NIST Center for Neutron Research

# UPDATE

# Flowing Coolant Through the NIST Reactor Thermal Shield Using Vacuum Instead of Positive Pressure

TRTR/IGOR September 2010

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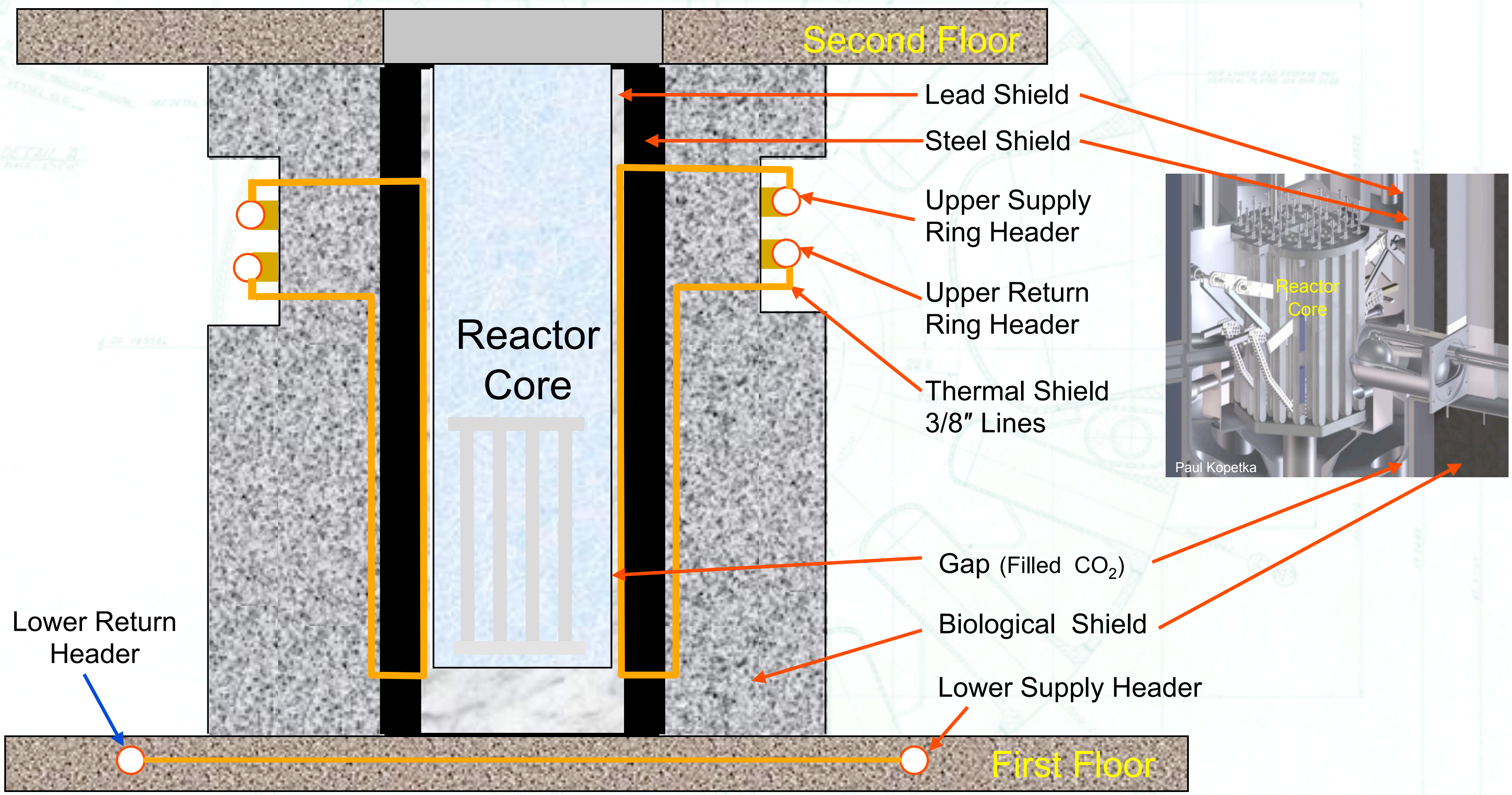
# Present System

- Function of the Thermal Shield is to limit heat production in the Biological Shield.
- Located between the Biological Shield and Reactor Core.
- It consists of 188 copper lines (9.5 mm (3/8") Inside Diameter) embedded in lead.
- Lines are attached to Supply and Return Ring Headers.
- The Headers are attached to a cooling system located below the Reactor in the Process Room.
- Working Conditions:
  - Line temperature: 38 °C (100 °F)
  - Supply Pressure: (48 to 69) kPa ((7 to 10) psi)
  - Flow: (8 to 11) L/min ((2 to 3) gpm)
- At present some line have stress cracks and leak water.

# Thermal Shield Cutaway View



# Present Coping Mechanisms

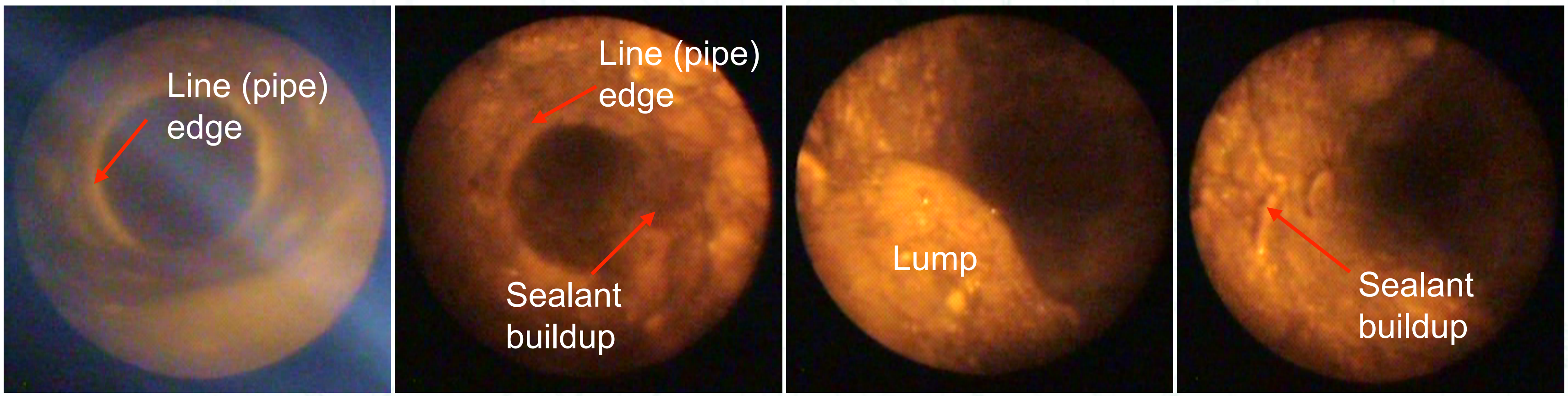
- When a leak is detected during cycle:
  - Isolate Line
  - When more than 8-in-a-row, let one line leak

- Perform repairs during shutdowns
  - Use sealant to plug holes
    - Temporary Solution: Typically 40-60 leaks per Cycle
    - Time consuming (affects shutdown duration)
    - Creates Radioactive Waste and Exposure
    - Potential Contamination of the experimental floor and its occupants
    - Risk of deterioration of functional lines (loss of flow and clogging)
    - Unknown effects on biological shield (e.g. detector wells)

# Thermal Shield Line Photos

Miniature Camera in 9.5 mm (3/8”)
inside diameter tube

Several feet into tube run

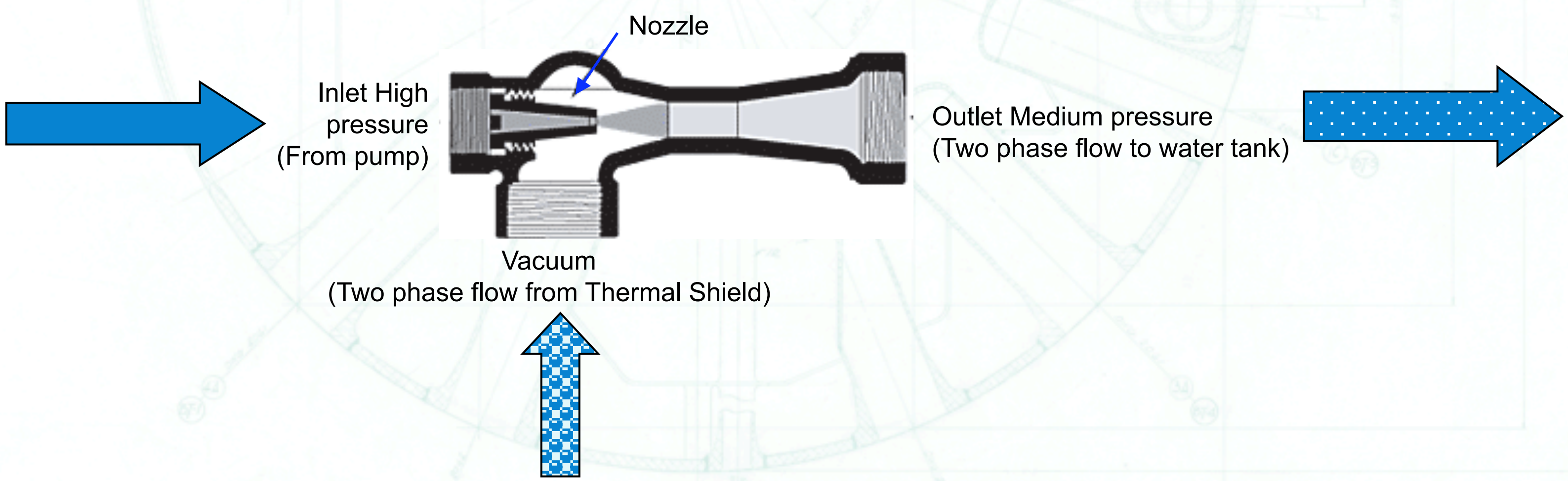


# Placing the Thermal Shield Lines under a vacuum

- **Purpose**
  - To eliminate water leakage through the various holes in the lines while lowering operator exposure (ALARA) to the activated Thermal Shield system.
  - To stabilize the lines from further worsening due to applying sealant that potentially causes decrease flow.
- **Prior Experience**
  - In the early 1960's the Australian Atomic Energy Commission, presently ANSTO, installed a vacuum system on their leaky HIFAR Shield Cooling lines. Ref. AAEC/TM133 and 149, ANSTO NTP/TN189

# Vacuum System Design

- **Design Approach**
  - Vacuum is achieved by using an eductor (i.e. jet ejector, aspirator). The eductor is a device that when a high pressure is applied to its input, a vacuum is generated from its side opening.



# Vacuum System Design

- A conservative design approach:
  - Replace the existing supply pump
  - Add eductors
  - Add a high pressure pump 690 kPa (100 psi) for the eductors.
  - Reuse the water storage tank, filter and heat exchanger

- $CO_2$ in the system
  - Surrounds the reactor vessel to decrease the formation of Argon
  - Is drawn through the holes in the lines
  - $CO_2$ solution under vacuum “boils” at low temperatures: two phase flow: higher friction: restricted flow.

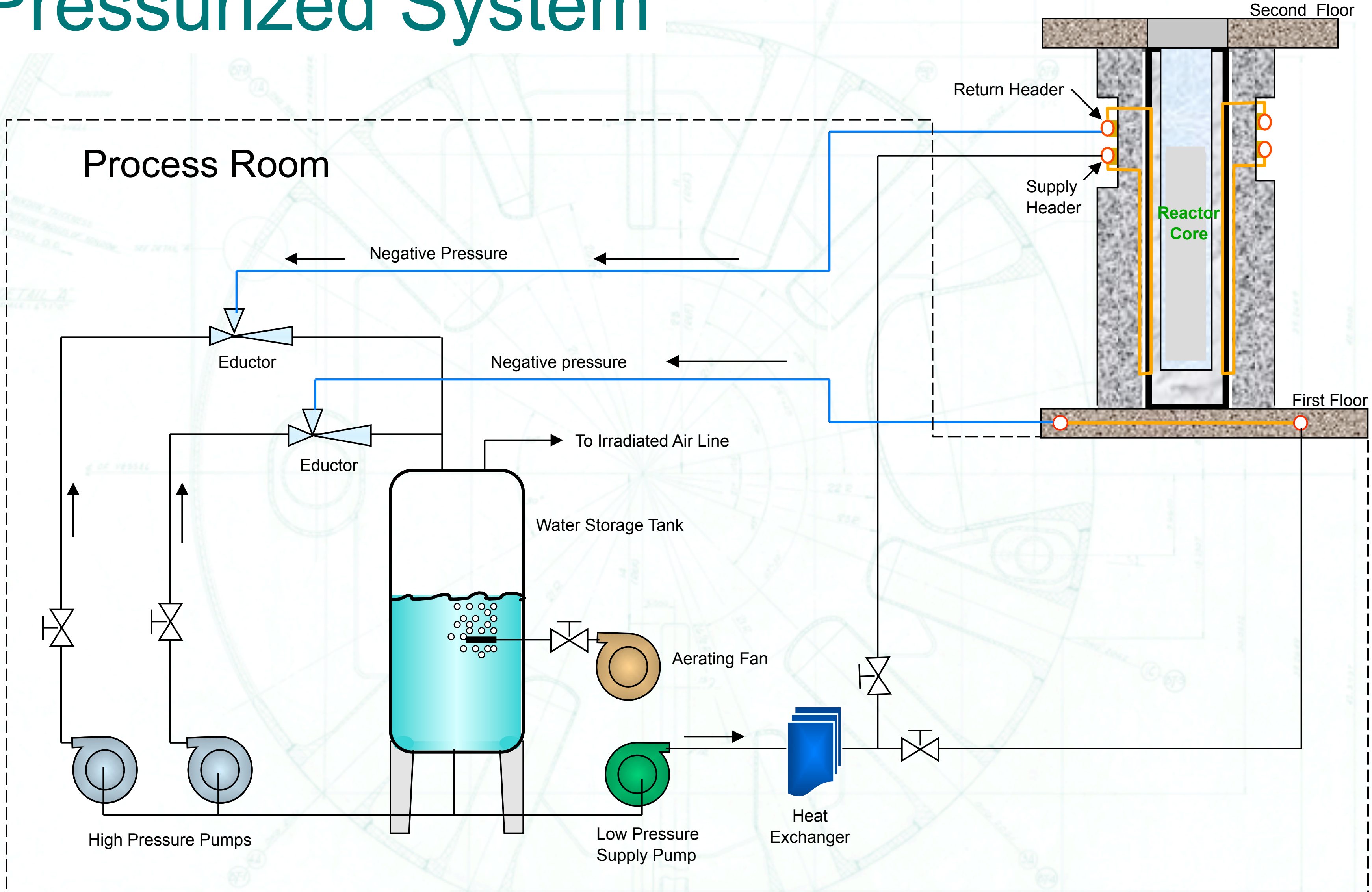
# Vacuum System Design

- Air in the system
  - Some air will be drawn in through the holes along with $CO_2$.
  - The influx of air into the system will have two effects:
    - Increases the amount of Argon that is exhausted out the stacks
      - Conservative calculations show that in the worst case condition the concentration of Argon exhausted would only increase from 2% to 2.6% of allotment.
    - Increases the pH of the water

# Vacuum System Design

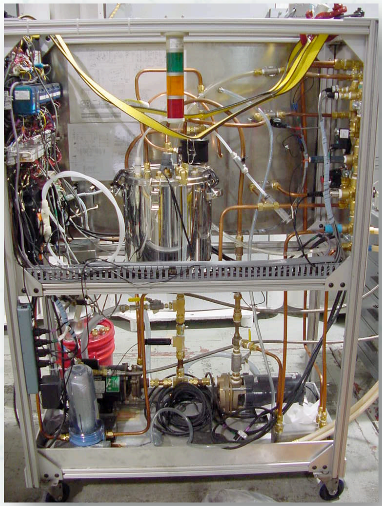
- pH compensation
  - Adding a one time dose of Magnesium Carbonate ($MgCO_3$) for pH compensation due to $CO_2$.
  - The $CO_2$ draws the pH of the water down to a pH around 5.
  - $MgCO_3$ brings the pH back up to 6.8 to 7.2
  - $^{27}Mg$ has short half life: 9.45 minutes
    - Compare $^{64}Cu$: 0.529 days = 762 minutes
  - As a pH control feature, air will also be introduced into the Water Storage Tank to mainly increase the pH of the water in the tank.

# Pressurized System



# Thermal Shield Tests

- **Testing Performed at the NCNR**
  - Single Line Test on the reactor
    - To determine:
      - Types of pollutants would be drawn through the holes
      - pH change in the cooling water due to $CO_2$
      - The amount of activity in the water under vacuum



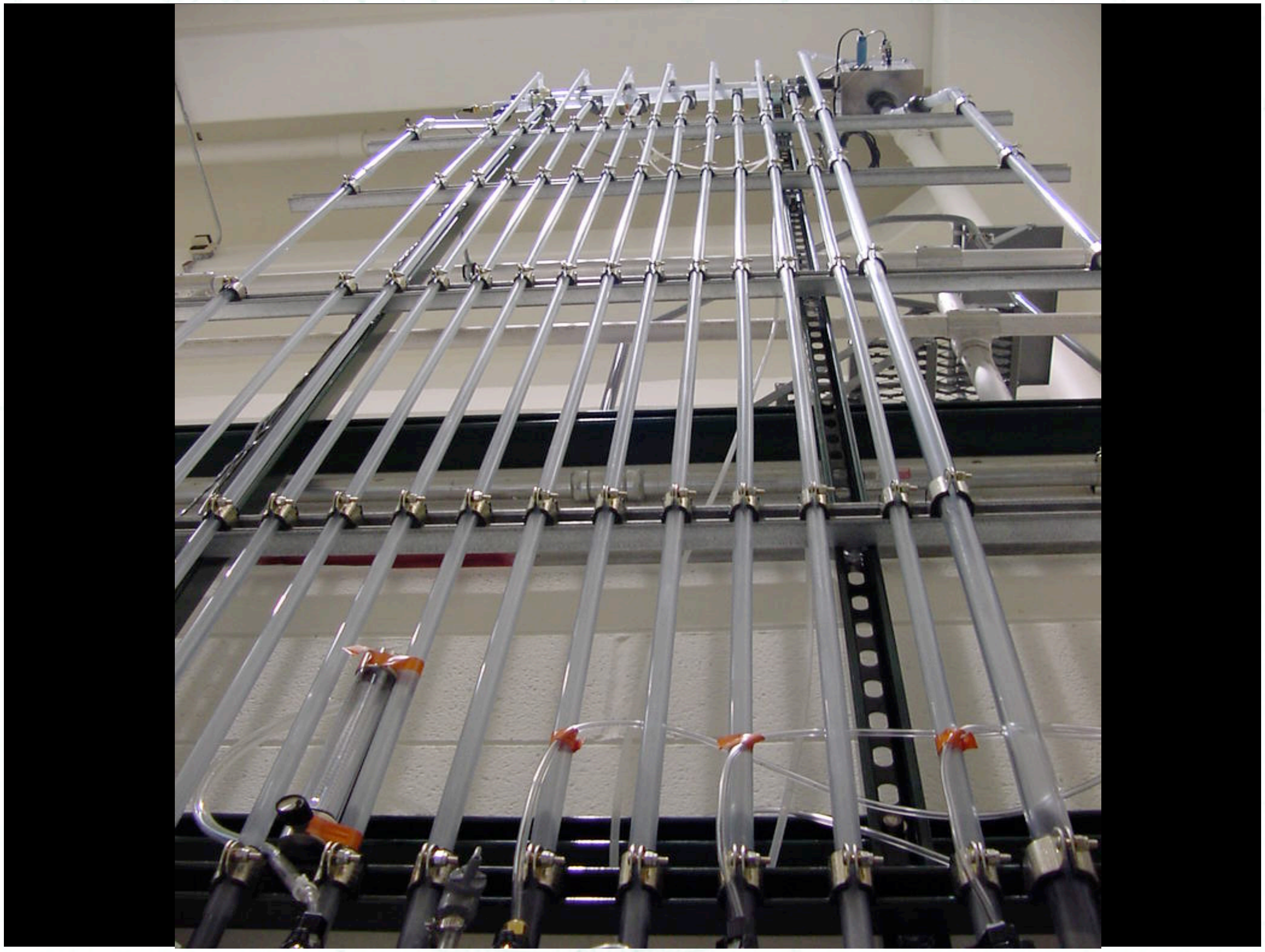
# Test Succeeded (~10 reactor cycles)

- Pumped water using Vacuum without leakage
- Neutralized Entering $CO_2$ with $MgCO_3$
- Established full control of pH ($6.5 < pH < 7.5$) through aeration
- Found no Copper Corrosion
  - Was Confirmed Independently by NIST Metallurgy
- Exposure Activation has decreased through:
  - Sealing the lines will not be necessary
  - Shielding can be placed around the headers
  - Elimination of leak water disposal

# Thermal Shield Tests

- Multi-line Test Stand
  - Standalone Test Stand built with clear tubing to mock the Thermal Shield Headers and six Lines.
  - To determine:
    - Interaction between leaky lines
    - Importance of hole location in a line
    - The data gathered was then used to help in a full system design for the actual Thermal Shield.
      - System was controllable with minimal amount of automatic equipment.

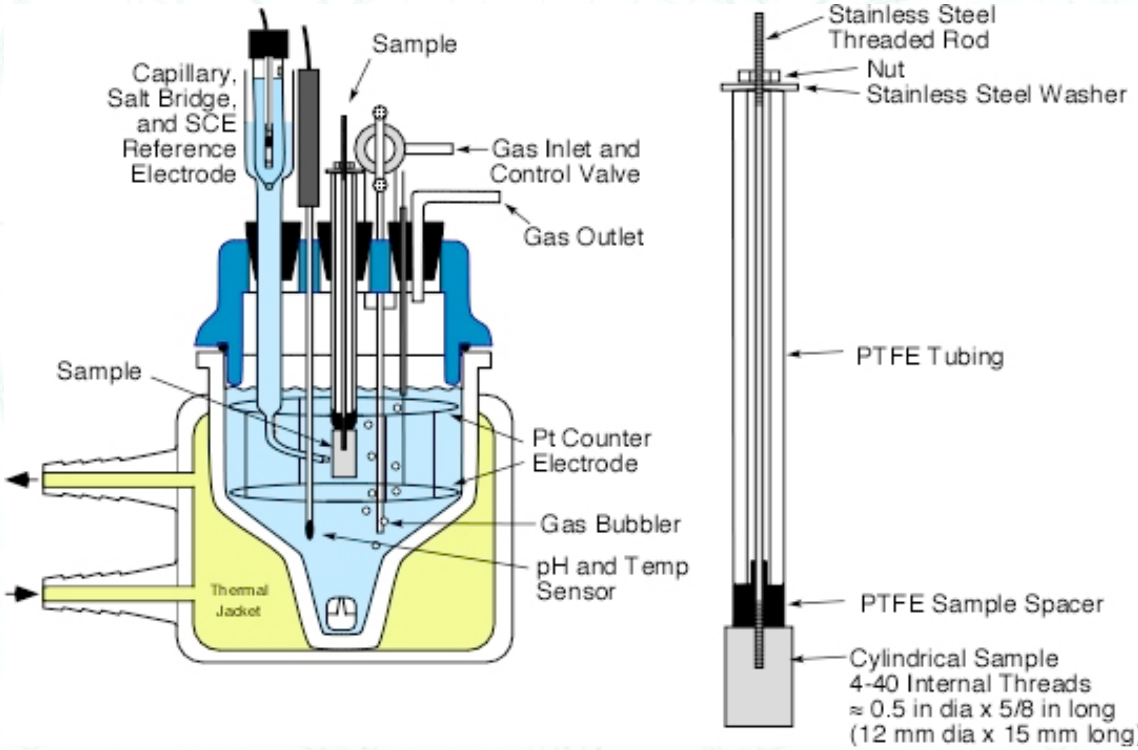
# Multi-Line Test Stand



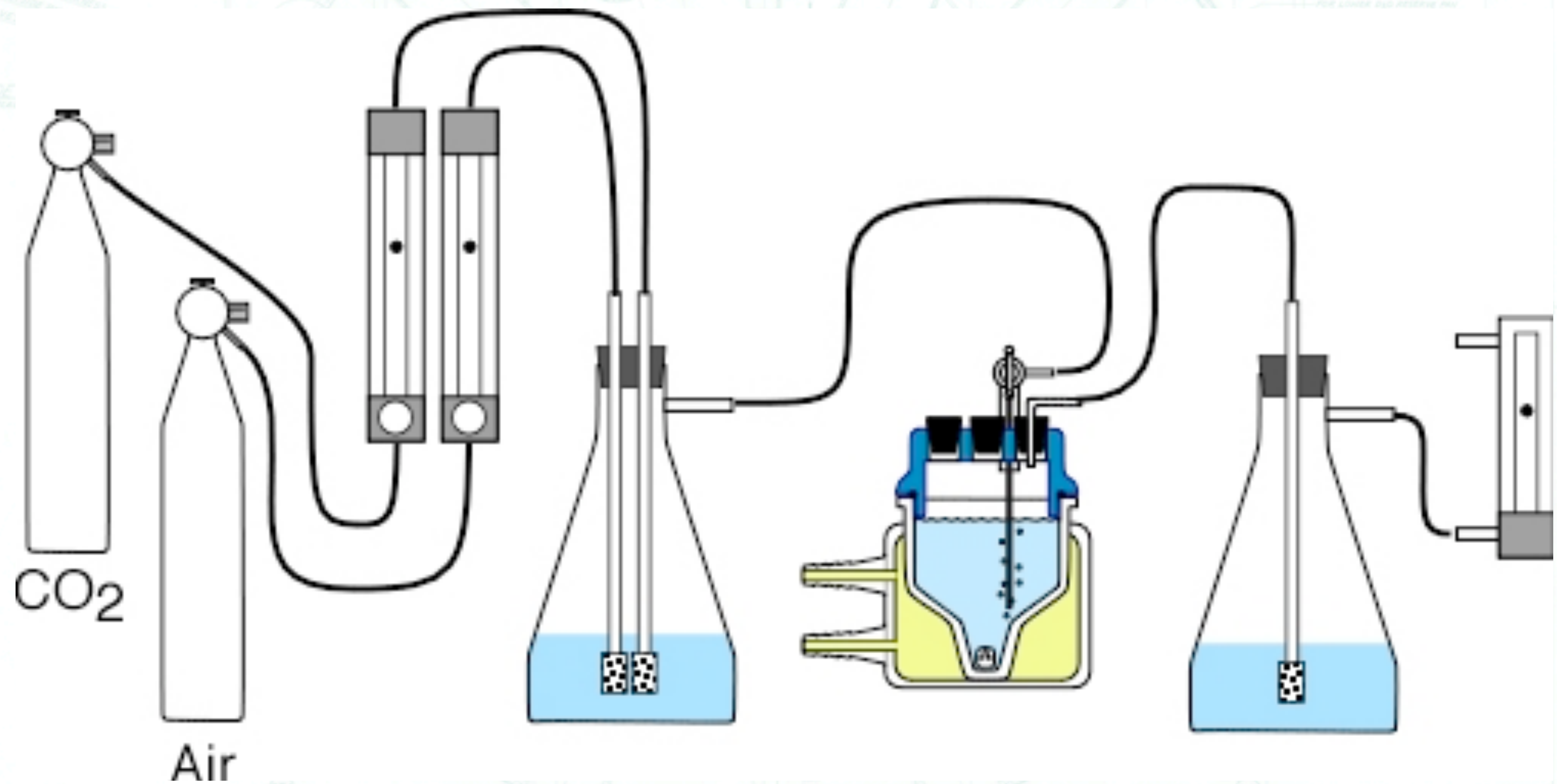
Six Line Test Stand

# Corrosion of Copper Lines

- Electrochemical Experiments
  - (Richard Ricker, Metallurgy, MSEL, NIST)



# Corrosion Cell Setup



# Projection Matrix

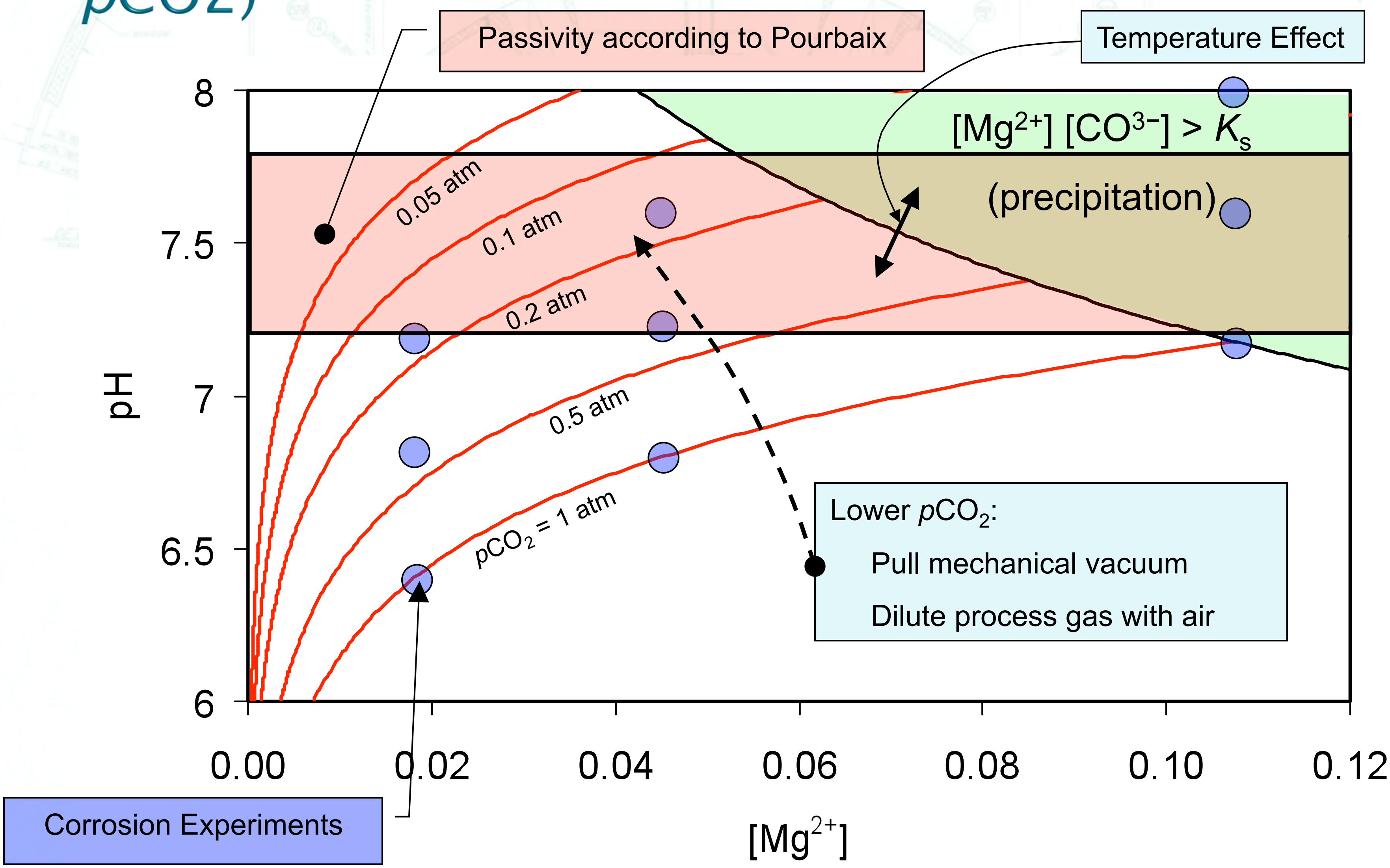
Concentrations in mol/L; pressure in atm.; grid values: Theoretical pH

| $pCO_2$ \ $[Mg^{2+}]$ | 0.018 | 0.045 | 0.113 |
|---|---|---|---|
| 0.16 | 7.2 | 7.6 | 8.0 |
| 0.40 | 6.8 | 7.2 | 7.6 |
| 1.00 | 6.4 | 6.8 | 7.2 |

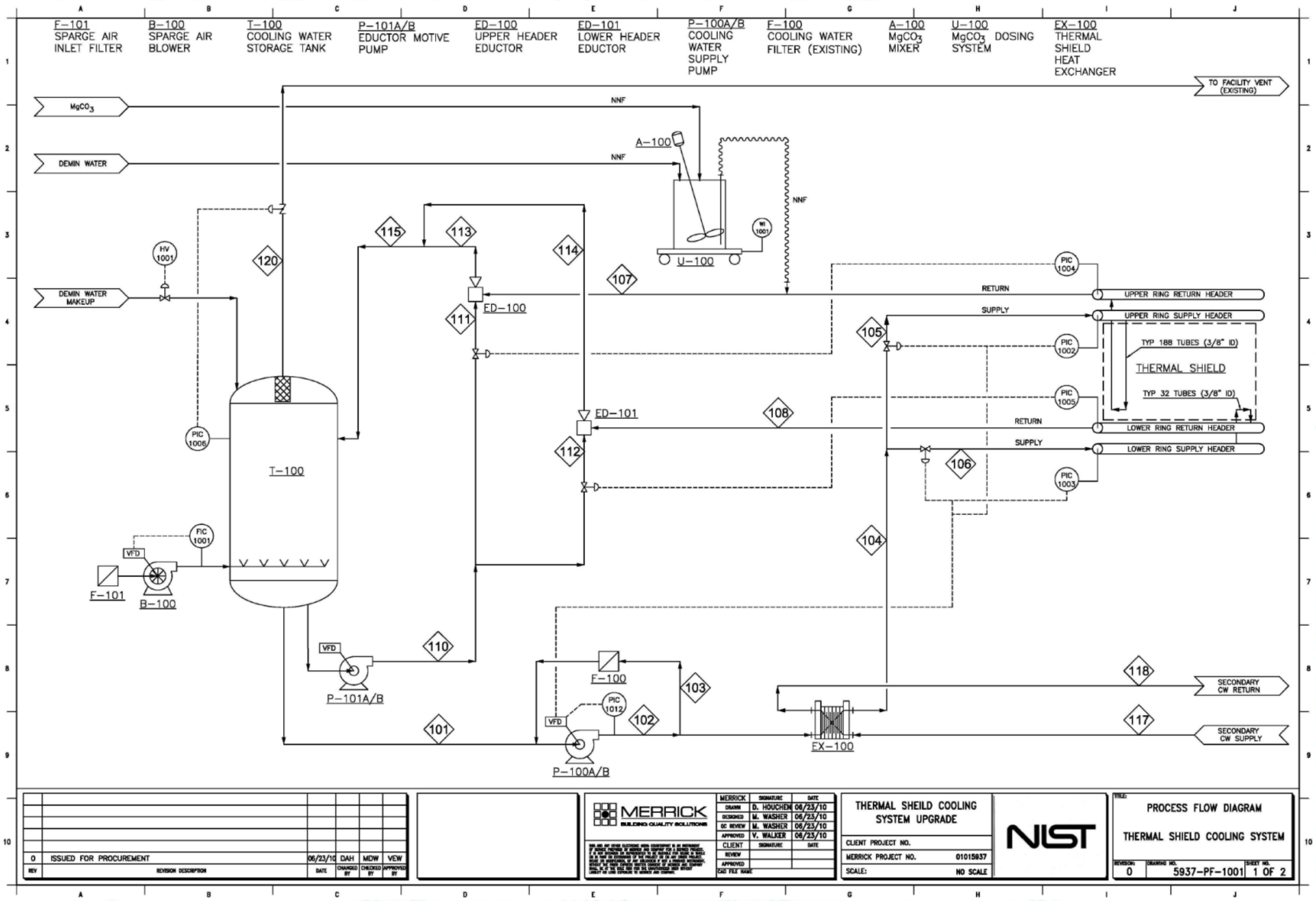
# Corrosion Test Matrix and "[H+] = $f$([$Mg^{2+}$], $pCO_2$)"

- The following figure illustrates the pH of the water as a function of the amount of $Mg^{2+}$ and partial pressure $p_{co2}$. A decrease in partial pressure, meaning an increase in vacuum, causes an increase in pH for a given amount of magnesium added to the water.
- For instance if we have 0.08 mol/L at 1 atm we get 7 pH, but at 0.5 atm we get 7.3 pH. Now solving for amount of $MgCO_3$ with 4921 L (1300 gal) of water in the tank: 84.3 g/mol x 0.08 mol/L x 4921 liters = 33187 g (73 lb.)

# Corrosion Test Matrix and "[H+] = *f* ([Mg2+], *p*CO2)"



# Process Flow Diagram

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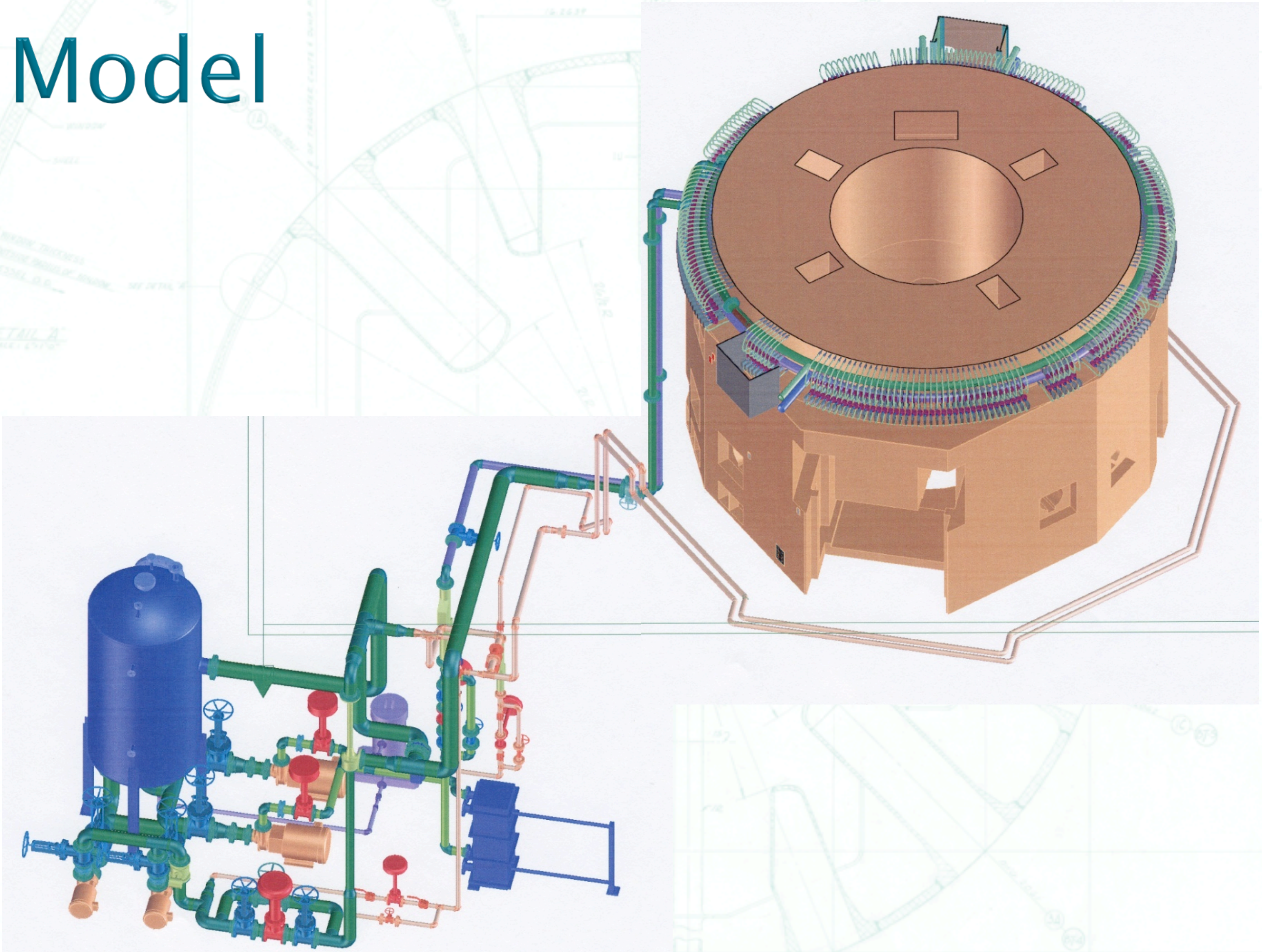
# Model



# Benefits of a Vacuum System

- No need to replace the lines
- Leakage in the line stop
- Controlled vacuum operation is feasible without damage to existing system
- Reactor operational improvement
- Very possible ALARA gains

# Follow-on

- Completed: Detail Design by Merrick & Company
- Fabrication, Installation and Training RFP: On the streets
- RFP award: Expected in September using American Recovery and Reinvestment Act (ARRA) money
- Full scale prototype will be assembled prior to full-up installation
- Full-up installation: April 2011
- Completion: Fourth quarter 2011
- NCNR Action Items
  - Engineering Change Request/Notice
  - Safety Evaluation Committee review

# NCNR Reactor