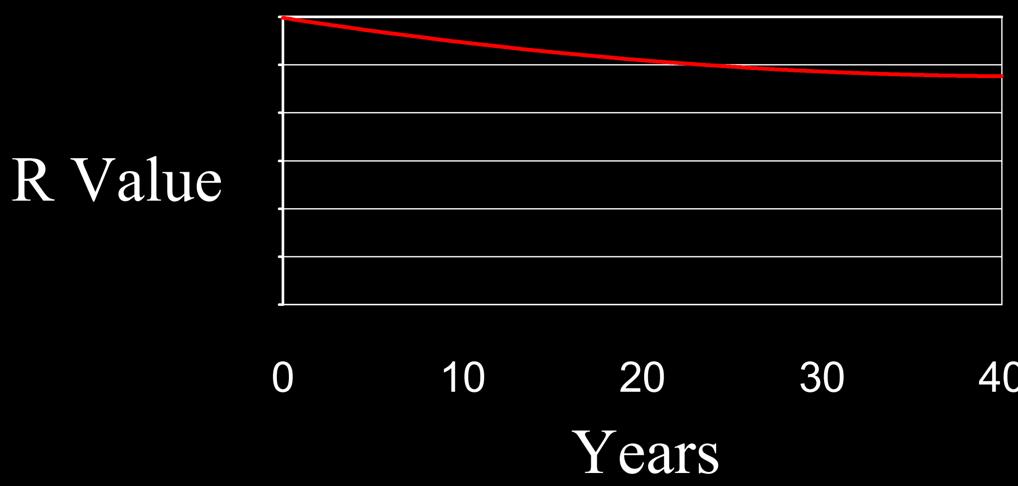
Experimental Progress In Predicting VIP Life-Long Performance

Thermal Visions
The Ultimate Insulator

Vacuum Panel Designed Life

- Vacuum panel life is not just predicted
- The panel is designed for a particular life



VIP Performance vs. Time

- Atmospheric gases such as oxygen and nitrogen permeates into the panel
- Water vapor permeates into the the panel

Focus of This Presentation

- Water vapor permeation into the VIP
  - Function of:
    - Barrier properties
    - Driving force (VIP exterior temperature and humidity)

Review of Proposed Theory

- At the last symposium in Vancouver, I proposed a theoretical model of VIP moisture environment in an appliance wall
- This presentation will cover measured temperature and humidity inside appliance walls
- First lets briefly review the theory

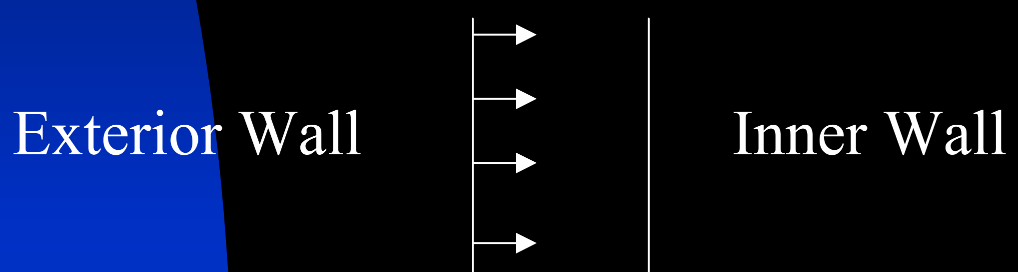
Refrigerator/freezer Application

- A first assumption is that the vacuum insulation panel is in the same environment as the exterior of the refrigerator/freezer
- I propose that this assumption is not only conservative but in error

Theory

The Special Case of a Refrigerator or Freezer

- Virtually continuous operation over its life
- The cooling system effectively provides a moisture pump to move the moisture that gets into the wall to the cold inner wall



Refrigerator/freezer

Theory

- Moisture may enter the refrigerator wall and move to the freezer inner wall
  - Coldest spot (lowest energy)
- Doors are of course handled separately

Approximate Moisture Permeance

- Permeance is a measure of the water transmission rate of a material
  - Grams of water per hour square meter, millimeter of mercury vapor pressure difference
- Or WVTR (water vapor transmission rate – grams/sq.meter Day)
- Steel* = 0 WVTR
- *Note there are penetrations
  - However, manufacturers are careful to maintain a good moisture barrier

Approximate Moisture Permeance

- Barrier film = 0.0026 WVTR
- Urethane > 5000 WVTR

What Is the Vacuum Panel Environment?

- Relative humidity and temperature
  - Vapor pressure results from both relative humidity and temperature
    - Note: temperature is still important by itself since barrier performance is a function of temperature and vapor pressure

What Is the Relative Humidity and Temperature in the Wall?

Theory

- If moisture gets into the wall it rapidly moves to the cold interior wall
- The maximum vapor pressure in the wall will be the vapor pressure of 100% relative humidity at the temperature of the cold inner wall

Vapor Pressure at 100% Relative Humidity

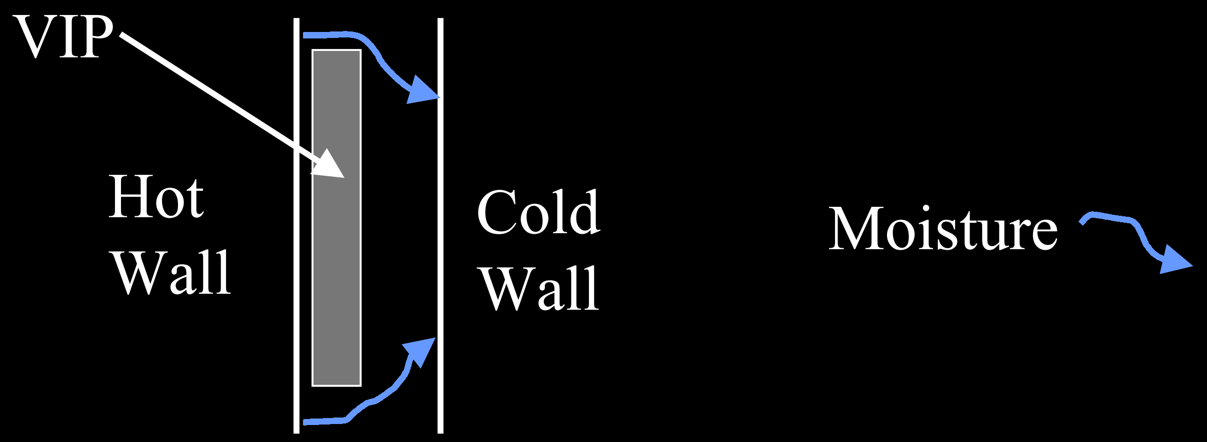
Theory

- Refrigerator at 3.3°C = 5.58 mm Hg
- Freezer at -23°C = 0.55 mm Hg
- The wall cavity will be at equilibrium with one of the above

Inside the Wall at the Hot Wall

Theory

- The vapor pressure must be equal to the cold wall
  - Result of the rapid diffusion of water through urethane foam



Inside the Wall at the Hot Wall

Theory

- A relative humidity inside the wall at the hot wall can be calculated from the vapor pressure
  - Refrigerator
    - If exterior temperature is 21.1°C, RH = 31%
    - If exterior temperature is 32.2°C, RH = 16%
  - Freezer
    - If exterior temperature is 21.1°C, RH = 3%
    - If exterior temperature is 32.2°C, RH = 1.5%

Thus, Vacuum Panel Environment for Moisture Is:

Theory

Refrigerator only

32.2°C

16 %RH

3.3°C

100% RH

Frig/Freezer if connected or Freezer only

32.2°C

1.5 % RH

-23.3°C

100% RH

Half barrier film area at hot wall condition and half at the cold wall condition

The Previous Slides Were Theory - Now What Does the Test Data Show

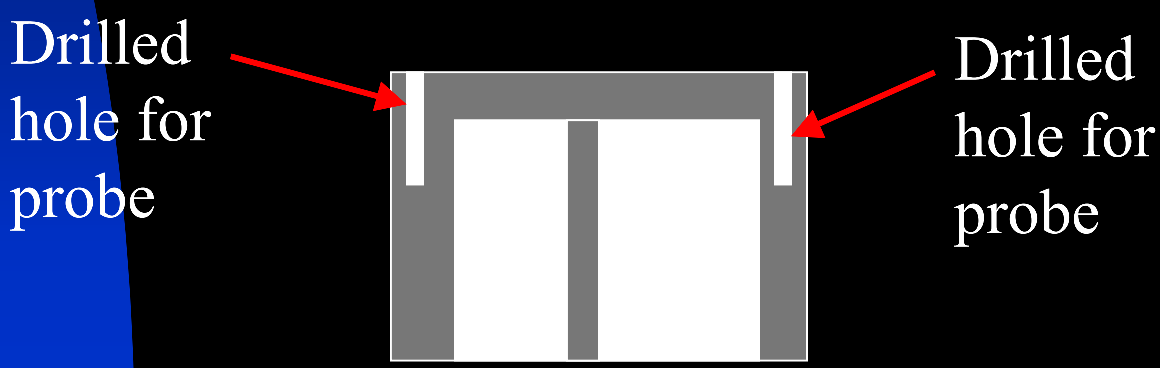
Test Unit

- Actual temperature and humidity were measured.
- Refrigerator/Freezer Test Unit
  - A 21 cubic foot (0.59 cubic meters) side by side refrigerator that had been operating in a residential house for 22 years was selected
  - Freezer wall thickness = 38 mm
  - Refrigerator wall thickness = 38 mm

Temperature and Humidity Measurement

Measurement

- A combined temperature/humidity probe was used.
- Holes were drilled into the refrigerator and freezer sidewalls from the back wall. The 9 mm holes were drilled parallel the sidewalls.



Test Results

Test Results

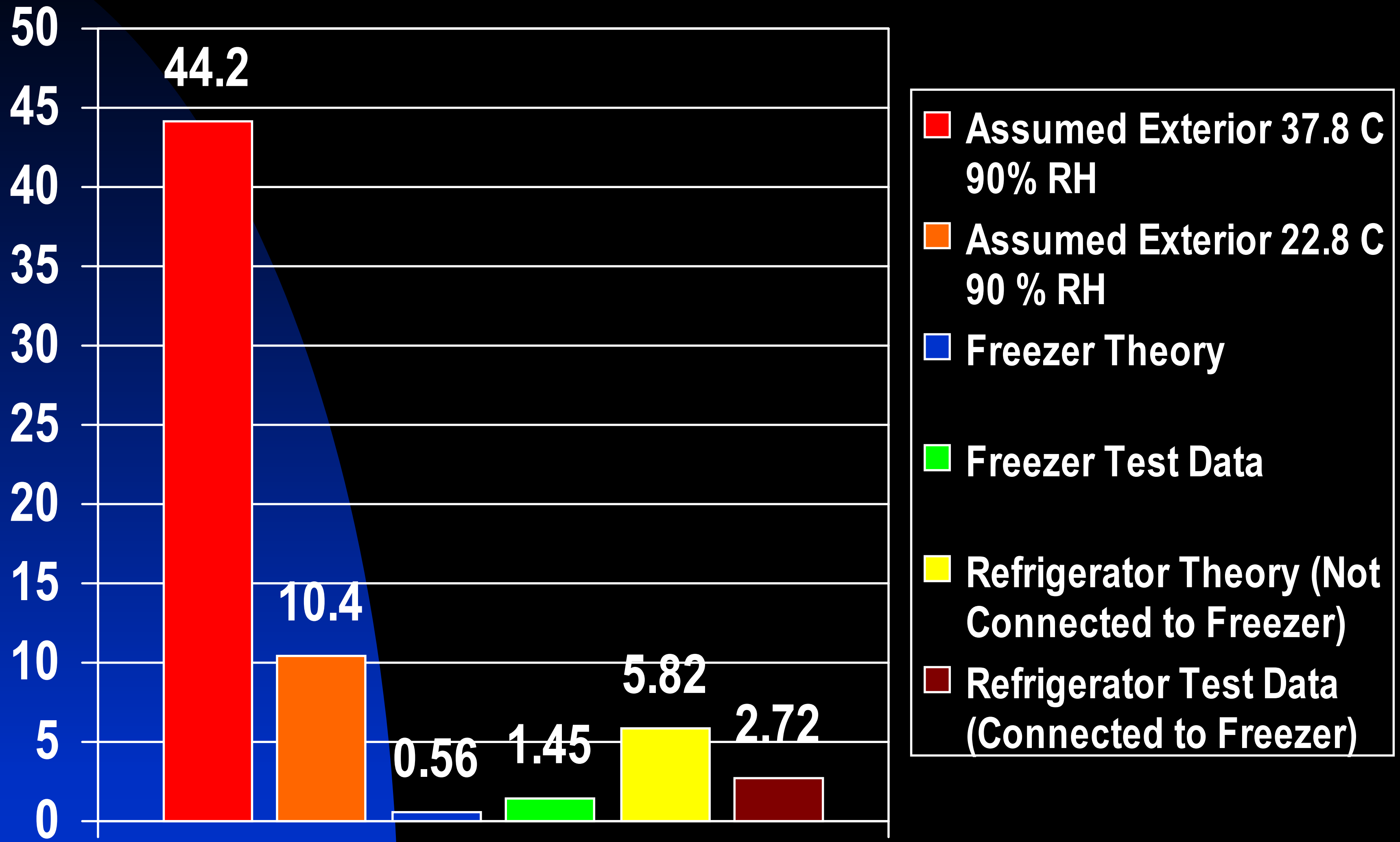
- Inside freezer wall: 8.9 C and 17% RH or vapor pressure 1.45 mm Hg

(Theory says 0.56 mm Hg)

- Inside refrigerator wall (connected to freezer): 14.4 C and 22% RH or vapor pressure 2.72 mm Hg

(Theory says same as freezer if refrigerator and freezer are connected: 0.56 mm Hg or 5.81 mm Hg if not connected)

Water Vapor Pressure (mm Hg)



Panel Environment

- Far less sever than the original assumption of the exterior room conditions
- If refrigerator is connected to the freezer, then there is less vapor pressure than a refrigerator by itself

What Does This Mean - Example

- VIP 508 x 584 x 25.4 mm
  - Metalized barrier film
  - 20 year life
  - Freezer wall
    - Requires about 5 grams of desiccant
  - Refrigerator wall connected to freezer
    - Requires about 10 grams of desiccant
  - Refrigerator wall NOT connected to freezer
    - Requires about 25 grams of desiccant

Now The Other Part of The Problem

- Moisture pickup in VIP before the appliance is turned on
  - Storage before shipment to appliance manufacturer
  - During shipment to appliance manufacturer
  - Storage before manufacture
  - Storage after manufacture
  - Shipment to distributor
  - Storage at distributor before consumer begins use

Calculation Before the Appliance is Turned On

- A bin method of calculation can be used
  - Time period selected (hour, daytime, nighttime, week, month, etc.)
  - Temperature and humidity defined for the time period
    - Climate data is available on the internet or from sources such as American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE)
  - Average water vapor pressure for each time period estimated
  - From the barrier film water vapor transmission rate versus vapor pressure: calculate required desiccant for the time period

Example – Exposure Before Appliance Is Turned On

- New Orleans, Louisiana, U.S.A. was selected as a sever location
  - Along the Gulf Coast of the United States – very hot and humid
  - Sever conditions for New Orleans were assumed

New Orleans Example

New Orleans		Vacuum Panel 508 x 584 x 25.4 mm		
May	Temperature	% RH	Vapor Pressure (mm Hg)	Grams of Desiccant
Day	29 C (84 F)	90	26.9	0.41
Night	23 C (73 F)	90	18.8	0.24
June				
Day	32 C (90 F)	90	32.5	0.55
Night	26.6 C (80 F)	90	23.6	0.34
July				
Day	33 C (92 F)	90	34.5	0.61
Night	27.8 C (82 F)	90	25.1	0.37
August				
Day	33 C (92 F)	90	34.5	0.61
Night	27.8 C (82 F)	90	25.1	0.37
September				
Day	29.4 C (85 F)	90	27.7	0.43
Night	23.9 C (75 F)	90	20.1	0.26
October				
Day	25.5 C (78 F)	90	22.1	0.30
Night	18.9 C (66 F)	90	14.7	0.17
			Total	4.66

Next Steps – Further Validation

- More temperature-humidity data in refrigerator and freezer walls should be collected
- Moisture gain in the desiccant before the unit is turn on should be collected
  - Desiccant weighed before inserted in the VIP and then appliance dissected after normal ship and storage to determine the final desiccant weight gain

Conclusions:

- The moisture environment in refrigerator and freezer walls is much less sever than the room ambient
  - Small amounts of desiccant required for very long life
- The environment and moisture pickup before the appliance is turned on should not be ignored