



ACR Technology Base: Containment

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 **AECL**
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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

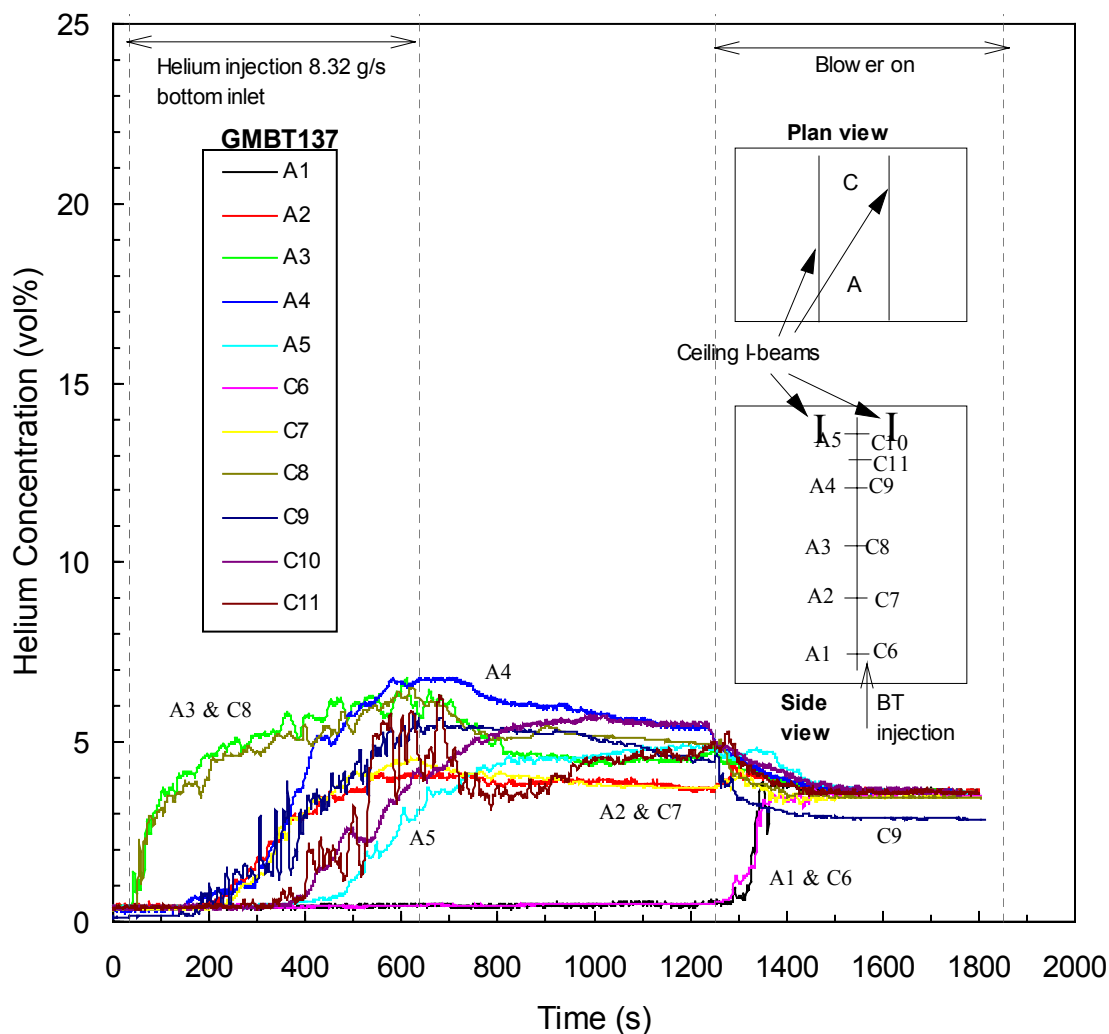


Large-Scale Gas Mixing Facility

- Volume: 1000 m³ (35000 ft³)
- 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

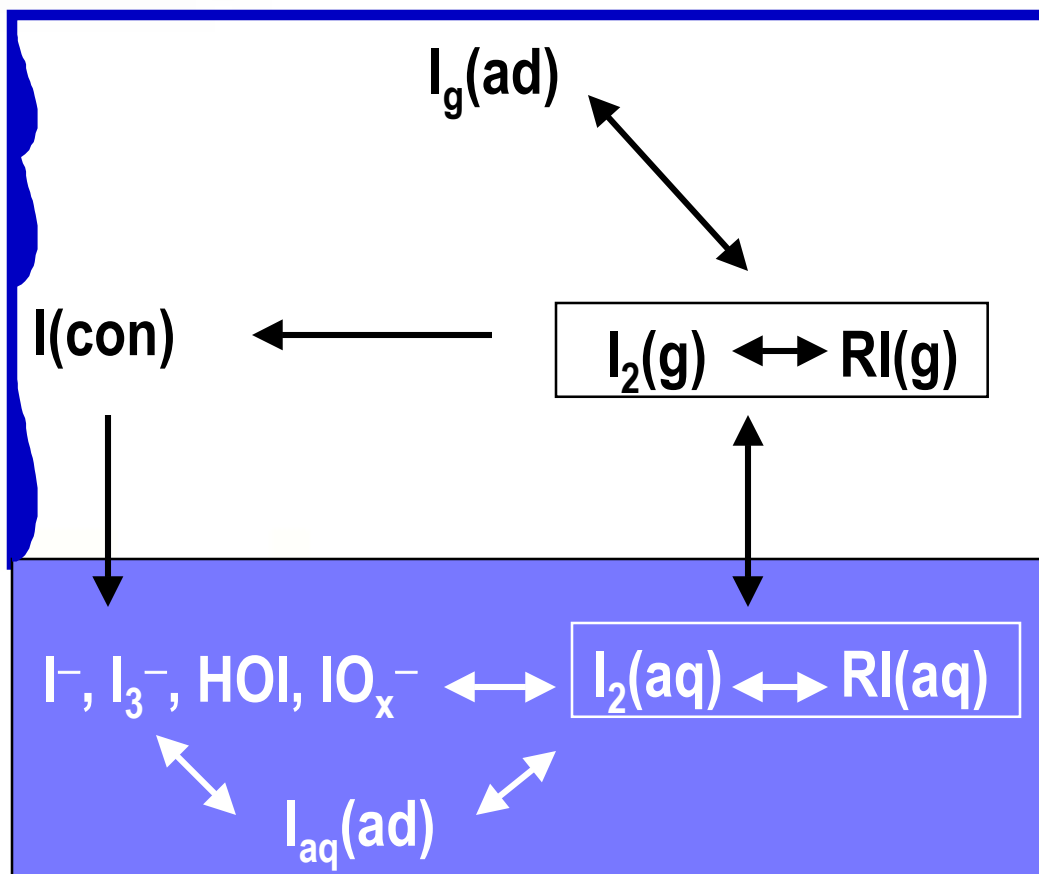


Iodine Behavior in Containment

- **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°C (80, 140, 190°F)**
 - **steps from 25 to 80°C (80 to 170°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

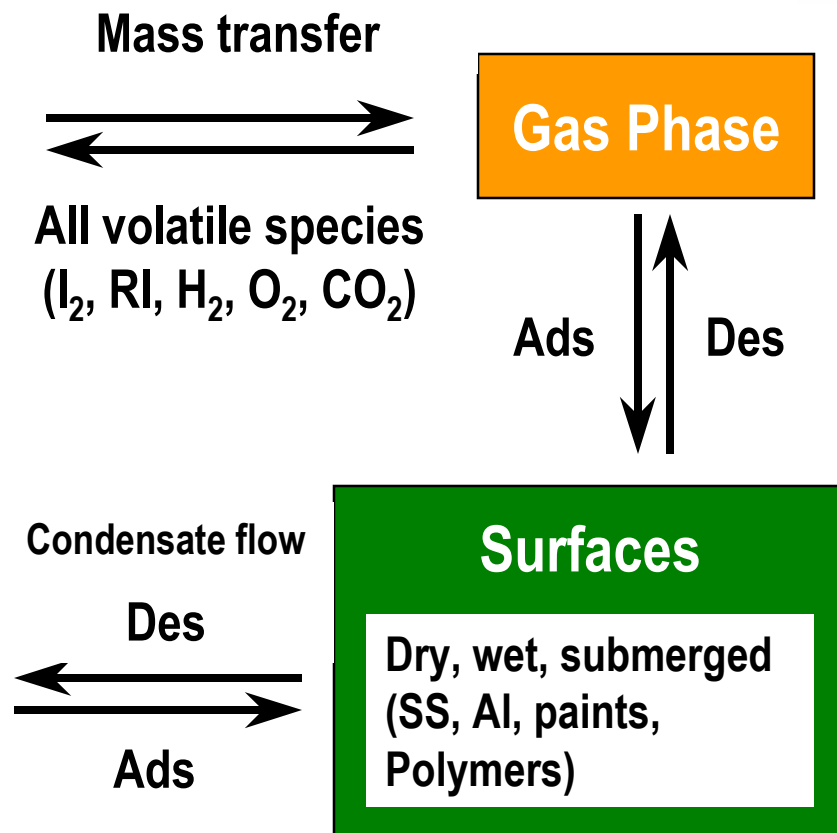
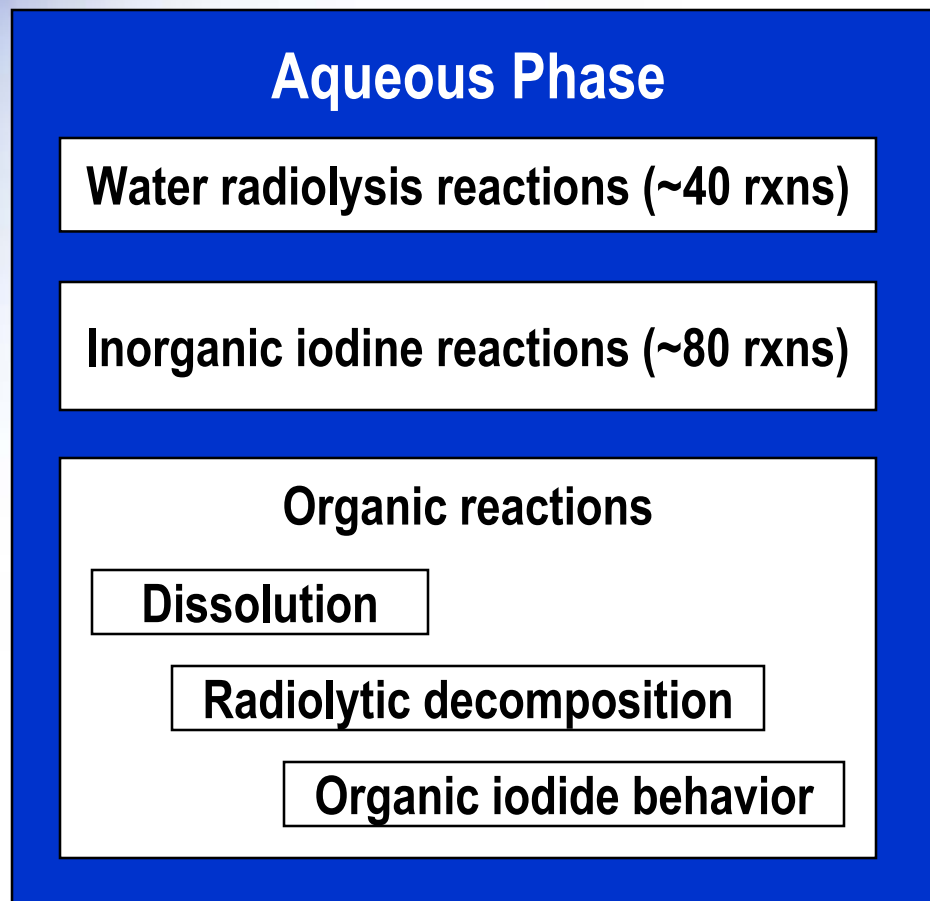
- A comprehensive mechanistic model, based on our extensive knowledge of relevant chemical reactions and mass transport
- Performs well when tested against bench-scale and RTF tests carried out over a wide range of conditions
- Due to its complexity and size, integration of LIRIC into a safety analysis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



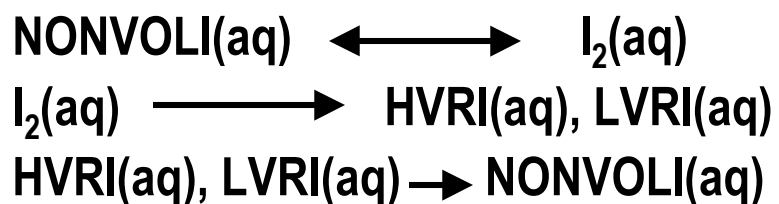
LIRIC





IMOD

Aqueous Phase



Dissolution

Radiolytic decomposition

Acid-Base Equilibria

Total 16 reactions

Mass transfer

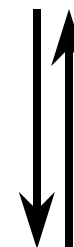


Gas Phase

Volatile Iodines
(I_2 , HVRI, LVRI)

Ads

Des



Condensate Flow

Des



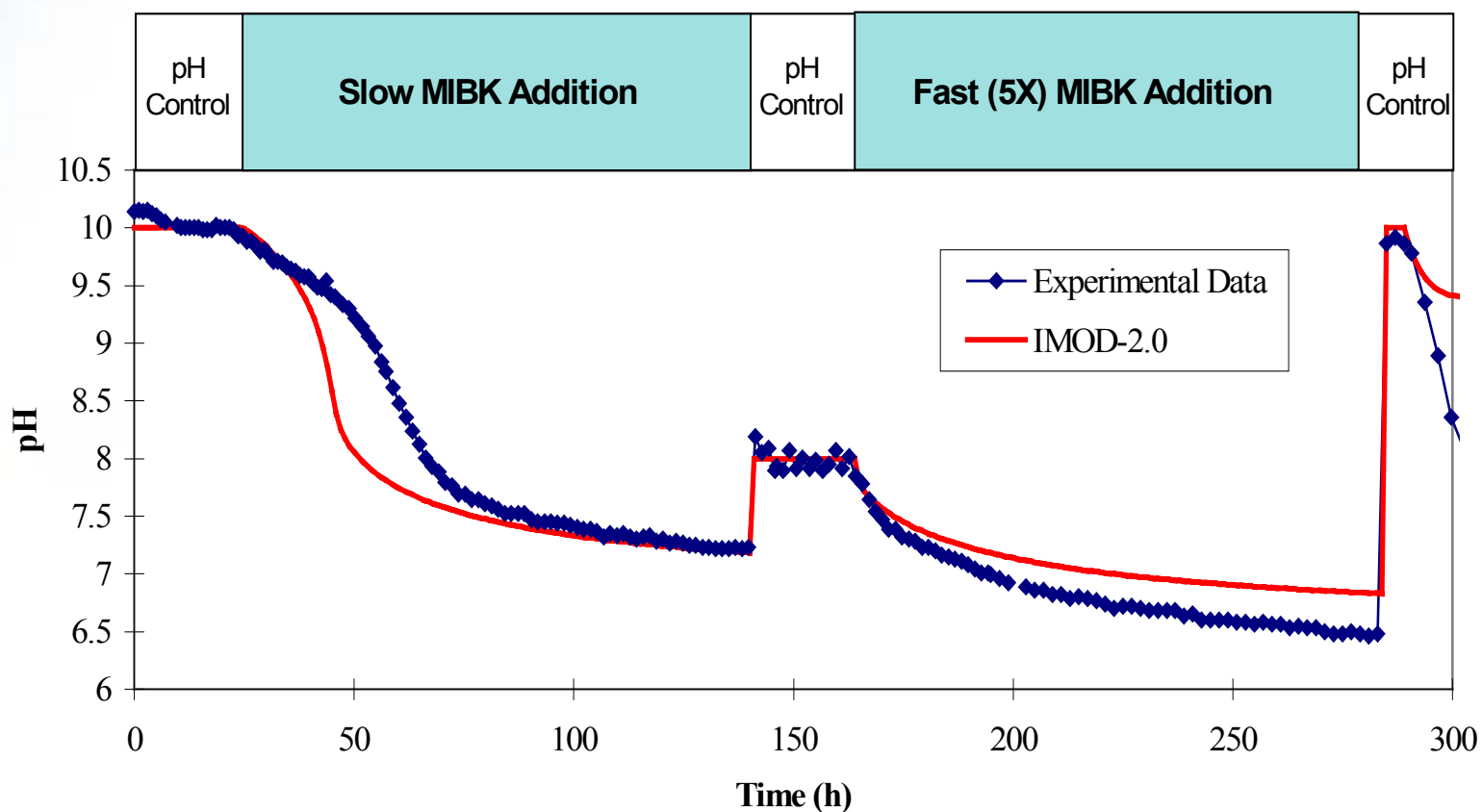
Ads

Surfaces

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

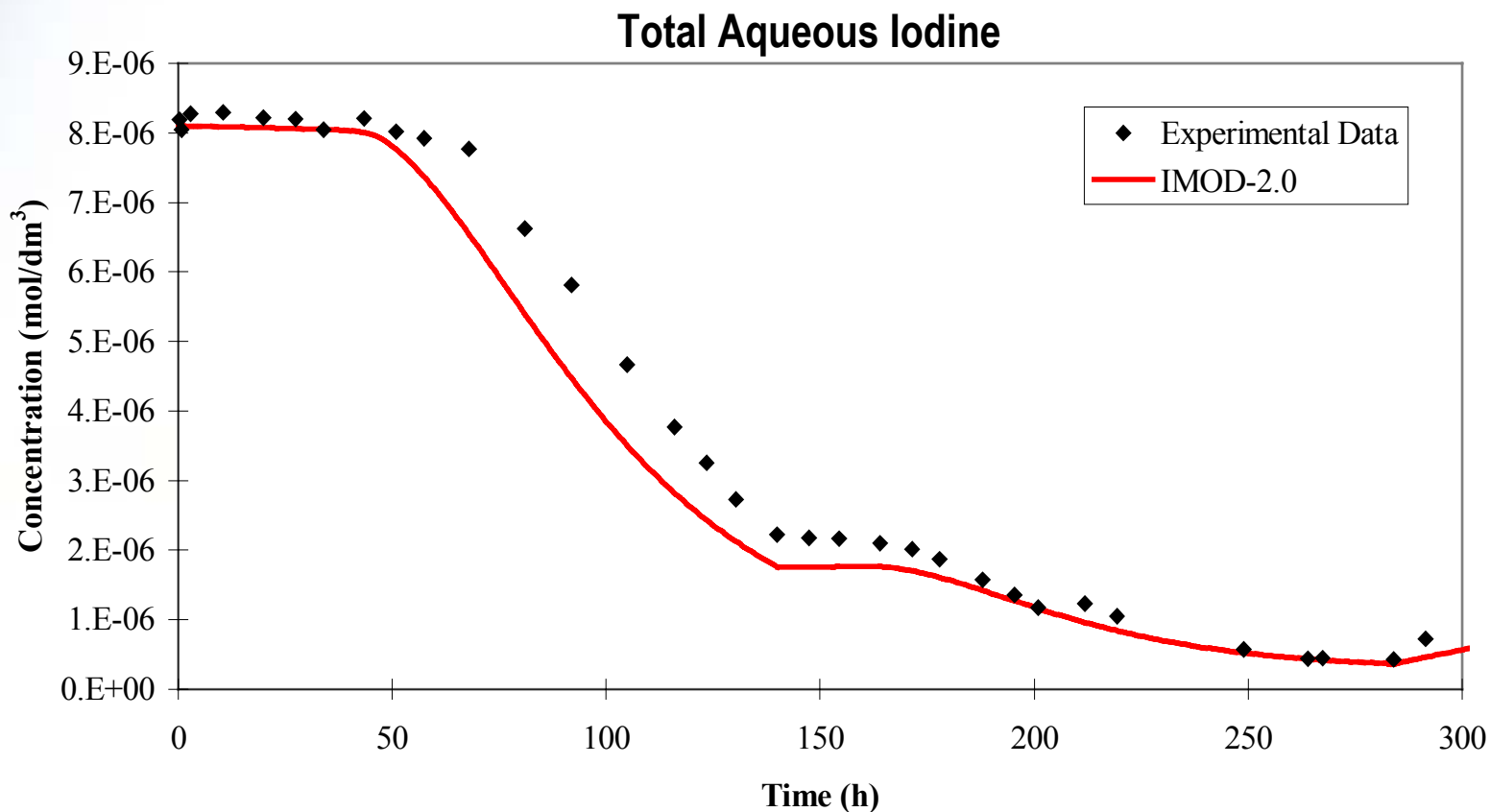


IMOD Simulation of an RTF Test (organic addition in a stainless steel vessel)



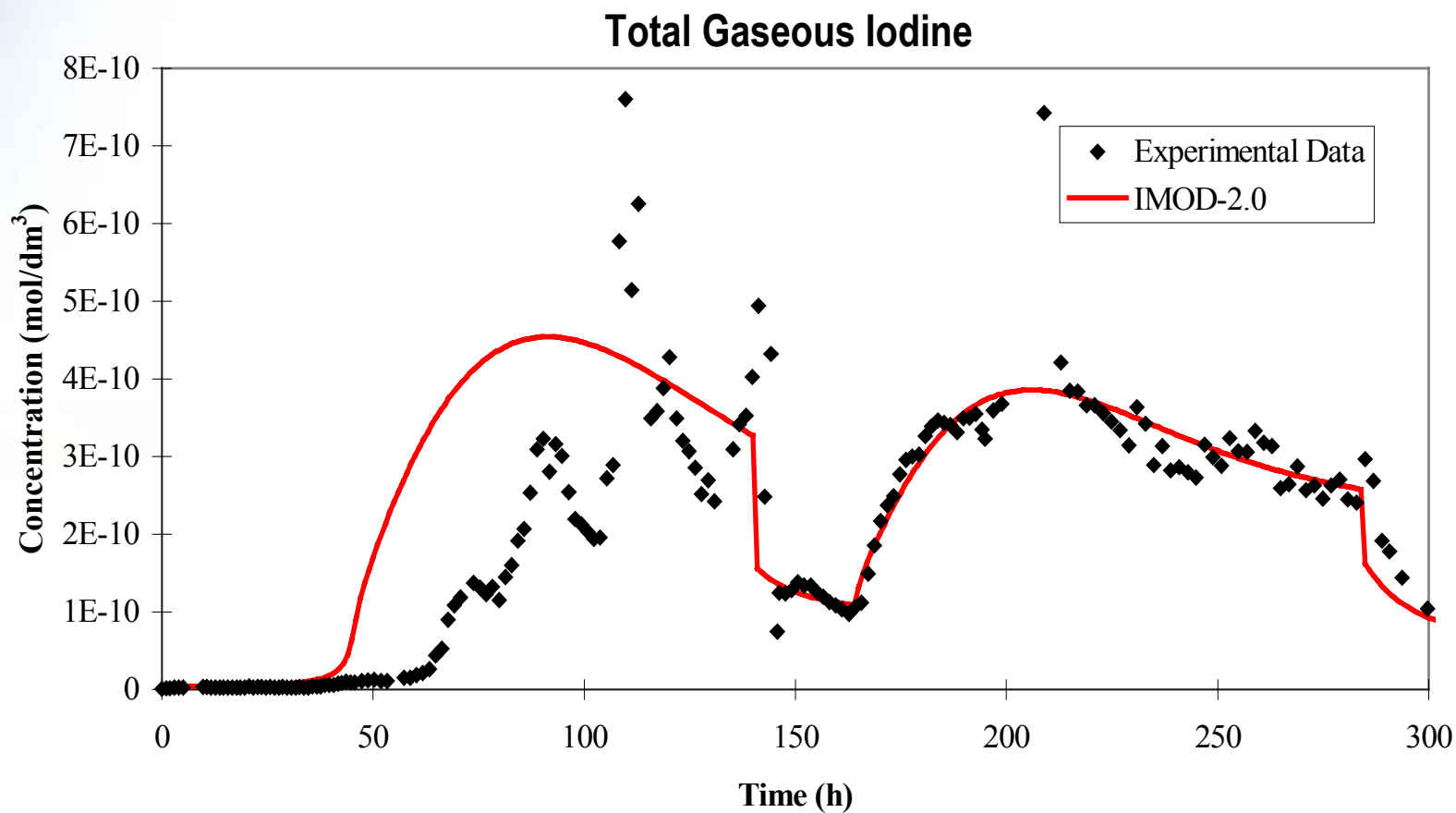


IMOD Simulation of an RTF Test (organic addition in a stainless steel vessel)





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





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-m³ (200 ft³) sphere and a 10- m³ (350 ft³) cylinder
- pressures up to 10MPa (1500 psi)
- temperatures up to 150°C (300°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 m³ (4200 ft³)
- electrically trace-heated and insulated to maintain temperatures in excess of 100°C (212°F)
- can be subdivided into 2 or 3 compartments



Combustion Codes

GOTHIC

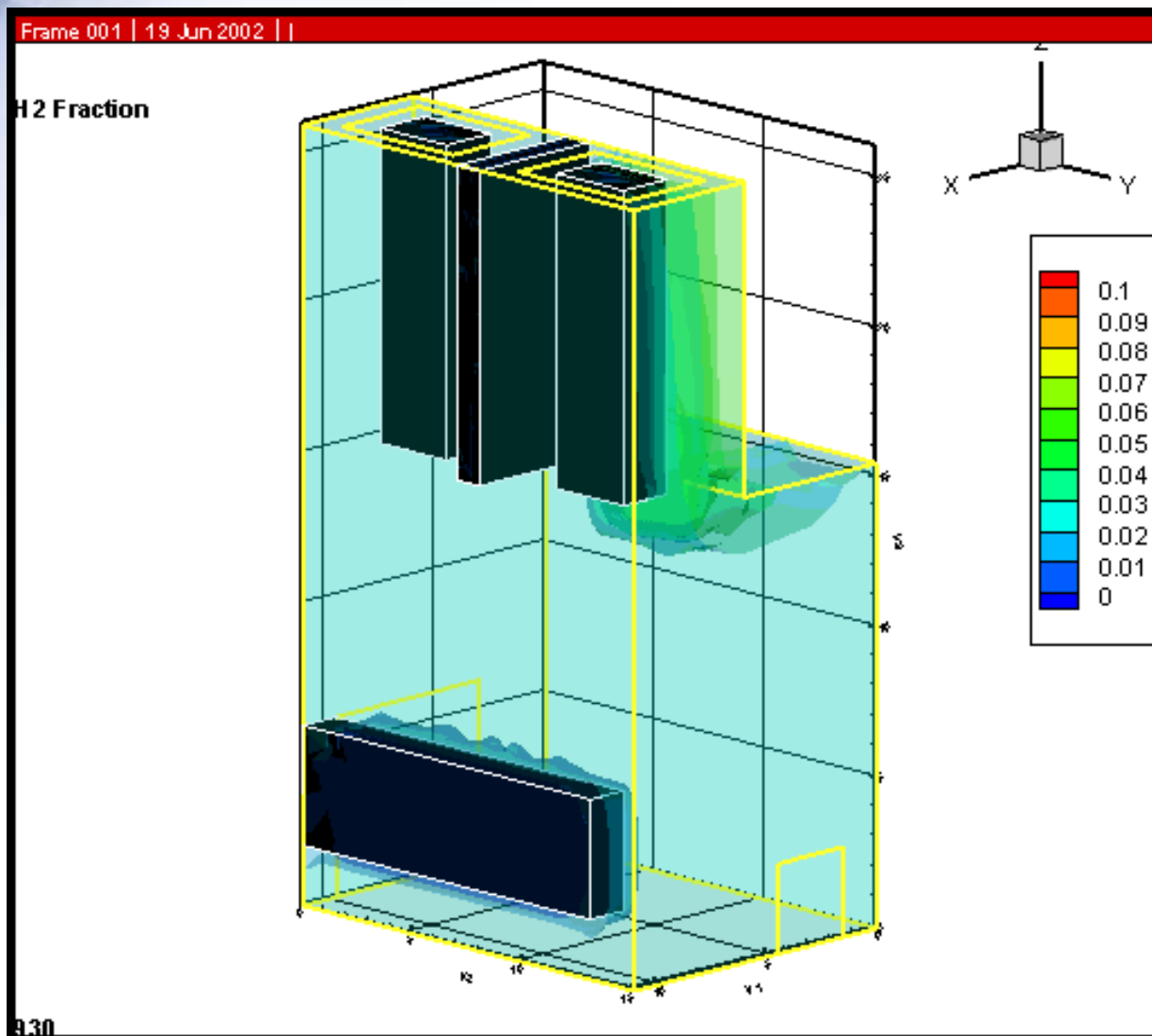
- Used to calculate hydrogen distribution inside containment and the combustion pressure in the event of an ignition

DDTINDEX

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



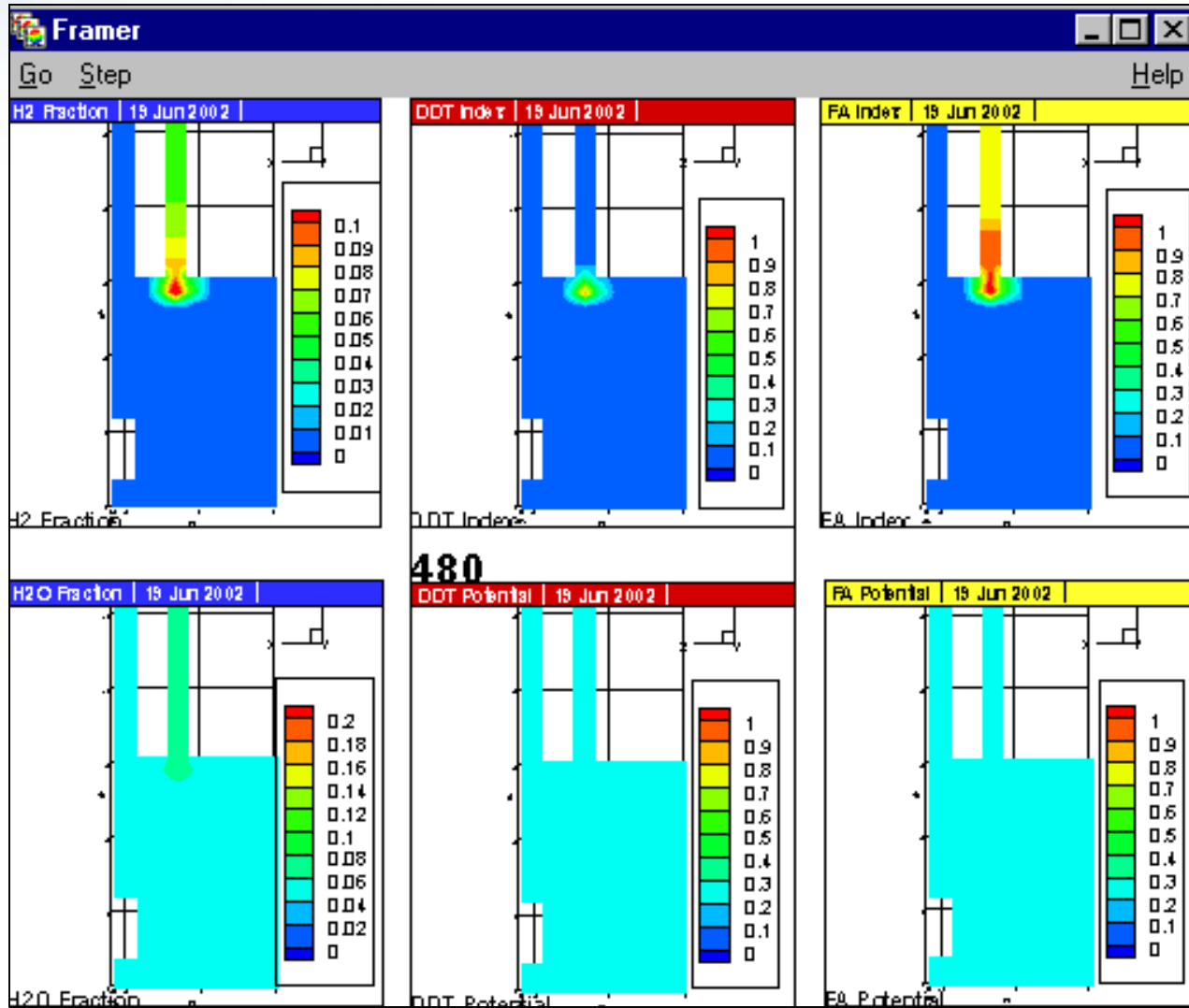
GOTHIC Example



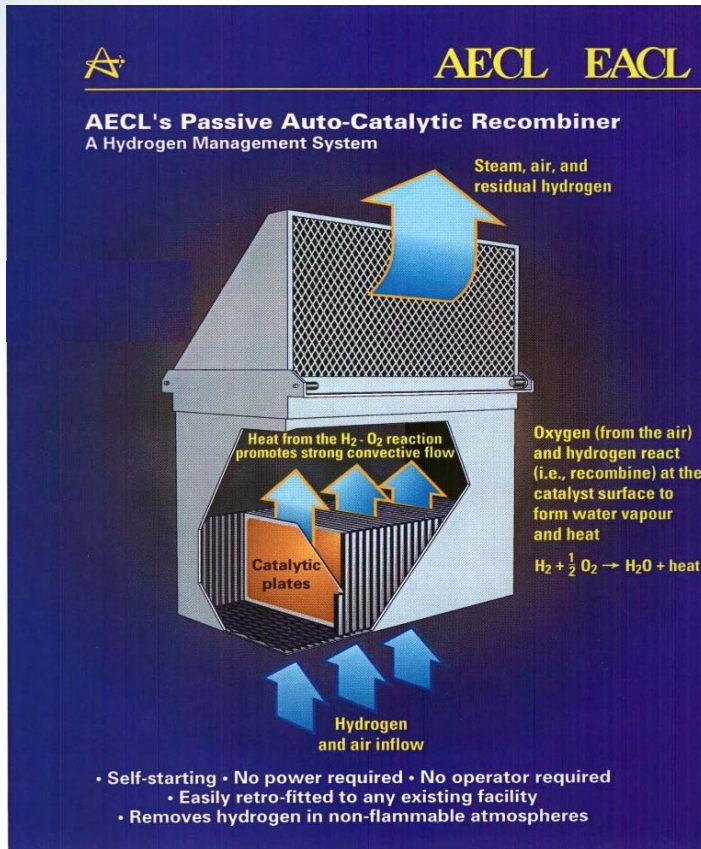
- Hydrogen distribution in containment during a large LOCA (header break)



DDTINDEX Outputs



Passive Autocatalytic Recombiners

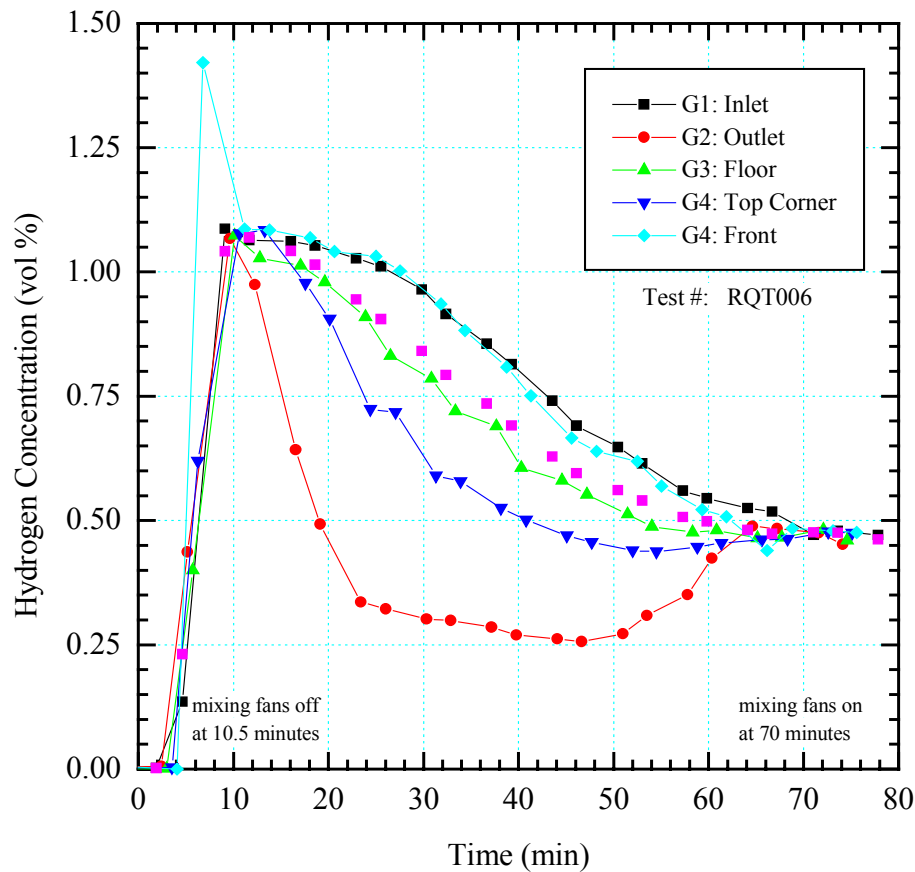


- recombine hydrogen with oxygen in a controlled fashion
- based on AECL's wet-proofed catalyst technology developed for heavy water production
- have been qualified with tests in the large-scale vented combustion facility



AECL PAR - Self-Start Test

Initial Conditions: 1.4% H₂, 100% R.H., T=14°C, P=98.4 kPa





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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