INNOVATIVE SEALS FOR SOLID OXIDE FUEL CELLS (SOFC)-SOFT SEALS

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INTRODUCTION

- **Requirements of Seals for SOFC**
  - Electrochemical-insulating to avoid shorting
  - Lowest possible thermomechanical stresses upon processing, during heatup, cooldown, and in steady state/transient operations
  - Long life (5,000-40,000h) under electrochemical and oxidizing/reducing environments at high temperatures ~600-850°C
  - Low cost

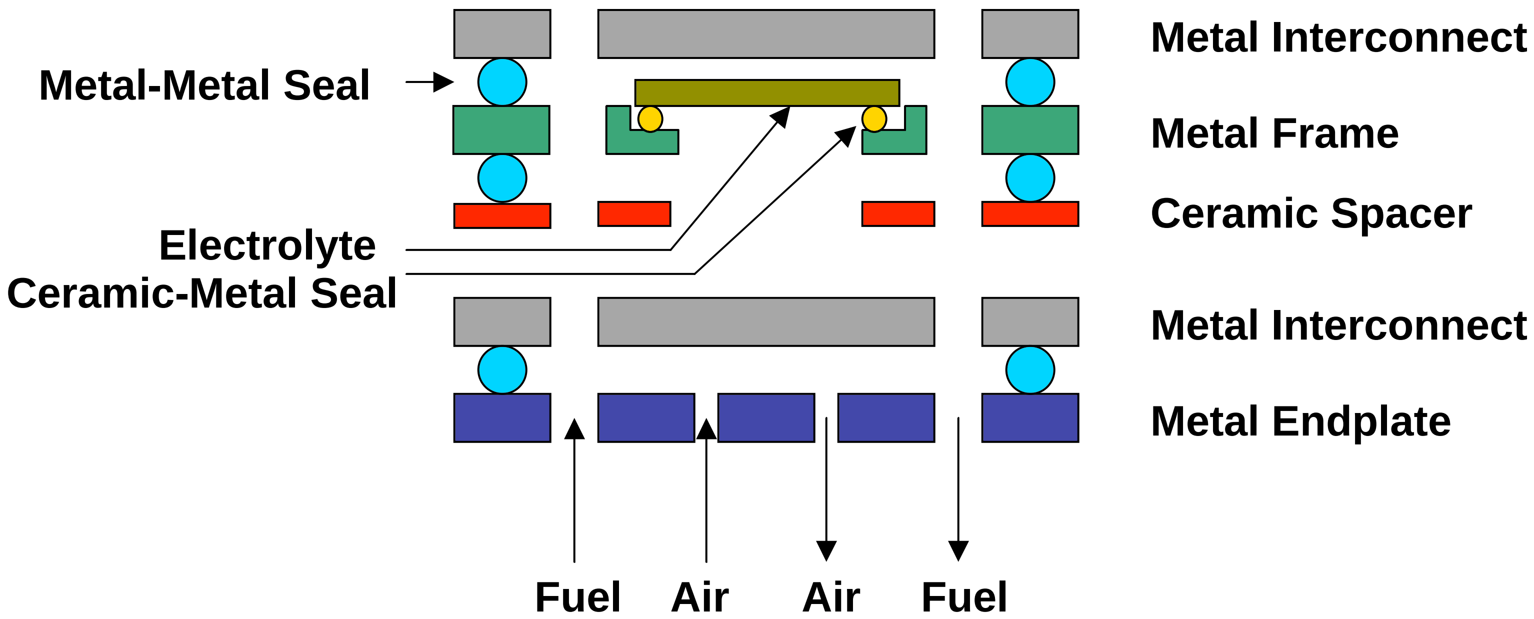
- **Type of Seals**
  - Ceramic-Ceramic (Electrolyte-Ceramic Insulator)
  - Ceramic-Metal
  - Metal-Metal
  - Rigid and/or Compliant
  - Chemical/Mechanical/Liquid

PROGRAM OBJECTIVES AND ACCOMPLISHMENTS

- **Phase-I**
  - Select self-healing glasses for functionality as seals for SOFCs
  - Demonstrate functionality of the self-healing seals by leak tests
  - Measure stability of the self-healing glass in SOFC environments
  - Develop approaches to toughening self-healing glasses as seals for SOFs
  - Survey commercial glasses suitable for making seals for SOFCs

- **Accomplishments**
  - Developed glasses displaying self-healing ability
  - Demonstrated ability of self-healing glasses in sealing components through leak tests overa range of temperatures between 25-800°C
  - Achieved 300 thermal cycles between 25-800°C without leak of seals and accumulated 3000 hours of hermetic seal performance at 800°C
  - These results provide great promise towards meeting SECA goals of seals for SOFC.

SEALS FOR PLANAR SOFC



- Metal-Ceramic and Metal-Metal Seals Must Work at 650-850°C in Corrosive Environments of Fuel and Air

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MATERIALS FOR CELL COMPONENTS

- Electrolyte: YSZ, 10-30 μm, dense
- Anode: Ni-YSZ Cermet, 25-600 μm, porous
- Cathode: Doped La-Perovskite, 25-2000 μm, porous
- IC (Interconnect): Doped Chromites/Alloys, 30 μm -5 mils, dense
- Seals: Insulating Ceramics/Glasses, dense
- Manifolds: Heat Resistant Alloys

- Operating Temperature: 650-850°C
- Fuels: Reformed PNG, Propane, Diesel etc.

- **Highly incompatible materials require seals**

POSSIBLE APPROACHES TO SEALS FOR SOFC

- **Rigid Seals**
  - Glass-Metal, Ceramic Polymer-Ceramic/Metal, Brazes: require stable glasses, brazes, preceramic polymers
  - Low leak rates but susceptible to failures due to stresses
  - Feedback to materials and seal concept modifications to reduce stress buildup and avoid failure
- **Compliant Seals**
  - Bellows, Viscous Glass, Wet-Seals (MCFC): require flexible seal designs, stable glasses with appropriate viscosity over a range of temperature, wet-sealing materials and their containment
  - Moderate leak rate, some concepts may require pressure
- **Our Approaches for Seals**
  - Self-Healing Glass Seals
  - Reinforced-Glass Seals
  - Layered Composite Seals

A SELF-HEALING SEALING CONCEPT FOR SOFC

- **Rationale:** A glass of appropriate characteristics can self-heal the cracks created upon thermal cycling and/or stresses created during SOFC operation. In addition, thermomechnical incompatibilities between ceramic and metallic materials requiring seals/joining can be alleviated using a self-healing glass seal.

- **Advantages:** Materials with dramatically different expansions can potentially be used for seals because this approach can alleviate/minimize thermomechanical stresses and chemical reactions. The leaks developed upon SOFC operation and thermal cycling can be repaired in situ by the self-healing concept.

- **Challenges:** Develop appropriate glasses which satisfy thermomechanical and thermochemical compatibilities, remain stable for long-time, and maintain self-healing capability.

- **Approach:** Thermophysical and thermochemical property measurements and optimization,self-healing ability, and leak testing to demonstrate self-healing seals.

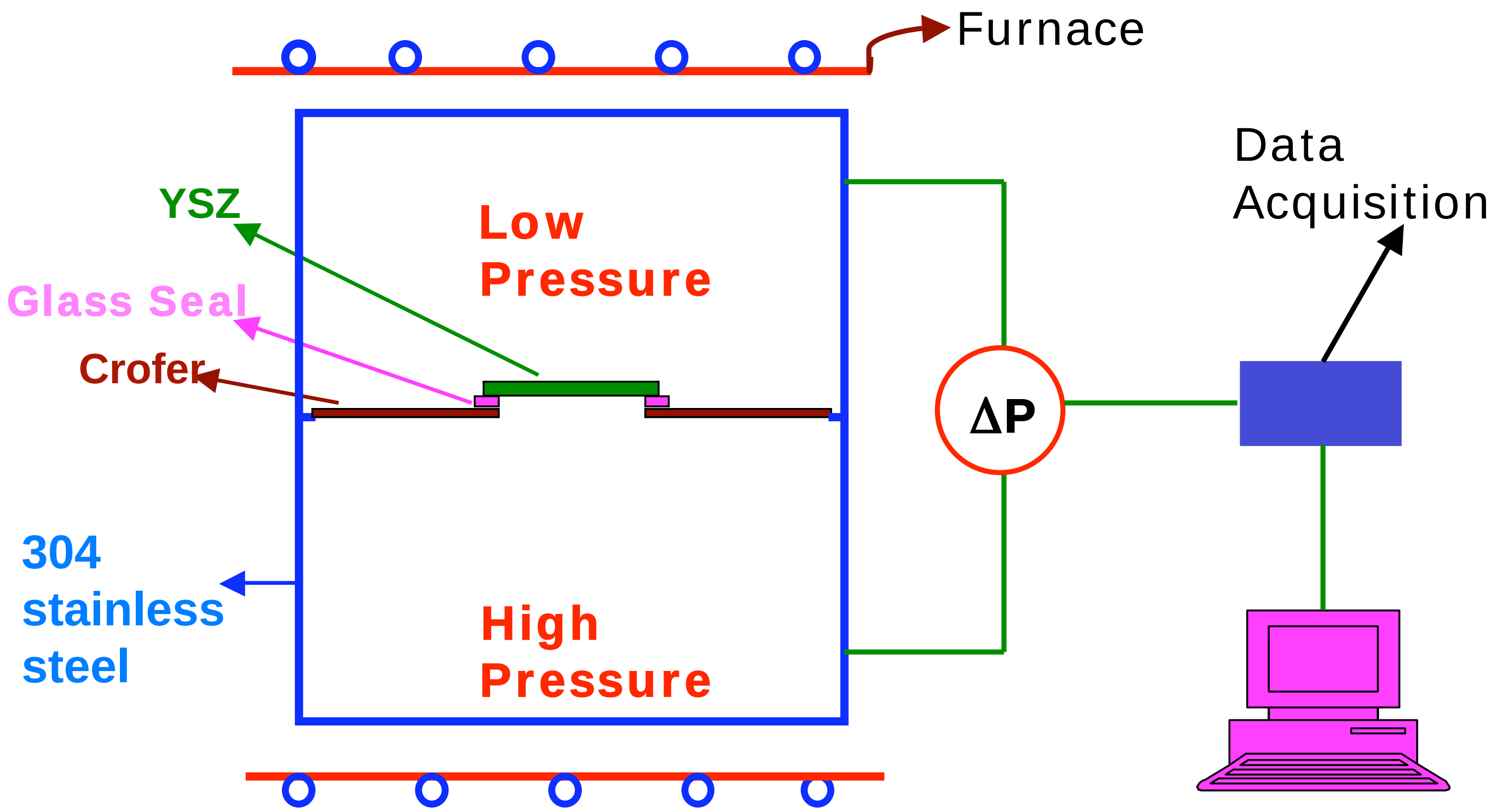
OBJECTIVES

- **Demonstrate Self-Healing Behavior of Glass**
- **Fabricate Seals Displaying Self-Healing Response**
- **Describe Performance and Durability of the Self-Healing Seals Under SOFC Conditions**
  - Fuel Environment
  - Dual Fuel-Air Environments
  - Thermal Cycles and Time

EXPERIMENTAL

- **Materials**
  - Electrolyte YSZ (Tape Casting and Sintering)
  - Metal (Crofer22 APU)
  - Sealant-Silicate Glass
- **Fabricate Seals Displaying Self-Healing Behavior**
  - Self-healing Behavior by Video Imaging
- **Performance and Durability of the Self-Healing Seals**
  - Testing at RT and High Temperatures
  - Effect of Pressure Drop Across The Seal
  - Effect of Thermal Cycling Between 25-800°C
  - Effect of Test Atmosphere Typical of SOFC
  - Effect of Time at 800°C on Seal Durability

A SEAL PERFORMANCE TEST SYSTEM



- **Continuous monitoring of leak test conditions**

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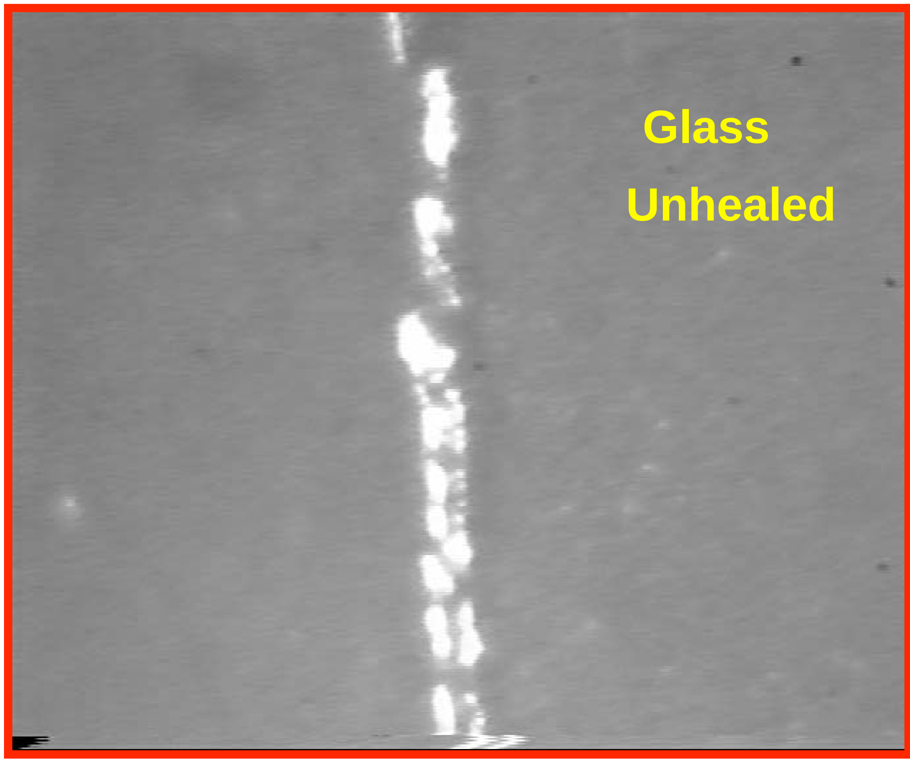
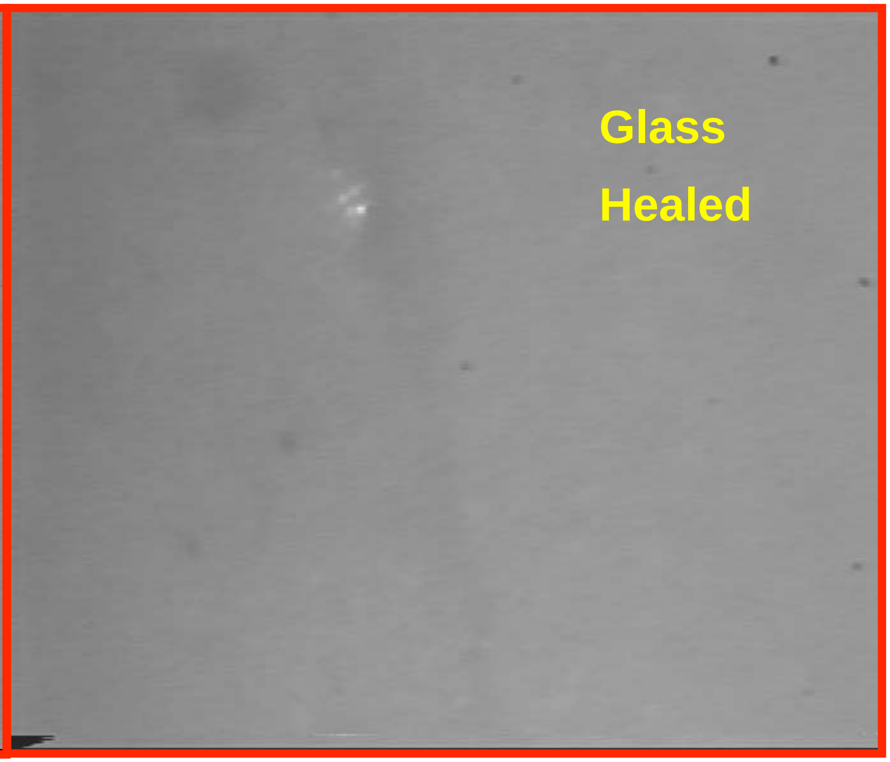
STUDY OF CRACK-HEALING BEHAVIOR OF GLASS





- **Demonstration of self-healing of crack**

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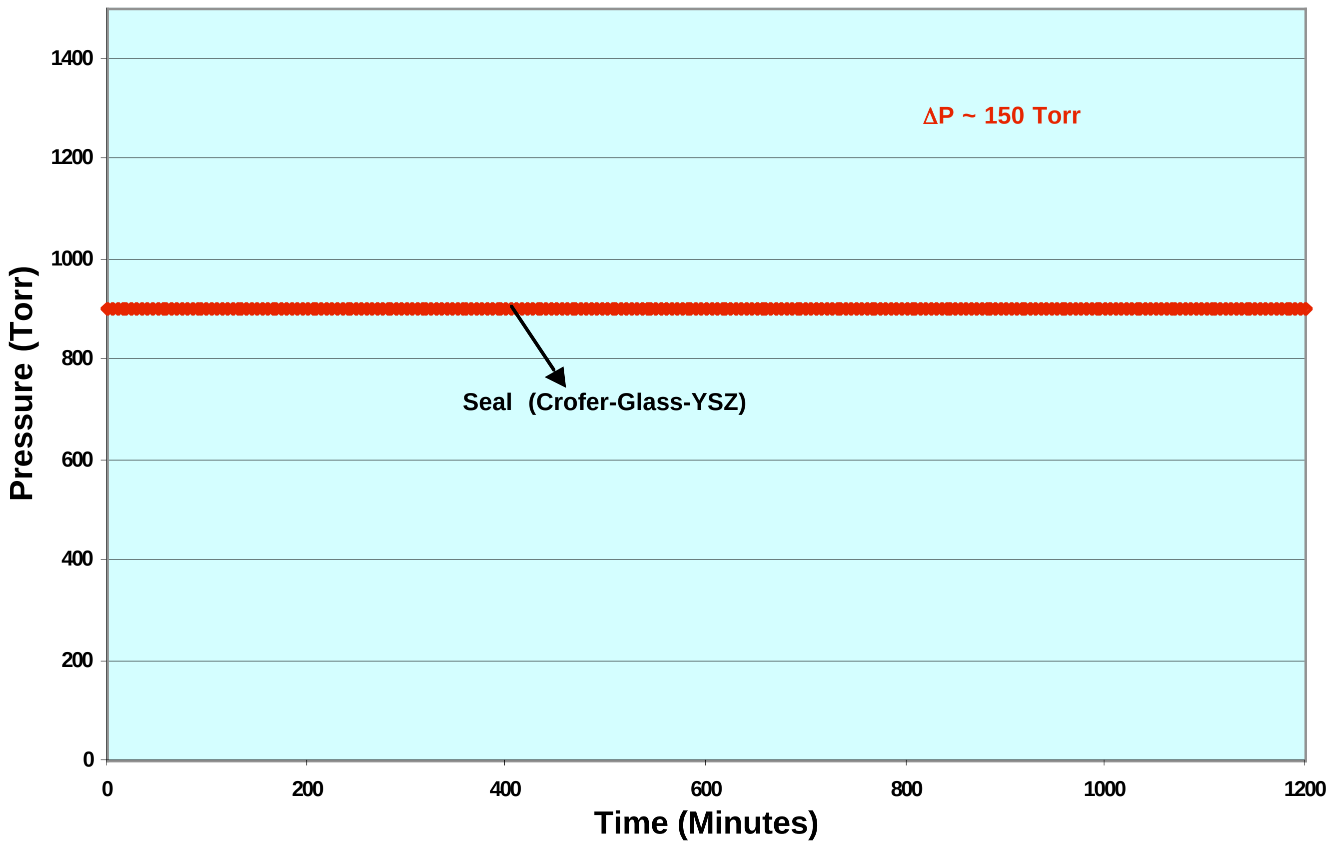
LEAK PERFORMANCE OF SELF-HEALING SEAL At 25°C



- Hermetic response

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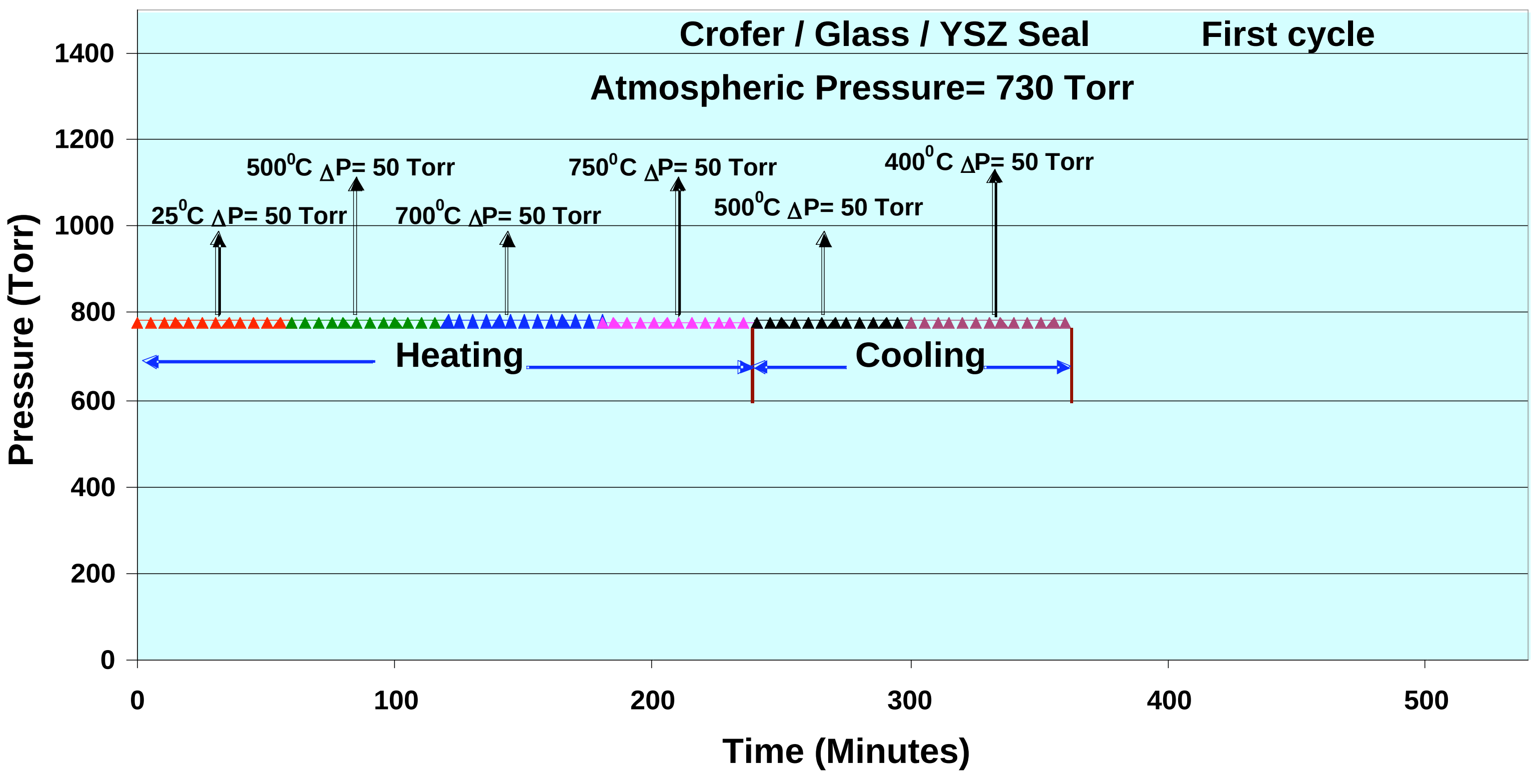
LEAK PERFORMANCE OF SELF-HEALING SEAL
At High Temperatures



- **Hermetic behavior upon heating and cooling**

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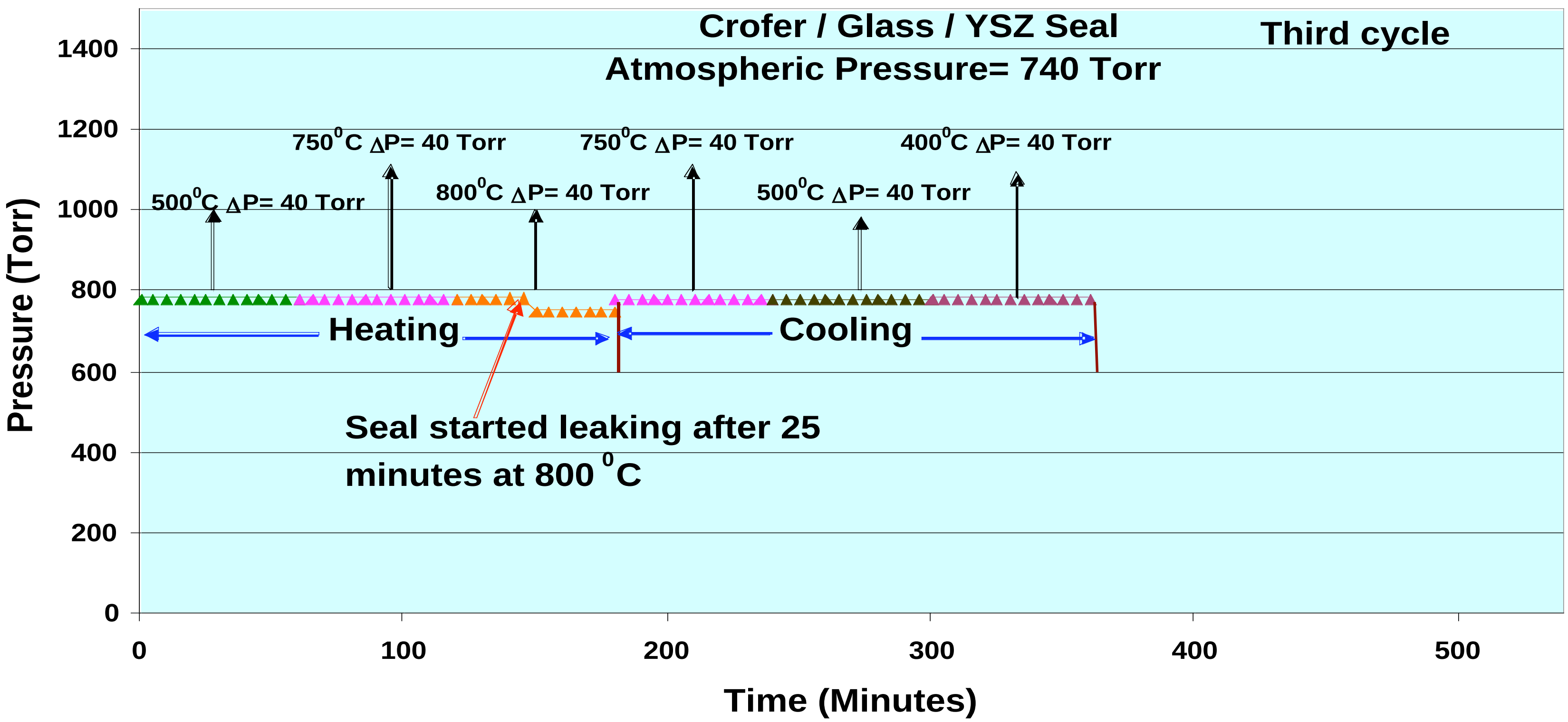
DEMONSTRATION OF SELF-HEALING BEHAVIOR OF SEAL AT HIGH TEMPERATURES



- **Hermetic behavior after self-healing**

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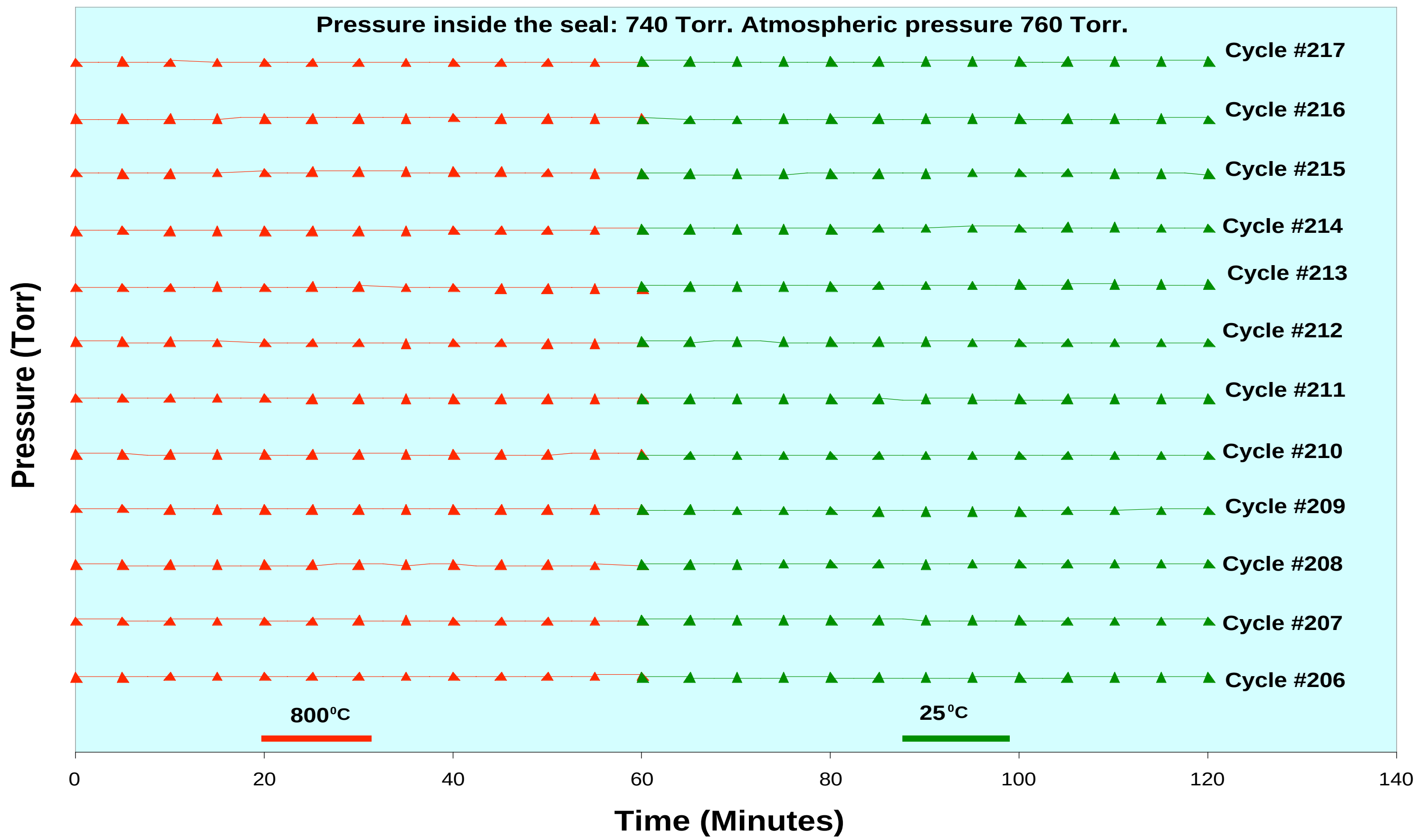
DEMONSTRATION OF SEAL DURABILITY UPON THERMAL CYCLING BETWEEN 25-800°C IN DRY FUEL



- **Hermetic behavior after 217 cycles/1700 h**

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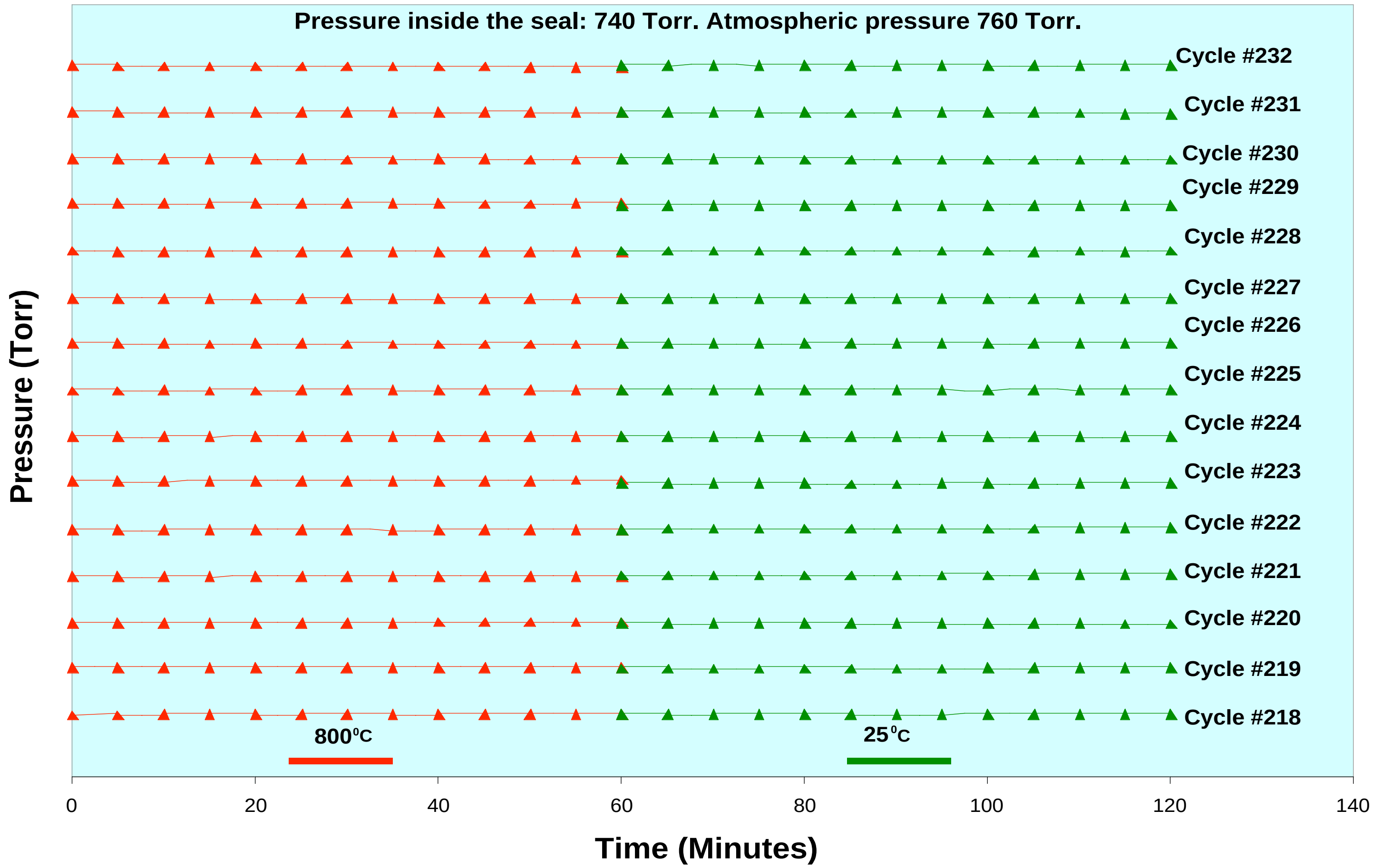
DEMONSTRATION OF SEAL DURABILITY UPON THERMAL CYCLING BETWEEN 25-800°C IN WET FUEL



- **Hermetic behavior after 232 cycles/2100 h**

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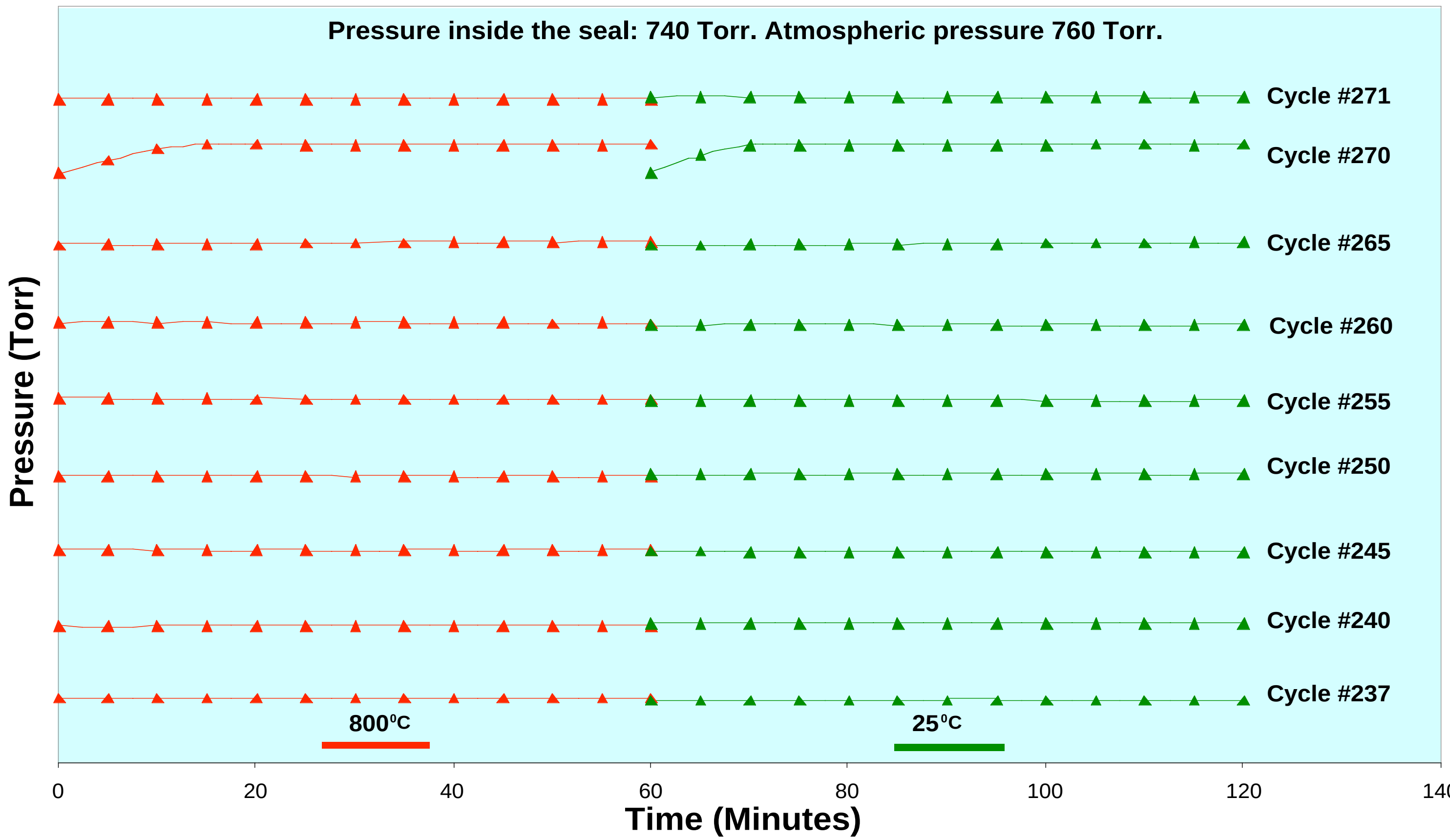
DEMONSTRATION OF SELF-HEALING ABILITY AND SEAL DURABILITY BETWEEN 25-800°C IN DUAL ATMOSPHERE



- **Self-healing in 271 cycle of leak in 270 cycle/2900 h**

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SUMMARY

- A self-healing sealing concept is developed for SOFC to satisfy significant thermochemical and thermomechanical incompatibilities among materials requiring hermetic seals.
- Seals incorporating self-healing concept were fabricated and tested under conditions prototypical of a SOFC.
- Performance of the self-healing seals for ~3000 hours and ~300 thermal cycles was demonstrated via leak tests as functions of temperature, pressure, thermal cycling, environment, and in situ self-healing.
- Long term leak test results demonstrated promise of the self-healing seals for potential applications in SOFC.

PROGRAM OBJECTIVES-Phase II

- Develop additional sealing glasses and demonstrate long-term stability
- Demonstrate toughening of glasses by fiber reinforcement
- Demonstrate seal durability of self-healing and reinforced-glasses
- Demonstrate and transition sealing technology to SECA team

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Thank You !