 10- m^3 (350 ft^3) cylinder
- pressures up to 10MPa (1500 psi)
- temperatures up to 150^{o}C (300^{o}F)
- vessels may be inter-connected by 30 cm (12 in) and 50 cm (20 in) diameter ducts

Diffusion Flame Facility (DFF)

- silo: 5 m (16 ft) in diameter and 8 m (26 ft) high
- Tests with H_2 / steam jet flames (up to 15 cm (6 in) diameter) in air / steam atmosphere (up to 30% steam by volume)

Large Scale Vented Combustion Facility

- rectangular enclosure with an internal volume of 120 m^3 (4200 ft^3)
- electrically trace-heated and insulated to maintain temperatures in excess of 100^{o}C (212^{o}F)
- can be subdivided into 2 or 3 compartments

Combustion Codes

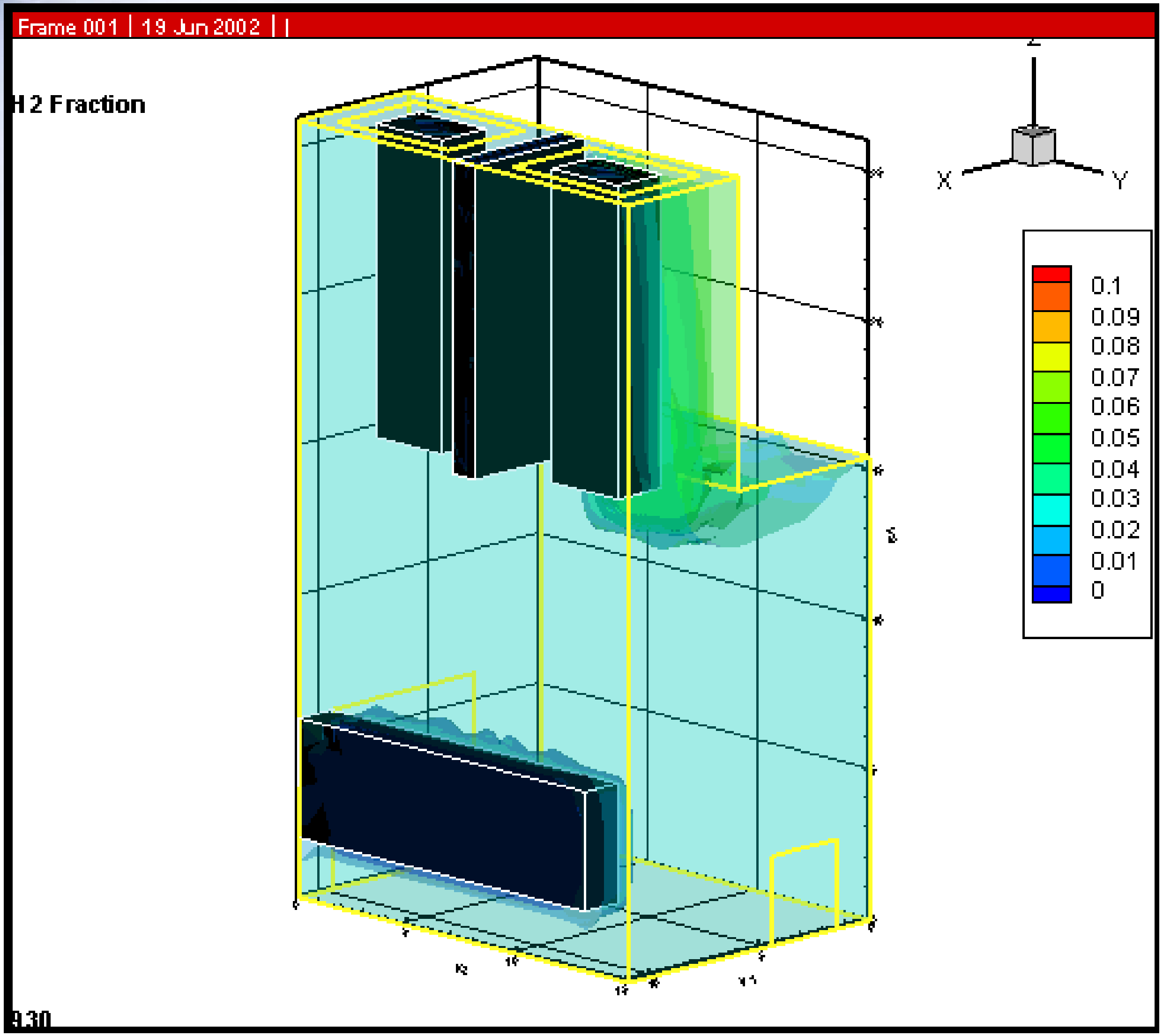
GOTHIC

- Used to calculate hydrogen distribution inside containment and the combustion pressure in the event of an ignition

DDTINDEX

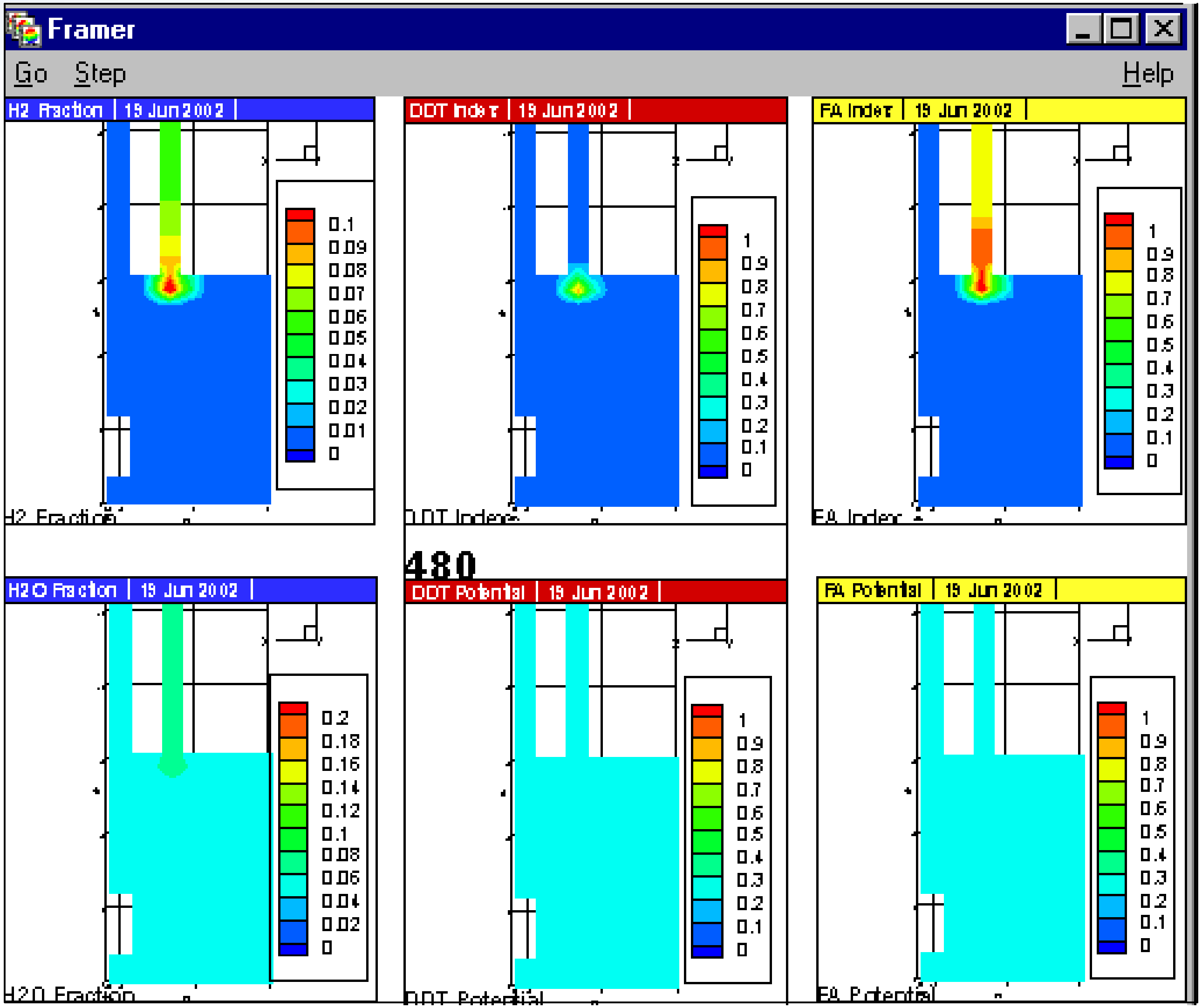
- Used to calculate a set of criteria for assessing the possibility of supersonic flames via flame acceleration and subsequent transition to detonation

GOTHIC Example

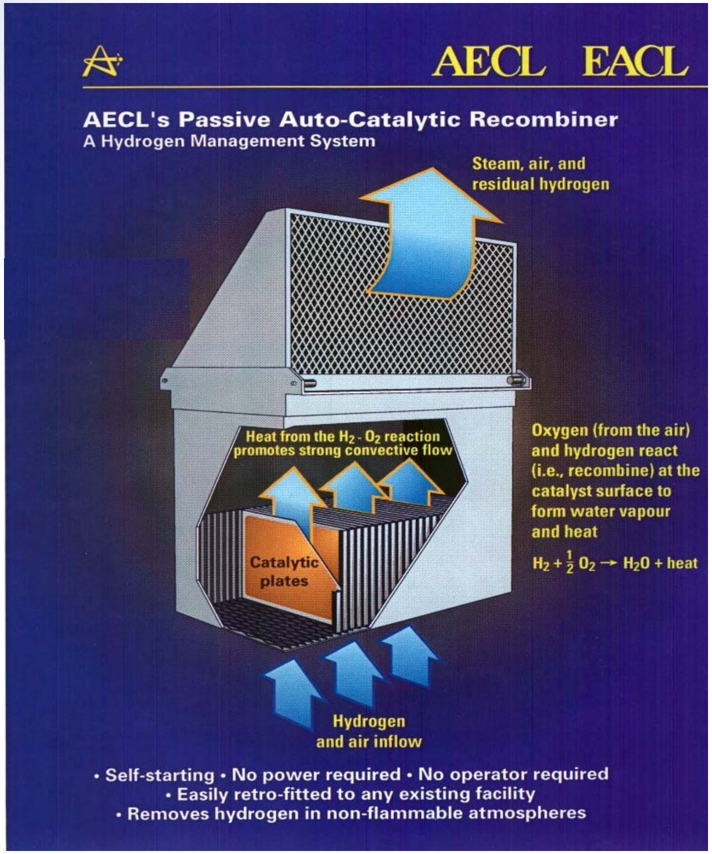


- Hydrogen distribution in containment during a large LOCA (header break)

DDTINDEX Outputs

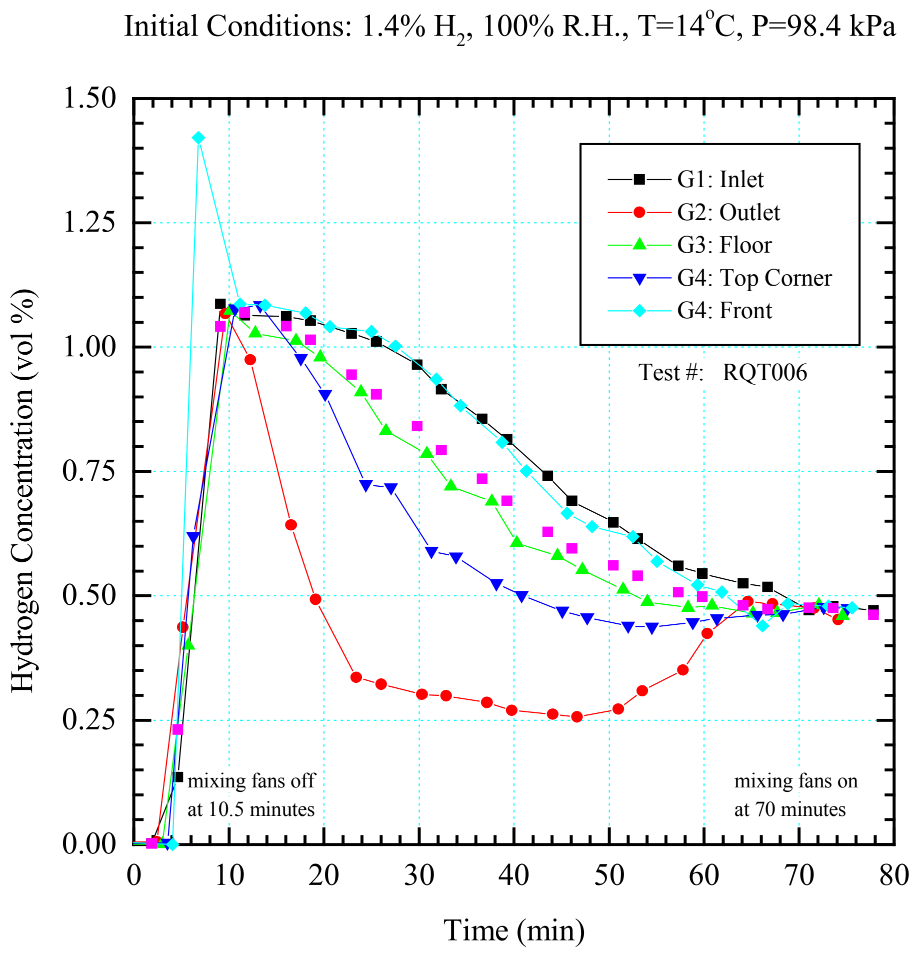


Passive Autocatalytic Recombiners



- recombine hydrogen with oxygen in a controlled fashion
- based on AECL's wet-proofed catalyst technology developed for heavy water production
- have been qualified with tests in the large-scale vented combustion facility

AECL PAR - Self-Start Test



Summary

- Research programs into areas relevant to containment are mature and widely-recognized
- Models and computer programs have been developed and validated for CANDU safety, licensing and design
- Only work required to support ACR is minor anticipatory R&D (e.g., qualification of passive recombiners for ACR conditions)

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