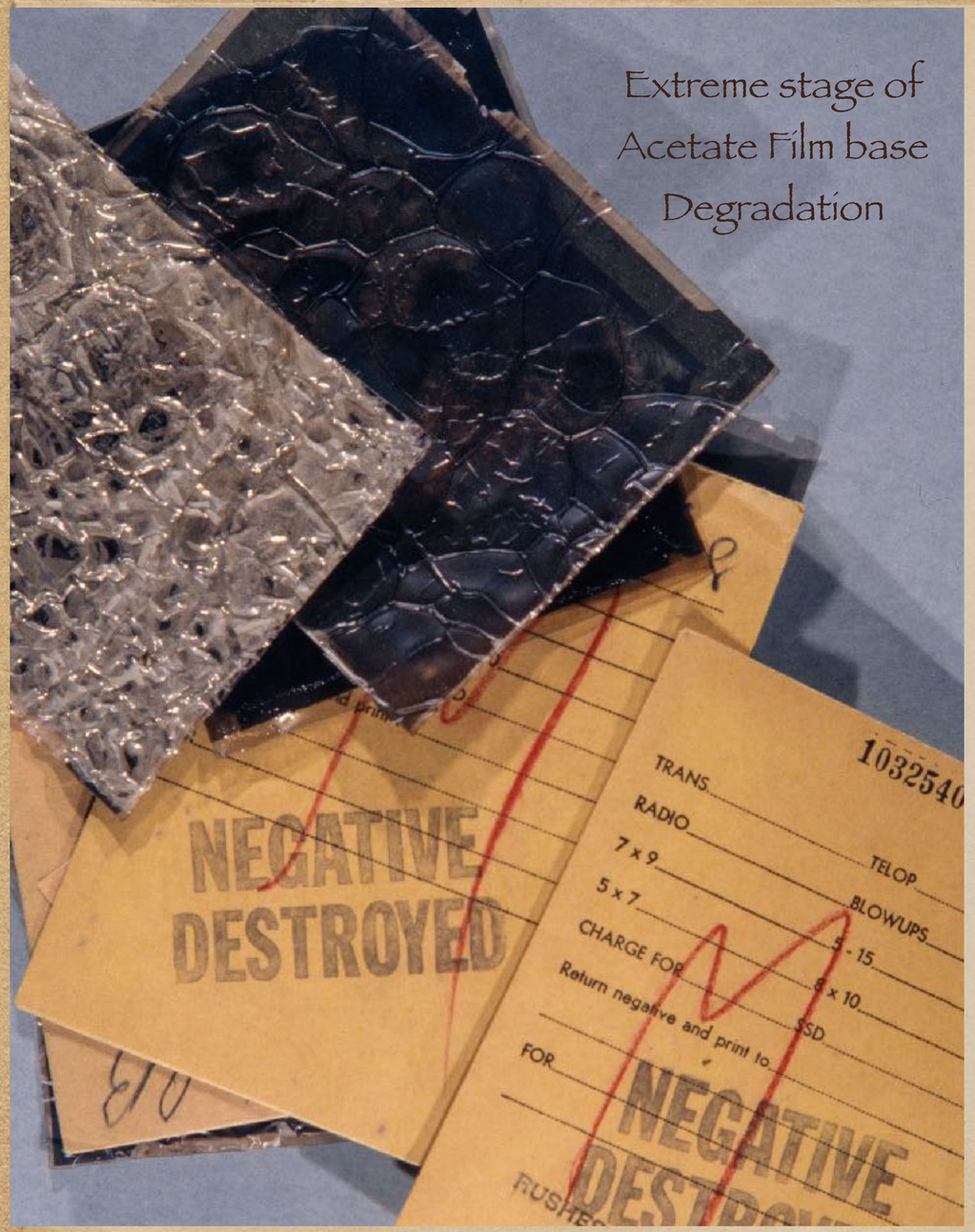
On the Cold Storage of Photographic Films, Prints, and Paper-based Collections

Two Significant Problems for 20th Century Photographic Materials

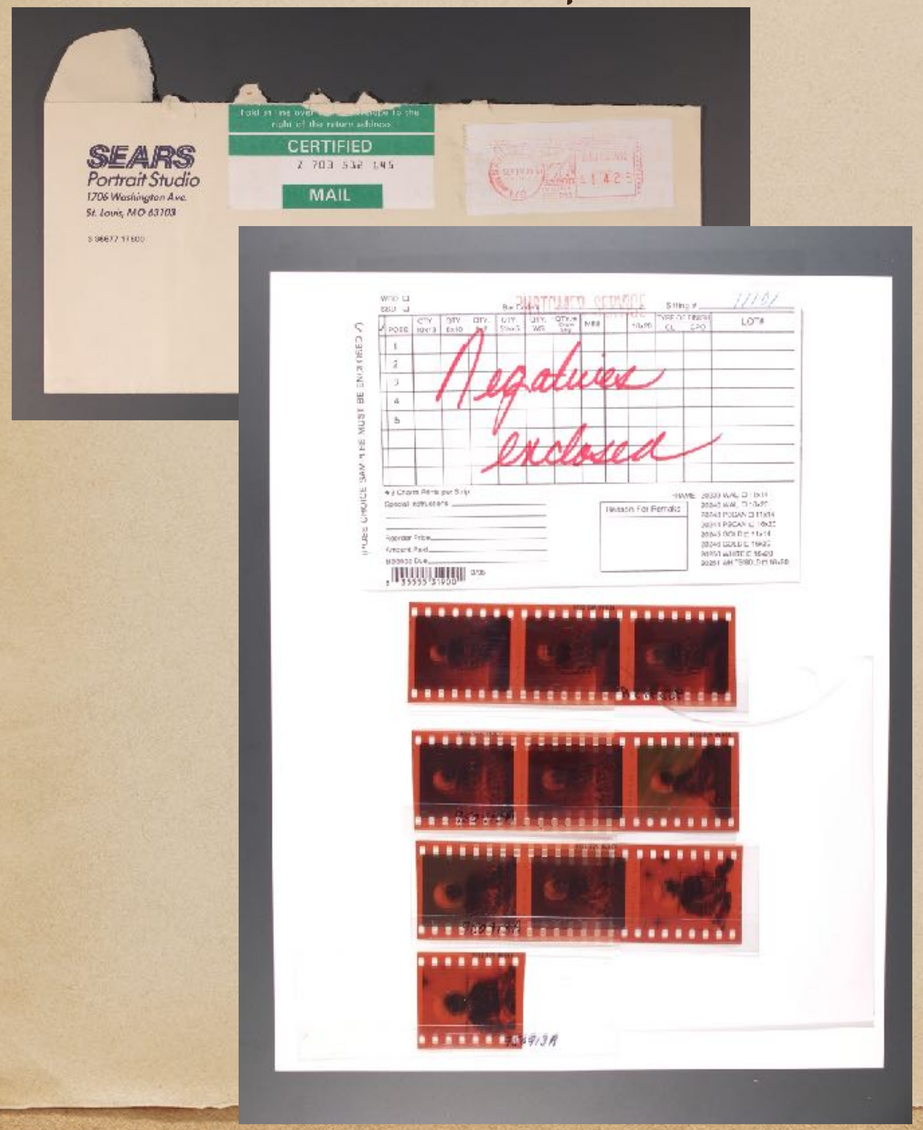
- Acetate base deterioration
- Light and Heat-induced fading and staining of color chromogenic film and print materials

Cold Storage is the only reasonable approach to address the preservation of the original artifacts

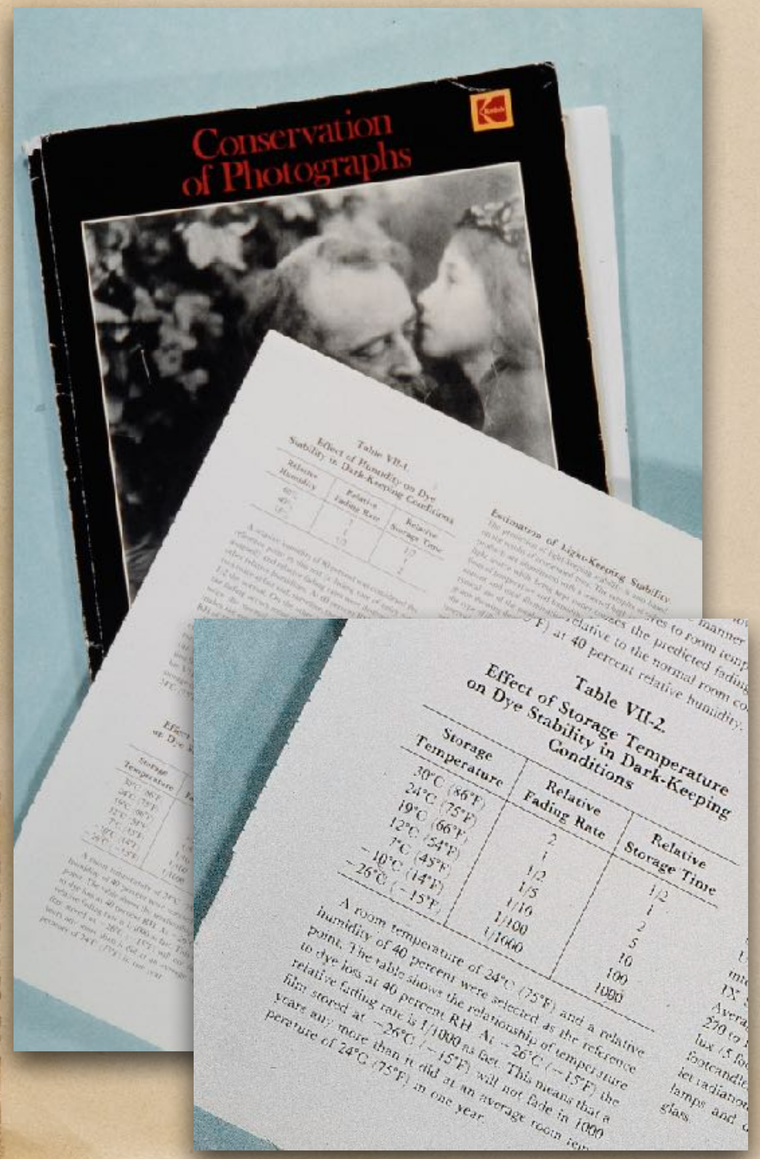


Chromogenic Color fading - this example is heat not light induced - cyan dye fades faster than magenta and yellow, so color balance shifts towards red

The Color Negative Film Process: chromogenic dyes on cellulose acetate or polyester terephthalate (PET, also called mylar, or “Estar”) base.



Color Prints: chromogenic dyes on fiber-base or resin coated (RC) color photo paper. RC paper was introduced in late 1960s and gave rise to “1 hour photo” processing in the 1970s.



Considerations

- Chemical Stability - colder and dryer slows aging rates, but..
    - "Time out of Storage" imposes practical limits on the benefits of cold storage. Collection management policies are key!
- Physical Safety - places limits on how cold, how dry, and the magnitude of allowable temperature/humidity cycling.
    - Staging - prevents temperature gradients from inducing moisture gradients humidity limits.
- Long term commitment to care
    - Curation, stewardship, chain of custody, etc., + education and training, operating manuals/guides, finding aids, etc.

Temperature is the easy part.
Cold storage is mostly about equilibrium moisture content.

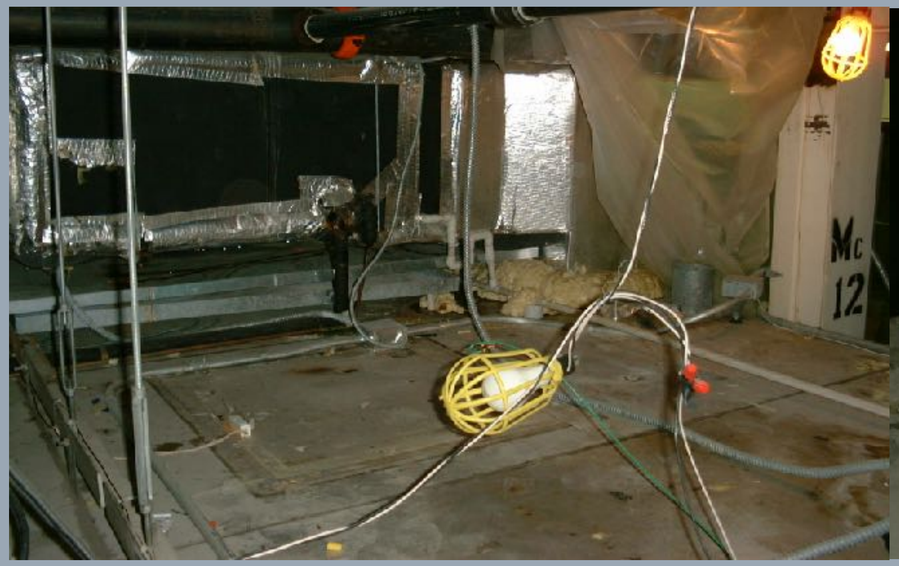
- Active humidity Control
  - Temperature/humidity conditions are achieved with HVAC systems used typically in combination with high volume desiccant dryers
    - This method is an excellent choice for large collections. It's expensive thus mainly in the purvue of larger institutions
    - Responsibility for upkeep resides primarily with facilities maintenance staff and outside contractors
- Passive humidity Control
  - Temperature/humidity conditions are achieved with conventional walk-in or reach-in freezers or refrigerators in combination with:
    - sealed cabinets
    - sealed containers
    - sealed packages
      - Metal foil bags (heat or tape sealed, typically single use).
      - CMI (critical moisture indicator) package design
- Combinations of these approaches can provide additional safety and security from equipment failures.

Large-scale, high security, actively climate-controlled cold storage.
This is an Iron Mountain® underground storage facility in Boyers, Pa.


FIRE

Actively climate-controlled cold storage vault on a smaller institutional scale.

...but maintenance was neglected



Shoddy wiring, poor insulation, a dehumidifier installed ad-hoc in an attempt to lower humidity, and worst of all, a failure of the remote-site monitoring equipment to alert staff.

Mould

Corrosion

Water damage

"Ferrotyping"

Freezer Storage (-20°C) using Passively Climate-controlled Gasket-sealed Museum Storage Cabinets

First of its kind in 1999, this subzero cold storage project implemented sealed cabinets with passive humidity control. The research was conducted at Wilhelm Imaging Research, Inc. and funded by the Smithsonian Institution .

"All the News That's Fit to Print"

The New York Times

National Edition

Midwest: A few clouds in the northern Great Lakes area. Highs from the upper 60's in the northern Great Lakes to the mid-80's in the central Plains. Weather map is on Page A22.

VOL. CL . . . . No. 51,873 | Copyright © 2001 The New York Times | TUESDAY, SEPTEMBER 11, 2001 | Printed in Chicago | ONE DOLLAR

The Show Outside the Shows

Designer graffiti by Stephen Sprouse splashes over the entrance to New York Fashion Week tents in Bryant Park. Fashion reviews, Pages A23-24.

Angel Franco/The New York Times

Scientists Urge Bigger Supply Of Stem Cells

Report Backs Cloning to Create New Lines

By SHERYL GAY STOLBERG

WASHINGTON, Sept. 10 — A panel of scientific experts has concluded that new colonies, or lines, of human embryonic stem cells will be necessary if the science is to advance, a finding that is likely to inflame the political debate over President Bush's decision to restrict federally financed research to the 64 stem cell lines that are already known to exist.

In a 59-page report that examines the state of human stem cell science, the panel also endorsed the use of cloning technology to create new stem cells that could be used to treat patients. Mr. Bush strongly opposes human cloning for any reason, and the House of Representatives voted in July to outlaw any type of cloning, whether for reproduction or research.

The report by the National Academy of Sciences, perhaps the nation's most eminent organization of scientists, is scheduled to be made public on Tuesday morning at a news conference in Washington. It does not address Mr. Bush's policy directly, though it strongly supports federal financing for stem cell research.

"High quality, publicly funded research is the wellspring of medical breakthroughs," said the report, a copy of which was provided to The New York Times by Congressional supporters of stem cell research. It added that federal financing, and the government oversight that comes with it, "offers the most efficient and responsible means of fulfilling the promise of stem cells to meet the need for regenerative medical therapies."

Though the academy often issues its reports in response to requests from the government, it embarked on this study on its own earlier this year. Indeed, the report was written and reviewed before Mr. Bush an-

KEY LEADERS TALK OF POSSIBLE DEALS TO REDUCE TAXES

BUSH IS UNDER PRESSURE

Compromise May Temporarily Tap Into Social Security — Lott Open to More Cuts

By ALISON MITCHELL and RICHARD W. STEVENSON

WASHINGTON, Sept. 10 — Key figures in both parties responded to the darkening economic outlook today by exploring possible compromises on additional tax cuts, and the Democratic chairman of the Senate Budget Committee suggested that such a deal could involve the politically perilous step of tapping temporarily into the Social Security surplus.

Pressure mounted on President Bush to drop his cautious approach to dealing with the weakening economy, much of it from within his own party. Republicans are voicing growing concern that the White House has underestimated public unease about the economy and the threat it poses to members of Congress up for re-election next year.

Confronted with polls showing that support for Republicans was eroding even before the government reported on Friday that the unemployment rate had surged, nervous Republicans moved on a variety of fronts.

In the House, Republican leaders agreed tonight to take up legislation in committee on Tuesday that would require automatic spending cuts if any Social Security money is spent on other government programs in the current fiscal year.

After accounting for the slowing economy and the tax cut signed into law by Mr. Bush in June, the Congressional Budget Office projected last month that the government would spend $9 billion of Social Secu-

Nuclear Booty: More Smugglers Use Asia Route

By DOUGLAS FRANTZ

ISTANBUL, Sept. 10 — The police in Batumi, a Black Sea port in Georgia, heard a rumor in July that someone wanted to sell several pounds of high-grade uranium for $100,000. The most tantalizing aspect of the tip was that one of the sellers was reportedly

In a Nation of Early Risers, Morning TV Is a Hot Market

By BILL CARTER

How much morning television can one nation watch?

Ever since the owlish Dave Garroway ambled through the "Today" program on NBC starting in 1952, sometimes accompanied by a chimpanzee, television screens have greeted awakening Americans with the combination of hard news, feature reports and soft celebrity interviews

CNN's owner, AOL Time Warner, and Fox's owner, the News Corporation.

That a cable network is willing to take on the broadcast networks' monopoly over national morning programs is evidence of how far the morning genre has come. The decision reflects the seismic shift that

Violence in Mideast Despite Plans to Talk

Israeli and Palestinian leaders settled on a date for long-deferred truce talks — today. But that did not stop them from continuing their all-but-declared war.

Two Israeli soldiers were slain before dawn today by Palestinian snipers near the heavily fortified checkpoint separating the Palestinian town of Tulkarm from Israel.

Shortly afterward, Israeli tanks began shelling Palestinian positions

"All the News That's Fit to Print"

The New York Times

National Edition

Midwest: Partly to mostly sunny in southern lakes and Plains. Abundant sunshine in Missouri and Ohio Valleys. Isolated showers in upper Missouri Valley. Weather map, Page C19.

Wilhelm

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U.S. ATTACKED

HIJACKED JETS DESTROY TWIN TOWERS AND HIT PENTAGON IN DAY OF TERROR

A CREEPING HORROR

Buildings Burn and Fall as Onlookers Search for Elusive Safety

By N. R. KLEINFIELD

It kept getting worse.

The horror arrived in episodic bursts of chilling disbelief, signified first by trembling floors, sharp eruptions, cracked windows. There was the actual unfathomable realization of a gaping, flaming hole in first one of the tall towers, and then the same thing all over again in its twin. There was the merciless sight of bodies helplessly tumbling out, some of them in flames.

Finally, the mighty towers themselves were reduced to nothing. Dense plumes of smoke raced through the downtown avenues, coursing between the buildings, shaped like tornadoes on their sides.

Every sound was cause for alarm. A plane appeared overhead. Was another one coming? No, it was a fighter jet. But was it friend or enemy? People scrambled for their lives, but they didn't know where to go. Should they go north, south, east, west? Stay outside, go indoors? People hid beneath cars and each other. Some contemplated jumping into the river.

For those trying to flee the very epicenter of the collapsing World Trade Center towers, the most horrid thought of all finally dawned on

President Vows to Exact Punishment for 'Evil'

By SERGE SCHMEMANN

Hijackers rammed jetliners into each of New York's World Trade Center towers yesterday, toppling both in a hellish storm of ash, glass, smoke and leaping victims, while a third jetliner crashed into the Pentagon in Virginia. There was no official count, but President Bush said thousands had perished, and in the immediate aftermath the calamity was already being ranked the worst and most audacious terror attack in American history.

The attacks seemed carefully coordinated. The hijacked planes were all en route to California, and therefore gorged with fuel, and their departures were spaced within an hour and 40 minutes. The first, American Airlines Flight 11, a Boeing 767 out of Boston for Los Angeles, crashed into the north tower at 8:48 a.m. Eighteen minutes later, United Airlines Flight 175, also headed from Boston to Los Angeles, plowed into the south tower.

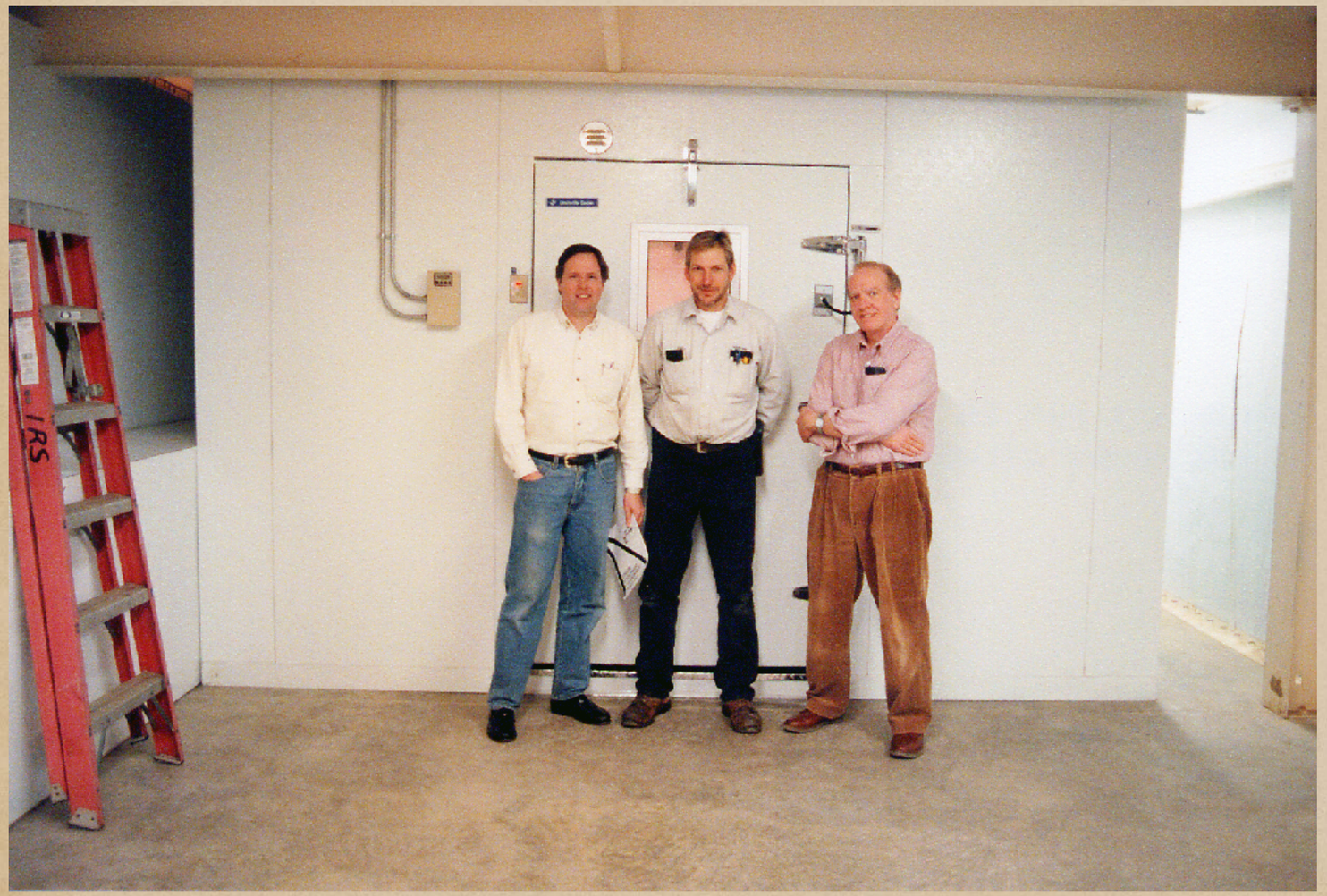
Then an American Airlines Boeing 757 left Washington's Dulles International Airport bound for Los Angeles, but instead hit the western part of the Pentagon, the military headquarters where 24,000 people work, at 9:40 a.m. Finally, United Airlines Flight 93, a Boeing 757 flying from Newark to San Francisco, crashed near Pittsburgh, raising the possibility that its hijackers had failed in whatever their mission was.

Kelly Guenther for The New York Times

SECOND PLANE United Airlines Flight 175 nearing the trade center's south tower.

In all, 266 people perished in the four planes and several score more were known dead elsewhere. Numerous firefighters, police

Freezer Storage (-20°C) using Passively Climate-controlled Gasket-sealed Museum Storage Cabinets



Construction and Installation

Freezer Storage (-20°C) using Passively Climate-controlled Gasket-sealed Museum Storage Cabinets

Construction and Installation

The Design and Operation of a Passive Humidity-Controlled Cold Storage Vault Using Conventional Freezer Technology and Moisture-Sealed Cabinets

Mark McCormick-Goodhart and Henry Wilhelm
Wilhelm Imaging Research, Inc., Grinnell, Iowa/USA

Presented at the IS&T Archiving Conference, San Antonio, Texas, April 22, 2004

Acknowledgements: We wish to thank the Smithsonian Institution, Washington, D.C., for sponsoring this research project. We also thank Delta Designs Ltd., Steel Fixture Manufacturing Company, and Viking Metal Cabinet Company for kindly donating cabinets.

Begin Construction...

Construction...

Walk-in freezers are readily available due to their wide-spread use in the food industry. Modular construction allows quick assembly. Site preparation for our project was minimal. We checked with the contractor to determine whether a heated slab would be needed under the freezer to prevent frost heaving. Because our vault was located in a fully heated building and away from the outer walls, the heated slab was not necessary.

...Time to Complete — 4 days

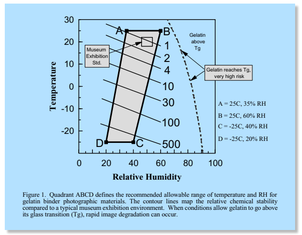
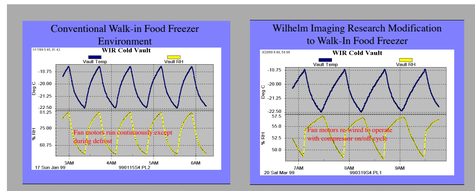


Figure 1. Quadrant ABCD defines the recommended allowable range of temperature and RH for gelatin binder photographic materials. The contour lines map the relative chemical stability compared to a typical museum exhibition environment. When conditions allow gelatin to go above its glass transition (Tg), rapid image degradation can occur.

The sealed cabinet method takes advantage of the natural thermodynamic properties of hygroscopic materials such as gelatin and paper to keep the climate inside the cabinets within the safe, allowable range as shown in the figure above. For more information about this topic please read the paper entitled: "The Allowable Temperature and Relative Humidity Range for the Safe Use and Storage of Photographic Materials," *Journal of the Society of Archivists*, Vol. 17, No. 1, 1996. It is available for free on our website: <wilhelm-research.com>



A minor wiring change enabled the fans to run only when the compressor runs, resulting in lower RH.

Freezer modifications...

Cabinet Installation...

The dimensions of the vault were planned so that cabinets would fit through the door, and equally important, could be erected vertically once inside the vault. Note the 4 to 6 inch clearance left between the cabinets and the inside wall of the vault (see photo on the far right). This gap improved air circulation and cabinet temperature uniformity.

...Time to Complete — 1 day

Cabinet modifications, methods, and experiments...

Only minor changes were needed to use the cabinets manufactured by Viking Metal Cabinet Company. Moisture vapor transmission studies showed that the key holes were a significant leak! They were easily covered using metal foil tape or readily obtainable vinyl magnetic signage material. The other cabinets required extensive modifications including silicone caulking, replacement of door gaskets, and covering vent holes. We installed cobaltous chloride indicator plugs in each cabinet for simple and quick observation of cabinet interior relative humidity. We also installed electronic temperature and RH sensors in each cabinet with wiring routed to data loggers located on the outer wall of the vault. This setup allowed real time precision monitoring of cabinet performance. Additionally, we lined the cabinets with conservation mat board to create a satisfactory moisture buffer for cabinets which contain only a small amount of collection material.

Bringing objects safely in and out of the vault was accomplished by thermally insulated transfer boxes. Shown above is one that was made from an ordinary picnic cooler. A radio transmitting temperature sensor (available at RadioShack® for less than $40.00) is a simple way to determine when the box may be safely opened. We conducted thermal staging experiments to prove the safety and efficacy of the method.

Lastly, we conducted a simulated power or equipment failure test to prove that the cabinets will protect the collection and will warm safely in the event of a vault failure. This test demonstrated that over time, small amounts of moisture accumulating in the panel seams will condense and cause some water droplets to fall from the ceiling. The cabinets easily protected the collection from this failure mode. The problem can likely be eliminated or greatly reduced by sealing the panel seams with metal foil tape on the outer surface of the walls.

Over four years of trouble-free operation, $1.46/day energy costs!

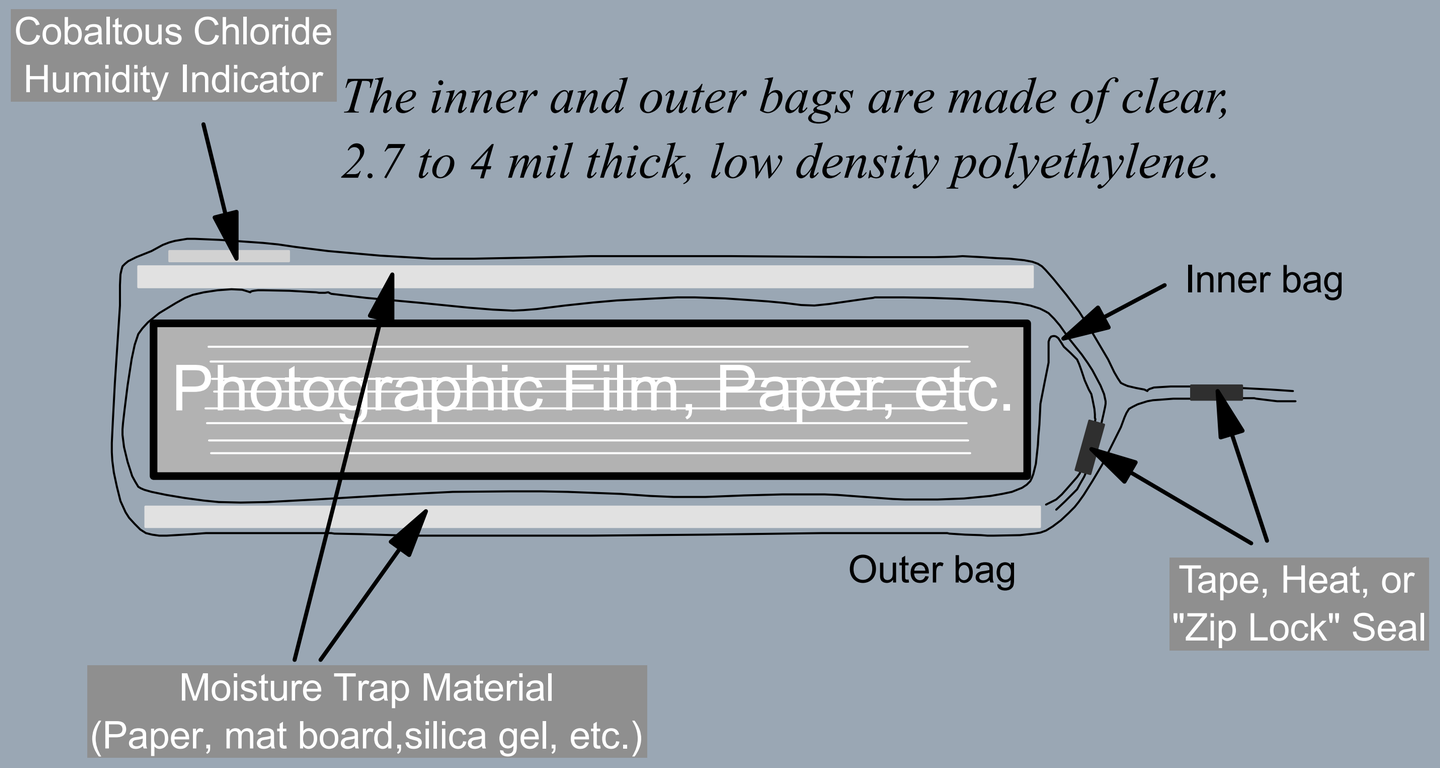
PDF version of this poster is available at: http://www.wilhelm-research.com/subzero/WIR_ISTposter2004_04MMG_HWh.pdf

-My personal family archive (over 12,000 images)-
Freezer #1 has been running since 1993 and contains 56 packages with drop-front box critical moisture indicator (CMI) design

Box_#8 humidity indicator reveals slightly higher moisture content because it was recently accessed without reconditioning the package before return to freezer.

Safe &Verifiable Package Design for Freezer Storage of Photo Materials

The inner and outer bags are made of clear, 2.7 to 4 mil thick, low density polyethylene.



Smithsonian Institution
Washington, D.C.

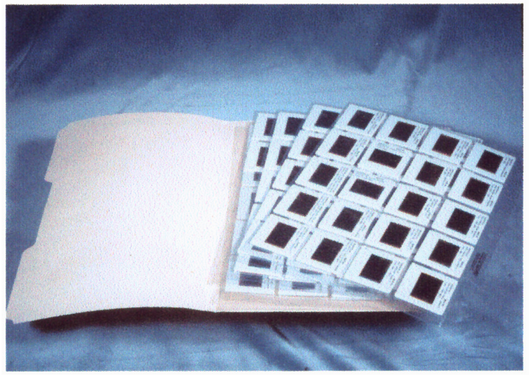
Shelf life Equation

$$t = \frac{m_D \Delta a'}{100 P_w}\left[\frac{X_k - X_0}{a_{wk} - a_{w0}}\right] 2.303 \log\left[\frac{a_{wa} - a_{w0}}{a_{wa} - a_{wk}}\right]$$

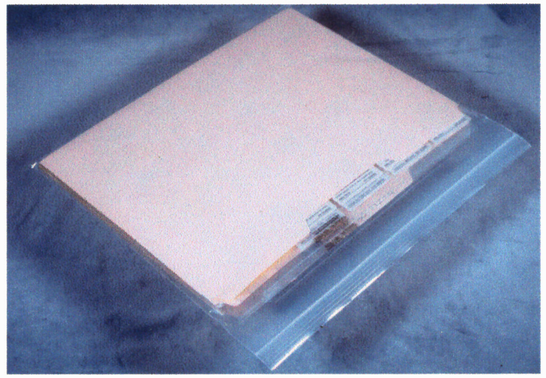
Download article at: https://www.aardenburg-imaging.com/wp-content/uploads/2015/11/Aal_2007_1206_TA-02.pdf

CMI Package Design

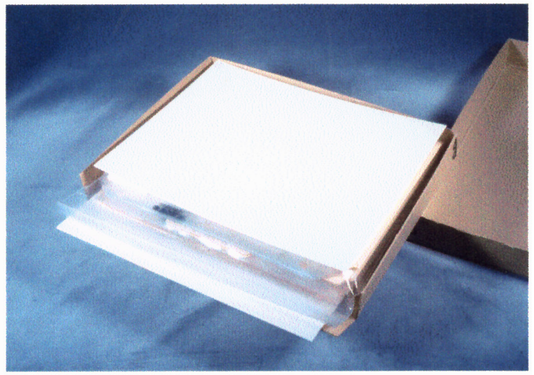
Drop-front Conservation Box Style



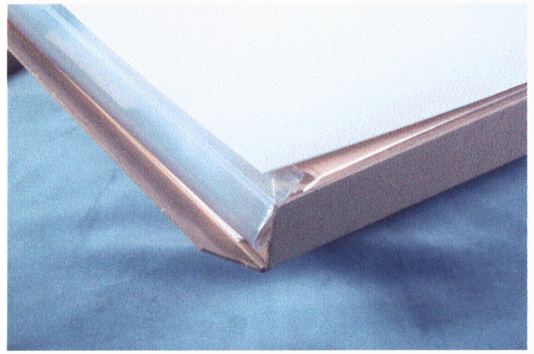
1. Photo materials are placed in standard-format plastic enclosures.



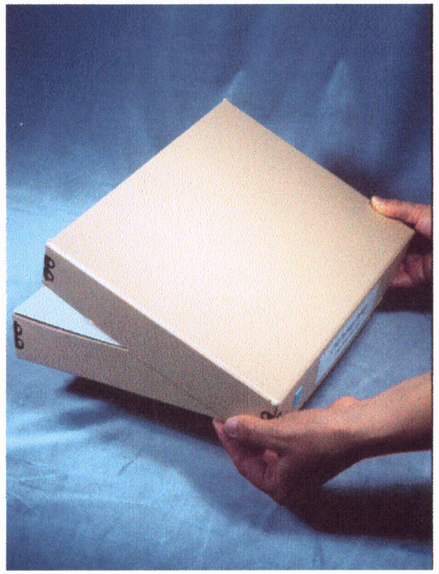
2. Enclosures and file folders are placed inside LDPE inner bag.



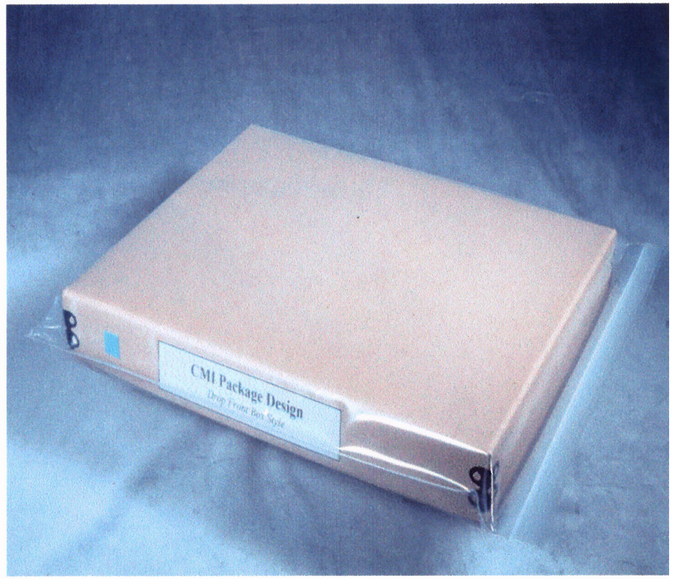
3. Dried mat board and inner bag is inserted into drop-front style box.



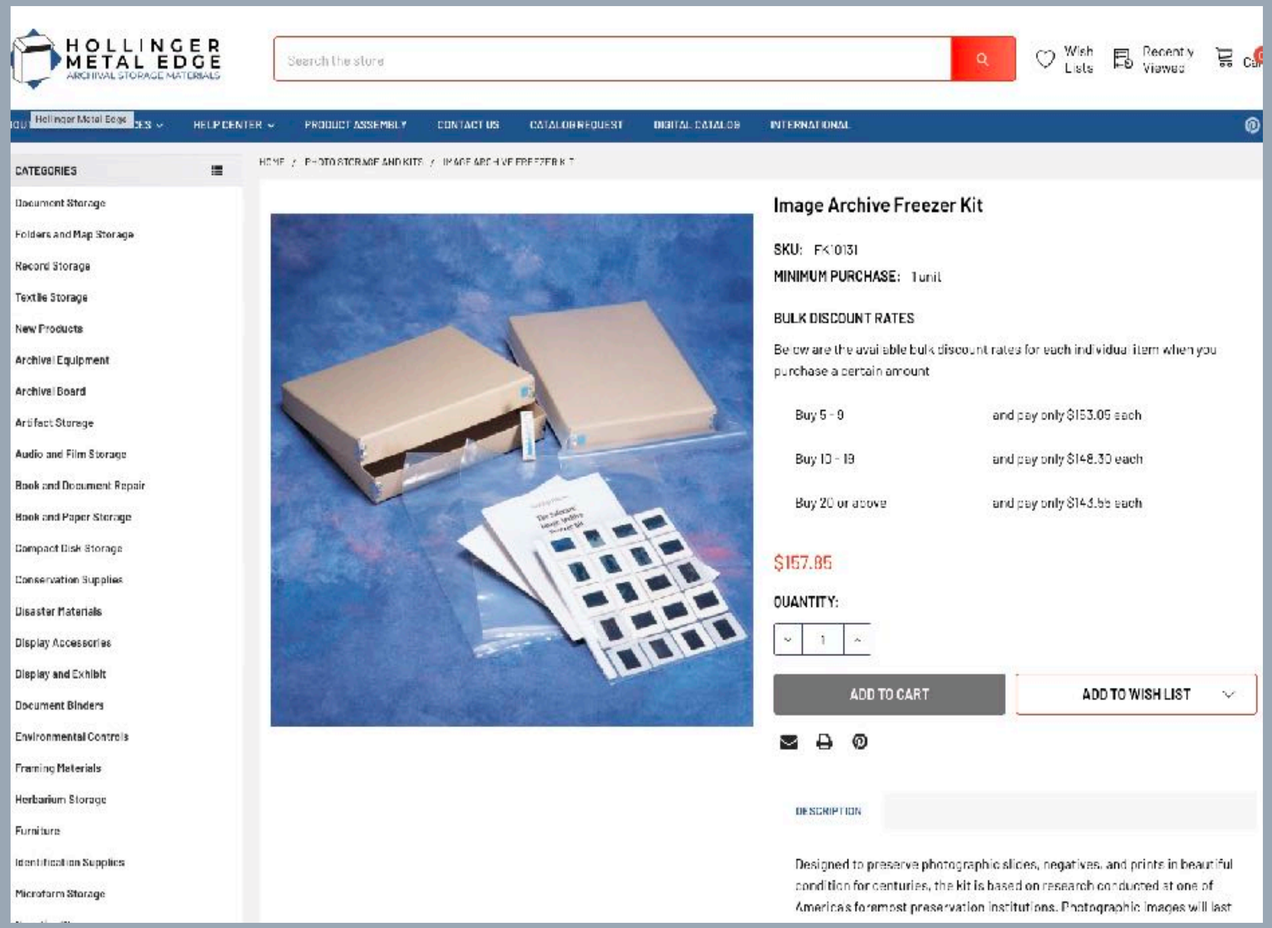
Close-up view of inner bag, mat board, and bottom of drop-front conservation box.

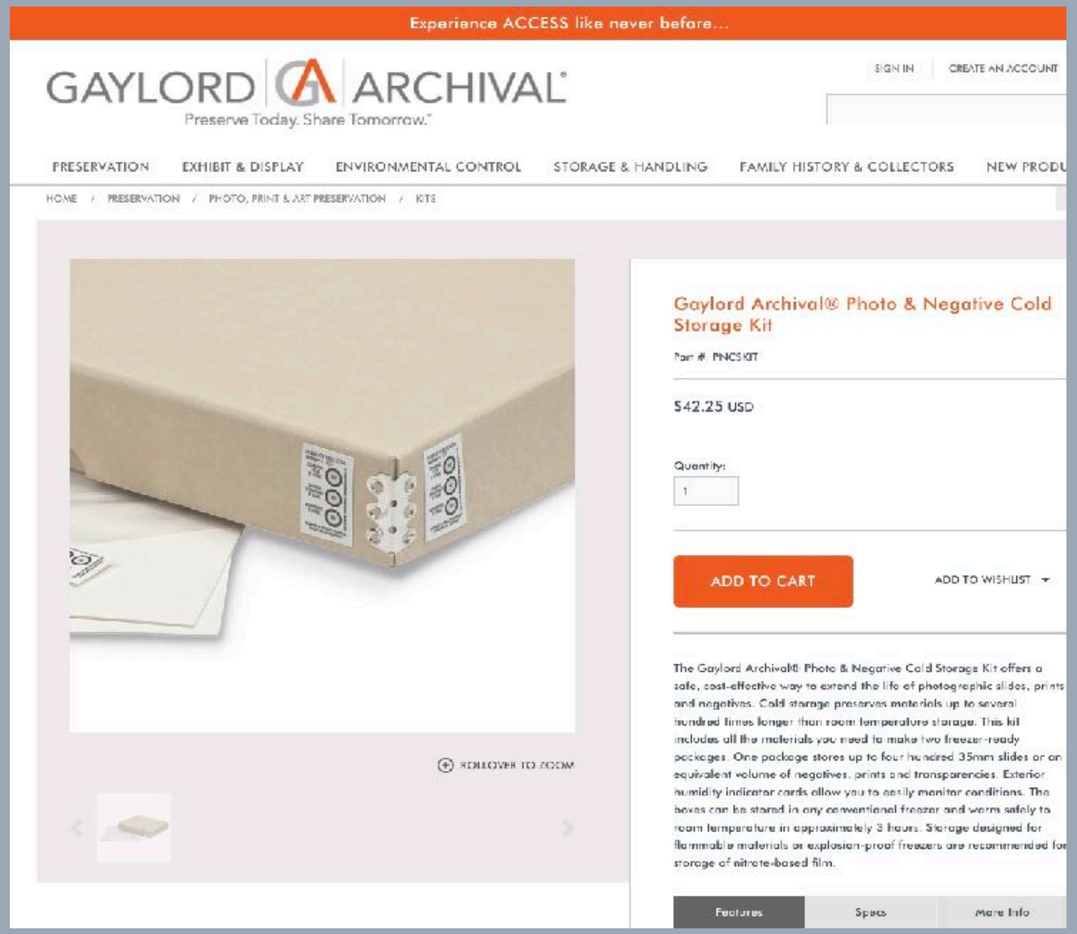


4. Box top is easiest to close by starting at the drop front.



5. Box is inserted into outer LDPE bag, and bag is sealed. Package is now complete.



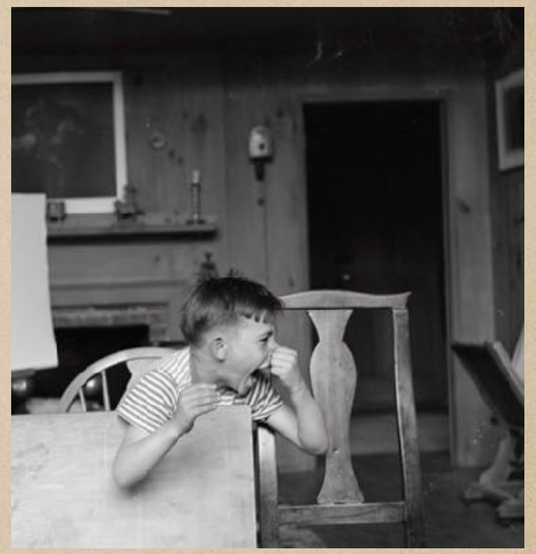


*not and endorsement - just an observation that the Smithsonian's CMI drop-front box design has found commercial application and is available from more than one archival materials & supplies vendor. The CMI packaging design and method is "open source", i.e. freely available for anyone to make and/or use.

Circa 1997: First Museum Use of the Metal Edge Freezer kit - preserving the film negatives photographed by Richard Avedon of Jacqueline Kennedy in her Inaugural Gown.

Freezer Storage of Norman Rockwell's Film Negatives at the Norman Rockwell Museum, Stockbridge, MA. (NRM.org)

“Coming and Going” by Norman Rockwell



Manual Defrost "Radiant shell" Reach-in Freezer, -20°C, with Sealed Containers

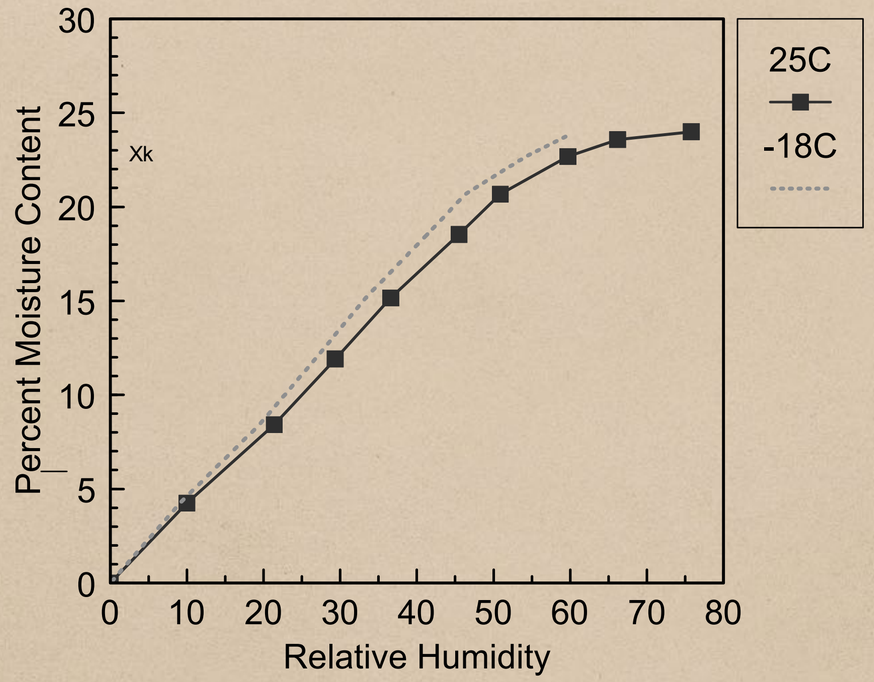
Redundant moisture control by 1) treating the freezer as a sealed cabinet while 2) the sealed containers establish a "microclimate within a microclimate". Relative humidity is easily monitored and adjusted.

Equilibrium Moisture Content (EMC)

- EMC is a fundamental material property of hygroscopic materials (e.g., paper, gelatin, cellulose acetate, microporous silica, etc.).
- EMC is evaluated directly by plotting Moisture Sorption Isotherms or Moisture Content Isolines
- EMC can be monitored indirectly by measuring equilibrium RH values in a sealed system (e.g., materials placed inside a vapor barrier bag or container with little free volume of air inside)
- EMC correlates best with Relative humidity (RH), not temperature or absolute humidity, but temperature plays a role.

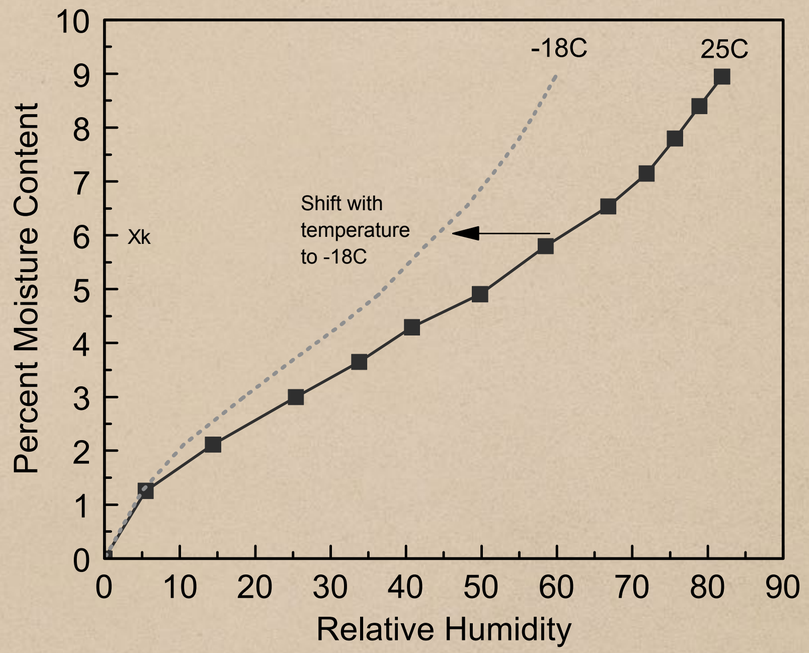
Equilibrium Moisture Content (EMC)

Moisture Absorption Isotherm Data for Silica Gel.

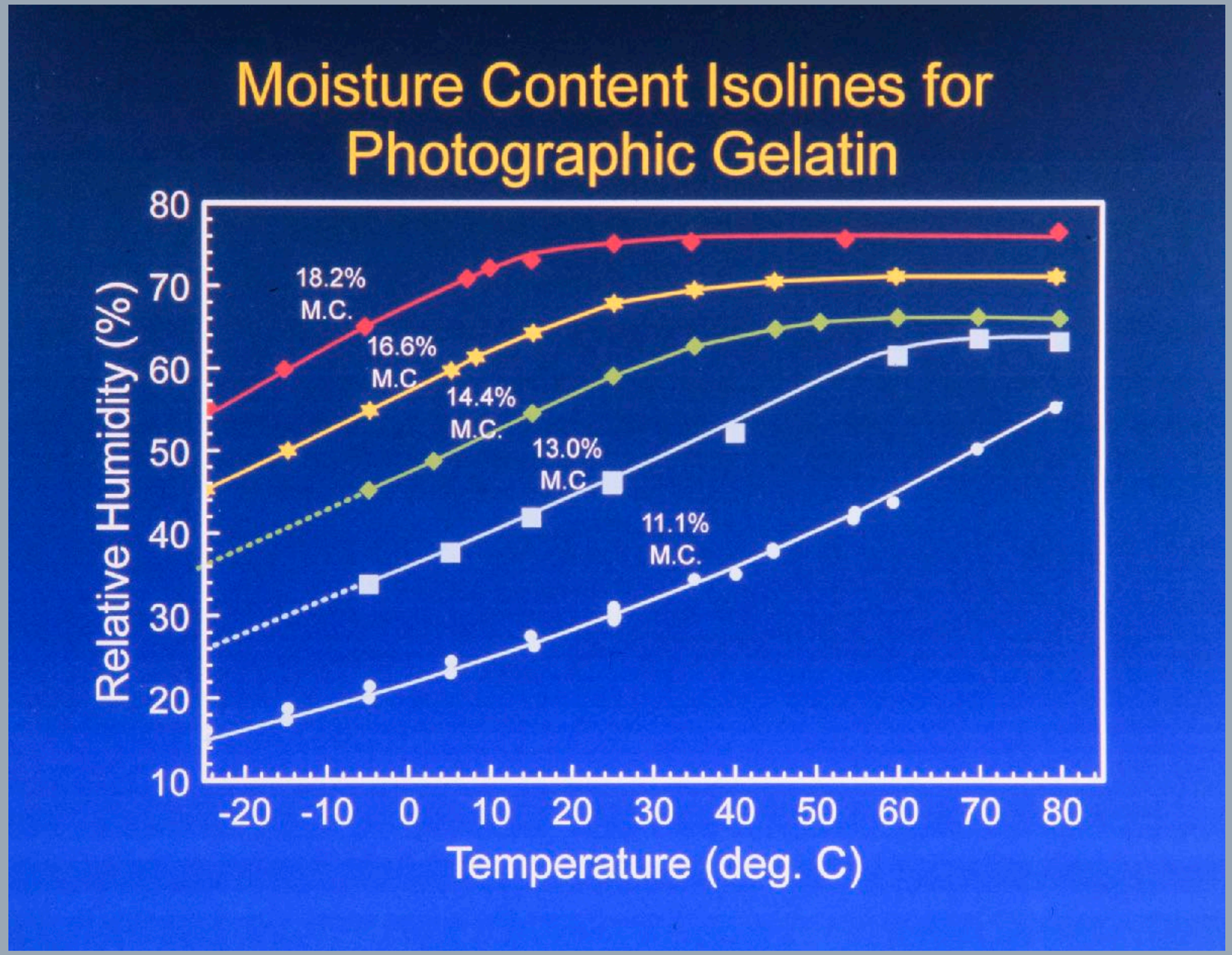


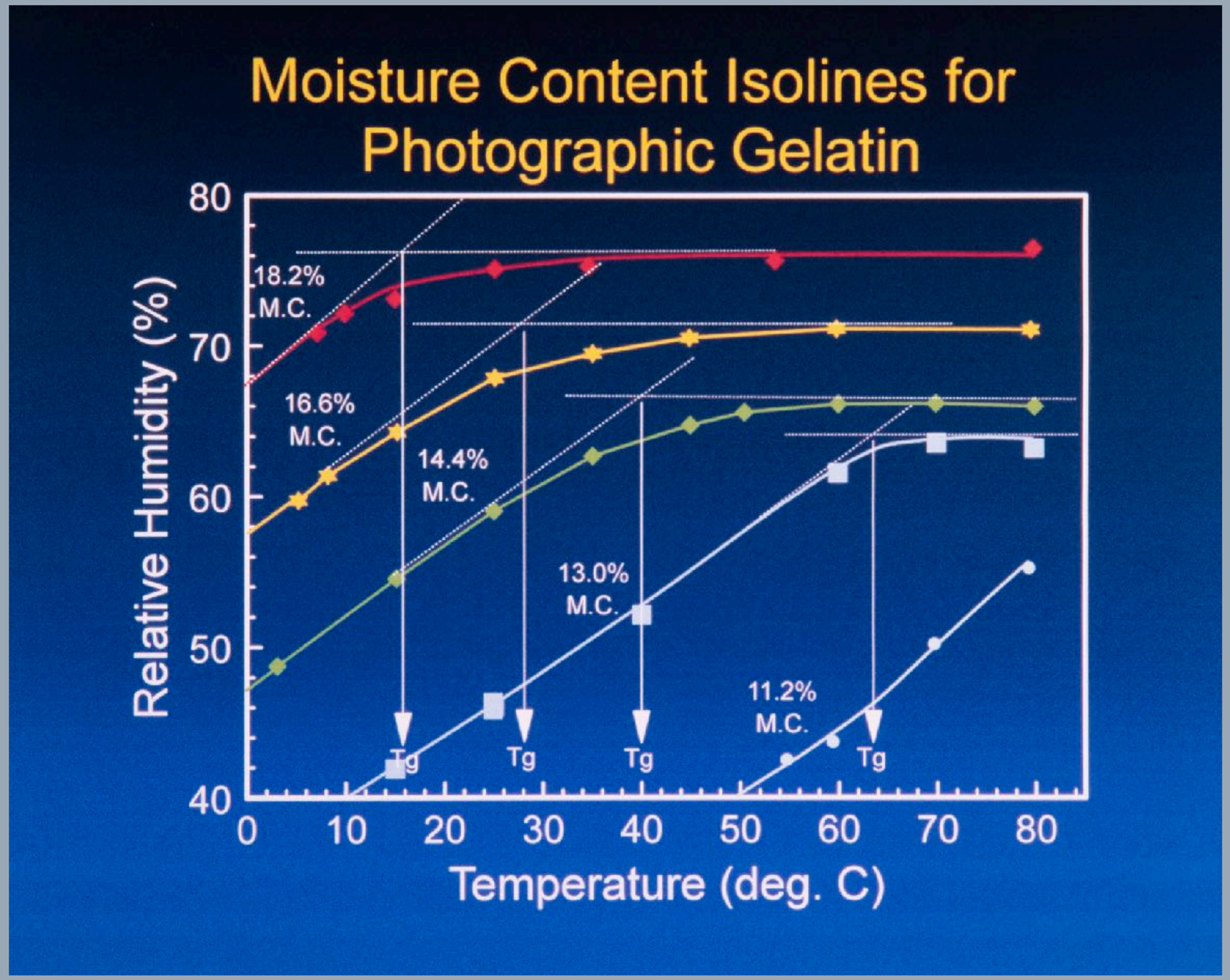
- Type 1 isotherm

Moisture Absorption Isotherm Data for Conservation Mat Board.

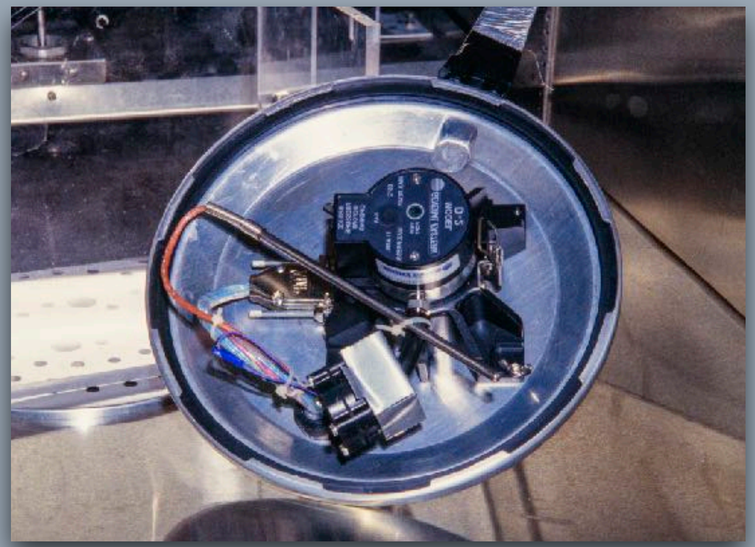


- Type 2 isotherm


Moisture Content Isolines for Photographic Gelatin
Relative Humidity (%)
80
70
60
50
40
30
20
10
18.2% M.C.
16.6% M.C.
14.4% M.C.
13.0% M.C.
11.1% M.C.
-20
-10
0
10
20
30
40
50
60
70
80
Temperature (deg. C)

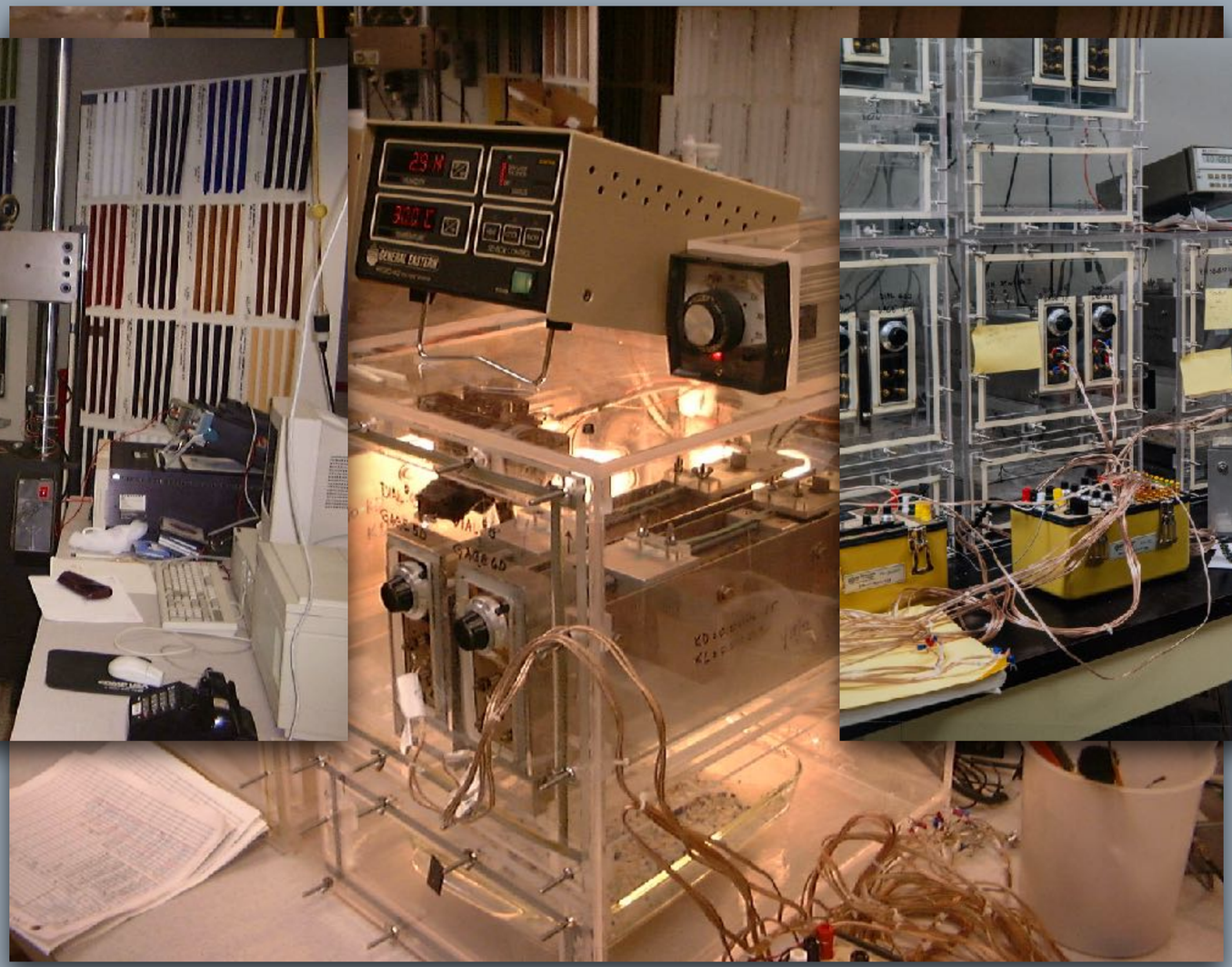

Moisture Content Isolines for Photographic Gelatin
Relative Humidity (%)
80
70
60
50
40
0
10
20
30
40
50
60
70
80
Temperature (deg. C)
18.2% M.C.
16.6% M.C.
14.4% M.C.
13.0% M.C.
11.2% M.C.
Tg
Tg
Tg
Tg

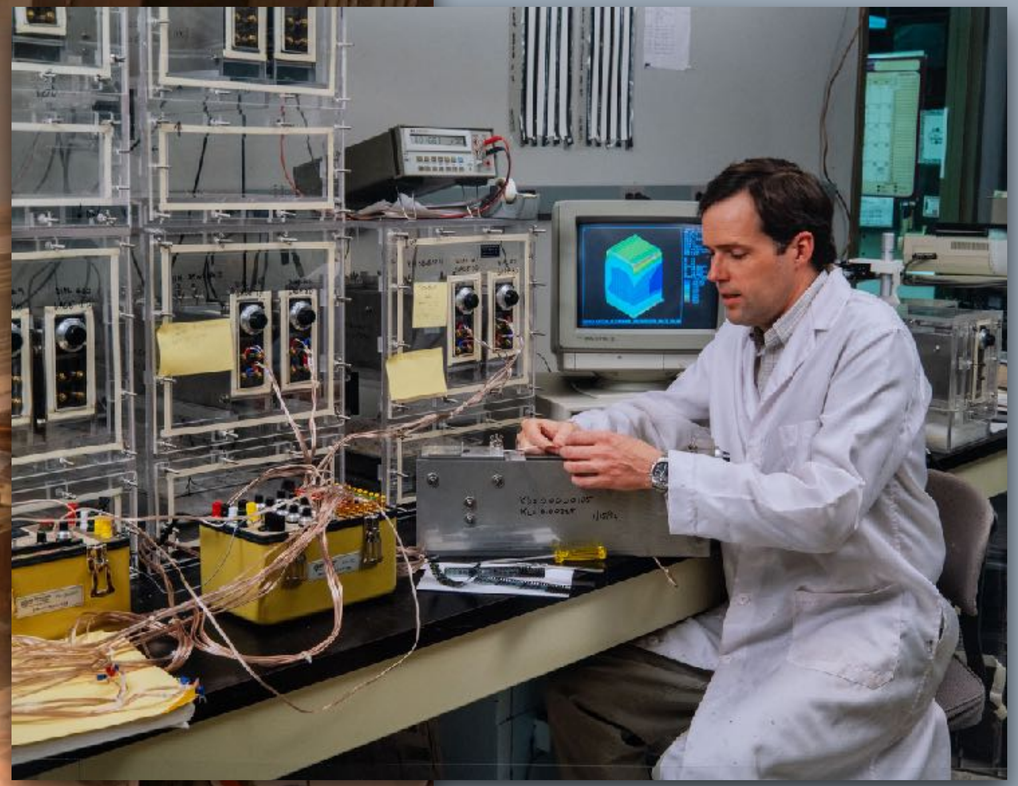
Silver Mirroring caused by Gelatin binder exceeding Glass Transition Temperature (T_g) for an extended period of time.



1994 - experimental method for determining the Moisture Content Isolines of Photographic Gelatin

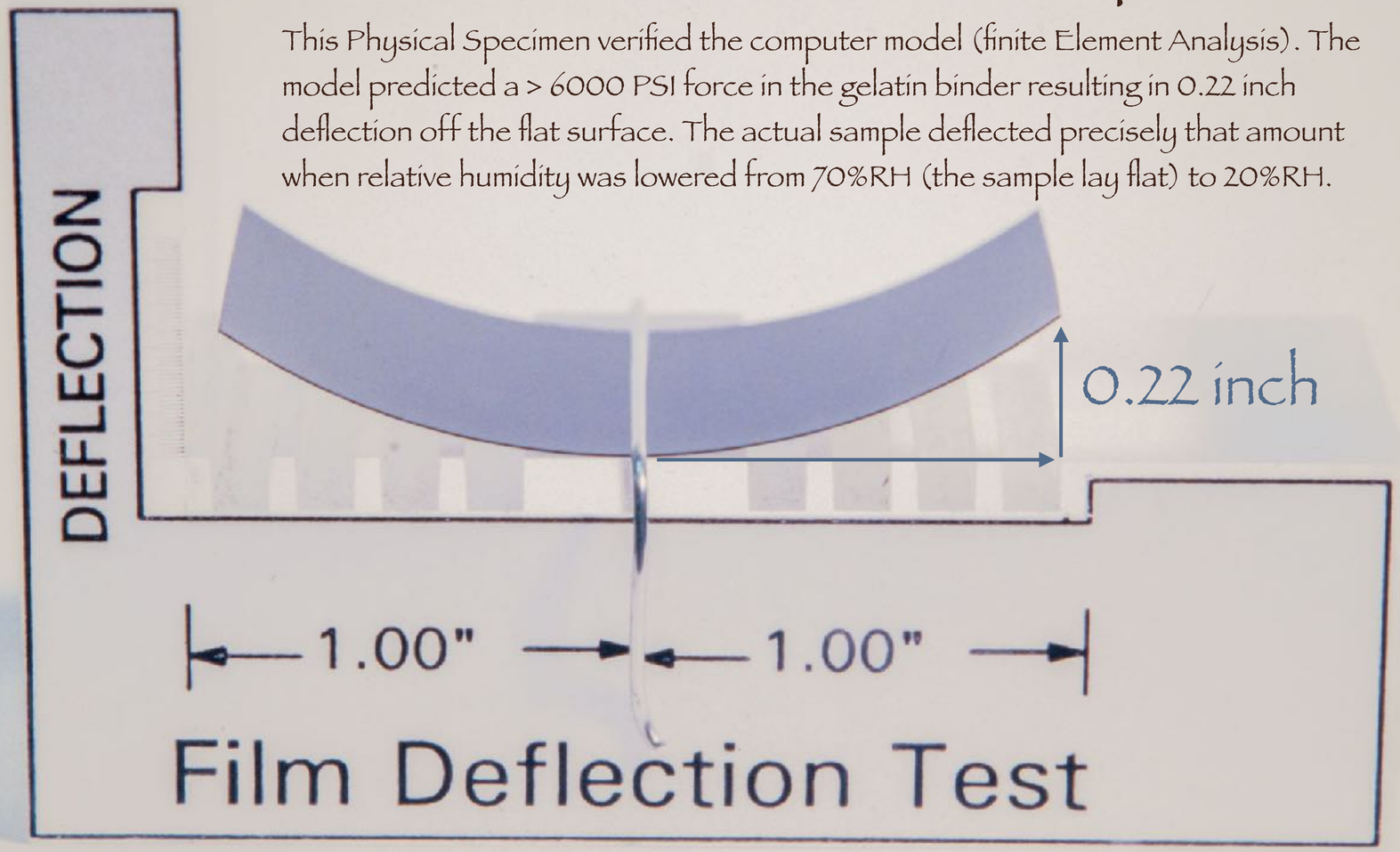
Determining Physical Safety Limits for Composite Multi-layer Structures (e.g., paintings and photographs)



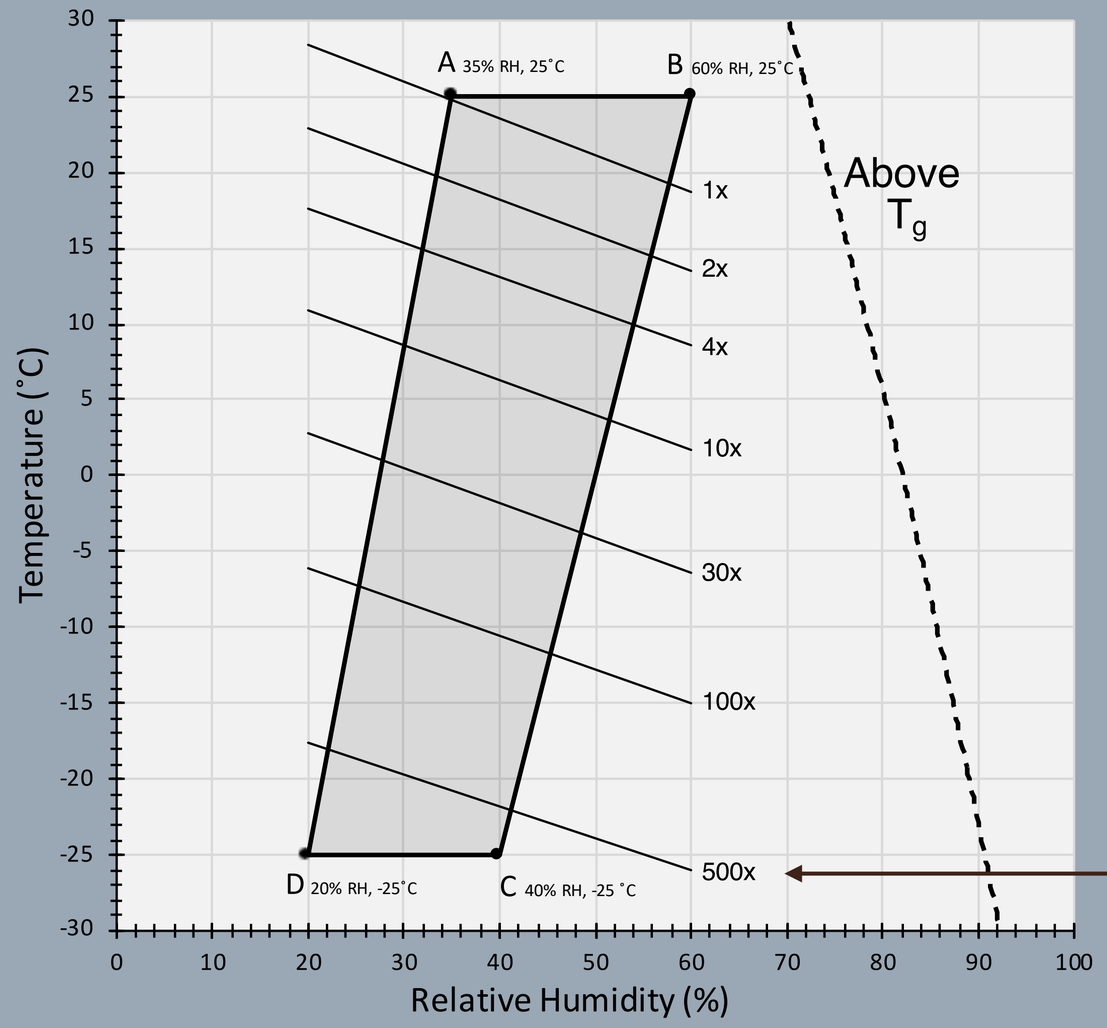


Empirical Test of Cibachrome Print Behavior for 70%RH to 20%RH desiccation at Room temperature.

This Physical Specimen verified the computer model (finite Element Analysis). The model predicted a > 6000 PSI force in the gelatin binder resulting in 0.22 inch deflection off the flat surface. The actual sample deflected precisely that amount when relative humidity was lowered from 70%RH (the sample lay flat) to 20%RH.



Physically Safe Range for Use and Storage of Photographic Materials.
Chemical Stability Improves as Temperature is Reduced.



Chemical stability contour lines based on chromogenic color dye fading in dark storage normalized (1X) to 24°C and 40% RH.

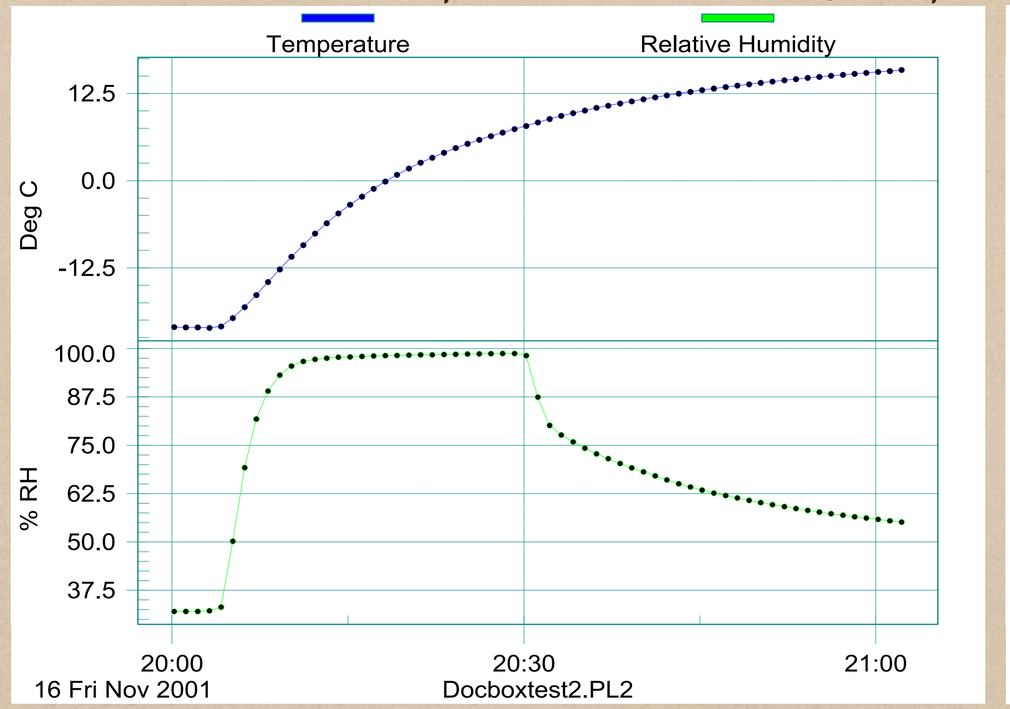
Reference: M. H. McCormick-Goodhart, "The Allowable Temperature and Relative Humidity Range for the Safe Use and Storage of Photographic Materials," Journal of the Society of Archivists, Vol 17, No. 1, United Kingdom, 1996.

see: https://www.aardenburg-imaging.com/wp-content/uploads/2015/11/AaI_2007_1206_TA-01.pdf

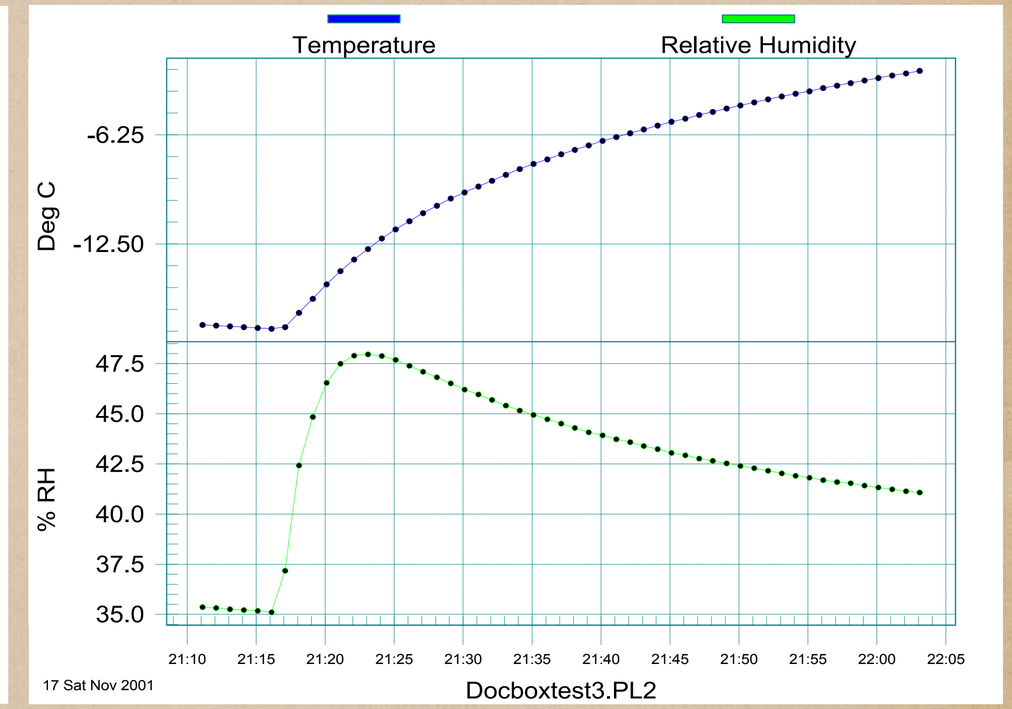
Why Temperature "Staging" may be needed.

Steep temperature gradients can cause moisture migration/condensation inside sealed microclimates.
One solution is to reduce the temperature gradient by temperature staging and/or thermal insulation.

Temp/RH Datalogger with significant thermal mass located inside empty document box



Box warmed in "zip lock" bag without additional insulation. Box walls warmed faster than the datalogger and released moisture into the free air space in the box.



Box warmed while enclosed in larger insulated container (e.g., a "picnic cooler"). Contents of box now warm safely without large humidity spike in the free space.

Instrumentation

- Electronic Hygrometers
  - Temperature compensated, thus they correctly measure the equilibrium humidity shift in sealed systems as the temperature changes. Caveat: make sure your chosen electronic Thermo/hygrometer is specified to work in subzero temperature environments. If the manufacturer doesn't specify, it probably won't work below 0°C.
- Mechanical Hygrometers
  - These instruments typically work by physical expansion/contraction of the sensing apparatus. Thus, the device is actually responding to changes moisture content in the sensor and only indirectly to relative humidity. Therefore, they are calibrated to room temperature only and indicate what the RH will be after a sealed package or container warms again to room temperature rather than the actual RH at cold temperature.
- Humidity Indicator cards
  - Work on chemically induced color changes caused by changes in moisture content of the paper card stock. Thus, they are calibrated to room temperature only and indicate what the humidity will be after a sealed package or container warms again to room temperature.
- NOTE: remember that sealed systems are "static weathering" microclimates. Leave ample time for hygrometers to reach equilibrium RH readings.

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