A SYSTEM APPROACH

TO

ARCHIVAL STORAGE

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March 20, 1991

Introduction

When I found Bill Doyle had scheduled me to talk between Bill Mulari and Dennis Speliotis, I wondered if I were the thorn between two roses, or the rose between two thorns.

The topic was provoked by the frequent repetition of two questions. The first, raised by Bill and Dennis, is:

Can D-2 iron particle tape be used for archival storage?

The other related question is:

How can acceleration factors relating short-term tests to archival life times by justified?

The reports of possible corrosion of metal particle tape which have been presented over the last 18 months have raised serious doubts about its use in the computer data community. Probably those doubts are the reason for this symposium.

Now Ampex is primarily concerned with iron particle media used in the D-2 video standard. The standard was developed starting in 1985 by a SMPTE group -- including broadcast studio users and manufacturers of recorders and tape -- to fill a need for a high density, high data rate, digital recorder. Six years later, the best evidence of the video industries' viewpoint on D-2 stability is that a major studio is re-recording its master tapes -- 2-inch Quad and C format -- onto D-2. In video, format obsolescence -- not archival stability -- is the life limitation. The originals are 10 to 30 years old.

Ampex Recording Systems is now transferring D-2 video technology to data storage applications, and encountering concerns about corrosion that the title of this symposium suggests. To protect the D-2 standard, RSD, with the cooperation of most of the tape manufacturers, had Battelle test all four in the Class II environment. Error rates were measured before and after the test on both exposed and control groups. Correlating the before and after data on the groups shows no degradation on a 28-day test -- 14-year equivalent life.
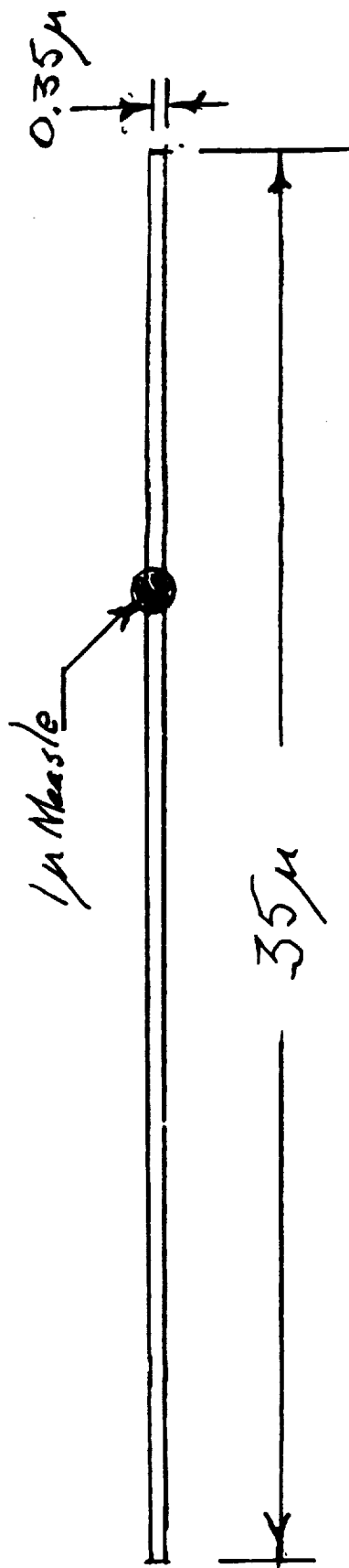
Similar results have been reported in Trans Mag and other journals by Sony, Maxell, Fuji and DEC. What is the explanation for

the contradiction between these reports and those of Bill Mulari and Dennis Speliotis? (Dennis is now inn a straddle position; he is co-author of the DEC paper that concludes metal particle tapes are stable when stored in cassettes.)
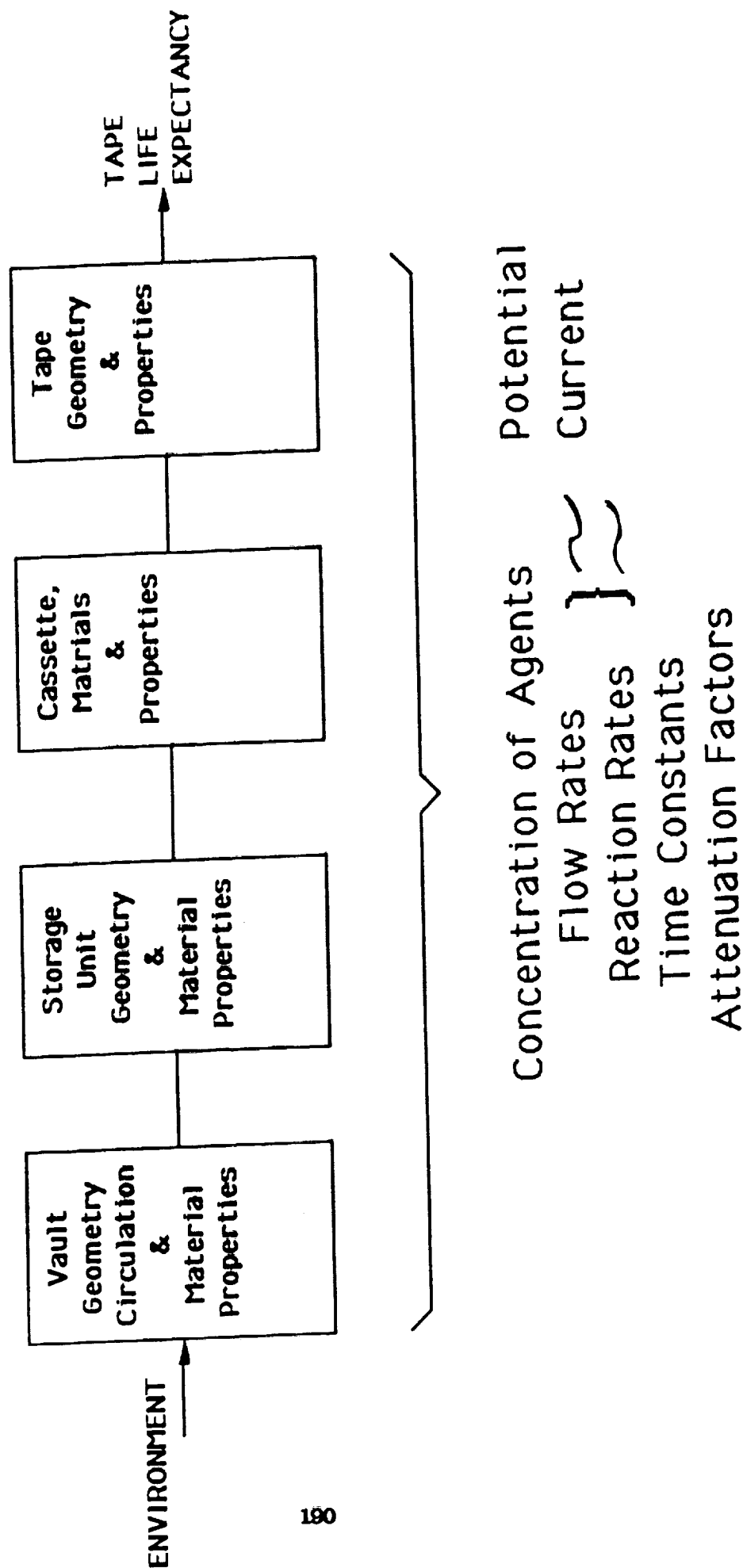
Well, this question takes us back to the first two and the topic of this talk. As is commonly the case in such differences, the results were obtained under different conditions. As will be shown, tapes stored in cassettes are invulnerable to corrosion. That is not surprising; cassettes were developed to protect tapes from the hazards of reel-to-reel recorders.
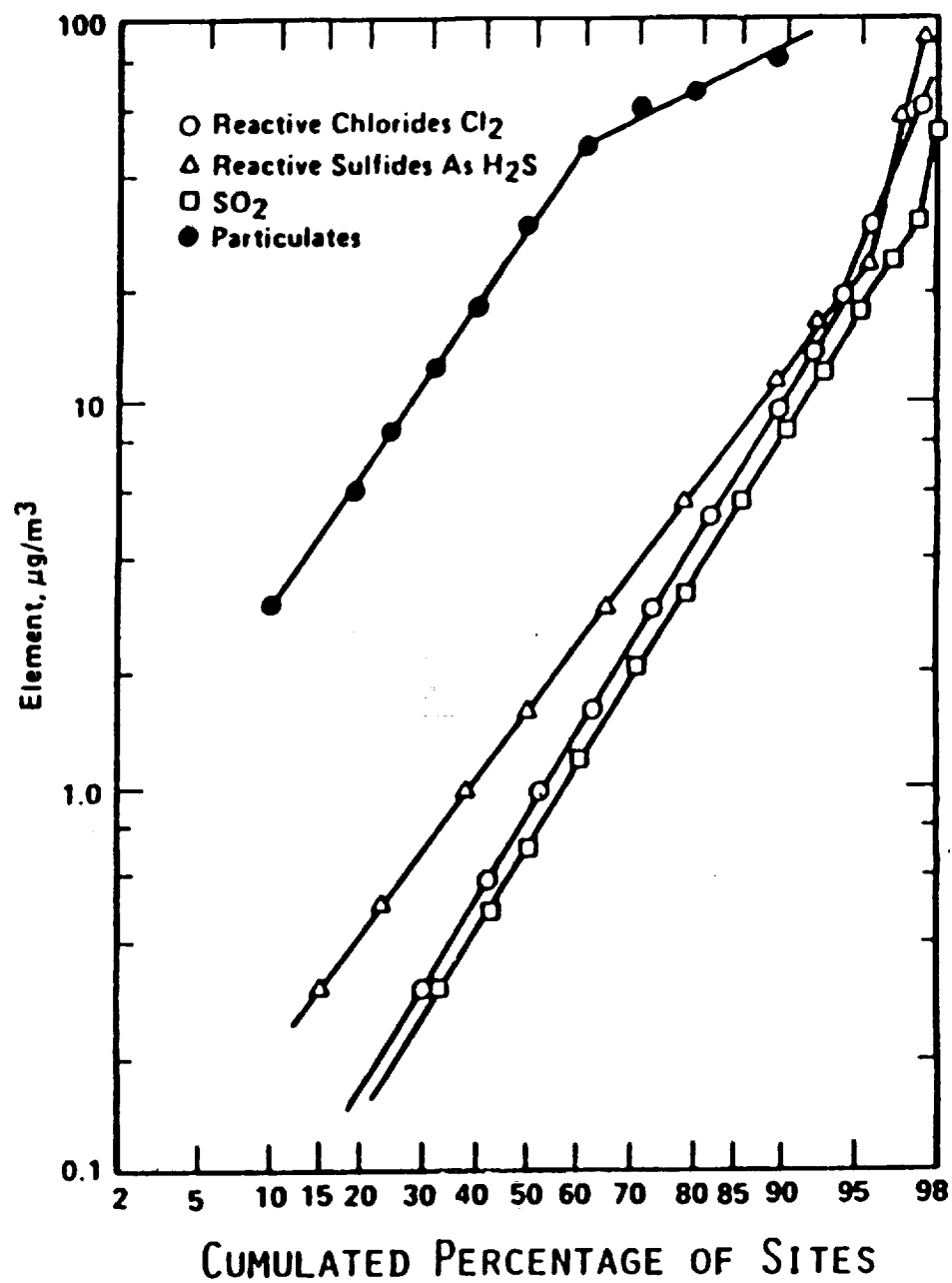
Bill Abbott commented that the measurements of the shielding effect of cassettes showed a "qualitatively different type of behavior than 'naked' tapes." To explain this requires a system approach.

Comparison of a Bit Cell
& a Measle

0.35µ

1µ Measle

35µ

BLOCK DIGARAM OF AN
ARCHIVAL STORAGE SYSTEM

ENVIRONMENT →

| Vault Geometry Circulation & Material Properties | Storage Unit Geometry & Material Properties | Cassette, Matrials & Properties | Tape Geometry & Properties |

→ TAPE LIFE EXPECTANCY

Concentration of Agents
Flow Rates
Reaction Rates
Time Constants
Attenuation Factors

} ~ Potential
~ Current

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Legend (on chart):
- O Reactive Chlorides Cl$_2$
- △ Reactive Sulfides As H$_2$S
- □ SO$_2$
- ● Particulates

Y-axis: Element, $\mu g/m^3$

X-axis: CUMULATED PERCENTAGE OF SITES

WORLDWIDE INDOOR POLLUTANT DISTRIBUTIONS FOR
ELECTRICAL AND ELECTRONIC EQUIPMENT

ADSORPTION IN BATTELLE TEST CHAMBERS

Gas Adsorption Rate
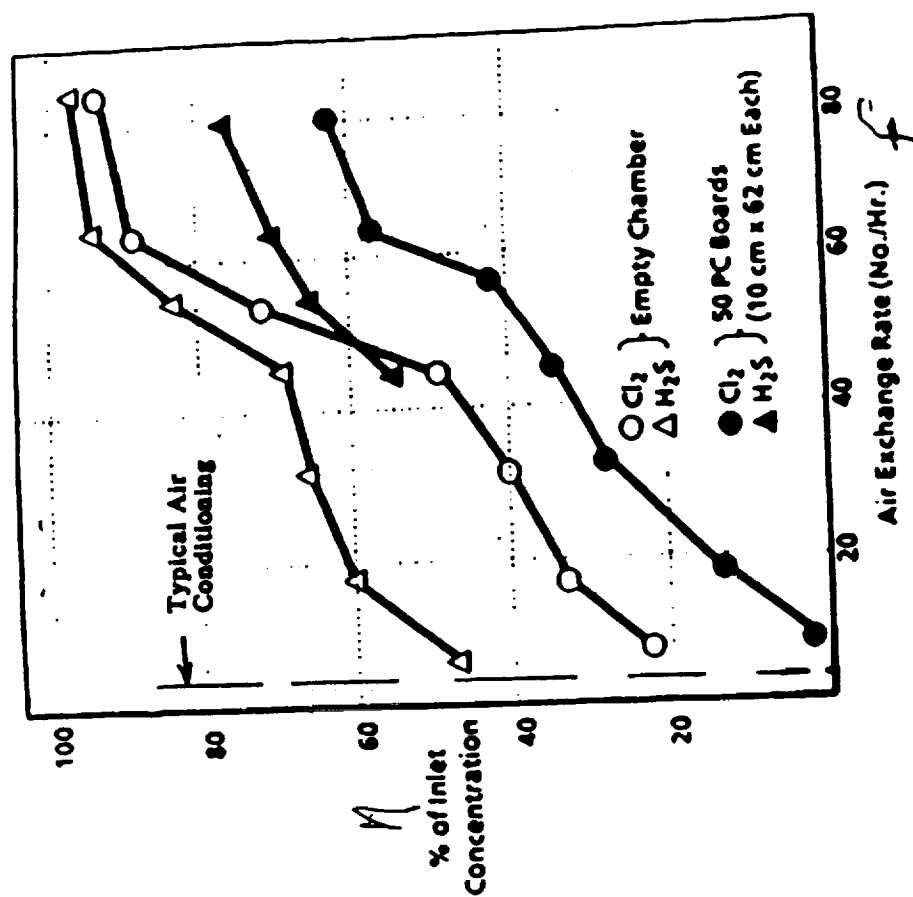
$$\frac{dQ}{dt} = \{[G]_{in} - [G]_{out}\} Vf$$

$$= k\,A\,[G]_{Avg}$$

$$\frac{2}{V} \sum k_i A_i = \frac{1-\eta}{\eta} f$$

Adsorption Coefficients

Gas	k_i cm/sec	Chamber Walls	Circuit Boards
Cl_2		0.20	0.093
H_2S		0.086	0.035

% of Inlet Concentration vs Air Exchange Rate (No./Hr.)

Typical Air Conditioning

○ Cl_2 △ H_2S } Empty Chamber

● Cl_2 ▲ H_2S } 50 PC Boards (10 cm x 62 cm Each)

GENERAL CORROSION REACTION

$$M + G \longrightarrow MG \qquad \begin{array}{l} M \ \text{Metal} \\ G \ \text{Gas} \end{array}$$

RATE FOR SECOND ORDER REACTION (Brackets indicate concentration)

$$\frac{d\,[M]}{dt} = \frac{d\,[G]}{dt} = -k\,[M]\,[G]$$

For [G] constant (as in Battelle chamber)

FOR FIRST ORDER REACTION

$$M = M_0 \exp -t/\tau$$

$$\tau = \frac{1}{k\,[G]}$$

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For low gas concentrations, the time constant is very long. Also, for $t \leq \tau$ the decay rate is constant.

Time Constants for
Vaults Without Air Circulation

For Diffusion
in a tunnel of length
d :

$$\tau = \frac{d^2}{3\Delta}$$

For chlorine in air, $\Delta \approx 0.1 \; cm^2/sec$ and for $d = 10 \; m$, $\tau = 10^3 \; hr$ or 40 days.

For Thermal Pumping

A daily temperature variation of $3°/k$ will cause air to flow in and out of any unsealed container or space, thereby carring corrosion agents into the container. Using perfect gas law, the daily mass flow is

$$\frac{1}{M_c} \frac{\Delta M}{\Delta t} = \frac{\Delta T}{\overline{T} \; \Delta T}$$

where M_c is the mass of air in the container and $\overline{T}$ is the average absolute temperature. The time constant is the reciprocal of these terms, about 1200 hours, 50 days.

For Barometric Pumping

Similarly

$$\tau = \frac{\overline{P} \; \Delta t}{\Delta P}$$

For $\overline{P} = 30$ in. Hg, $\Delta P = 1 in \; \Delta t = 3$ days, $\tau = 90$ days.

ERROR RATE MEASUREMENT

ALL ERROR DATA PRESENTED IS "RAW" TO PERMIT DETECTION OF ANY CHANGE IN THE MEDIA. (WITH ERROR CORRECTION APPLIED, MOST CASSETTES WOULD RUN ERROR-FREE, AND CORROSION EFFECTS WOULD BE UNDETECTABLE).

SYMBOL (OR BYTE) ERROR RATE (SER) IS USED FOR D-2 DATA BECAUSE THE REED-SOLOMON ERROR CODING IS SYMBOL ORIENTED.
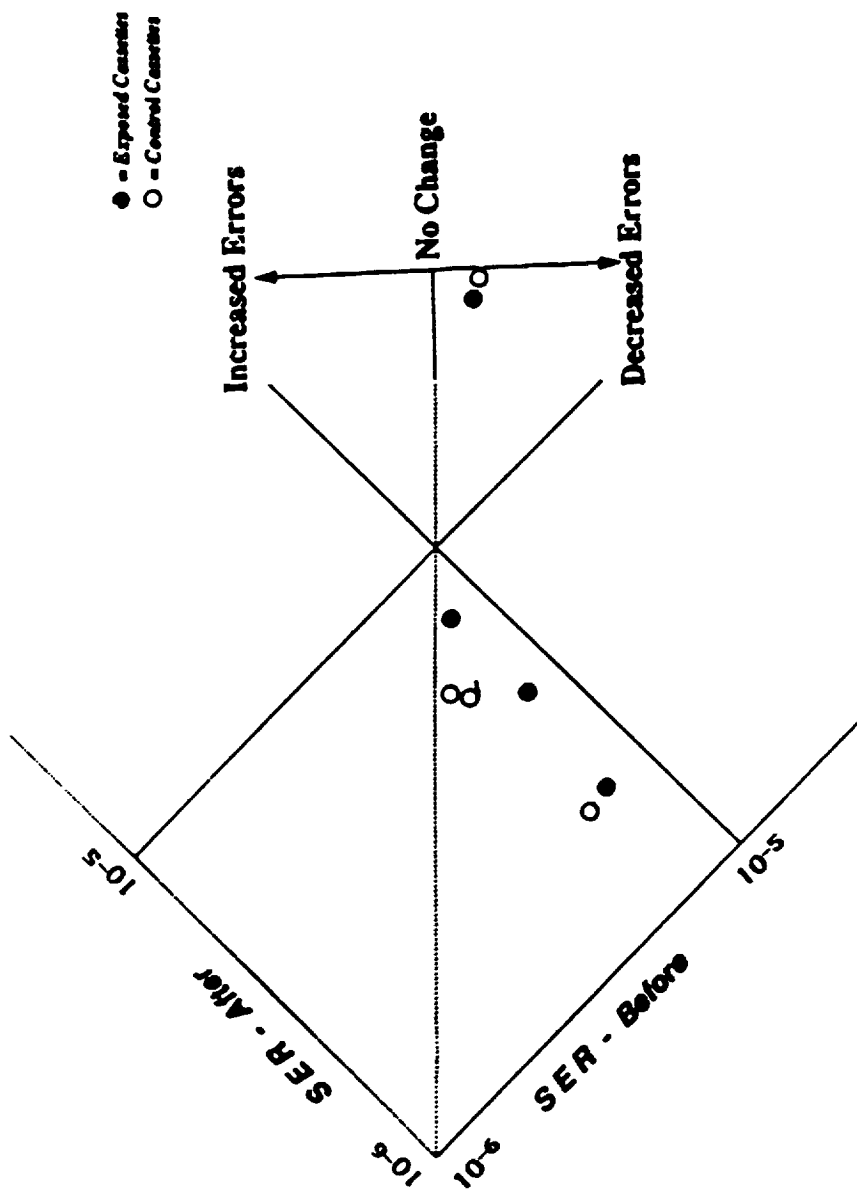
BURST AND NON-BURST ERROR DATA ARE PRESENTED. NON-BURST DATA INDICATE ERRORS IN INDIVIDUAL BITS DUE TO LOSS OF SNR, MEASLES, ETC. BURST ERRORS ARE PRIMARILY DUE TO SURFACE DEFECTS.

POST TEST DATA ARE PLOTTED AS A FUNCTION OF PRE-TEST FOR THE SAME CASSETTE. POINTS BELOW THE "NO CHANGE" LINE INDICATE IMPROVEMENT.

Correlation of Non-Burst Error Rates Before and After Exposure Period

of D-2 Tapes From Four Manufacturers

AMPEX
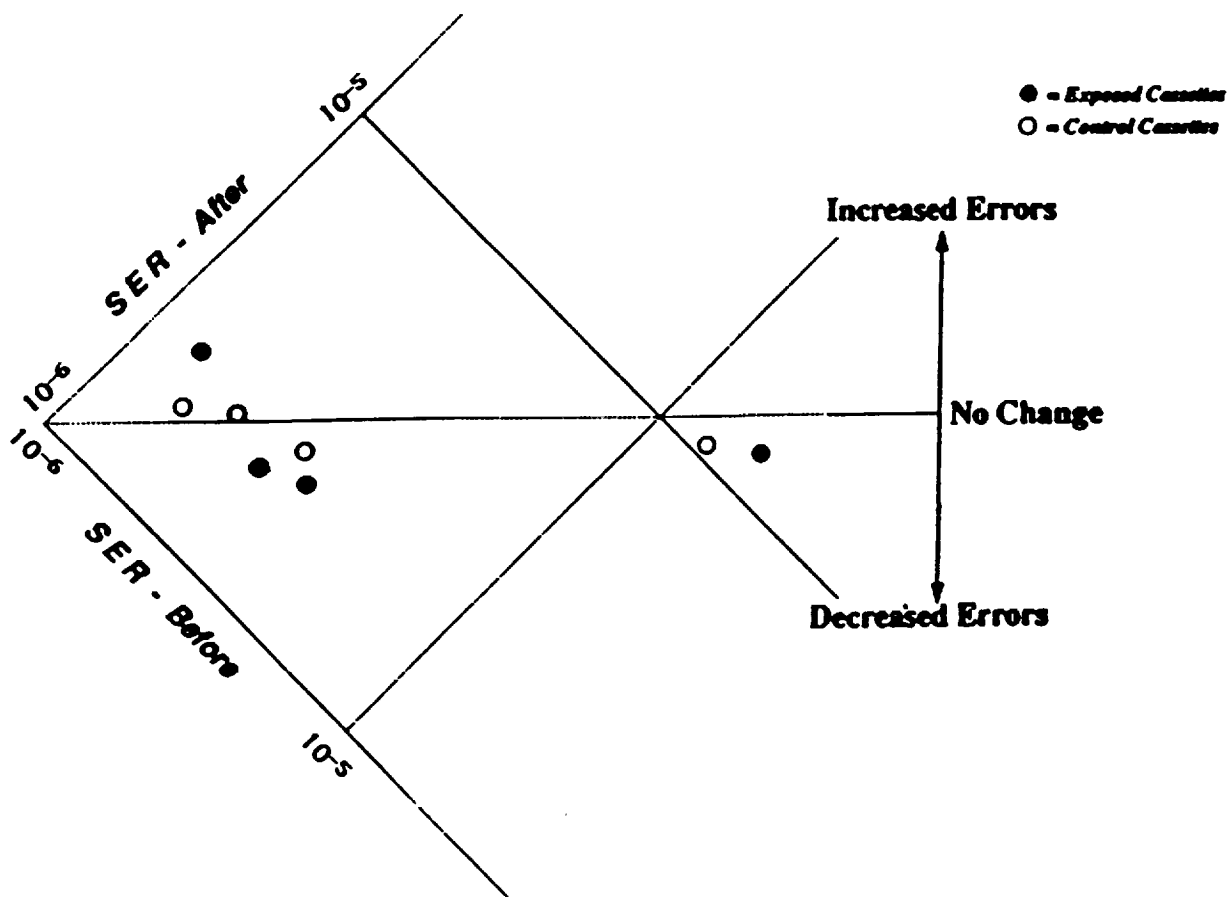
Correlation of Burst Error Rates Before and After Exposure Period
of D-2 Tapes From Four Manufacturers

● = Exposed Cassettes
○ = Control Cassettes

Increased Errors

No Change

Decreased Errors

SER - After

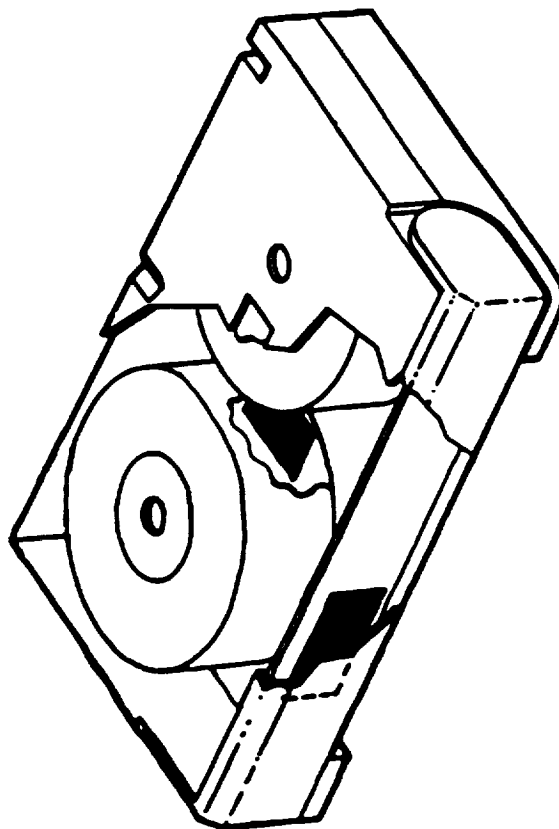10⁻⁵

10⁻⁶

SER - Before

10⁻⁵

10⁻⁶

AMPEX

SHIELDING TEST

STANDARD D-2 CASSETTES (SMALL SIZE) WERE FITTED WITH BATTELLE METAL COUPON SAMPLERS AND EXPOSED FOR 28 DAYS. A COMPARISON OF RESULTS OF THREE INTERNAL SAMPLERS WITH AN EXPOSED ONE INDICATES THE CASSETTE HAS ATTENUATED THE CORROSIVE ENVIRONMENT TO NEGLIGIBLE PROPORTIONS.

THE DIFFERENCE BETWEEN THE PRESENT RESULTS AND THOSE REPORTED BY SPELIOTIS FOR "NAKED" TAPE ARE ATTRIBUTABLE TO THE CASSETTE SHIELDING FACTOR.
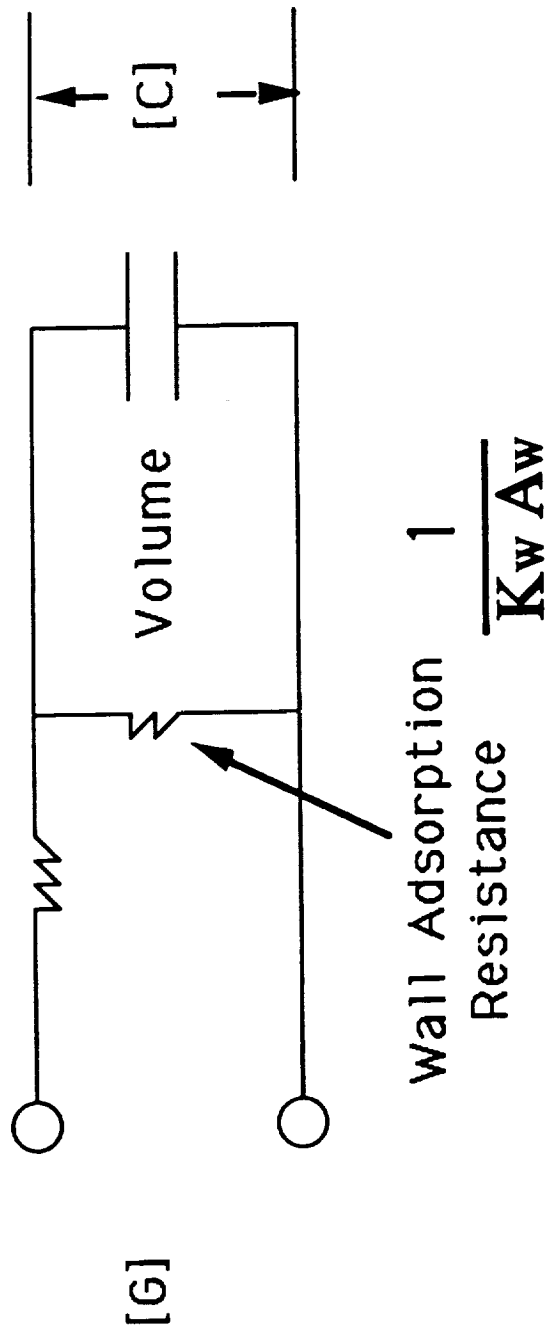
Silver Sampler Film Measurements for Various Locations on D-2 Cassette

Sampler Locations on D-2 Cassette

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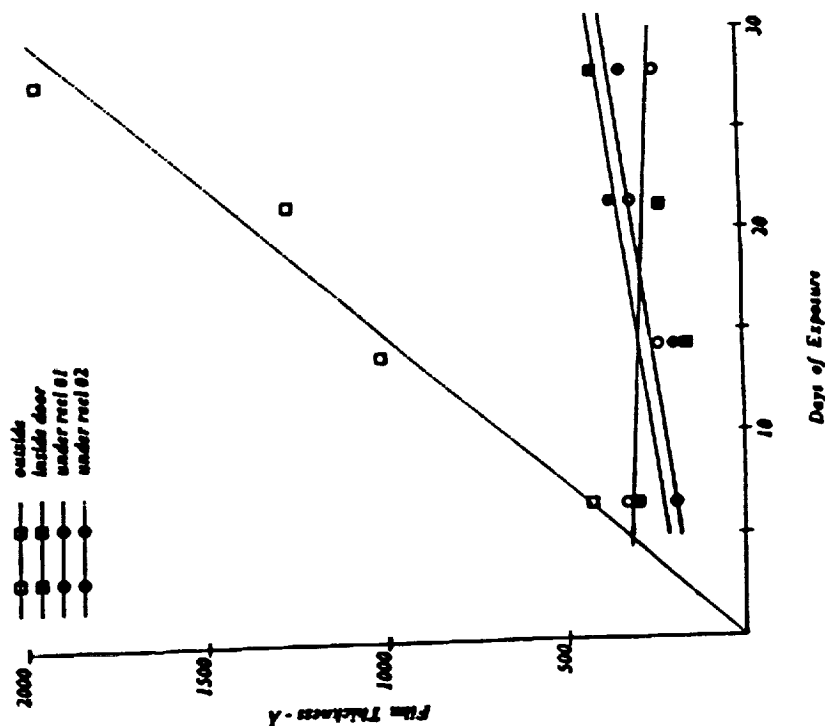
CASSETTE IMPEDANCE MODEL

Diffusion Resistance $\quad R_D = \dfrac{\ell}{\Delta A_x}$

[G]

Volume

[C]

Wall Adsorption Resistance $\quad \dfrac{1}{K_w A_w}$

$$\frac{[C]}{[G]} = \frac{1}{\dfrac{K_w A_w \ell}{\Delta A_x} + 1} \quad \text{Attenuation Factor}$$
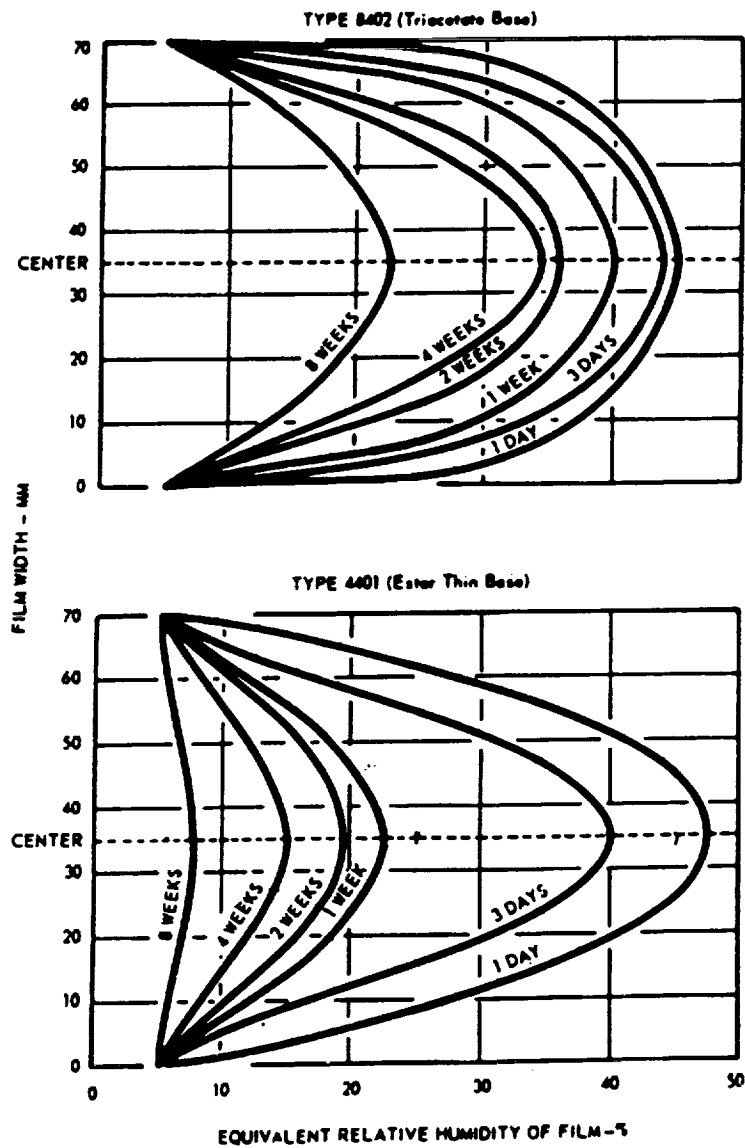
Fig. 6.10   Moisture Gradients During Conditioning of
Aerial Film Rolls at 70°F -5% RH

Data from "Manual of Physical Properties"
   - Eastman Kodak Co.

DETERMINATION OF TIME CONSTANTS
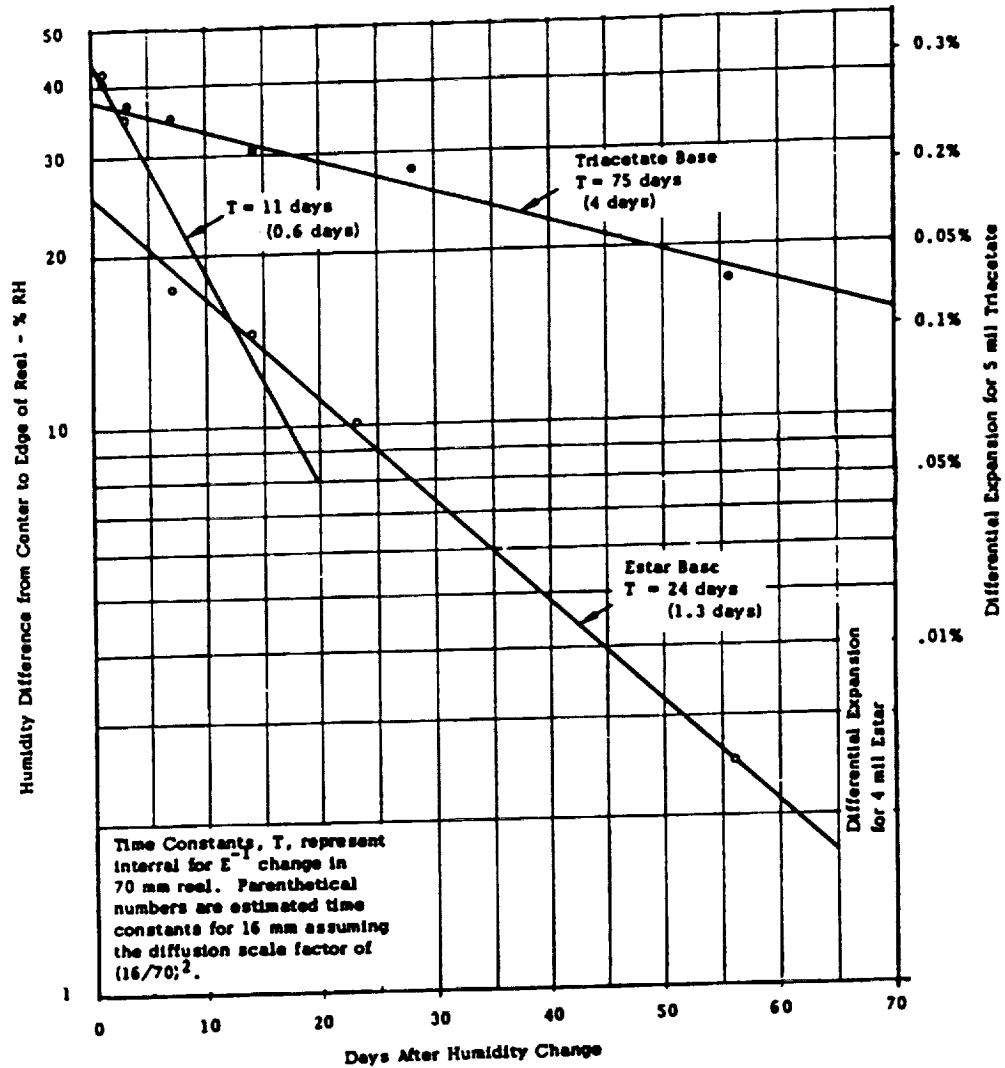# FOR MOISTURE DIFFUSION

Fig. 6.11 Difference in relative humidity between center to
edge of a 70 mm reel following a step change from
70°F - 50°$_\lambda$ RH

$$\tau = T \left\{ \frac{W}{70 \ mm} \right\}2$$
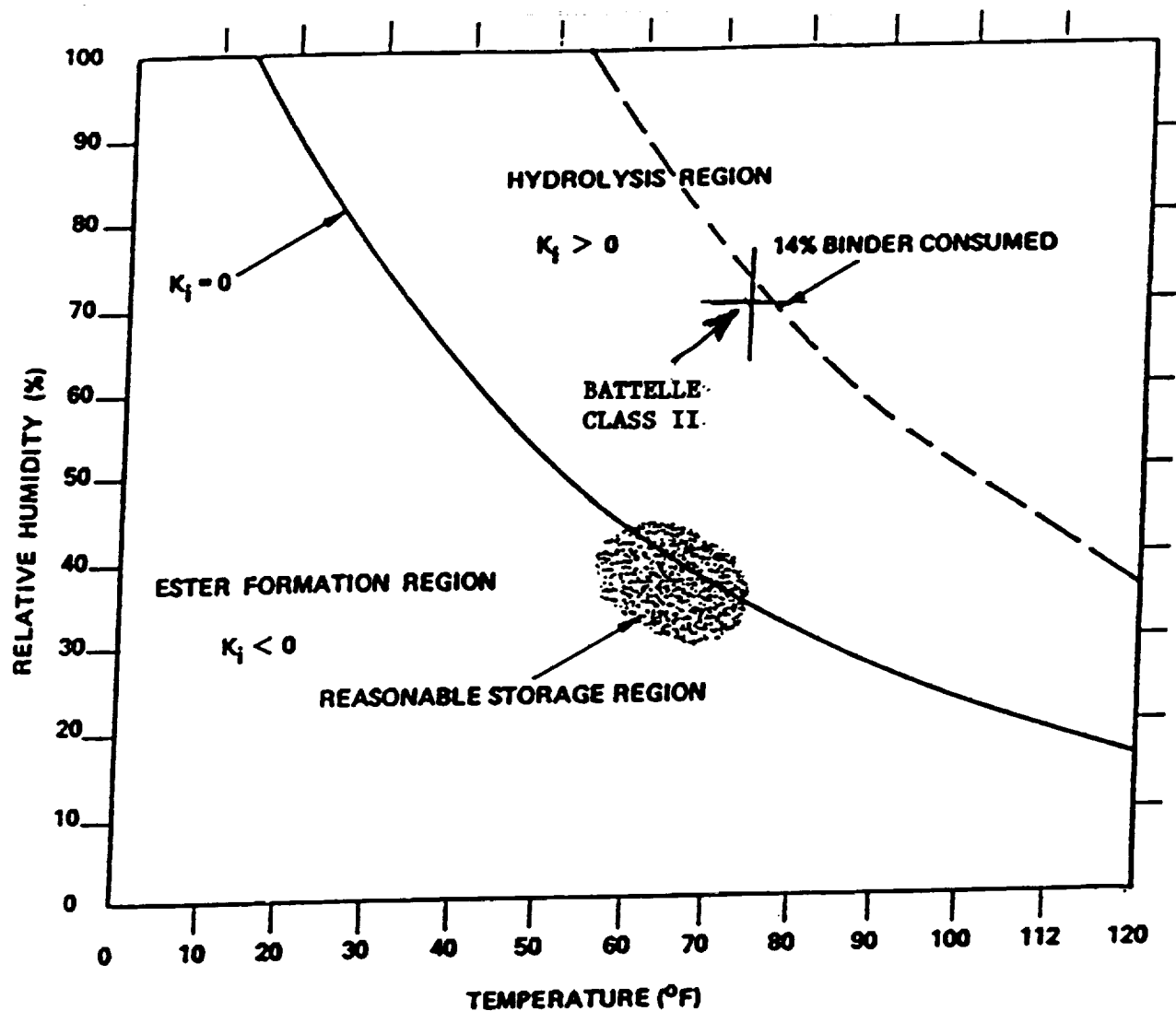
FROM BERTRAM & ESHEL

Figure 37   Hydrolysis equilibrium curves vs humidity and temperature.
$K_i = 0$ indicates initial equilibrium. Dashed curve denotes 14% binder
hydrolysed from an initial 6.7%.

Conclusions

1. The archival life of four brands of D-2 tape have been shown to exceed 14 years in the Battelle Class II environment. No evidence of corrosion was found.

2. The cassette is a necessary element for achieving this life. Dangling tape out of a cassette invites failure.

3. Extended exposure of any type of tape to high temperature and humidity causes binder degradation and coating failure. Archival storage is not possible in such environments.

4. An archival storage system includes: the tape, its cassette, other protective enclosures (if used), the storage vault, and its material parameters and the environment. Methods of determining time constants and attenuation factors for estimating storage life have been suggested.

5. There is a need for research -- perhaps here at the University of Alabama -- to determine adsorption coefficients of tapes, cassettes and other materials used in archival storage to use in life predictions.

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