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AN EMPIRICAL APPROACH TO PREDICTING LONG TERM BEHAVIOR OF METAL PARTICLE BASED RECORDING MEDIA

By

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AN EMPIRICAL APPROACH TO PREDICTING LONG TERM BEHAVIOR OF METAL PARTICLE BASED RECORDING MEDIA

Alpha iron particles used for magnetic recording are prepared through a series of dehydration and reduction steps of α-Fe_2O_3-H_2O resulting in acicular, polycrystalline, body centered cubic (bcc) α-Fe particles that are single magnetic domains. Since fine iron particles are pyrophoric by nature, stabilization processes had to be developed in order for iron particles to be considered as a viable recording medium for long term archival (i.e. 25+ years) information storage. The primary means of establishing stability is through passivation or controlled oxidation of the iron particle's surface.

The usual technique of producing the protective layer is through re-oxidation of the iron particle's surface after synthesis starting with a mixture of 0.1% O_2 and 99.9% N_2. The oxygen content is slowly increased to 20% (the composition of air) so as to maintain the reaction at room temperature. This results in a particle that is stable in air provided it is not subjected to any form of 1) mechanical abuse that could disturb the outer layer, or 2) source of heat that would initiate combustion.

The nature of the passive layer on iron particles has been found to consist of either Fe_3O_4, γ-Fe_2O_3 or a mixture of the two. The thickness of the passivation (or total) oxide layer is typically about 3.0 nm. The condition of passivity slows down the oxidation of iron, but, the formation of the iron-oxide layer around metallic iron particles does not preclude further oxidation. The continued stability of iron particles is controlled by the integrity of the oxide layer and the kinetics of diffusion of iron ions through it.

Since iron particles used for magnetic recording are small, additional oxidation has a direct impact on performance especially where archival storage of recorded information for long periods of time is important. Further stabilization chemistry/processes had to be developed to guarantee that iron particles could be considered as a viable long term recording medium.

In an effort to retard the diffusion of iron ions through the oxide layer, other elements such as silicon, aluminum and chromium have been added to the base iron to promote more dense scale formation or to alleviate some of the non-stoichiometric behavior of the oxide or both.

The presence of water vapor has been shown to disrupt the passive layer, subsequently increasing the oxidation rate of the iron.

A study was undertaken to examine the degradation in magnetic properties as a function of both temperature and humidity on silicon-containing iron particles between 50-120°C and 3-89% relative humidity. The methodology to which experimental data was collected and analyzed leading to predictive capability is discussed.

EXPERIMENT

To study the effect of temperature and humidity on the stability of passivated iron particles as a function of silicon content, three particle batches were prepared from the same precursor containing 0.81, 0.95 and 1.12% silicon by weight.

As stated earlier, the oxidation process of iron particles is diffusion controlled. The increase in oxide thickness is determined by how fast iron ions can migrate to the surface (passivation kinetics). It is assumed that the reduction in σs is proportional to the oxide thickness; therefore, Fick's second law of diffusion for concentration dependent systems can be applied:

$$Y^2 \simeq D\ t$$

where:

Y = diffusion distance in cm

D = diffusivity in cm^2/sec

t = diffusion time in sec.

For this analysis, the data are plotted as specific magnetic moment versus the square root of time. The resultant slope is therefore the rate of degradation expressed as EMU/gram-sec$^{0.5}$ for a given temperature and humidity condition.

Analysis of the interactive effects of temperature, humidity and percent silicon on the degradation of magnetic properties of iron particles were determined using a statistical experimental design package run on an IBM AT compatible computer. The characteristic measured was the $\log_{10}$ of σ_s loss per second$^{0.5}$ (rate of degradation).

The procedure of data analysis consists of selecting an initial mathematical model (usually a quadratic equation to analyze interaction and curvature effects of the form $Y = C_o + C_1X_1 + C_2X_2 + C_{13}X_1X_3 \ldots. + C_{11}X_{12} + C_{22}X_{22} \ldots.$) where C_n is a constant and X_n is the level setting of the respective factor. The model is then used to "fit" the data.

RESULTS AND DISCUSSION

Dry Conditions. The first series of oxidation rate experiments were run at the "dry" conditions for the selected temperatures. Oxidation at various temperatures allowed generation of σs vs. time curves for iron particles containing 0.81, 0.95 and 1.21% silicon sample at various temperatures.

Figure 1 shows the change in specific magnetic moment with time for the 1.12% silicon sample at various temperatures. As temperature increased, the rate of degradation of σs also increased. Differences in the rate of degradation at a given temperature between the three samples studied containing different amounts of silicon are slight, indicating that the iron particles all behave the same at low humidity, independent of Si content or initial σ_s value.

Activation energies for degradation of the 0.81, 0.95 and 1.12% silicon-in-iron powder samples were determined to be 0.383, 0.263, 0.333 eV, respectively when the rates of degradation were plotted against the absolute temperature (Arrhenius plot). Thus, the energy requirement to initiate the oxidation reaction for the various Si-contents is essentially the same and all degrade at essentially the same rate as a function of temperature. However, these activation energies are only ~10% of the value for diffusion of iron through any of the possible iron oxides. The implication is that the primary mechanism for the loss in magnetic properties is not due to lattice diffusion but rather diffusion along some short circuit path such as linear or planer defects present in the oxide shell.

Moisture Effects. Magnetic moment loss is shown as a function of humidity at constant temperature (70°C) for the 0.81, 0.95 and 1.12% silicon samples in Figures 2, 3 and 4 respectively. As the humidity increases, the rate at which the magnetic moment degrades increases markedly with decreasing Si content.

Figure 1.

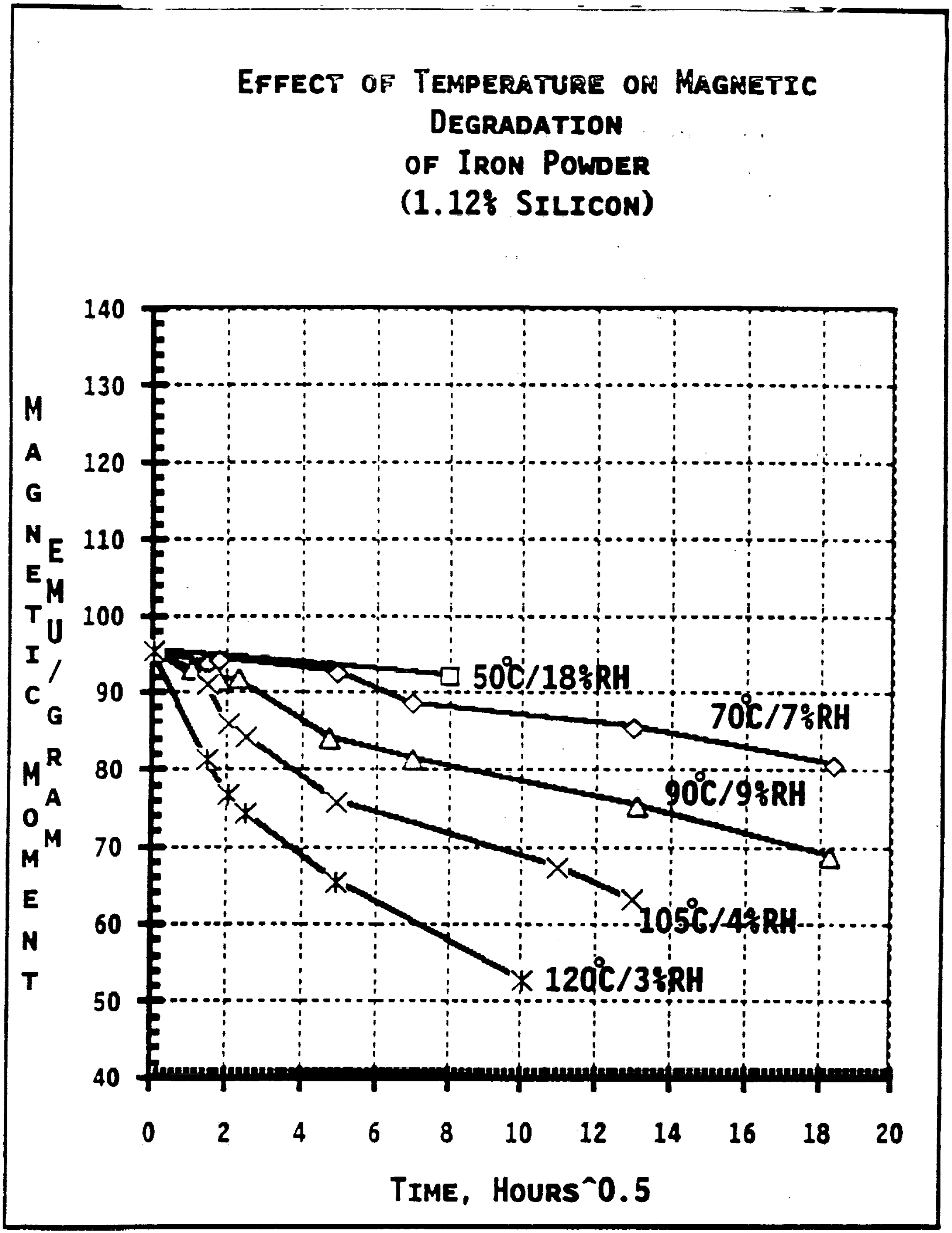

EFFECT OF TEMPERATURE ON MAGNETIC DEGRADATION
OF IRON POWDER
(1.12% SILICON)
MAGNETIC MOMENT
EMU/GRAM
140
130
120
110
100
90
80
70
60
50
40
0
2
4
6
8
10
12
14
16
18
20
TIME, HOURS^0.5
50°C/18%RH
70°C/7%RH
90°C/9%RH
105°C/4%RH
120°C/3%RH

Figure 2.

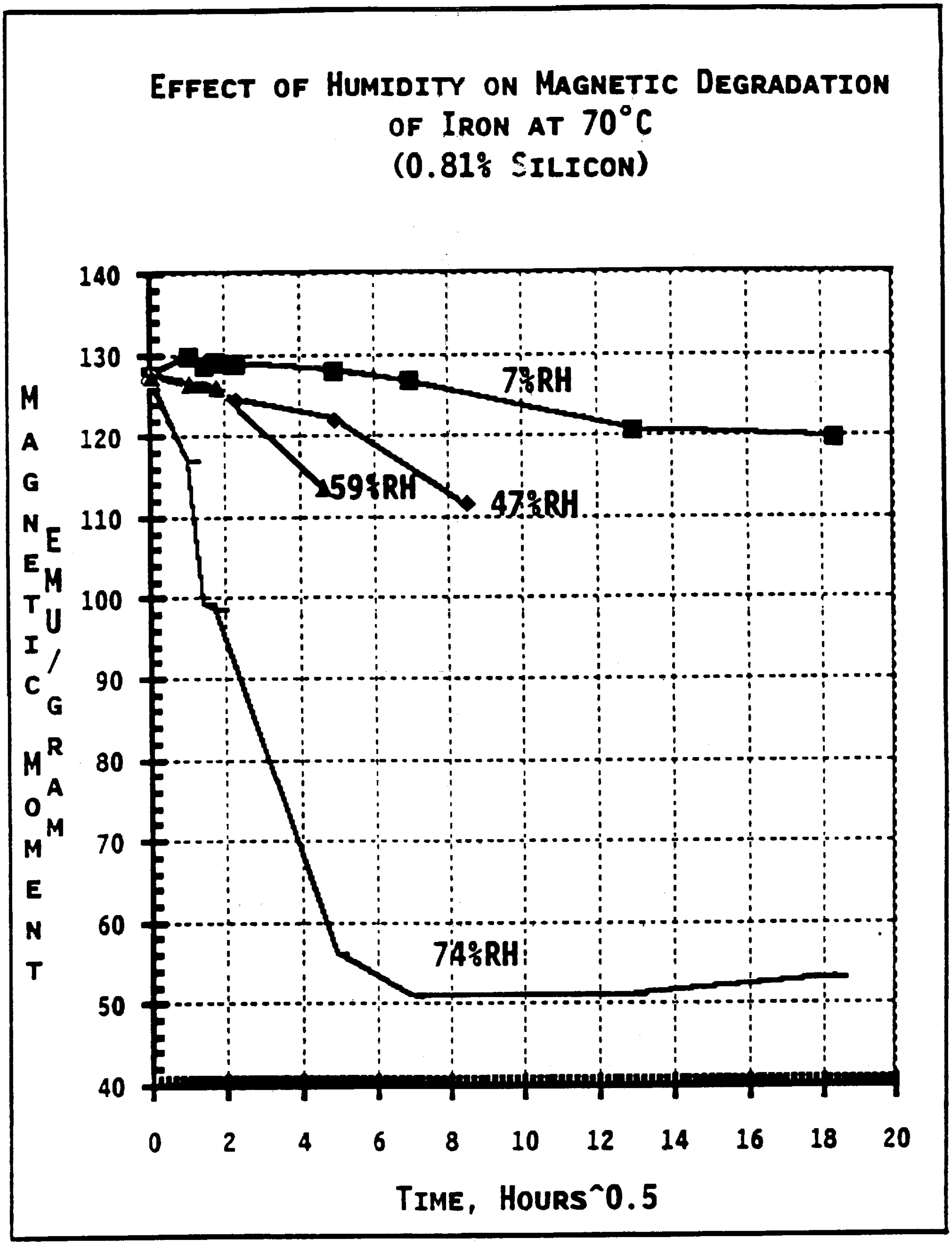

EFFECT OF HUMIDITY ON MAGNETIC DEGRADATION
OF IRON AT 70°C
(0.81% SILICON)
MAGNETIC MOMENT
EMU/GRAM
140
130
120
110
100
90
80
70
60
50
40
0
2
4
6
8
10
12
14
16
18
20
TIME, HOURS^0.5
7%RH
59%RH
47%RH
74%RH

Figure 3.

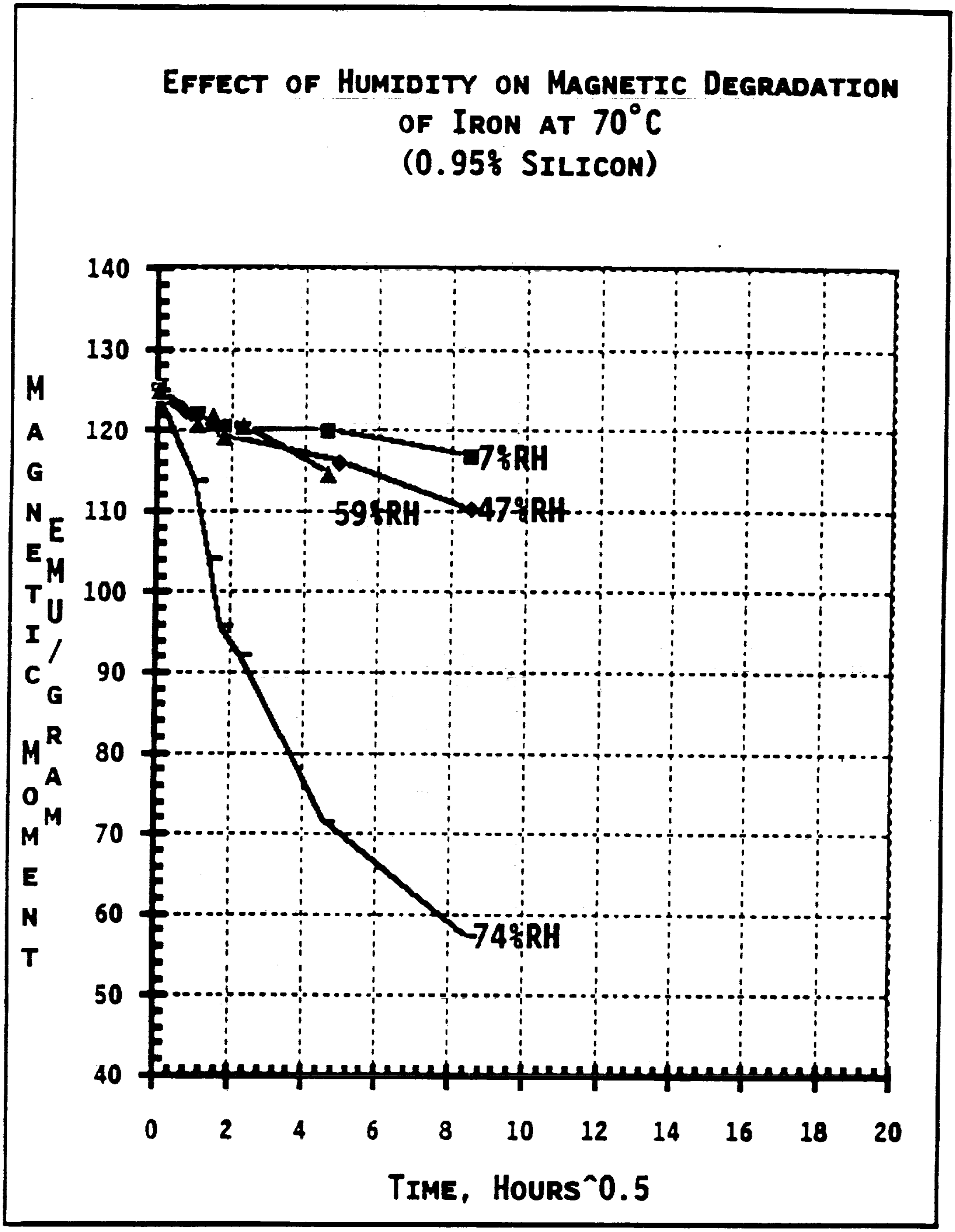
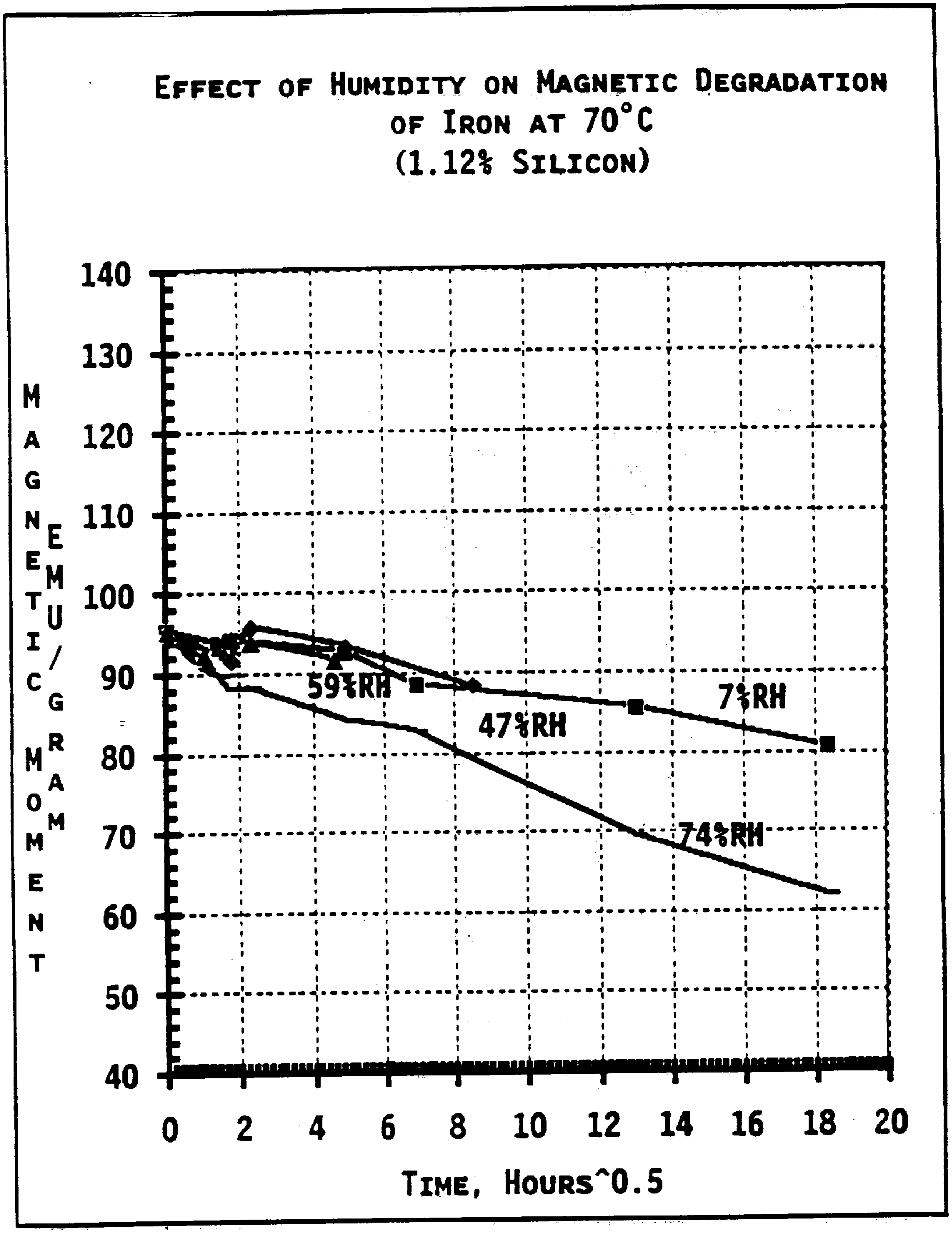

EFFECT OF HUMIDITY ON MAGNETIC DEGRADATION
OF IRON AT 70°C
(0.95% SILICON)
MAGNETIC MOMENT
EMU/GRAM
140
130
120
110
100
90
80
70
60
50
40
0
2
4
6
8
10
12
14
16
18
20
TIME, HOURS^0.5
7%RH
47%RH
59%RH
74%RH

Figure 4.


EFFECT OF HUMIDITY ON MAGNETIC DEGRADATION OF IRON AT 70°C
(1.12% SILICON)
MAGNETIC MOMENT
EMU/GRAM
140
130
120
110
100
90
80
70
60
50
40
0
2
4
6
8
10
12
14
16
18
20
TIME, HOURS^0.5
59%RH
47%RH
7%RH
74%RH

Degradation is most rapid for the 0.81% Si-containing iron particles. The sample containing 0.95% silicon is more resistant to degradation until the relative humidity is above 59% at 70°C. Finally, the sample containing 1.12% silicon is the most resistant to degradation exhibiting almost the same rate of loss at 7% relative humidity as it does at 74% relative humidity.

There appears to be a threshold value of relative humidity that is observed at the 0.95% silicon level and possible the 1.12% level, above which the degradation rate increases very rapidly.

As silicon content increases, the critical humidity (the humidity where rapid degradation occurs, at a given temperature) also increases. However, the degradation ceases at σ_s value of 50-60 EMU/gr for the 0.81% silicon sample (Figure 2). The trend appears to be the same (a saturation limit) for the 0.95 and 1.12% Si particles also.

Interaction of Temperature, Humidity and Silicon. The three parameters of this study (temperature, percent relative humidity and percent silicon content) interactively influence the degradation of the iron particles. Thus, statistical analysis was performed to quantify the contribution of each variable and present it in a manner that could be easily visualized. The measured characteristic was the $\log_{10}$ of the degradation rate in specific magnetic moment (EMU/gram-second$^{0.5}$) as derived from the results of the experimental matrix.

The design predictor equation determined using XSTAT is as follows:

$$\begin{aligned}\log_{10}(\text{Rate}) = -14.76 &+ 25.26(X_{Si}) + 0.04176(X_{RH}) \\ &+ 0.0015(X_T * X_{RH}) - 0.05963(X_{Si} * X_{RH}) \\ &+ 0.000068(X_T)^2 - 12.49(X_{Si})^2 \\ &+ 0.000219(X_{RH})^2\end{aligned}$$

where:

X_i = concentration of silicon in weight percent

X_T = temperature in degrees Celsius

X_{RH} = percent relative humidity

The percent variance explained (how well the regression equation predicts the data) was 96.03% so the model can be considered as quite good. Solving the predictor equation via the computer produces two dimensional contour plots of percent relative humidity versus temperature at constant silicon content. The values of constant degradation rate were transferred to a psychrometric chart (Figures 5, 6 and 7) so the relationships between absolute humidity (expressed as pounds of water per pound of dry air), percent relative humidity and temperature as a function of silicon content could be observed. The non-linear degradation behavior becomes very obvious when presented in this manner. A rate value can be taken from the contour plots for a given temperature, humidity and percent silicon content and be used to determine how long it would take for the magnetic moment to degrade to some predetermined value.

Figure 5.

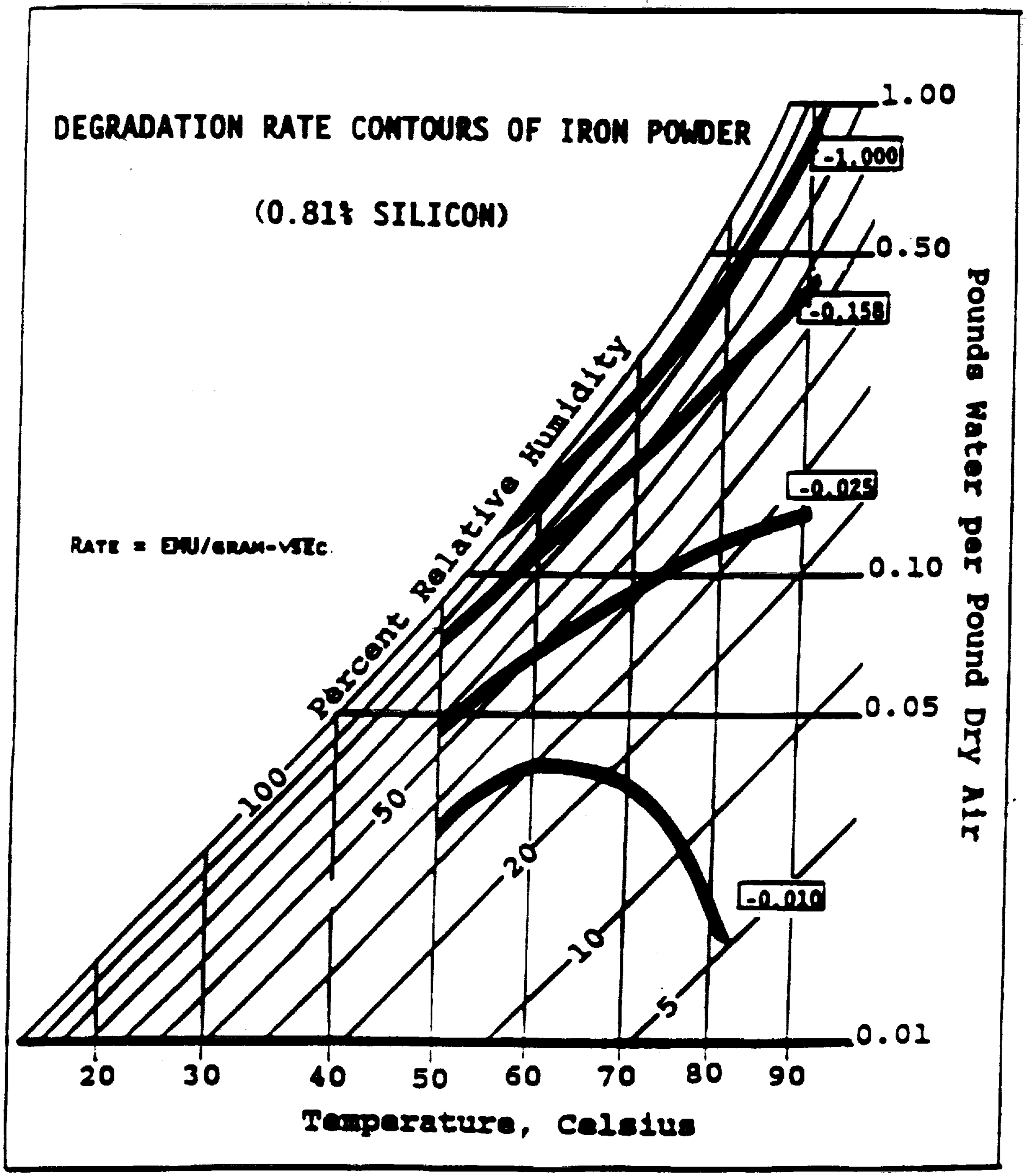

DEGRADATION RATE CONTOURS OF IRON POWDER
(0.81% SILICON)
RATE = EMU/GRAM-√SEC
Percent Relative Humidity
100
50
20
10
5
-1.000
-0.158
-0.025
-0.010
1.00
0.50
0.10
0.05
0.01
Pounds Water per Pound Dry Air
20
30
40
50
60
70
80
90
Temperature, Celsius

Figure 6.

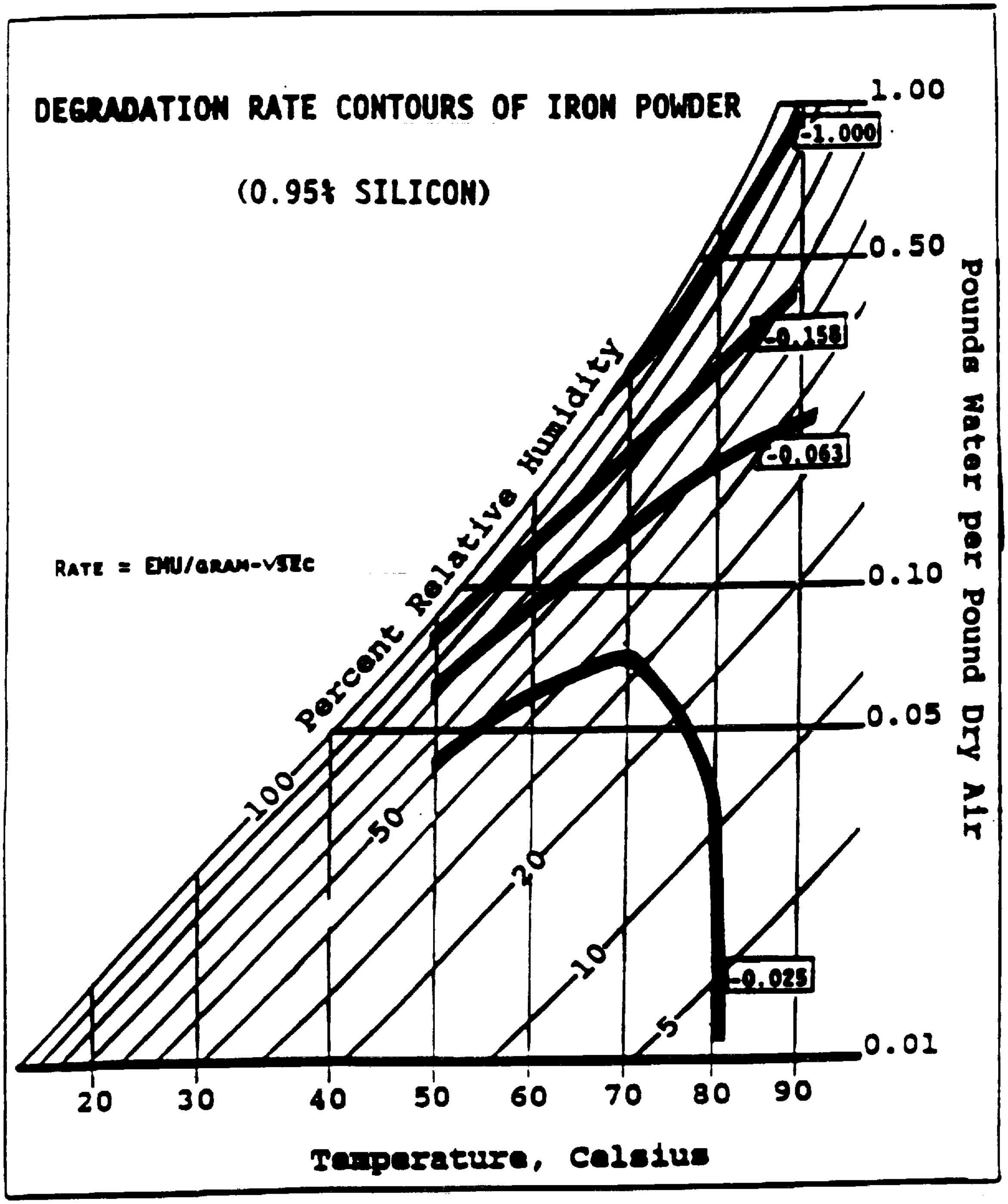
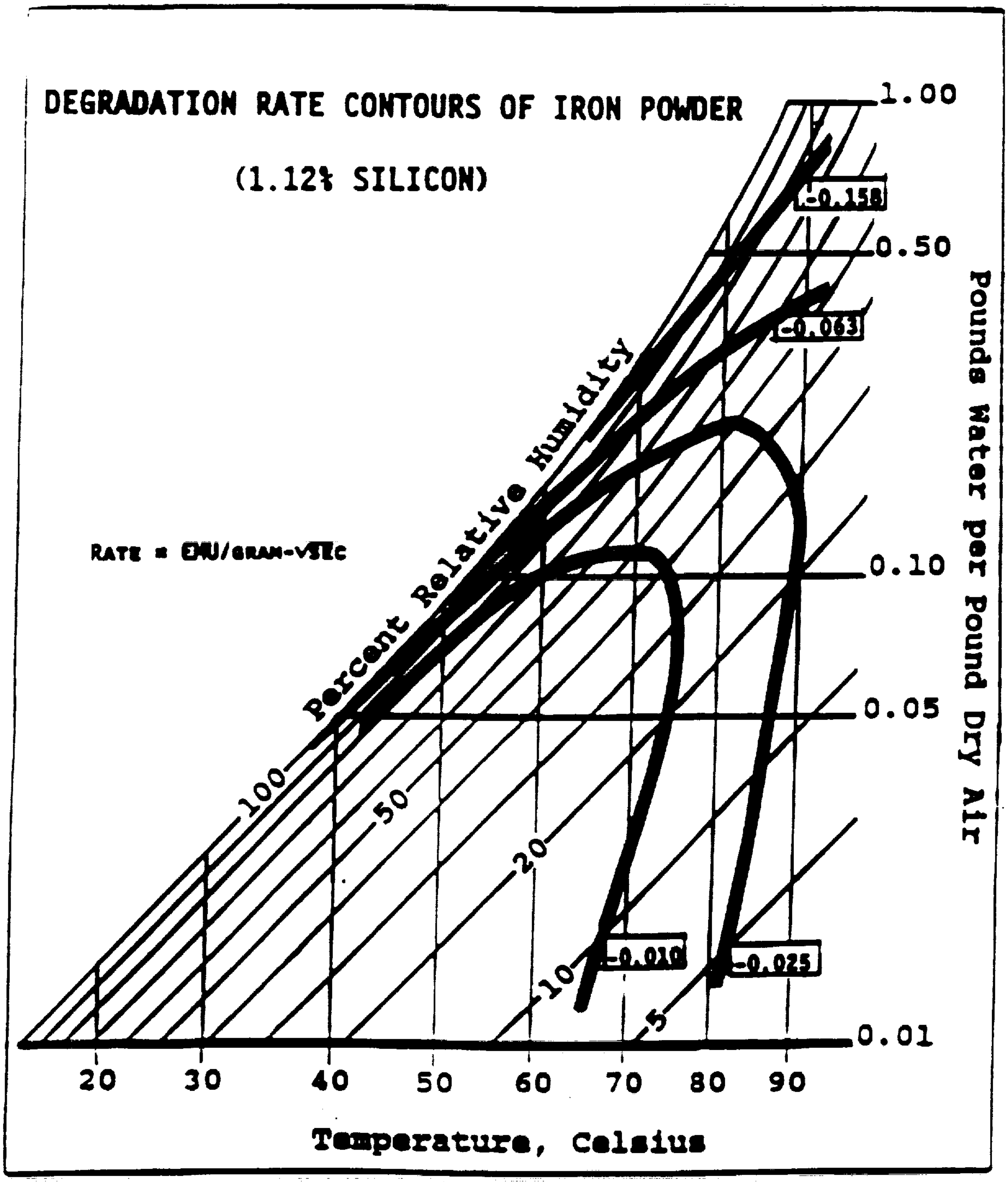

DEGRADATION RATE CONTOURS OF IRON POWDER
(0.95% SILICON)
RATE = EMU/GRAM-√SEC
Percent Relative Humidity
100
50
20
10
5
-1.000
-0.158
-0.063
-0.025
1.00
0.50
0.10
0.05
0.01
Pounds Water per Pound Dry Air
20
30
40
50
60
70
80
90
Temperature, Celsius

Figure 7.


DEGRADATION RATE CONTOURS OF IRON POWDER
(1.12% SILICON)
RATE = EMU/GRAM-√SEC
Percent Relative Humidity
100
50
20
10
5
0.158
0.063
0.010
0.025
1.00
0.50
0.10
0.05
0.01
Pounds Water per Pound Dry Air
20
30
40
50
60
70
80
90
Temperature, Celsius

For a constant absolute humidity (above the critical value, depending on silicon content) increasing temperature will cause the degradation rate to decrease. It appears that relative humidity is the controlling factor. The corrosion rate appears proportional to the thickness of the adsorbed water layer on the surface of the test specimens. The higher the relative humidity, the thicker the adsorbed layer, hence the faster the corrosion rate.

The behavior observed in the contour plots follows an expression of the form Rate = $A_e\ (b\%RH)_e-(Q/RT)$, where at low humidity temperature is the controlling factor, then a transition occurs where humidity effects prevail. It is obvious that special precautions should be taken when attempting to predict long term, low temperature behavior based on high temperature data with a system that is humidity sensitive. Actual archival stability could be less than expected unless humidity control is considered. The value of statistical analysis to the interpretation of oxidation behavior is clearly evident.

CONCLUSIONS

This study has shown the effects of percent silicon content, temperature and percent relative humidity on pre-passivated fine iron particles used for magnetic recording.

When the iron particles were exposed to various temperatures between 50 and 120°C at very low humidity it was observed that the degradation rates were not affected by either the silicon content or the initial value of the magnetic moment. TEM micrographs revealed that the oxide layer grew thicker leading to a condition of passivity.

It was shown that for a given temperature there exists a critical relative humidity value above which the degradation rate of magnetic moment increases markedly. The presence of silicon appears to increase the critical humidity value at which rapid degradation occurs. When the magnetic moment degrades to 50-60 EMU/gram it remains constant for additional exposure time.

A parametric expression has been proposed to relate silicon content, temperature and humidity to the initial rate of specific magnetic moment degradation for the iron particles used in this study.

Up here, if you increase temperature and maintain constant absolute humidity in the air, the degradation rate actually slows down, which means you might make a prediction conservatively that you might have better lifetime than you thought.

What these numbers correspond to is that they are EMUs per gram per root second of degradation rate; and what I can really translate it to is that to sustain a 10 percent loss in the EMUs per gram of the powder--the magnetic signal--this -1 value corresponds to 3 minutes that will lose 10 percent of its signal.

By the time we get down here to the .01 rate, 13.5 days to lose 10 percent; and then, the next contour line, which would be down here, .001, which is a five-year rate. Five years under more normal operating conditions based on data from much accelerated conditions. Five-year lifetime for the particles to lose 10 percent of their signal.

Again, remember, if we get it into tape, there is an additional layer of shielding; put it in a cassette, another layer.

What we are doing is proposing this methodology to do testing to really be able to do empirically derived predictive testing for determining what is the lifetime of tape--what is acceptable. How long will that really take? You have to be able to quantify what these rates are--these rate constants--as a function of both temperature and humidity.

So, to summarize, our feeling is that metal particle media based on the data I have shown you, both for environmental exposure conditions--we saw numbers on the order of 1 to 2 percent over three years--some of this methodology here.

We feel that metal particles are a viable vehicle for high-density recording. They are not as stable as the gamma iron oxides. They are not as stable as the chromium dioxide. But we feel that, within acceptable limits, it is a viable vehicle and that, for whatever lifetime you need before it's recopied to a new format or rerecorded, we think that the metal particles themselves do provide a good means--an excellent means of recording at high densities.

I have also then shown you that the data must be collected and crunched to give true archival predictions as to what the lifetime of the tapes will be. The manufacturers will be able to substantiate their claims with this kind of data as to how long the tape will last.

Thank you.

(Applause)

DR. KRYDER: Okay. The second speaker from Ampex is John Corcoran. John just recently retired from Ampex, last March, but is now working as a consultant for them.

John spent 30 years in optical and magnetic recording. John will be talking on the archival stability of metal particle tape. John?

ARCHIVAL STABILITY OF METAL PARTICLE TAPE

Mr. John Corcoran
Consultant/Ampex Corporation

MR. CORCORAN: I think most of the other speakers all come from the tape manufacturing community; I actually come from the recording community.

About five years ago, SMPTE, a group of 31 companies, representing broadcasters, tape manufacturers, and equipment manufacturers, started to put together what is now referred to as the D-2 standard.

Actually, it should be called the proposed D-2 standard; it takes forever to get these things done.

The question of tape stability was a key issue then.

(Showing of viewgraphs)

MR. CORCORAN: I happen to have here a paper, and I have copies of it if anybody wants, prepared by a chairman of the committee, Robert D. Thomas of ABC. And one of the key conclusions of the group at that time was that metal particle tape will be satisfactory "under rigorous broadcast conditions and the use of barium ferrite would not be beneficial before at least 1990."

(Change of viewgraph)

MR. CORCORAN: Now, four tape manufacturers report their earliest experimental tapes--and Allan made one, and Darlene has made another; and Sony has separately reported on this, and I believe Hitachi has--tapes that they made 12 or 13 years ago, all of which still play back the original recording signals in an acceptable manner.

Three digital recorder manufacturers in the last year have reported that tapes protected in the cassette will not degrade. Ampex presented a paper on this; Digital Equipment Corporation has presented a paper on this. Dr. Speliotis was a co-author on that paper; he did the magnetic work. And Exabyte has also looked at that.

The effect of the cassette on protecting the tape is much larger than is generally realized. In spite of these facts, the question of stability of tapes is still with us; and I don't know how long it is going to remain with us.

There is considerable evidence; I would like to point out, though, that tapes will survive very well under what I will call archival conditions. Now, archival conditions do not include continuous storage at high temperature and humidity.

There is a considerable number of papers that have been presented before--Bertram, Cuddihy--on what happens if you try to do that. And it won't work with the metal particle tape, and it won't work with iron particle cobalt gammaferric oxide tape either. (Change of viewgraph)

MR. CORCORAN: Here's a chart comparing the uses of various types of tape and various applications over the years. You will see that metal particle tape here has become more common. The most recent one I've added here is a metal particle in a 3480 cartridge.

(Change of viewgraph)

MR. CORCORAN: In our studies, we have taken samples of tape from four different manufacturers, all that were available last year: Ampex, Sony, Fuji, and Hitachi. And we ran them in this Battelle environment, we measured the error rates of those tapes beforehand; we measured them after.

What I have done here is plot the before versus after error rate measurements on three or four cassettes of each of the four brands. Now, this data happens to be for what I call "non-burst errors," where you have isolated single errors. That does not necessarily mean random, but they are isolated. They are not clumps.

ERROR RATE MEASUREMENT

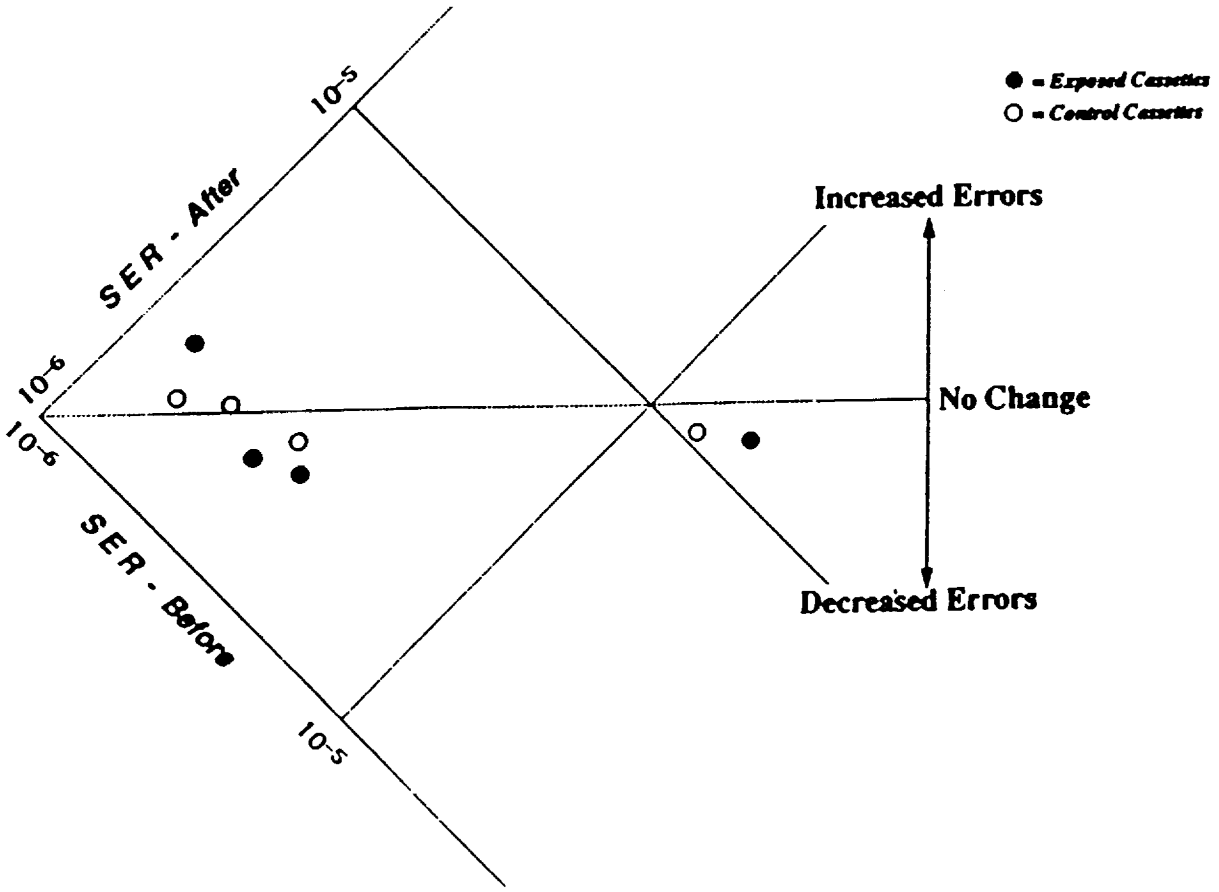
ALL ERROR DATA PRESENTED IS "RAW" TO PERMIT DETECTION OF ANY CHANGE IN THE MEDIA. (WITH ERROR CORRECTION APPLIED, MOST CASSETTES WOULD RUN ERROR-FREE, AND CORROSION EFFECTS WOULD BE UNDETECTABLE).

SYMBOL (OR BYTE) ERROR RATE (SER) IS USED FOR D-2 DATA BECAUSE THE REED-SOLOMON ERROR CODING IS SYMBOL ORIENTED.

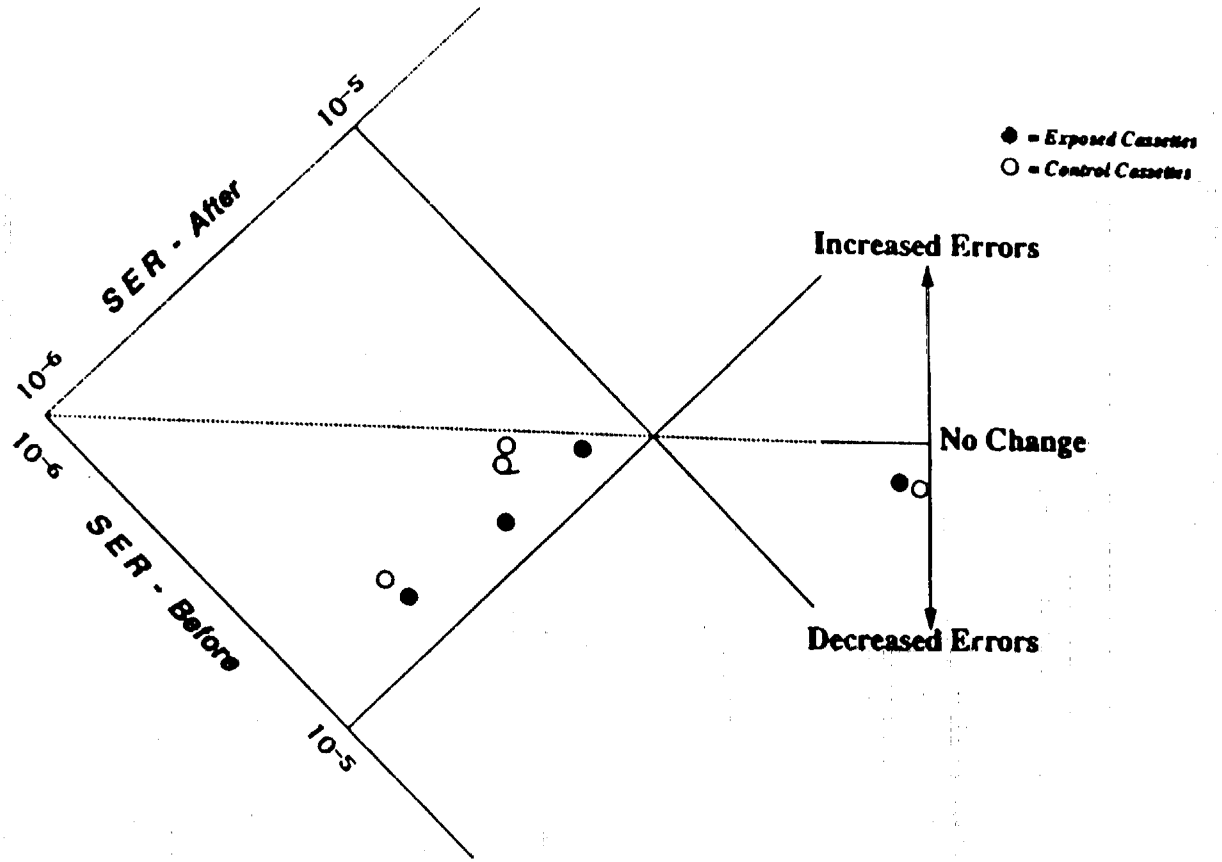
BURST AND NON-BURST ERROR DATA ARE PRESENTED. NON-BURST DATA INDICATE ERRORS IN INDIVIDUAL BITS DUE TO LOSS OF SNR, MEASLES, ETC. BURST ERRORS ARE PRIMARILY DUE TO SURFACE DEFECTS.

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



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



The data generally shows the error rates are lower after exposure. The black dots represent the exposed data; the clear dots represent controls. We kept controls with them.

They both go down, indicating probably our transport improved. (Change of viewgraph)

MR. CORCORAN: And we did the same thing with looking not at the isolated errors, but at clumps of errors; and some of us feel that clumps are more likely to be produced by corrosion than single ones. We get exactly the same effect. The tapes did not degrade.

(Change of viewgraph)

MR. CORCORAN: Now, I would like to mention barium ferrite. Barium ferrite is considered to be one of the more stable materials that we can have. Unfortunately, we don't have very much of it.

Ampex had one sample, which we have run on recorders; and we had trouble with shedding. And this is not uncommon when we try a new tape on a recorder. It turns to dust, and then we have to tell the chemist: Go back and fix up the formulation.

We would like to have other samples in the D-2 format. Some day it may prove to be an interesting media; but at the present time, it just isn't available. Thank you.

(Applause)

DR. KRYDER: Okay. Thank you, John. The final speaker this afternoon, before we break into the discussion will be Dennis Speliotis. Dennis was born in Greece and obtained his university education in the United States, receiving a Ph.D. in Solid State Physics in 1961. He worked at IBM from 1961 to 1967 and became Manager of Recording Physics.

Dennis subsequently taught at the University of Minnesota from 1967 to 1971, where he established the Magnetics Research Laboratory. He was a co-founder and vice president of Microbit Corporation, where he worked on electron beam memories.

Since 1977, he has been President of Advanced Development Corporation in Burlington, Massachusetts, doing consulting in advanced magnetic materials and magnetic recording. He co-founded in 1984, and is President of, Digital Measurement Systems, Inc., also located in Burlington, which manufactures advanced vibrating sample and torque magnetometers.

Dennis will talk about corrosion and barium ferrite, and I'm sure he will give us some comparisons to other media.

CORROSION AND BARIUM FERRITE

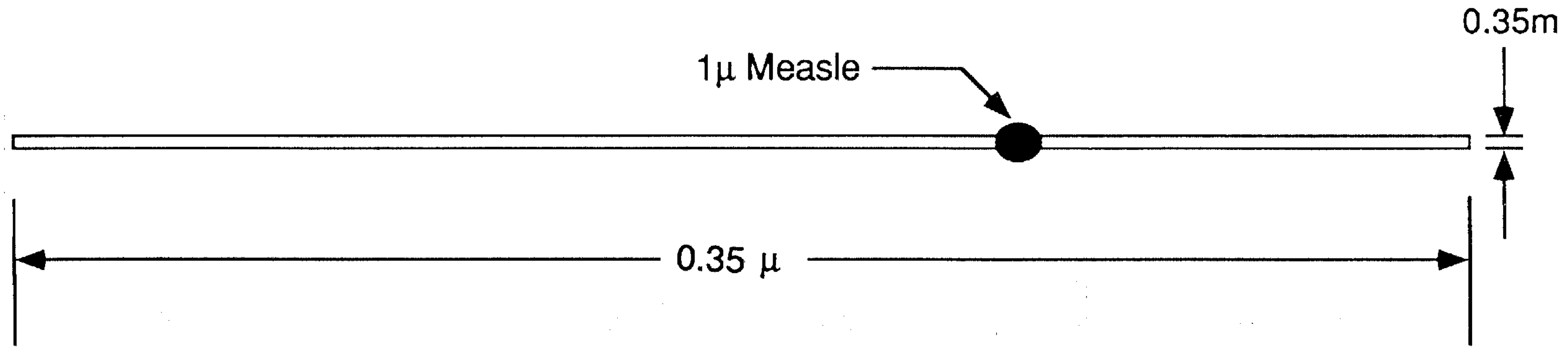
Dr. Dennis Speliotis
Advanced Development Corporation

DR. SPELIOTIS: Thank you, Mark. I have had two pieces of advice, one from the chairman of our session and one from Dr. Hariharan. One was: Be very brief. And the other one was: Be very nice. And interspersed between those two also was: Be controversial.

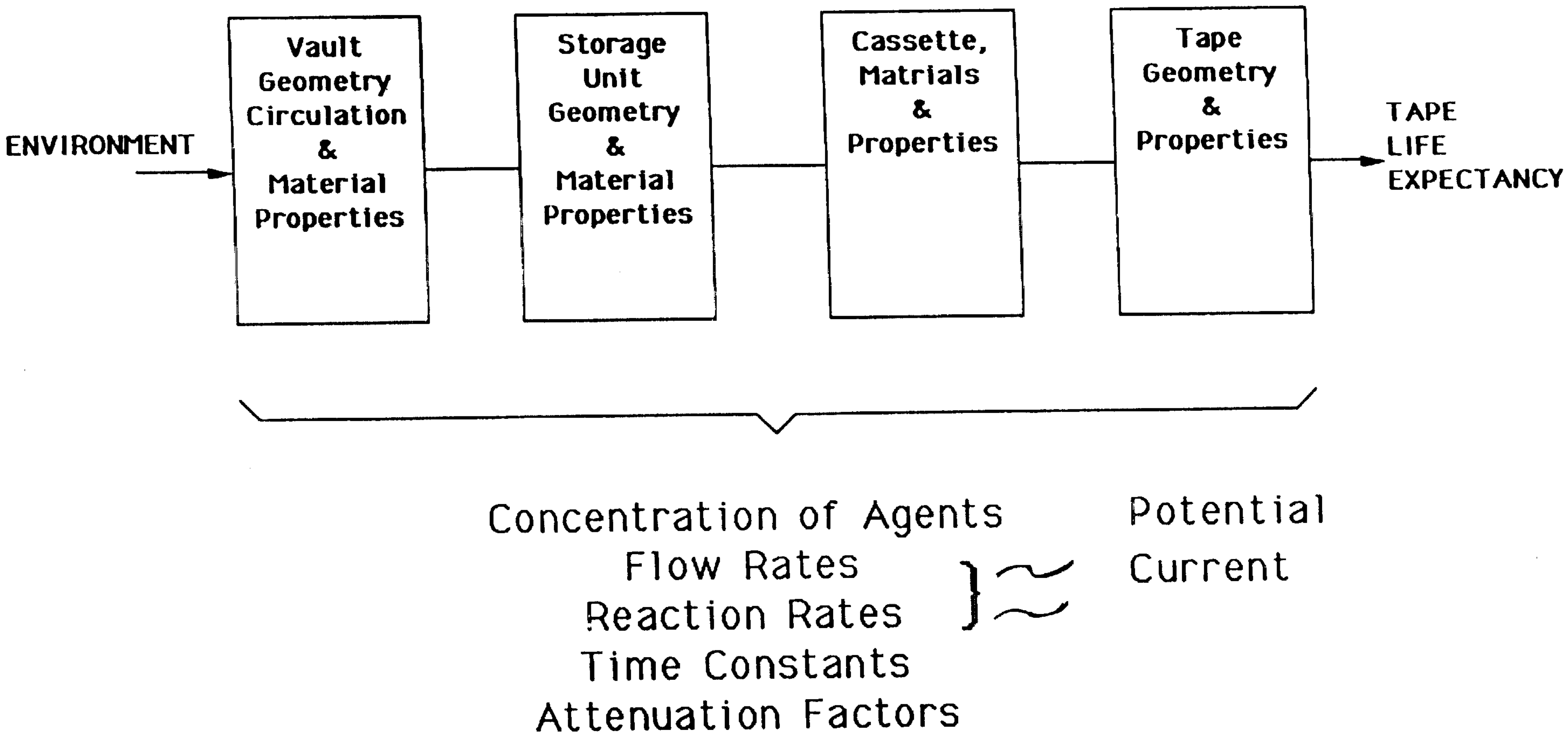
This advice is rather conflicting, but I will try to satisfy all the suggestions if I can help it.

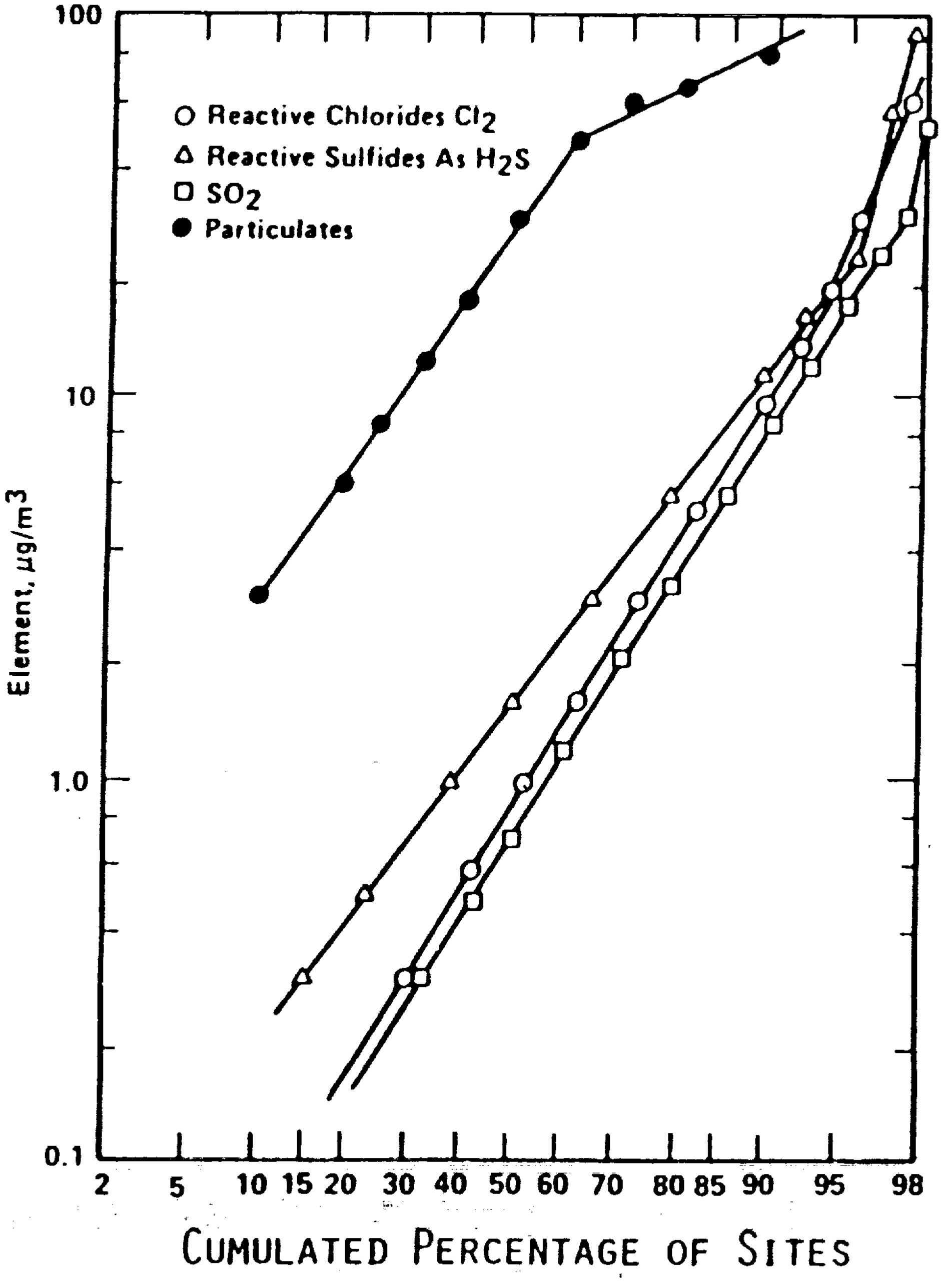
(Laughter)

Comparison of a Bit Cell and a Measle



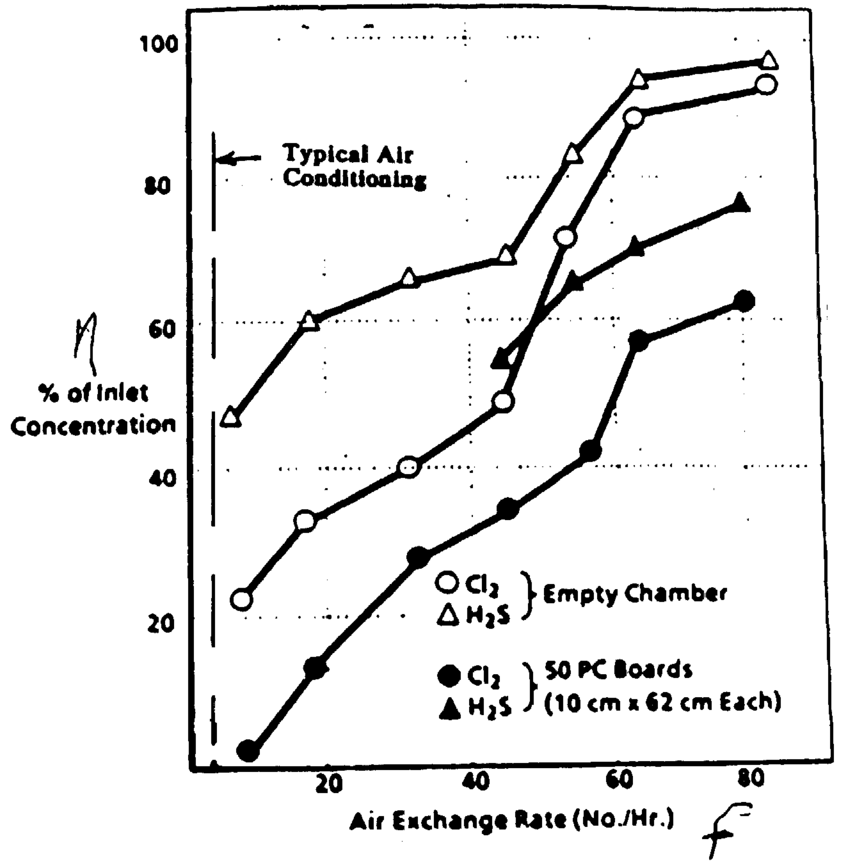
BLOCK DIGARAM OF AN ARCHIVAL STORAGE SYSTEM





WORLDWIDE INDOOR POLLUTANT DISTRIBUTIONS FOR ELECTRICAL AND ELECTRONIC EQUIPMENT

ADSORPTION IN BATTELLE TEST CHAMBERS



Gas Adsorption Rate

$$\frac{dQ}{dt} = \{[G]_{in} - [G]_{out}\} V f$$

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

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

Adsorption Cofefficents

k_i cm/sec

Gas	Chamber Walls	Circuit Boards
Cl_2	0.20	0.093
H_2S	0.086	0.035

GENERAL CORROSION REACTION

$M + G \longrightarrow MG$

M Metal
G Gas

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

$$\mathbf{M = M_0\,exp\ - t/\tau}$$

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

For low gas concentrations, the time constant is very long. Also, for $\mathbf{t} \leq \tau$ 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

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

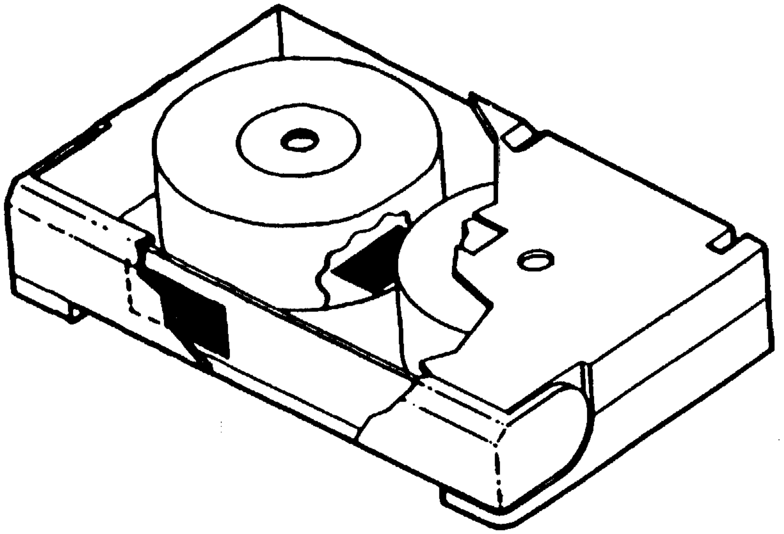
For $\overline{P}$ = 30 in. Hg, $\Delta P = 1 in$ Δt = 3 days, τ = 90 days.

SHIELDING TEST

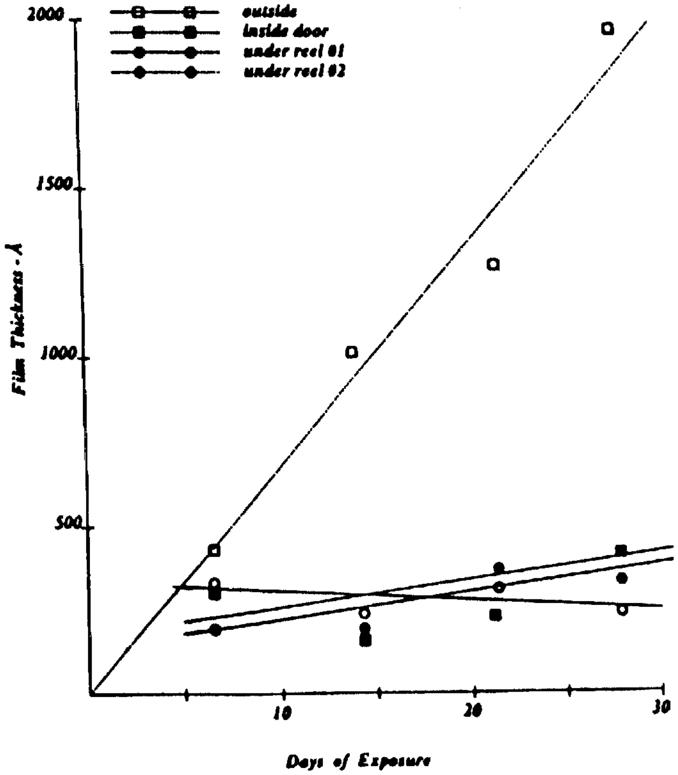
STANDARD D-2 CASSETTES (SMALL SIZE) WERE FITTED WITH BATTELLE METAL COUPON SAMPLERS AND EXPOSED FOR 28 DAYS. A COMPARISON OF RESULTS OF THREE INTERNAL SAMPLERS WITH AN EXPOSED ONE INDICATES THE CASSETTE HAS ATTENUATED THE CORROSIVE ENVIRONMENT TO NEGLIGIBLE PROPORTIONS.

THE DIFFERENCE BETWEEN THE PRESENT RESULTS AND THOSE REPORTED BY SPELIOTIS FOR "NAKED" TAPE ARE ATTRIBUTABLE TO THE CASSETTE SHIELDING FACTOR.

Sampler Locations on D-2 Cassette

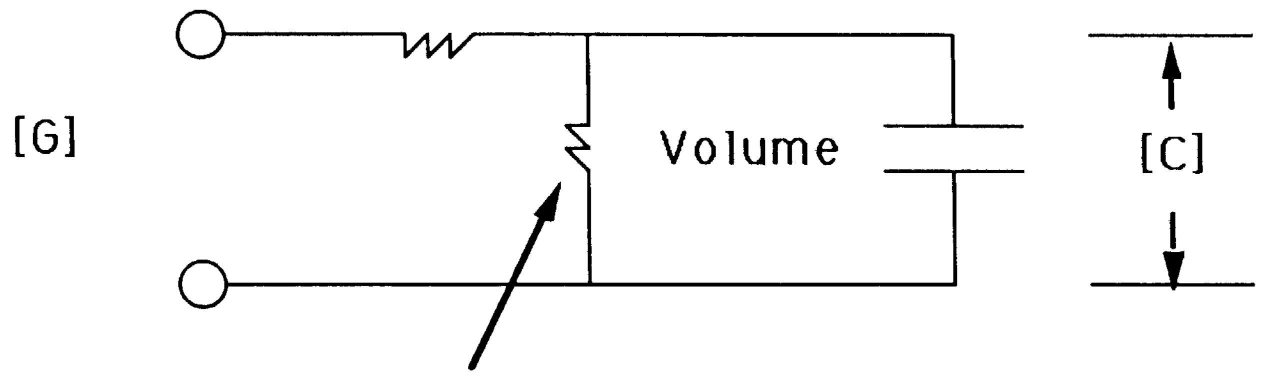


Silver Sampler Film Measurements for Various Locations on D-2 Cassette



CASSETTE IMPEDANCE MODEL

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



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

$$\frac{[C]}{[G]} = \frac{1}{\dfrac{K_w A_w \ell}{\Delta A_x} + 1}$$ Attenuation
Factor

DIFFUSION INTO REELS

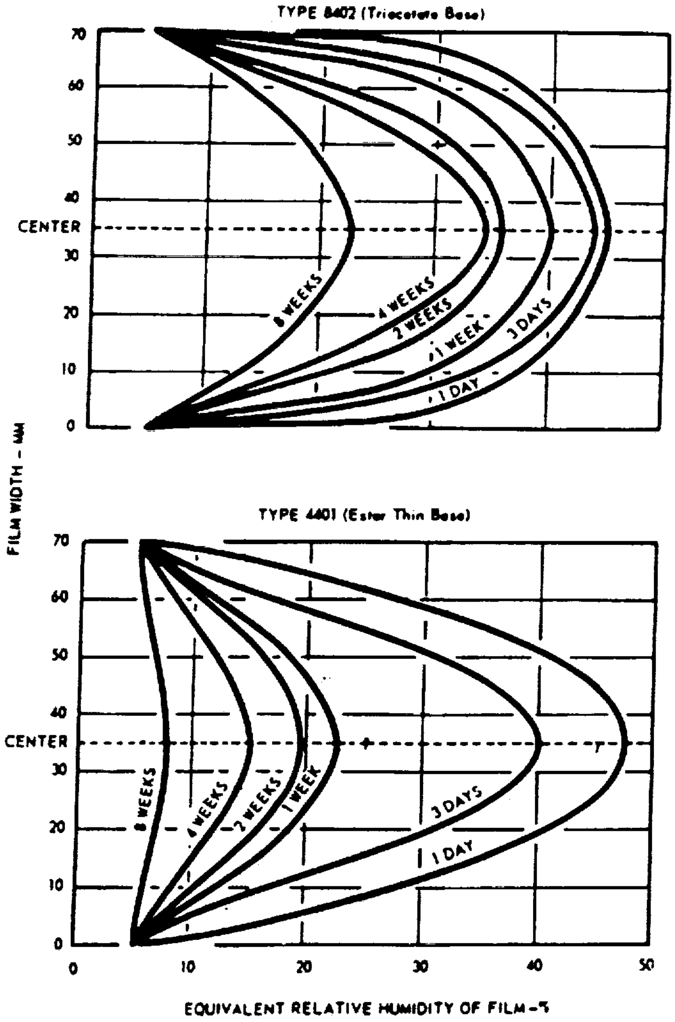


Fig. 6.10 Moisture Gradients During Conditioning of Aerial Film Rolls at 70°F -5% RH

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

DETERMINATION OF TIME CONSTANTS FOR MOISTURE DIFFUSION

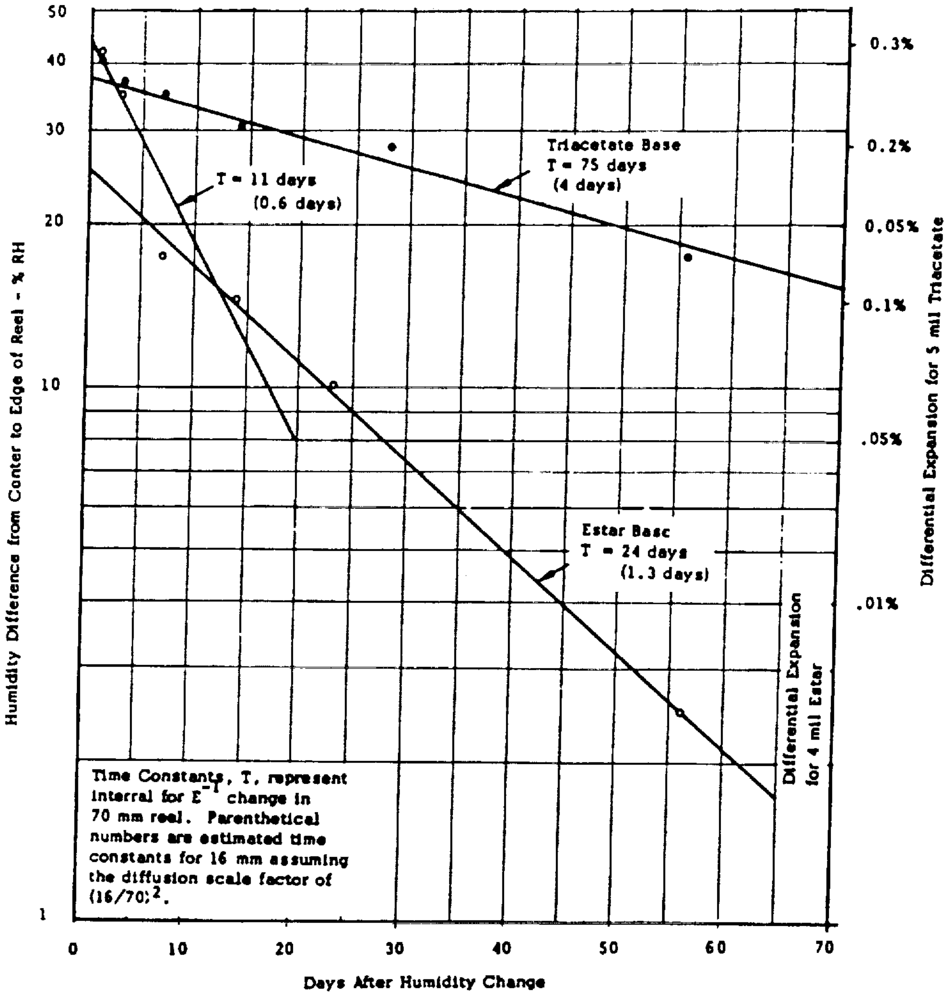


Fig. 6.11 Difference in relative humidity between center to edge of a 70 mm reel following a step change from 70°F - 50°λ RH

$$\tau = T \left\{ \frac{W}{70\ \text{mm}} \right\}^2$$

FROM BERTRAM & ESHEL

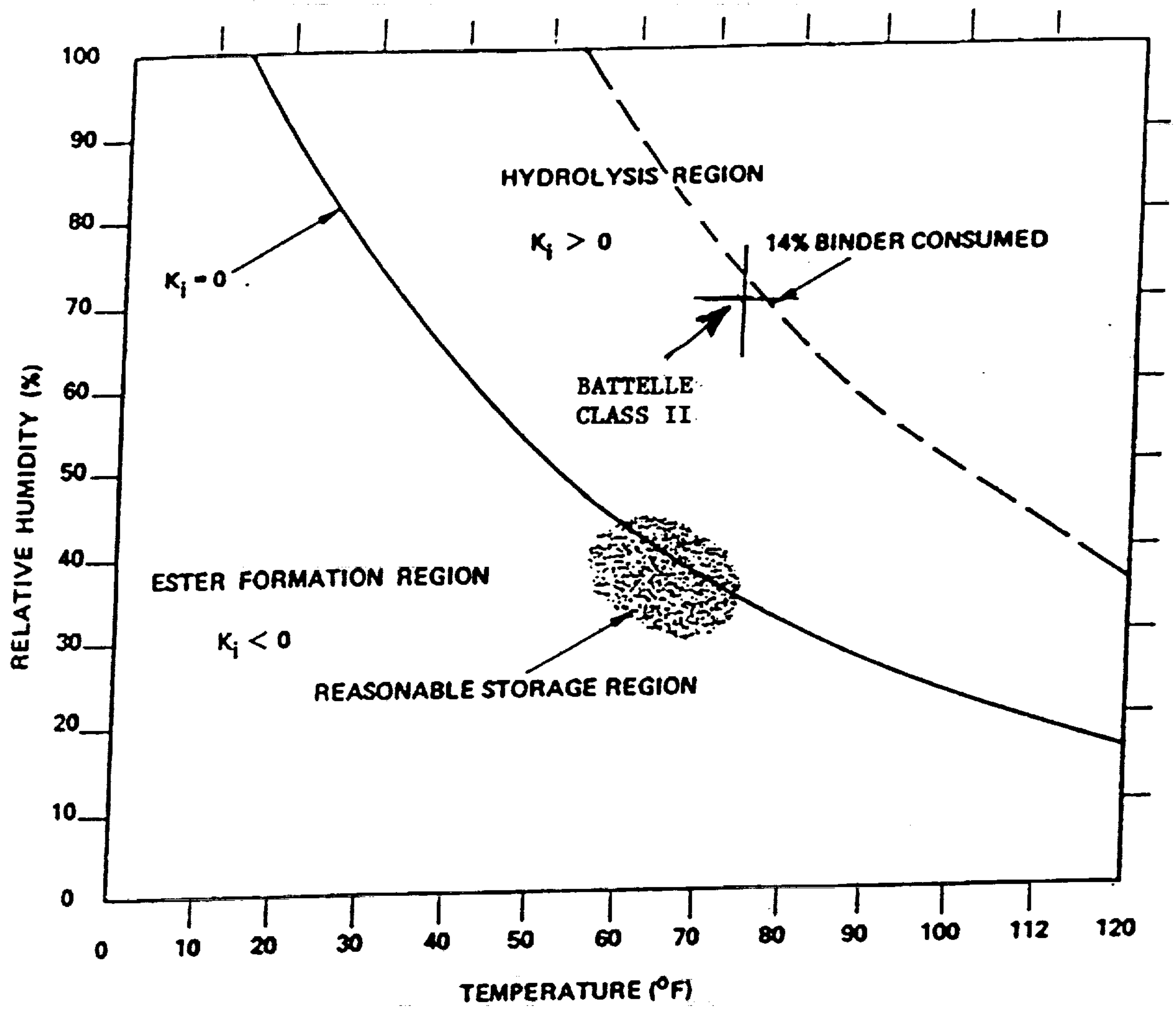


Figure 37 Hydrolysis equilibrium curves vs humidity and temperature. $K_i = 0$ indicates initial equilibrium. Dashed curve denotes 14% binder hydrolysed from an initial 6.7%.

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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DR. SPELIOTIS: Well, we already heard about various kinds of tapes and their stability. There is one important issue, however, that I would like to remind everybody; and that is, we didn't hear very much about gammaferric oxide *per se.* Why? Primarily because the performance of γ-ferric oxide is not adequate to meet the demands of high density data storage.

So, really stability and archivability are important, but performance is also important. We are talking about high performance media. We talk about terabytes of data; some people even talk about petabytes of data, 10^{15}.

So, obviously, high density is very important. What we would really like to have is very stable media that will also have high performance.

If we keep this in mind, I submit to you that most of today's highest usage media, such as Co-dopted γ-Fe_2O_3 and chromium dioxide are not extendable to very high densities. Therefore, they will fall by the wayside in the future--no doubt about it.

Co-doped γ-Fe_2O_3 is not extendable because if we add more Cobalt, the temperature dependence of the coercivivity becomes excessive. This is a reversible change--not irreversible. It is just a reversible temperature change; coercivity drops as the temperature goes up. Chromium dioxide is not extendable because we cannot go up in coercivity very much. There is only one way that has been found to extend the coercivity of chromium dioxide to very high values, which is required for high density storage, and that is to dope it with Iron; but the total amount of Iron in the world would not be enough to satisfy even a minuscule percent of the requirement.

Iron doping of chromium dioxide is another possibility, but that is limited. Maybe the maximum coercivity that can be obtained is about 1,000 Oersted , which is not good enough.

So, I am going to scratch off the list for the future chromium dioxide and cobalt-modified iron oxide. That leaves metal particles and ME. Nobody has talked about ME, and I will say a few words. Metal-evaporated tape is a very natural extension of the technology to go to high density data storage. Why? Because we can get very high coercivity in metal particles and very high magnetization at the same time, which is beautiful.

On ME, of course, we get high coercivity, very high magnetization, and thinness, which is also very important to go to high density.

So, it is only logical that the Japanese and us, later adopted the use of metal particle and are beginning to adopt ME for high density storage media.

Now, there is a new material; John said it is not available, but it is becoming available: barium ferrite. Barium ferrite is a very stable material; Darlene did not mention it, but on her chart of stability, there are only two materials that are really stable. And I don't think anybody argues with this.

Plain γ-Fe_2O_3 and barium ferrite. On Darlene's chart, those were the only ones that had red dots, meaning stable under all conditions--no change. Okay.

Now, barium ferrite also is a material which allows you to attain any coercivity you want--any-- including higher coercivities than metal particles. If you want 5,000 Oersteds, if you can write on it, you can have it.

Now, there is one problem with barium ferrite; and that is that the magnetization is relatively low, about 60 EMU per gram. However, as you saw, on many of the metal particles, the magnetization is dropping and is dropping very rapidly. Pure alpha iron has a magnetization of 210 EMU per gram; today's metal particle tapes use particles which because of the oxide required to protect them, plus the silicon fortification--what is called armor fortification--silicon alumina, ceramic fortifier- the effective magnetization with the particles is about half of that of a-Fe.

Now, with these particles that are used today in metal particle media, the size of the particles typically is about 1,500 Angstroms in length and about 1/8th to 1/10th of that in diameter.

They have a protective coating roughly on the order of 3 nanometers, about 30 Angstroms.

Now, let us make a simple calculation. If you take this particle and make it smaller, and you must make it smaller because you cannot extend the high-density capacity of metal particles without using smaller particles (the particles are already too large as they are today for real high density). If you make it smaller, like 1,000 angstroms in length, and about 100 angstroms in diameter and have roughly not 30 angstroms of protective coating, but maybe 25, you calculate the magnetization of that particle to be below that of barium ferrite.

So, metal particles are not extendable into the real high-density requirements of the future. I can take the best metal particle tape that is available today, and compare it with barium ferrite experimental tapes; the barium ferrite, in spite of its low magnetization, outperforms the metal particle tape in absolute signal--not in noise--it outperforms it in noise at much lower density--but in absolute signal, for any density over 75 Kfci.

At densities above 75 Kfci the barium ferrite tape has higher absolute signal than metal particle tapes. The reasons for this are beyond the scope of this conference; there are certain fundamental demagnetization processes that are very different in the case of barium ferrite than in the case of metal particles.

Now, many of us have also heard--and I think I should say a few words--about ME tape--the metal-evaporated tape that in some quarters is supposedly going to be the ultimate successor of all of these tapes. It is going to be the high-density, high-definition media of the future. And the question is: How, for example, does barium ferrite tape compare with ME tape recording-wise? The performance is identical within half a dB at anything above 130 Kfci.

So, if you really want to talk about high density, I think the real possible contenders are barium ferrite and ME tape. MP tape is not extendable.

Now, let's go to the subject of our seminar here, which is called instability. There are some very important issues; Allan made a very important distinction between long-term archivability versus environmental stability. It is obviously a complex issue.

What I will show you are some error rates that were measured using a Media Logic ML-4500 tape tester, which uses an Exabyte drive. The measurements were done on 8 millimeter metal particle, ME, and some experimental barium ferrite tapes, all of them 8 millimeter. We did immediately read after write.

These tapes were exposed to a corrosion test which was only temperature/humidity; 7.5 weeks, at $50^{o}C/80\%$ relative humidity.

When I put the tapes in the chamber, they did not have the protective plastic box; I just put the cassette in, the way you mount it on a recorder, simply because I didn't want to be limited by diffusion effects, if any, in that period of time.

(Showing of viewgraphs)

DR. SPELIOTIS: Here are some typical results and error maps, before and after corrosion, for 40,000 tracks, on the Exabyte drive. These are not single bit errors; the machine

Corrosion Test: 7.5 Weeks 50C, 80% RH
Dropout vs. Threshold (20/28/80)

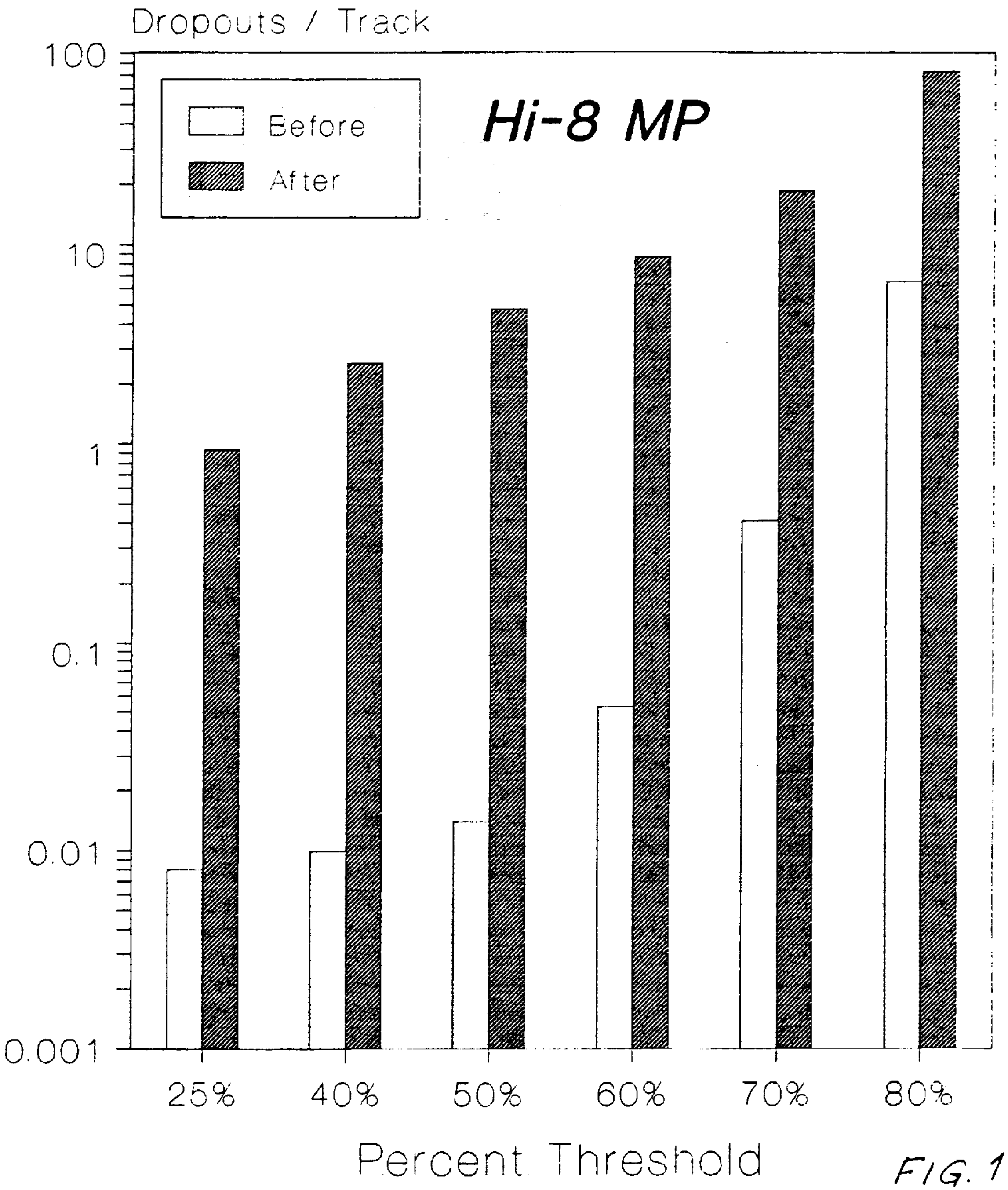


FIG. 1
Hi 8 MP Tape
before and after
corrosion

Corrosion Test: 7.5 Weeks 50C, 80% RH Dropout Size Distibution (75% TH., 28G)

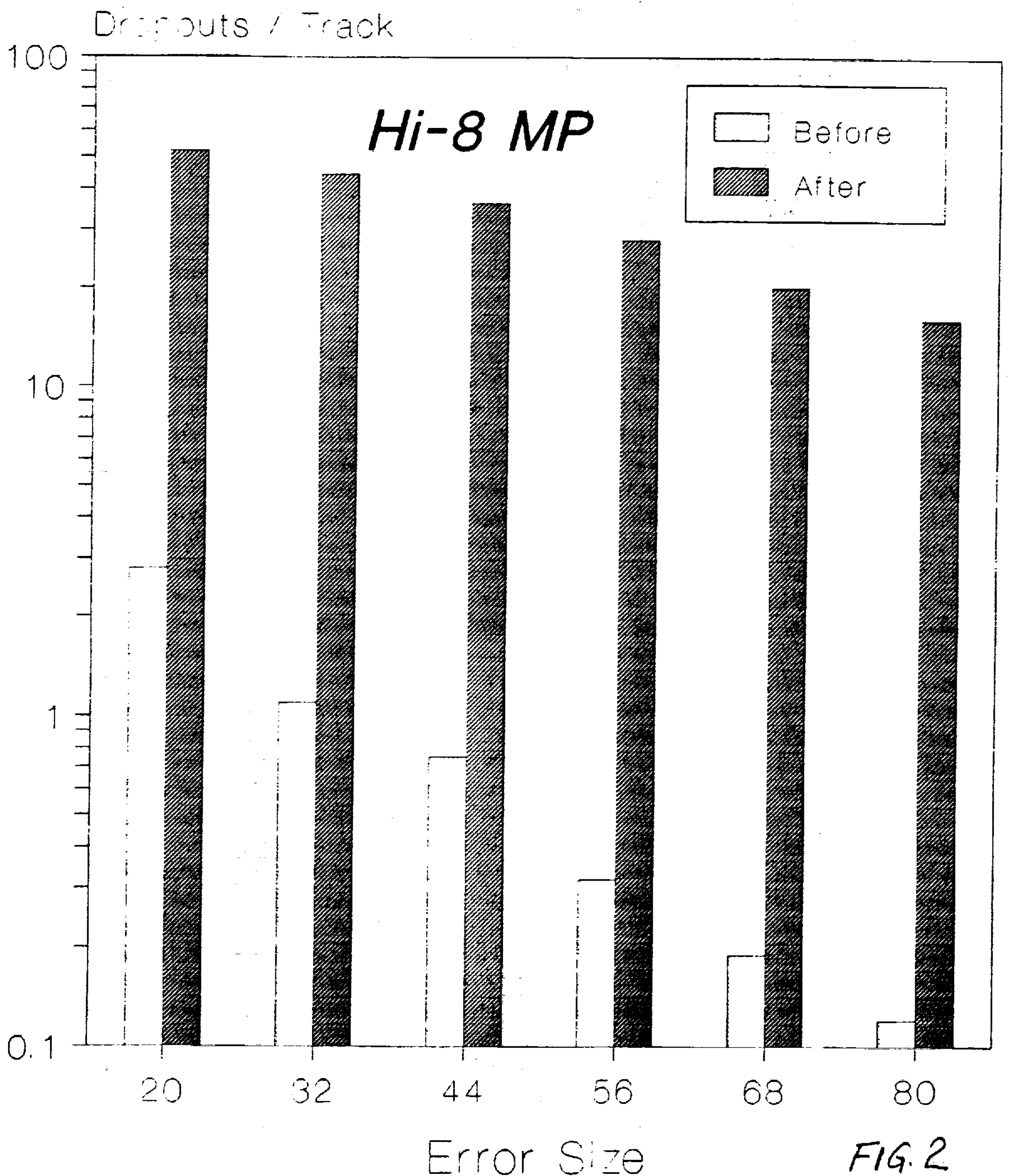


FIG. 2
HiBMP Tape
before and after
Corrosion

Corrosion Test: 7.5 Weeks 50C, 80% RH
Dropout vs. Threshold (20/28/80)

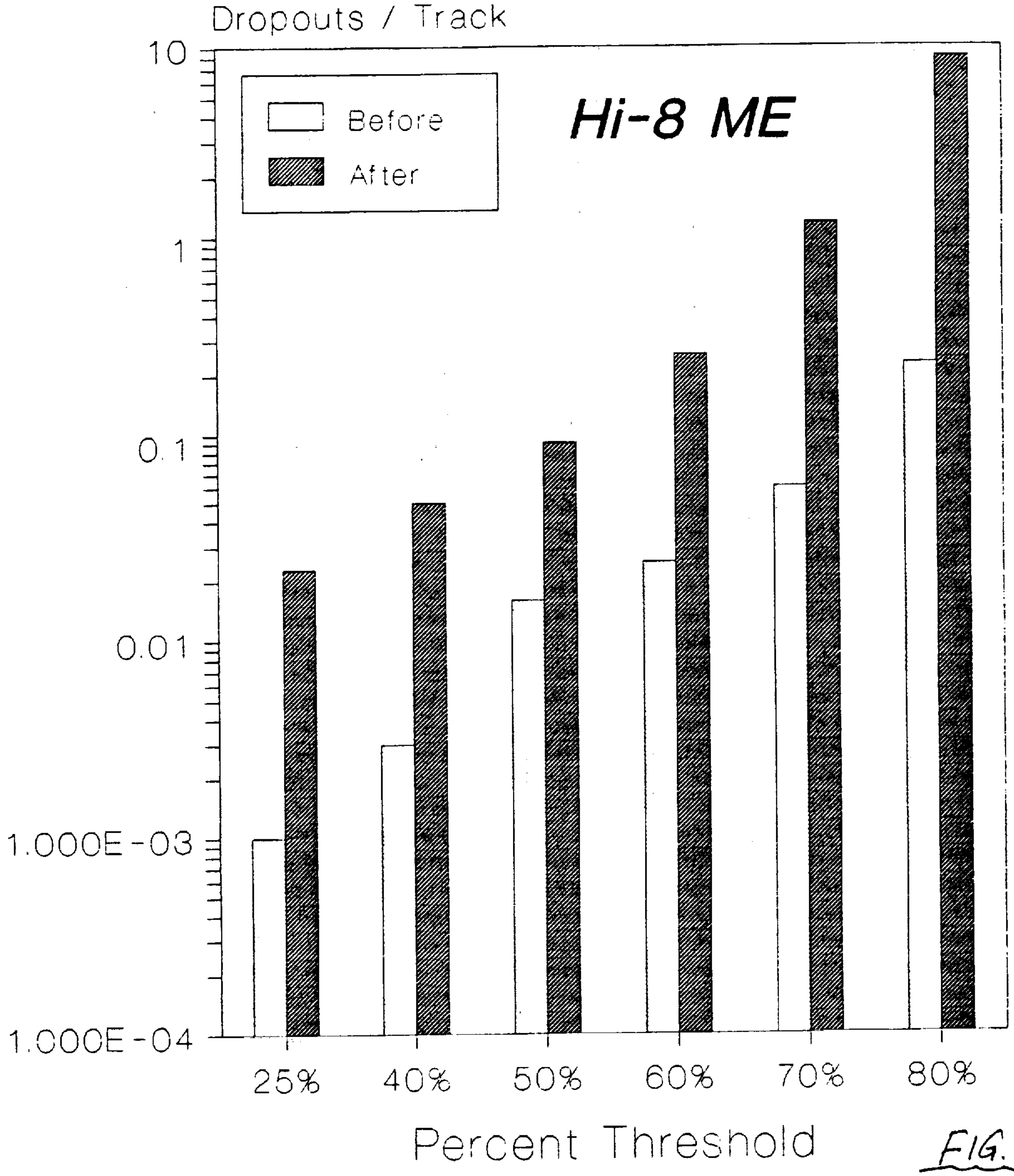


FIG. 3

Hi8ME Tape before and after corrosion

Corrosion Test: 7.5 Weeks 50C, 80% RH
Dropout Size Distibution (75% TH., 28G)

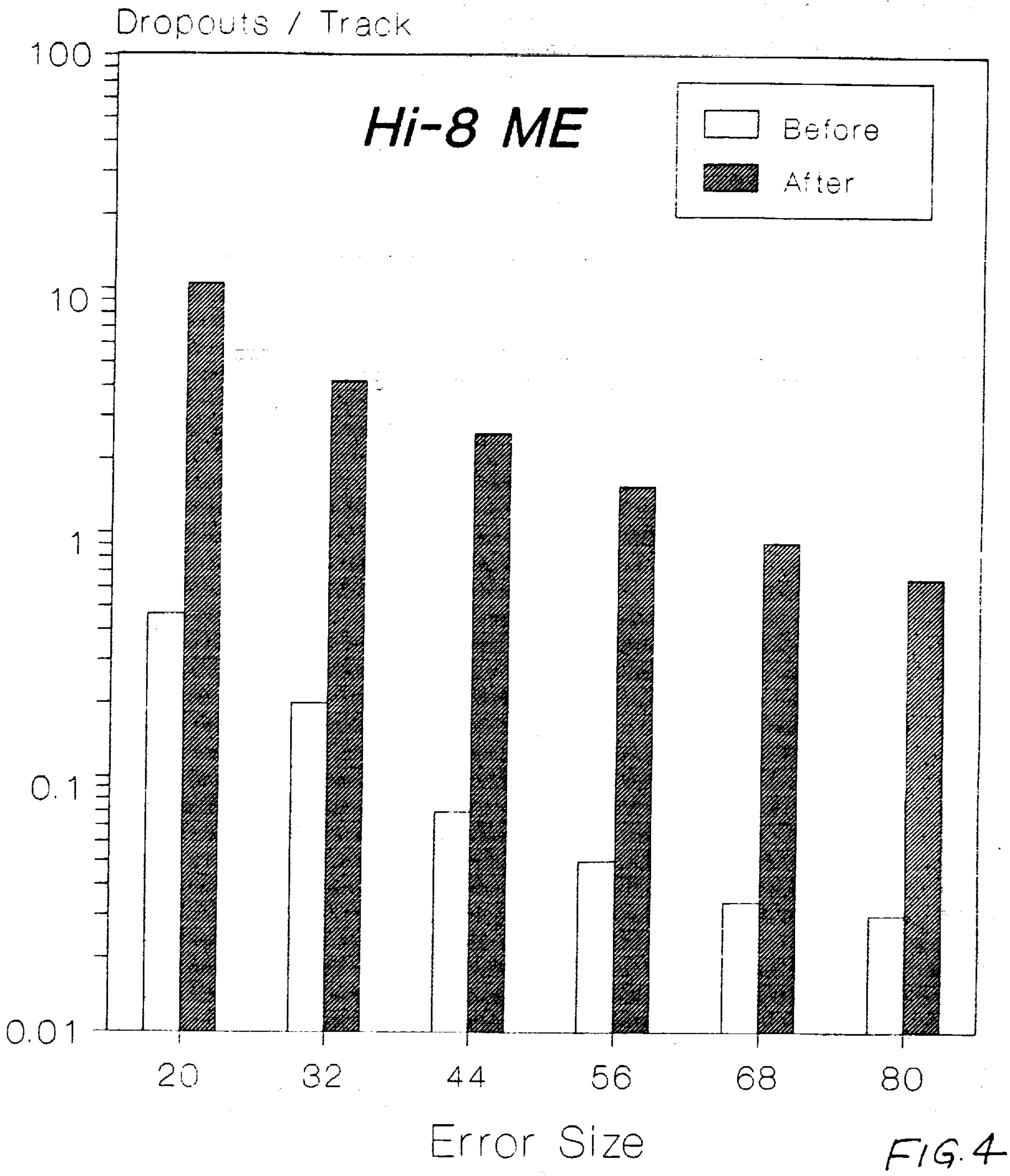


FIG. 4
Hi8 ME Tape
before and after
Corrosion

can certainly count single bit errors, but they are larger errors because the data correction in the Exabyte drive can handle blocks of errors.

In any case, there was a very large increase in error rates in the MP tapes.

(Change of viewgraph)

DR. SPELIOTIS: ME tape has a much higher signal- to-noise ratio than MP; and when you look at it before corrosion, it is very clean. So, there is nothing to show before; there are hardly any errors.

But there is a lot of difference between different ME tapes; and I'll show two of them, both of them after corrosion, for manufacturer A and manufacturer B. There are relatively a lot of errors, a much larger increase percent-wise than on MP tape.

And there are many, many errors at the front part of the tape on which I had done a lot of testing for short blocks; and the rest of the tape, I hadn't looked at, but there was some corrosion.

There is clearly some diffusion limitation; there is edge corrosion. This is one edge of the tape; this is the other edge. And this is down track. And there is some significant edge corrosion limited by diffusion apparently and a tremendous difference between manufacturers.

(Change of viewgraph)

DR. SPELIOTIS: Of course, the same thing applies to MP tape. There is a very big difference between the unfortified armor protected particles and the plain oxide protected particles.

(Change of viewgraph)

DR. SPELIOTIS: Here is a metal particle tape, again with excessive testing on the front: once every day for 20 minutes and then it was put back into its cassette enclosure (this was not exposed to an accelerated corrosion test but was in my office for one month).

The tape developed a pretty large number of errors in one month. In the beginning, this was very clean; when I opened the cassette from its plastic sealed case, it was very clean. It was just sitting in the office which is typical of most offices.

DR. SPELIOTIS: Here is a barium ferrite tape measured similarly to the MP tape--no effect. So, magnetically and error-wise--and of course, the extent of the errors is the real criterion, I think-- there is a very significant difference for these tapes, even in a normal office environment, without doing any accelerated corrosion testing.

Now, to summarize: Is there a disagreement between what the other speakers said and what I have said? I don't believe there is any disagreement at all. Let me state the view as I perceive it including the tests that John Corcoran referred to: the published data, a very extensive study by many people over many months--that was done on behalf of Digital Equipment Corporation.

This is going to be published this August in the *Journal of the Electrochemical Society,** and it is a study of the stability of MP tapes.

* *J Electrochem. Soc.*, **138** (1991) 2504-2509

Corrosion Test: 7.5 Weeks 50C, 80% RH
Dropout vs. Threshold (20/28/80)

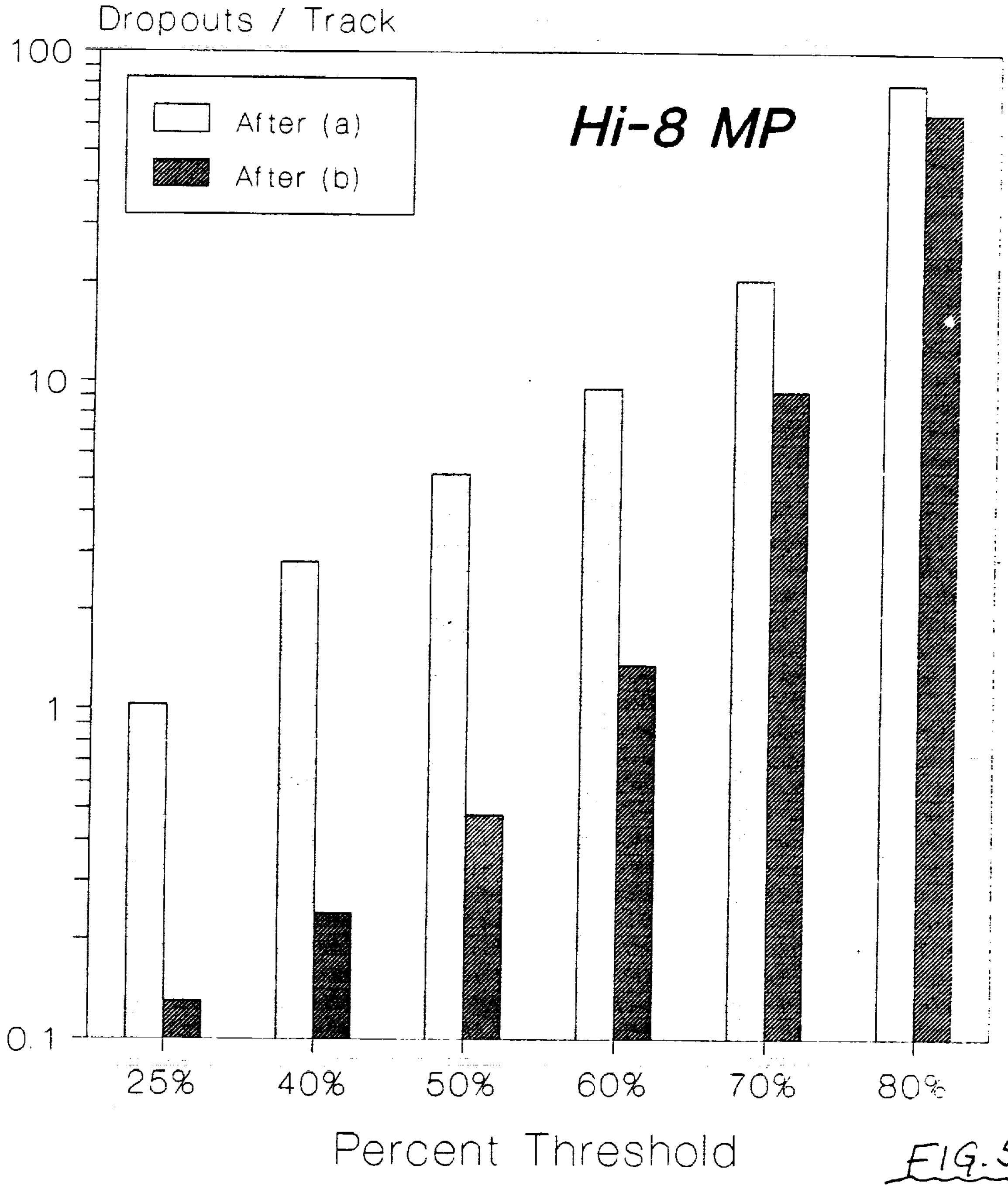


FIG. 5
Two different
Hi 8 MP Tapes
after corrosion

Corrosion Test: 7.5 Weeks 50C, 80% RH
Dropout Size Distibution (75% TH., 28G)

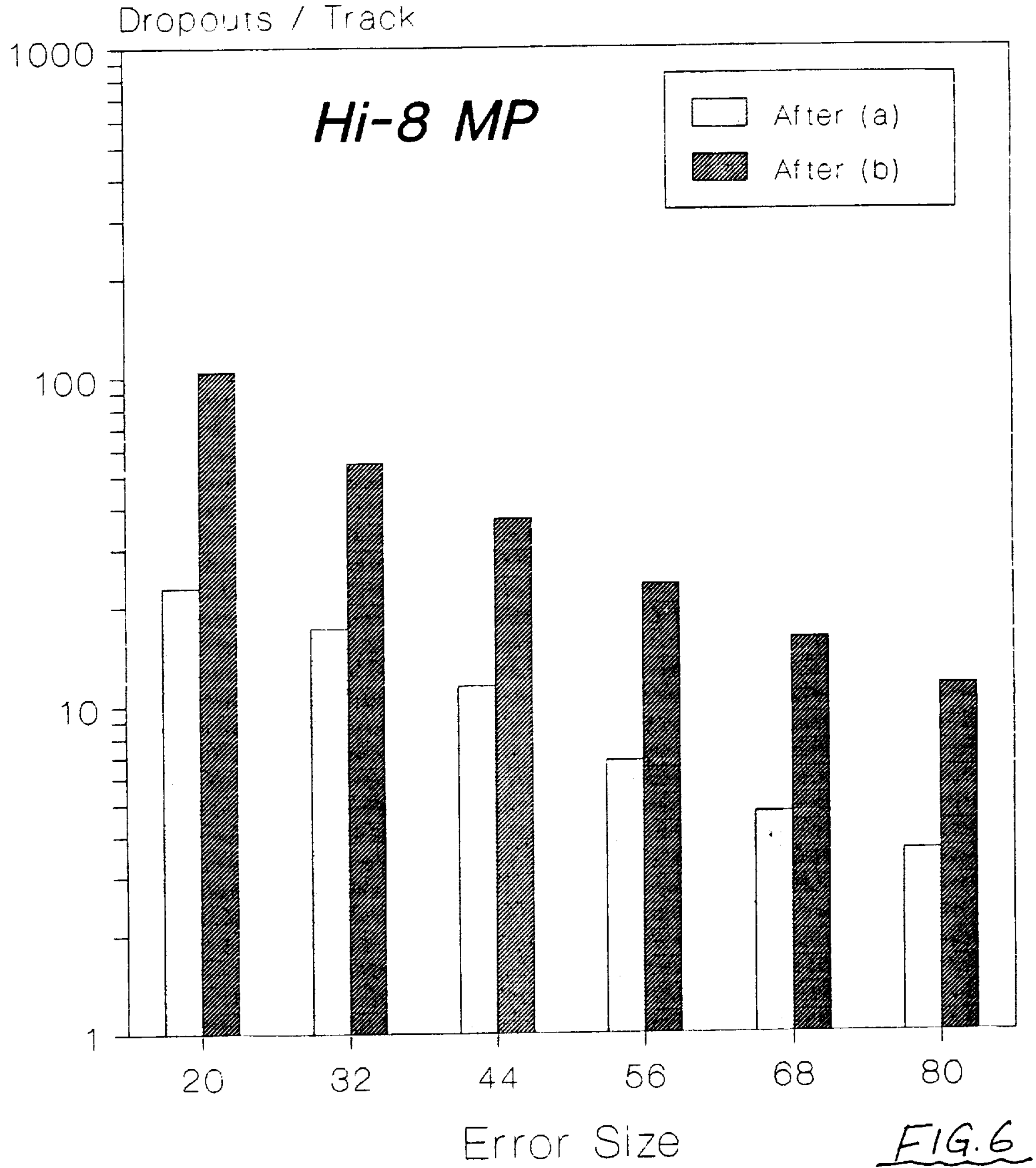


FIG. 6
Two different
Hi8MP Tapes
after corrosion

Corrosion Test: 7.5 Weeks 50C, 80% RH
Dropout vs. Threshold (20/28/80)

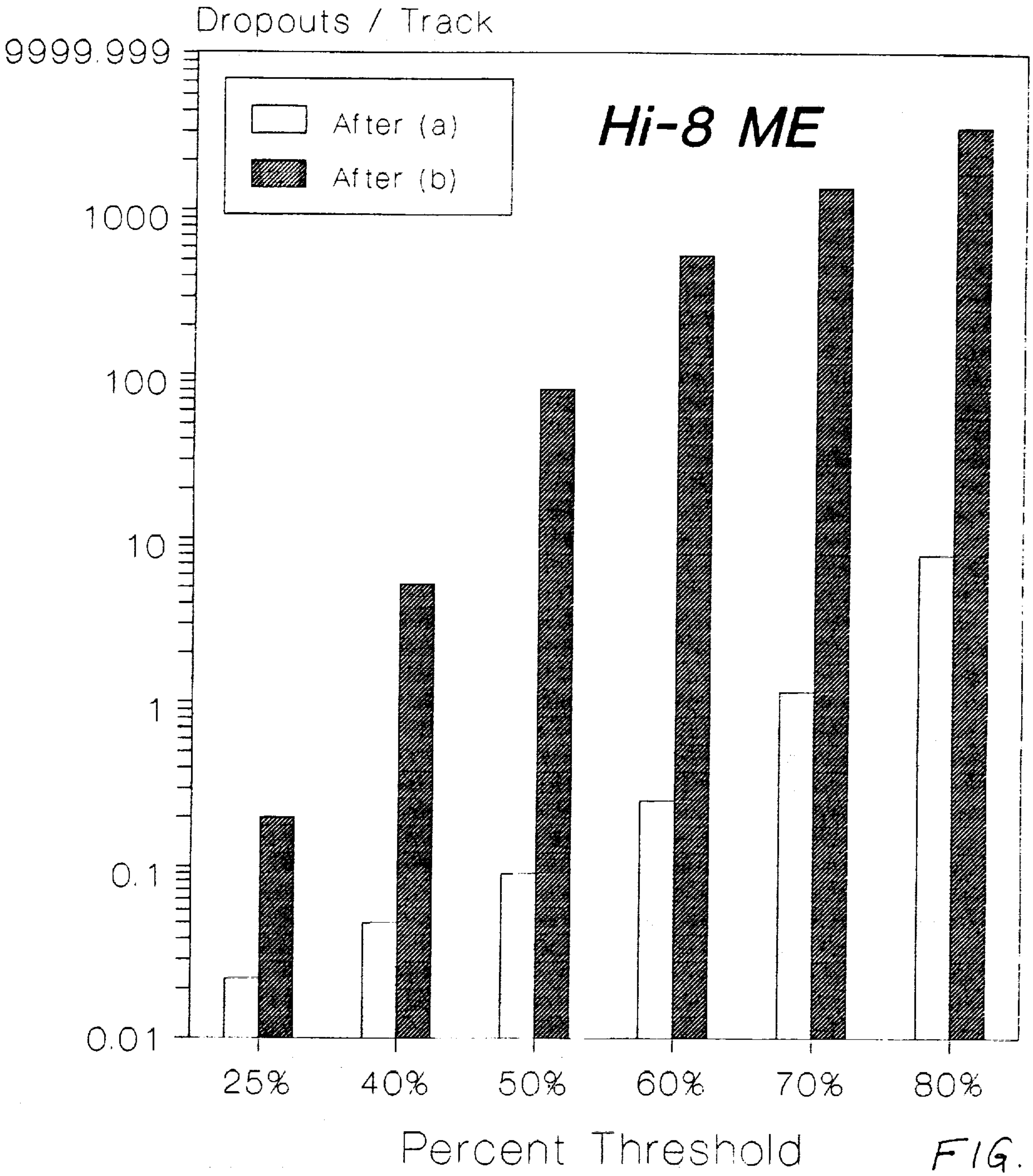


FIG. 7
Two different
Hi8ME Tapes
after Corrosion

Corrosion Test: 7.5 Weeks 50C, 80% RH
Dropout Size Distibution (75% TH., 28G)

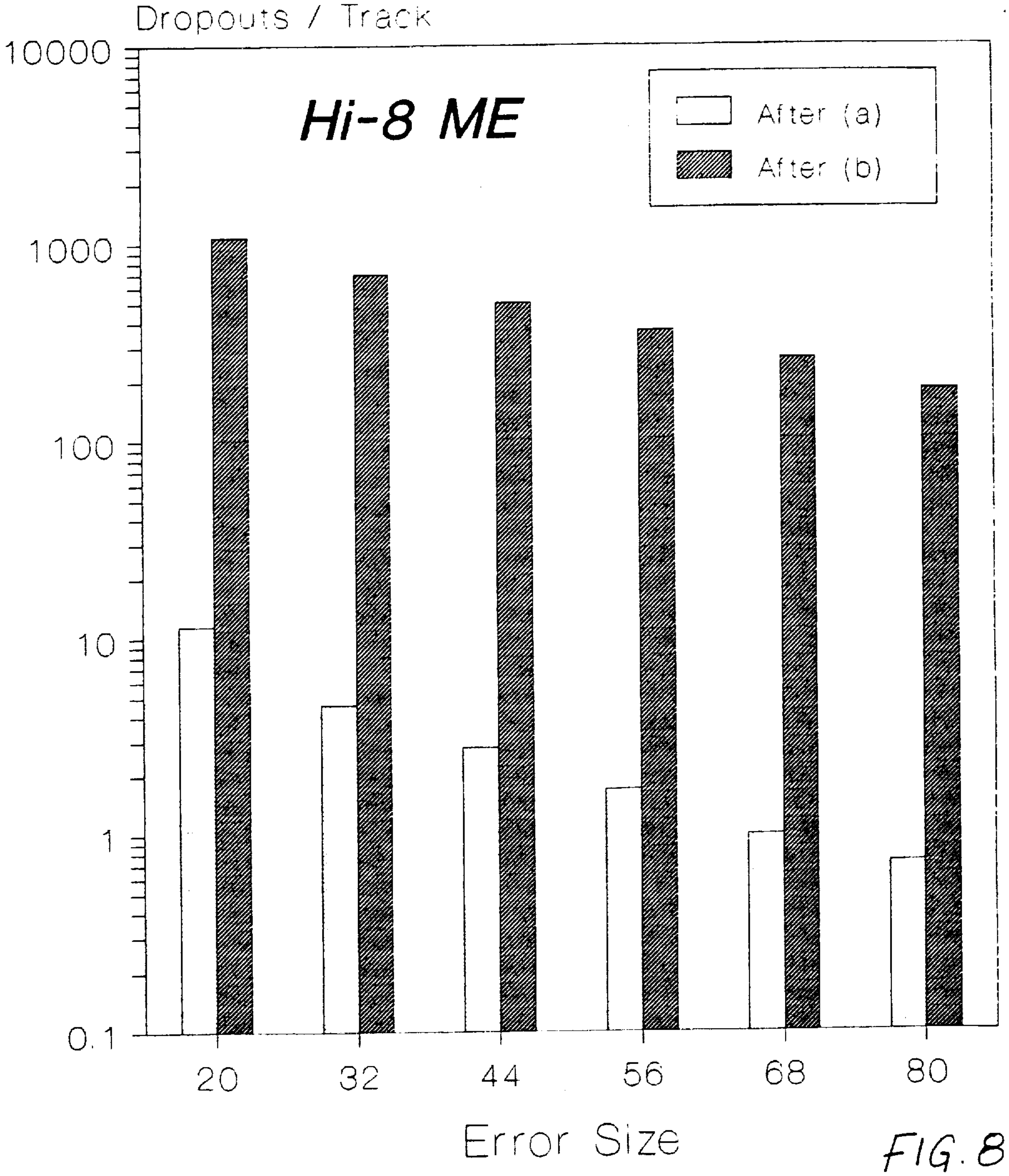
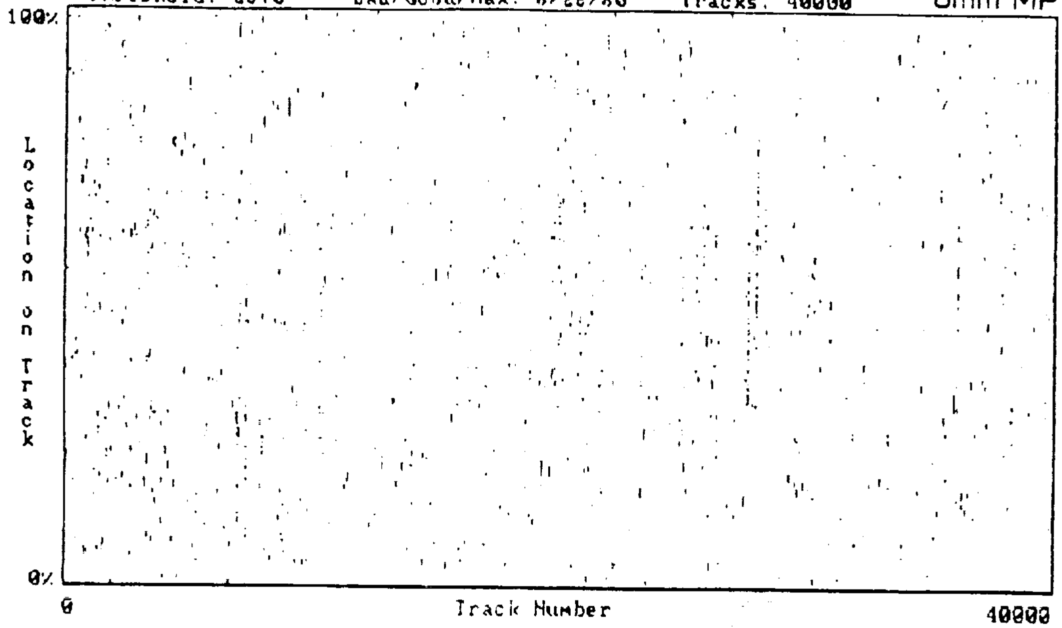


FIG. 8
Two different
Hi8ME Tapes
after Corrosion

DROPOUT MAP

Unit: 1 8MM EXABYTE ROTARY HEAD 10:11:52 12/11/90
Operator: KP Lot: corrosion test Cartridge:
Current: 15.22 mA Frequency: 4.0000 MHz Location: 5.00%
Threshold: 25.0 Bad/Good/Max: 8/28/80 Tracks: 40000

8mm MP



Before

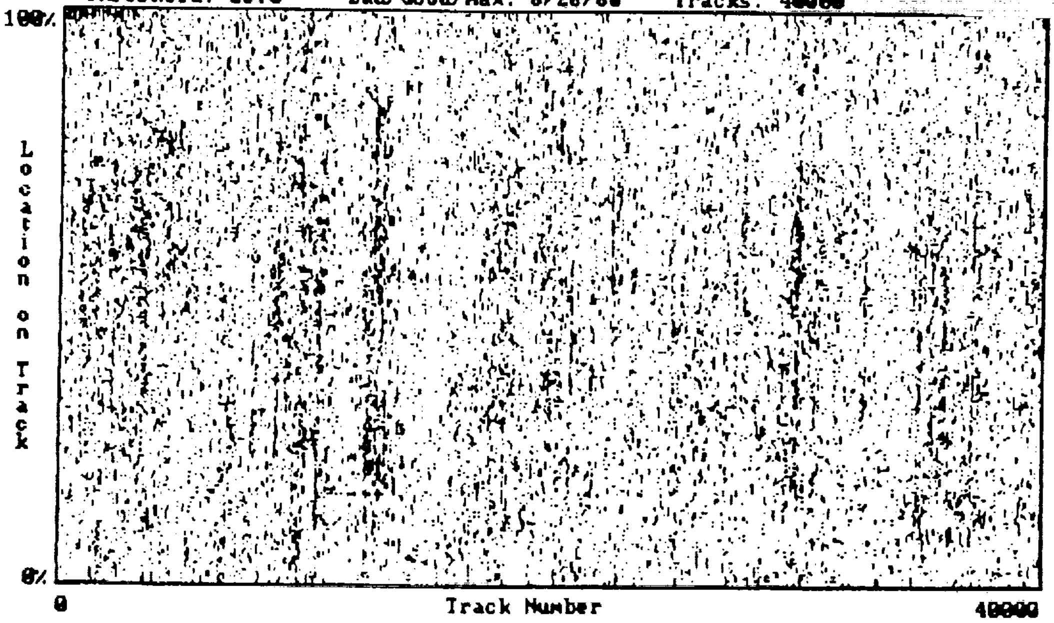
FIG. 9

Error maps of 8mm MP Tape before and after Corrosion

DROPOUT MAP

Unit: 3 8MM EXABYTE ROTARY HEAD 12:45:53 02/19/91
Operator: KP Lot: 7.5 WKS TH Cartridge:
Current: 14.28 mA Frequency: 4.0000 MHz Location: 5.00%
Threshold: 25.0 Bad/Good/Max: 8/28/80 Tracks: 40000

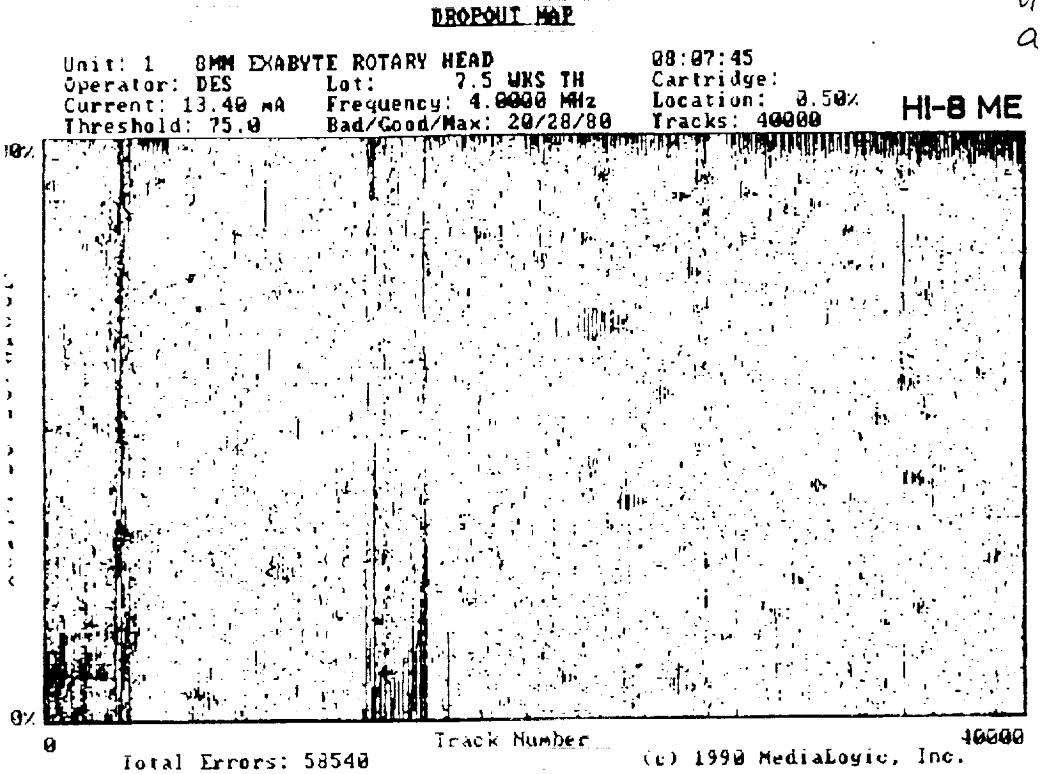
8mm MP



After

FIG.10

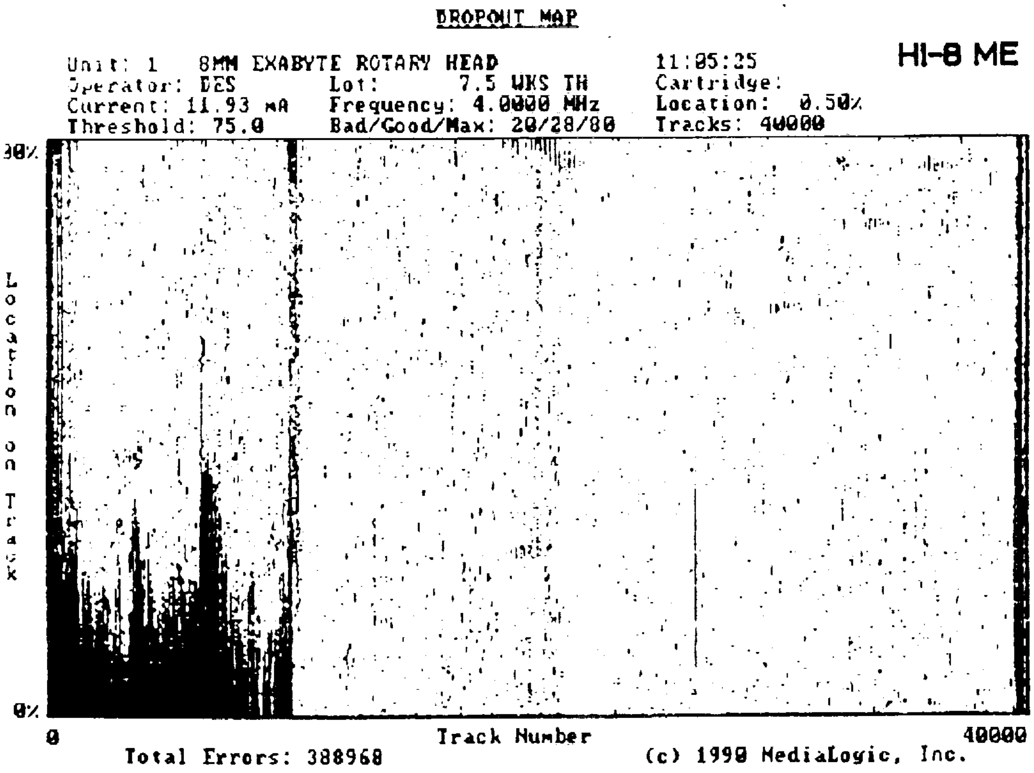
Error maps of two different Hi8ME Tapes after Corrosion



```
                              DROPOUT MAP
Unit: 1    8MM EXABYTE ROTARY HEAD               08:07:45
Operator: DES          Lot:        7.5 WKS TH    Cartridge:
Current: 13.40 mA      Frequency: 4.0000 MHz     Location:  0.50%
Threshold: 75.0        Bad/Good/Max: 20/28/80    Tracks: 40000
```

```
          Total Errors: 58540                    (c) 1990 MediaLogic, Inc.
```

After (a)



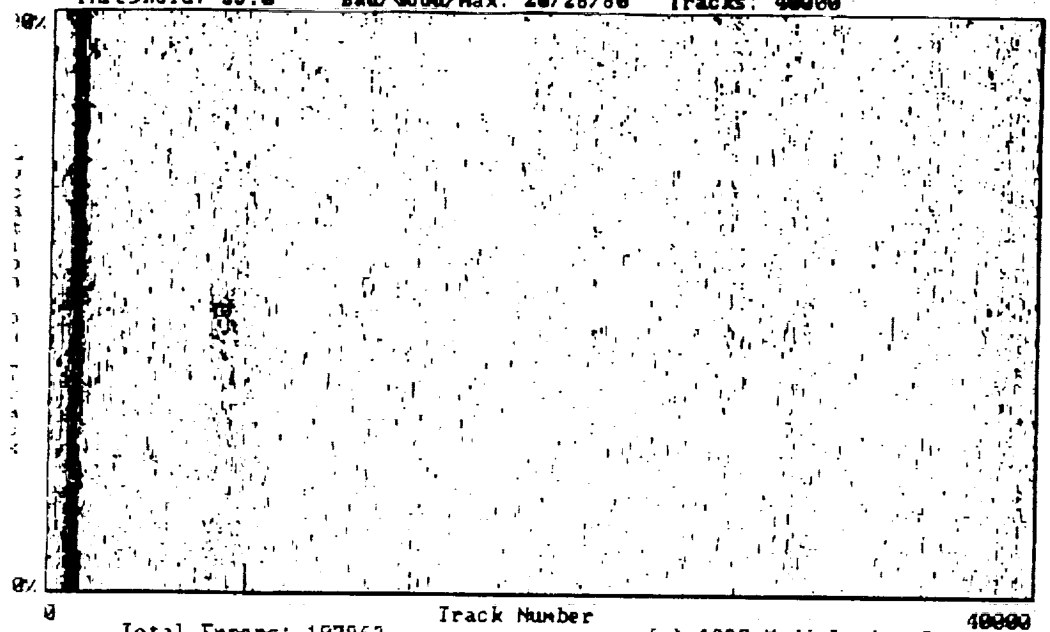
```
                              DROPOUT MAP
Unit: 1    8MM EXABYTE ROTARY HEAD               11:05:25
Operator: DES          Lot:        7.5 WKS TH    Cartridge:
Current: 11.93 mA      Frequency: 4.0000 MHz     Location:  0.50%
Threshold: 75.0        Bad/Good/Max: 20/28/80    Tracks: 40000
```

```
          Total Errors: 388968                   (c) 1990 MediaLogic, Inc.
```

After (b)

ORIGINAL PAGE IS
OF POOR QUALITY

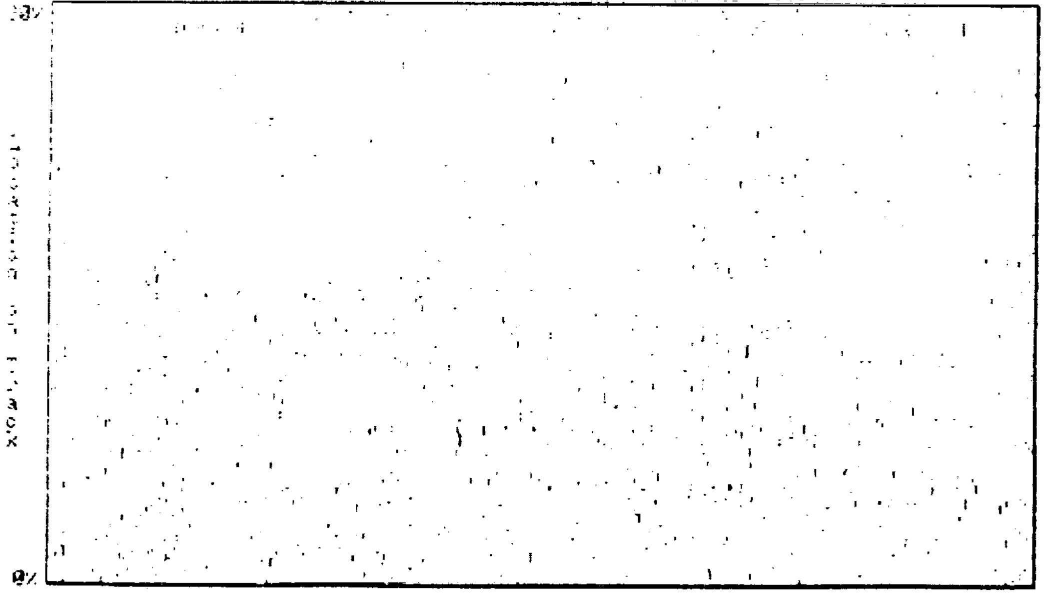
```
Operator: DES          Lot:      Hi8MP   K-G        Cartridge:          4H50097
Current: 14.00 mA      Frequency: 4.0000 MHz        Location:  0.50%
Threshold: 25.0        Bad/Good/Max: 20/28/80       Tracks: 40000
```



```
Total Errors: 107862                          (c) 1990 MediaLogic, Inc.
```

DROPOUT MAP

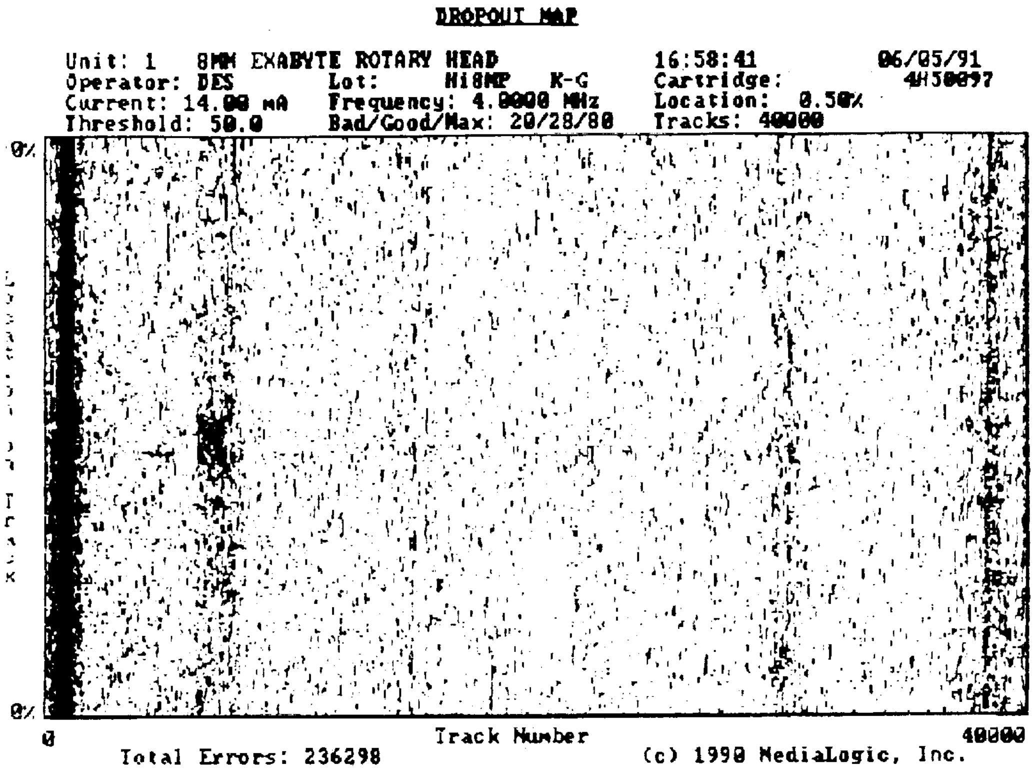
```
Unit: 1   8MM EXABYTE ROTARY HEAD              01:14:44
Operator: DES          Lot:      BF/T/MAY91      Cartridge:          BT1C-02
Current: 14.00 mA      Frequency: 4.0000 MHz     Location:  0.50%
Threshold: 25.0        Bad/Good/Max: 20/28/80    Tracks: 40000
```



```
Total Errors: 2871                            (c) 1990 MediaLogic, Inc.
```

FIG. 11

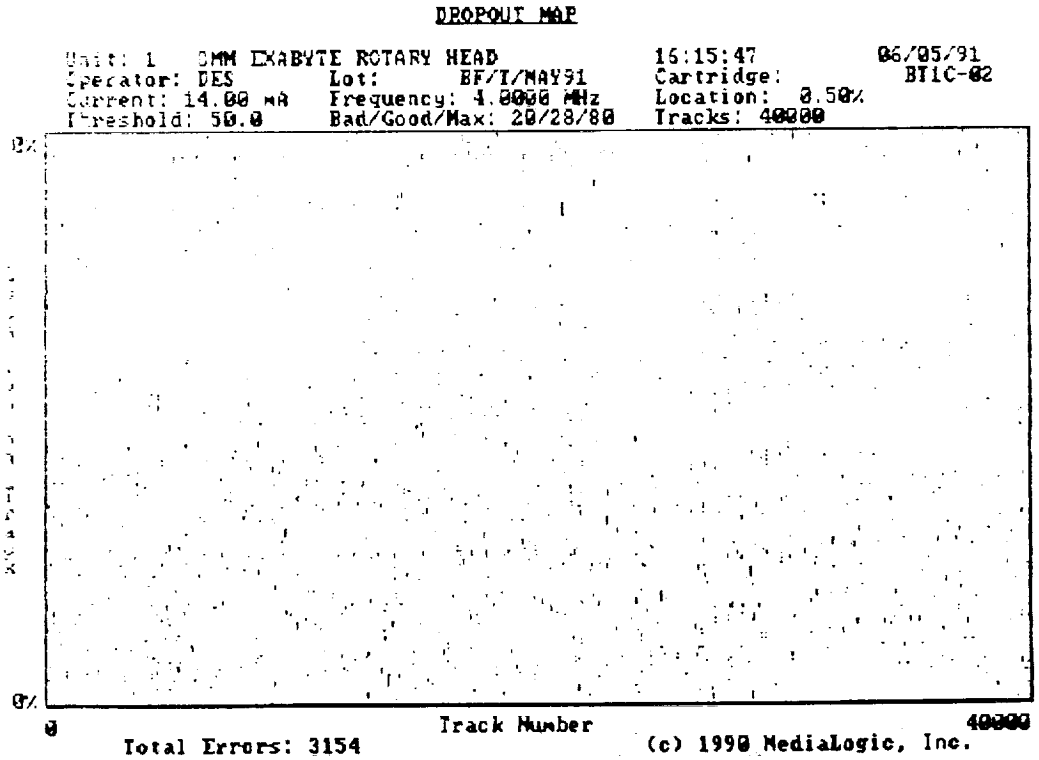
Error maps of Hi8MP and BaF Tapes after 1 MG testing.



```
                          DROPOUT MAP

Unit: 1   8MM EXABYTE ROTARY HEAD        16:58:41         06/05/91
Operator: DES      Lot:     Hi8MP   K-G   Cartridge:         4H50097
Current: 14.00 mA  Frequency: 4.0000 MHz  Location:  0.50%
Threshold: 50.0    Bad/Good/Max: 20/28/80 Tracks: 40000
```

```
Total Errors: 236298                      (c) 1990 MediaLogic, Inc.
```



```
                          DROPOUT MAP

Unit: 1   8MM EXABYTE ROTARY HEAD        16:15:47         06/05/91
Operator: DES      Lot:     BF/I/MAY91    Cartridge:         BT1C-02
Current: 14.00 mA  Frequency: 4.0000 MHz  Location:  0.50%
Threshold: 50.0    Bad/Good/Max: 20/28/80 Tracks: 40000
```

```
Total Errors: 3154                        (c) 1990 MediaLogic, Inc.
```

FIG. 12
Error maps of Hi8MP and BaFe Tapes after 1 mon testing.

What we found was: If you take these tapes inside the cassettes and expose them to a Battelle environment, which is a very moderate temperature/humidity but with polluting gases present, there is some increase in errors, but no problem at all.

Our opinion is that the cassette protects the tapes primarily because there is not enough chlorine, including diffusion, but even if there were diffusion, there is not enough chlorine to really get in and do the damage. Now, if we expose prerecorded tapes to a Battelle test outside that protected case, (open tape with data) all the tapes, including ceramic protected, were destroyed; after seven days they were unreadable.

And then, after rewriting them, they were unreadable--all gone!

Now, the same test on prerecorded tapes inside their cassettes, exposed to a temperature/humidity test for anywhere from 10 days to 70 days. We found that after 30 days or 40 days, there was some increase in error rates, but not a very big problem.

After 70 days, most of the tapes had data that was unrecoverable, on a temperature/humidity test, inside the cassettes.

We interpret this to mean that there is plenty of humidity around and is doing a job on these tapes. On the Battelle test, the humidity is very low--relatively--and the temperature is moderate; and there is not enough chlorine, which is presumably the primary culprit to damage the tapes.

I don't think these findings are in disagreement with what other people presented; but if there are some opposite opinions, they should come out at the following discussion.

One very worrisome thing about the metal particle tapes that were studied at DEC was that on the Battelle test, we kept taking the tapes out of the chamber every couple of days to determine what was the change in error rates.

This particular Battelle test was a 12-day test, and we took the prerecorded tapes and measured the change in error rates every two days. Normally what you would expect to happen due to corrosion would be that you would have initially some rapid corrosion because of surface effects, and then, it would level off because the corroded surface would become an inhibitor for further corrosion. What we found was exactly the opposite.

For several days of exposure, corresponding to years of projected life, not much change; and then an exponential, dramatic increase in error rates near the end of the test. This really needs to be tried over again and understood.

If it is true, it could mean that we are sitting on a time bomb. It would have these tapes looking fairly stable and fairly good; but after some time, they would fall apart. Thank you.

(Applause)

DR. KRYDER: Could I get all the panel members to come forward, please? I will ask them to sit in the order that they spoke, but leave some extra space for Mike Younker. Mike is an interpreter here for Sony.

(Pause)

DR. KRYDER: I invite questions from the audience to get us started. Go ahead.

PARTICIPANT: Yes. 18 months from now, I will have to start shipping a system with high density tape. What tape should I plan to use? (Inaudible)

DR. SPELIOTIS: You know my answer.

DR. KRYDER: Well, what is your answer? He has got to ship it in 18 months.

DR. SPELIOTIS: 18 months? I think it will. Barium ferrite tape will be available in adequate supply definitely in 18 months.

PARTICIPANT: But it has to be tested.

DR. SPELIOTIS: Right. You have to test it; so, it has to be available much earlier than that.

PARTICIPANT: There are now five companies that have D-2 tape. You will now have your option to look at various sources. I don't think there is any hope that that is going to be available -- (Inaudible)

DR. KRYDER: Could I ask the people to pass the microphone around for those who are speaking?

PARTICIPANT: 8 millimeter, 4 millimeter -- (Inaudible)

(Inaudible discussion)

DR. KRYDER: John, can you repeat the question?

PARTICIPANT: (Inaudible)

MR. CORCORAN: For instance, the other questions like: Do you want it all in one cassette? Do you want many cassettes to a lot of different people? What data rate do you want?

PARTICIPANT: (Inaudible)

MR. CORCORAN: Okay. Now, you can do that in four small D-2's or two big D-2's. If you do it in Exabyte, they are about 2 or 5 gigabytes, depending on which one. So, you could do that with 20.

PARTICIPANT: (Inaudible)

MR. CORCORAN: Right. Now, what data rates do you want them to read at?

PARTICIPANT: (Inaudible)

MR. CORCORAN: I think if you will use the metal particle tape, under the "normal commercial practice" and you don't expose it to high humidity for an extended period of time, you will not have any trouble with it.

DR. SPELIOTIS: But you cannot guarantee this for shipment.

MR. CORCORAN: The tapes that we used and I showed data on were shipped back and forth, from Redwood City to Battelle and back.

PARTICIPANT: With the 85 degree temperatures, I could easily achieve those -- (Inaudible) -- if they were sitting out on an aircraft tarmac --

MR. CORCORAN: Well, I'd be a little surprised if you got 85^{0} Celsius on a tarmac. I know it will get up to 55 or 60, but not 85.

DR. REAGOR: The tentative recommendation we are having with regard to chromium dioxide and metal particle is that you are in various zones of safety. You are very safe if you are between 30 and 50% RH and less than 50° C.

If you go beyond that, you are going into a zone of more risk. If you get up to 70-80% RH for any extended period of time, you are taking a risk.

Now, we are talking about several different risks, not only pigment, but we are also talking about changes in the hydrolysis of the binder and also in the stability of the polyester.

So, again, what we are talking about is the degree of risk that you want to take as you are implementing these types of systems.

DR. KRYDER: A question in the back?

PARTICIPANT: (Inaudible)

MR. HADAD: What kind of problems?

PARTICIPANT: (Inaudible)

MS. CARLSON: There are probably two different mechanisms that could occur; and therefore, it is very difficult for us to make a recommendation without knowing what the mechanism of failure is. But there are probably two different mechanisms.

One: Remember the slide I talked to you about -- If it was sitting for a long period of time in a hot and humid environment, you could get outside of the track, could get outside of the format that the recorder could play back. Or else, you could have signal degradation.

Now, unless we see what you actually have, it is very hard to know what implementation procedures we would recommend; but we can talk about it. There are two obvious mechanisms that can be going on.

MR. HADAD: Yes. I would say it would be more of a physical phenomenon, the -- changing, which is common to all tapes, as opposed to a magnetic change. I showed the data, of course, where we get the magnetics; and in periods of up to six months in those high temperature/humidity conditions, there would only be a loss in magnetization of 1 or 2 percent.

PARTICIPANT: (Inaudible)

MR. HADAD: But again, you said some of those tapes had been shipped from some long distance; and that was the result of receiving it from Germany?

PARTICIPANT: Yes. (Inaudible)

MR. HADAD: Okay.

DR. KRYDER: Another question?

PARTICIPANT: (Inaudible)

(Inaudible discussion)

DR. KRYDER: Speak up, please.

PARTICIPANT: (Inaudible)

MR. HADAD: It would be awfully difficult to monitor. Foreign matter getting on them is very randomized; and I think it would be very difficult to model that. So, the idea would be just to keep the tapes in as clean an environment as possible, although we recognize that --

MR. CORCORAN: It would show an error rate like I showed. If you are getting additional dirt, the error rate is going to degrade.

PARTICIPANT: I would think it would be a higher random error rate.

MR. CORCORAN: Yes.

PARTICIPANT: (Inaudible)

MR. CORCORAN: We did not see it. Okay? Now, there is undoubtedly some condition you might find it in, but we did not find it in the Battelle test.

DR. HADAD: That would be independent of format, of course.

DR. REAGOR: Let me go into that. From a user's standpoint in tape storage, we do the analysis of the particulate impact; and we can actually predict particulate deposition rates onto surfaces.

From the models we have used and from actual examination of the tape storage areas of particular environment, particulate contamination contributing to future degradation is not an issue.

The shielding from the containers is so high that the actual deposition velocity, since there is no movement in the cartridge, there is no impetus to pull particles from the environment in, as their natural grounding movement brings a very small amount just to the openings that are exposed.

The biggest concern we have had with the magnetic tapes, in particular the 3480s, are localized contaminants from the people that operate the systems.

And we have been able to show that, even in the cleanest of a data center, the localized input of a person walking up and removing a cartridge and putting the nextone in, it is the dirt on that person that leads to the problem and the failure. And we can actually tell you the color of their hair and who used it last and things of that nature.

(Laughter)

DR. REAGOR: And that is the issue that we have started to address in terms of the air flow dynamics in the data center around a tape reader and the fact that you have to change it in order not to strip off the dirt of a person--and these are things we are not actually looking at--and actually have it come up in the air and flow inside the tape reader at the point of change.

DR. KRYDER: Another question?

PARTICIPANT: (Inaudible)

MS. CARLSON: I think that the point that Dennis made earlier was that for systems that used 2000 fci or 1600 fci--you know, nine-track tape--you should stay with nine-track tape because that is a very stable environment. However, you cannot get up to 45 Kfci or 100 Kfci; you just cannot get the performance from the 9-track tape system

PARTICIPANT: (Inaudible)

DR. KRYDER: Let me just briefly summarize that. I was asked to repeat the question. The second one was: Is there an effect of horizontal versus vertical storage basically on the tape? Go ahead, John.

MR. CORCORAN: I think in general the rule still is that you should store the reels with the axis horizontal. Now, we tend to have smaller cassettes today; I think perhaps the problem is less intense than when we had big 12 and 14 inch reels. But you will still do better if you keep them horizontal.

PARTICIPANT: Why? (Inaudible)

MR. CORCORAN: You don't have slippage of the reel packs.

PARTICIPANT: (Inaudible)

MR. CORCORAN: The smaller cassettes do have less tape on them. If the ratio of O.D. to I.D. exceeds 3, cinching can occur regardless of how large or small the tape is.

PARTICIPANT: (Inaudible)

MS. CARLSON: First of all, I would always recommend rewinding to the beginning of tape or to the end of the tape, specifically because polyester does deform; and if you have it exposed, you are going to get crease marks or deformations on any of the bending radii that you are storing it on.

So, in archives, that is one of the things that was mentioned early today. Some of the systems unload, but dont rewind the tapes. That's fine as long as you are not having those tapes stay in that condition for more than three months.

After three months, you should really have it stored at beginning of tape or end of tape because you will lose data at those crease marks.

DR. KRYDER: What was the first question? I'm sorry; I missed it.

PARTICIPANT: (Inaudible)

DR. KRYDER: Don't you really mean: How realistic are their tests and the extrapolations from those?

MR. HADAD: Personally, I feel the temperature/ humidity are the major issues. And in terms of smoke or ozone, no, we have not addressed those. Looking at it just as a background level, leaving it constant, and then we are more concerned in our own modeling. And again, those models that I showed were only the particles; we haven't gotten to the tape yet. That's proposed.

But all of that other was sort of background; and we felt the temperature/humidity was the most critical.

DR. KRYDER: Dennis, do you agree with that?

DR. SPELIOTIS: Yes, I think temperature/humidity is the most damaging. I believe the gases are not so severe; there are not so much of them around. For metal particles, there is a lot of iron in a D-2 cassette, a lot of iron and there is not enough chlorine to affect it.

PARTICIPANT: (Inaudible)

MS. CARLSON: It's 45. That's cobalt-doped; that's not iron oxide. (Inaudible discussion)

MR. HADAD: It's a cobalt modified --

MS. CARLSON: Yes.

MR. HADAD: Cobalt modified γ-Fe_2O_3.

(Inaudible discussion)

MS. CARLSON: Yes. Co-doped γ-Fe_2O_3 is a fairly stable material. The only problem that you have is at high temperature and humidities, the cobalt will diffuse into the γ-Fe_2O_3; and therefore, you lose coercivity.

And in a normal controlled environment, that is very good. However, the point that Dennis made is that at about 50 KFCI, cobalt-doped is as high as you are going to be able to get with cobalt-doped material.

PARTICIPANT: (Inaudible)

DR. REAGOR: From our standpoint in the Bell system--the Bell Companies--we went from the open reel iron oxide tapes to the chromium dioxide tapes, not because of looking for better quality materials; it reduced the size of our storage by about 80 percent. We could put the same amount of information, and now that bulk to protect our things for archiving is a lot smaller. And so, when we went to that mode, it was not because--and I think you have been hearing this--it is not done because the material may be that much better; it is because it is giving the end user a better storage capacity per inch.

And depending on what that end user needs and what those requirements are for archiving and how much data they project they are going to have, that may govern what you want and what you are going to use in the future.

But in terms of my area, it was strictly space. We were running out of space to keep the tapes; and you know, it costs money to maintain that space.

PARTICIPANT: (Inaudible)

DR. KRYDER: Another question?

MR. CROSBY: I'm Jim Crosby, and I would like to make a comment about -- (Inaudible)

DR. KRYDER: That's cobalt damage.

MR. CROSBY: As a matter of fact, it has a coercivity of 600 -- (Inaudible)

DR. KRYDER: No, it's cobalt.

DR. REAGOR: Okay.

DR. KRYDER: All right. We had a question over here and then another.

PARTICIPANT: (Inaudible)

DR. KRYDER: Let me briefly repeat the question. Let me paraphrase the question: He's pointing out that it is not unusual in some parts of the world, particularly in Washington, D.C. for instance yesterday -- (Laughter)

DR. KRYDER: To sit at 85 or 90% relative humidity for days on end. And how do these tests relate to that sort of an environment?

MR. HADAD: The data has shown the lowest temperature on that was 50^{0} C; that is still considerably above that, but we don't have worldwide data yet from, say, shipping tapes over there and letting them sit in that environment and correlating it back to our environmental chamber being at those types of temperatures. But what we are doing with the experimental matrix is coming down to what I would call the lower temperatures, which are more in line with those kinds of locations in the world. And eventually, we will have to develop that kind of correlation.

Right now, we are just using it to fit the model. We will establish a series of conditions where enough change can be observed in a short enough time to build a model and then extrapolate it further.

I know you run into danger when you extrapolate outside your experimental region; you always run into a danger as to how good the model fits once you have left your original boundaries. But this is something that is going to take some time obviously; it is just sort of in the process now.

DR. KRYDER: Dennis?

DR. SPELIOTIS: By the way, making a model on the basis of magnetic data can be very deceiving because most people measure the entire change of magnetic moment of a piece of material; and typically, the coating thickness is about 3 micrometers. That does not matter at all in recording.

At high density recording, it is only the top .2 or .3 micrometers that has anything to do with the signal that you read out of the tape. Therefore, you must measure of the change in surface magnetization, and not in the average bulk magnetization.

We did some such measurements and found that for all the tapes regardless of whether they were double protected with ceramic coating or just the oxide, roughly, the average surface magnetization change was three times greater than the total magnetization change.

If you take this three-time multiplier for the loss in magnetization, you will find out that you are in trouble under some conditions. So, you must look only at the surface and not inside.

In that respect perhaps, the error rate change is the most realistic measurement, except that error rates aree composites. You cannot blame the particles alone; it could be the particles, or it could be the binder; or, it could be the surface; or it could be any combination of the above, and you have to sort of separate the effects.

DR. KRYDER: Okay. Another question?

PARTICIPANT: Somebody earlier said that there was really a difference between archival and environmental. And most of what has been talked about really strikes me as being environmental -- (Inaudible)

DR. KRYDER: Right.

PARTICIPANT: If you protect the tape against these things, aren't there any archival problems? Will it be here 100 years from now? Will it -- (Inaudible)

DR. KRYDER: Okay. Let me repeat the question. The question was: We have been having a lot of comments about having tapes in the typical environments--shipping to Saudi Arabia and so forth; and what if they are properly stored in the "archival environment"? How long will these various tapes really last?

MS. CARLSON: Maybe I can address that. The bottom line of that is recorder obsolescence.

Historically, in the last 20 years, the weakest link in the chain has been either binder hydrolysis or recorder obsolescence. That's the balancing act that has been going on.

Binder hydrolysis--the chemistries that have been coming on board have really improved a lot. So, the biggest question is: What is your recorder obsolescence or your recorder half-life?

MR. HADAD: Yes. One thing that Pat said is that it would be around forever; but then, I sort of wrote down the next thing he said. ***"Make sure we will be around long enough to make the copy."***

(Laughter)

MR. CORCORAN: Could I give you a criterion? The earliest video recorder made at Ampex in about 1955 was a quad recorder. Those things were used in the studios until somewhere around 1975. They have since disappeared into museums; there are a few places you can find them.

They had these little glass things in them called vacuum tubes. You can't find the replacement parts.

Somebody gave a talk about TBM and finding the replacement parts on that; and that was built from 1968 to 1972. That will give you a kind of rough criterion as to what the typical life of these systems are.

DR. KRYDER: They are probably going to get shorter, though, I would argue. Technology tends to change faster.

PARTICIPANT: There are ways around that. There is the obsolescence of chips, and people now make -- chips that they can put -- (Inaudible)

DR. SPELIOTIS: γ-Fe_2O_3. (Inaudible discussion)

DR. KRYDER: I guess another comment could be made. I mean, if you are willing to spend the money, the tapes still exist. Even if the drive doesn't exist, we could undoubtedly recover it; but you have got to pay for the development of that drive again.

PARTICIPANT: (Inaudible)

DR. KRYDER: We have a question down here?

PARTICIPANT: (Inaudible)

DR. SPELIOTIS: Seven and a half weeks was the test.

PARTICIPANT: Okay. (Inaudible)

DR. SPELIOTIS: There have been some correlations. This was an accelerated test; 50^{o} C/80% relative humidity. This is not a standard operating environment. The correlations show that seven and a half weeks correspond to seven years in real life; those correlations have been done by other laboratories.

DR. KRYDER: A question in the far corner?

PARTICIPANT: (Inaudible)

(Inaudible discussion)

MS. CARLSON: You must be in a situation where budgets aren't of concern; but boy, in the last five years, we have had to do more with less.

PARTICIPANT: (Inaudible)

DR. KRYDER: Okay. We have another question?

PARTICIPANT: What's the wicked truth about -- (Inaudible)

(Laughter)

MS. CARLSON: In some conditions, yes.

DR. SPELIOTIS: The problem is much worse obviously with 4 millimeter than with 8 millimeter. I would think the reliability of 8 millimeter is much better than 4 millimeter. 4 millimeter is probably a real problem spot.

The other question is about the corrosion stability of these tapes. If you keep them in a real archival environment; low temperature, humidity, there is no problem. But 8 millimeter is now finding its way as backup storage for many small computer systems--home computers, office computers.

Those tapes are going to be trouble . (Inaudible)

So, it depends on what environment and how you use it.

PARTICIPANT: (Inaudible)

DR. KRYDER: Can he expect a problem in that environment?

MS. CARLSON: Yes. Normal tape packs--and I think Dr Bharat Bhushan has done a little bit of this tape pack analysis, where what happens is that you do get stress relaxation in the tape pack; and therefore, you have a differential in tension. And so, that is the reason why you recommend retensioning.

Unfortunately, with 8 millimeter, I don't know when and how much at this particular moment in time; but you will have to retension most cassettes.

PARTICIPANT: (Inaudible)

MS. CARLSON: Retension once a year.

MR. HADAD: Once a year is what we recommend.

PARTICIPANT: (Inaudible)

DR. REAGOR: One of the other things that we noticed also in our studies, and all studies we did on the tapes was on virgin tape, it turns out when you manufacture the tape, it was stress-induced during the manufacture and the initial first run; and actually if you take it through one low temperature cycle, you can actually remove that initial stress that sometimes later relaxes when you are using it.

PARTICIPANT: (Inaudible)

DR. REAGOR: Yes.

DR. KRYDER: Other questions?

PARTICIPANT: One issue that we have come across is how we got started in this entire discussion; and that is, we wanted to -- (Inaudible) --

DR. SPELIOTIS: On typical MP tapes in the market, as much as two orders of magnitude difference in error rates under some conditions from one tape to another, the best to the worst.

DR. KRYDER: A question?

PARTICIPANT: (Inaudible)

DR. KRYDER: Yes. So, I guess to sum the last two comments, there are variations from vendor to vendor; and there are also variations even within one good vendor that are significant.

PARTICIPANT: (Inaudible)

DR. KRYDER: Okay.

PARTICIPANT: (Inaudible)

DR. SPELIOTIS: For a long time, from the beginning of our modern era until five or six or seven years ago, most of the data was stored on plain gamma--no chromium, no metal, nothing--and gamma is stable.

So, I think that is one of the main reasons we have not lost the data. Now, we are moving into new media, and these are not as stable as the old ones; they are not.

MR. HADAD: The data I presented, again, under ambient conditions, it is routinely maybe a dB change after three years. I think that is pretty stable. I don't know that there is that much reason to be concerned with those kinds of numbers. I imagine there are 2 percent changes in some cases, exposed to 30^0 C/70% relative humidity. Again, maybe we are getting too excited, or we see the curves of the downward slope; but yet, we ought to rescale the axis.

With a 0 to 100% loss, our line is way up here, of course we know with our Lotus and Excel spreadsheets that we can take just a little bit of that and blow it up; and it looks like the curve goes straight down. So, three-year data, 1% , somewhere around there.

PARTICIPANT: (Inaudible)

(Inaudible discussion)

MR. HADAD: Yes, it is much worse there. Now, you are starting to exceed the material. You know, basic material properties, at 85^0 C, you have pushed the glass transition point of the base back.

At the moment, we can't do anything about that; you just can't recommend tape to be in that environment. You can't recommend something that will be that high.

MS. CARLSON: The point that I would like to make on that is that's the reason why archive systems are system-specific. In that particular case, there are workarounds. If you are in a situation where you are at high temperature and humidity, what you would do is you would identify those tapes and then copy them over onto an archival media. All of these systems can be used in an archive way if it's implemented properly.

Is there any reason why that high temperature and humidity tape has to be kept forever?

PARTICIPANT: No, I think the issue is that -- (Inaudible)

MR. CORCORAN: Let me comment. We have a number of DCRSi recorders out there in that desert. And I heard no trouble about the tapes. In fact, the one complaint we got was that they kept reusing them, and they never bought any more.

(Laughter)

MR. CORCORAN: Now, they were rerecording them almost every night and then rerunning them. But I'm pretty sure they didn't go through the glass transition temperature, or I don't think they would have got any data.

PARTICIPANT: (Inaudible)

MR. CORCORAN: I hear what you are saying, but I think what you have to do is distinguish between this "archival condition," when you are trying to go for long life, and the extreme environment for maybe a week.

And it is routine, for instance in electronic news gathering cameras, to have trouble with humidity and so forth on site. But that doesn't generally destroy an archival; it will muck it up in a week, though.

DR. REAGOR: And in your case, what you are trying to do is sending a package data system --

To be honest with you, from a user's standpoint, I would look at it as: What I send is dependent upon what the person who is going to receive it can do with it. So, that format and the type and the volume is going to be based on who you are sending it to.

And the real key is the transportation issue and the protection. No matter what material you are hearing right now, the key seems to be that we don't leave it sitting on the dock in the hot sun on a humid day, unless it is in some type of a protective container.

And I think the issue you are raising, that is: I had to call them and say "Hey, guys, don't leave this in the back seat of your car four days before you read the tape." This is really the thing that you are going to have to do.

DR. KRYDER: Did you have a question?

PARTICIPANT: (Inaudible)

DR. KRYDER: I'll repeat the question. If we wait two years for barium ferrite to be developed, do we have the perfect medium; or are there some down sides to that?

DR. SPELIOTIS: Let me say one thing about that. The Japanese industry has already developed barium ferrite as a copy tape for DAT audio. In other words, they record on metal particle masters, classical music, for example, and for multiple distribution, they copy by anhysteretic transfer onto Barium ferrite tapes.

They are not marketing them yet; I don't know why, but they have been developed.

DR. KRYDER: But that is not his question. The question: What is the down side to it?

MR. HADAD: The chemistries are probably going to be very similar to the binder system. Still, we haven't gotten entirely around all the environmental problems with the polyester urethanes that everybody is using. They are subject to hydrolysis, mobile lubricants--all the things that we need also had some -- to it; and they are probably going to be present in the next two years.

DR. KRYDER: Could I get the panel to agree that if the world does go barium ferrite, the stuff would be as stable as gamma was?

DR. SPELIOTIS: Absolutely -- no change.

MS. CARLSON: Barbara brings up a point, and it depends upon-- Barium is toxic; it is a heavy metal; it is a toxic metal. And it depends upon the pigment -- if that material is going to be a toxic waste issue. In the research that we have done, we have seen a wide variety of experimental products that could be toxic. The design engineers have modified it so it won't be. I am anticipating that, by the time it is on the market, barium will not be a toxic waste issue.

DR. REAGOR: As a user, I can address this. If there is a toxic question concerning any of the materials, from a large user's stance, that is something we would not want to get involved in --

To give you an example of that right now, the EPA is just about ready to make telephone poles toxic waste.

(Laughter)

DR. REAGOR: That would cost my own company about $500 million a year from now on if that happens. So, we are doing a lot of work right now on telephone poles.

MR. CORCORAN: Could I make one other point about -- From a system viewpoint, it has a drawback on low frequency signals. (Inaudible) -- where we have to put in things like audio and control signals. The barium ferrite is not very good at that. It works great at the high frequencies, but not in high syncopation --

DR. SPELIOTIS: But John, all high density future systems, including DAT, digital video, etc., are going to be PCM or band-limited digital.

MR. CORCORAN: We have to build a whole new family of recorders to do that.

PARTICIPANT: (Inaudible)

MR. CORCORAN: Well, this will be another family. (Laughter)

DR. KRYDER: A question over here?

PARTICIPANT: Is that the only down side for the -- (Inaudible)

MR. CORCORAN: Every time we tried changing the tape--and I do this routinely--trying to bring in some new tapes and try them on the machines, we encounter another problem. And then, we have to find a way to resolve that. Now, for instance, this could be solved by changing the control track electronics. But these are the kinds of things that you stumble through as you try to move forward.

MR. HADAD: It's not a direct swap out to any existing -- right now.

MR. CORCORAN: Yes, but the down side is that it's hard to predict what they are going to be until you actually get it on the machine and try it.

DR. KRYDER: Any time you change part of a recording system, you have to change other parts--that's my experience.

(Laughter)

DR. REAGOR: Earlier, you had referred to the metal evaporated tape as having sort of like this linear corrosion and then, all of a sudden, it went exponential. And you said it was opposite from what you expected.

DR. SPELIOTIS: This was on MP, and not ME tapes.

DR. REAGOR: But from the work we have done on metal surfaces, that is what you would expect.

DR. SPELIOTIS: Yes?

DR. REAGOR: When you are doing gas phase corrosion of a metal surface, whether it is particle size or whether it is a full layer, and you store that with a very smooth, clean surface, then you have to basically have an initiation period for what they call "mound formation"; that's the corrosion term.

And so, you have to start to develop a spot that finally starts to corrode, and that initiation period can be very long. And then those mounds finally grow together. I noticed on your data published, you almost look like in the early stages that you have clusters of corrosion, which would be exactly what you would expect in mound corrosion of a clean metal surface.

So, what we are seeing here is--and I don't want to scare anyone, because I don't think it is going to accelerate after ten years and finally fall off the edge-- but I think it tells us that the metal particles and the metal surfaces are behaving like the metals do. And so, you can now extrapolate even a little further and look at these metal systems and say: Okay, what are the corrosion dynamics of these materials in the real world?

And then, you can go to a Battelle test that does copper surfaces; and if the copper metal surface behaves in this way and is accelerated this way, it is applicable to a metal particle surface or to a metal evaporated tape surface; and so, there is some correlation here.

And what you were saying and describing basically fits into that whole field.

DR. SPELIOTIS: By the way, the corrosion of chromium dioxide and cobalt-modified iron oxide, as far as I can understand, does not involve any significant change in the volume of the particle. There are other mechanisms, like the diffusion of the cobalt that lowers the coercivity in the case of cobalt modified. But in the case of metal particles, the particle grows very significantly in size when it oxidizes--20 or 30 percent growth.

Now, what is going to happen? It's going to distort the surface; it is going to do some damage -- and it's a different mechanism of corrosion.

MR. HADAD: I think that some of those charts that I showed, though, that under normal operating conditions, you are not going to get that kind of corrosion. I want to mention something regarding metal particles starting off as a clean surface; they are not. There is a passive layer. They already are corroded to some degree.

Passivity, just by definition, is an oxide layer that protects further inside the core. And so, I don't know; I've never observed it with metal particle tapes where there is some long induction period and then they take off. They already come pretty corroded, as Dennis said; the EMUs per gram of pure iron is 210. The material you use for making magnetic tape is 115 or so.

They are precorroded, but they give the outward appearance that people are interested in. The sheer fact alone that that oxide is present is actually protecting further those particles. They have already started corroding and stopped.

Of course, their passivation kinetics determine how long these things are going to last; and what we see is that they are going to last many, many years. Of course, the process will continue; but it is way beyond, I'm sure, our lifetime or our expectations of the media.

DR. KRYDER: A question down here?

MR. ROBINSON: Since I've been invited to make a presentation on tape recording, I thought I might say a word or two. I doubt that the coercivity change of the tape will make a difference, you know, going from Germany to here.

If I were you, I would do what I've done in the lab many times, trying to test machines: I would check my tracking.

(Inaudible discussion)

MR. ROBINSON: Let me just say another word. If I were using metal particle tape, I think I would clean the heads also because of brownstaining. Exabyte, I think, recommends once a day. (Inaudible) So, I would be very concerned about that.

I would also be concerned about using 8 millimeter without my track -- If you recall my presentation, the ID-1 Working Group, including Sony, DataTape, Ampex, and others, selected a 1.6 mm And we also said, in answer to many, as was reported, that we would make our track as powerful as possible.

I believe we need some advice from manufacturers --from you folks--about whether we are doing the wrong thing when we go with a half mil track width with metal particle tape just because that gives us a hell of a lot more data on tape. Do our users really want just a hell of a lot more data on tape, or do they want a reliable system? Do they really want to crossplay that stuff when they ship it in from the Gulf? Or what do they want to do?

So, in the ID-1, we try to be as reasonable as we can and build in the tolerances that it takes to make the damned things work. But we need advice from you guys. One of the biggest problems I ever had with tape recorders was making the damned media work.

(Laughter)

MR. ROBINSON: On the system 600, we went through two or three tapes to get the quality we needed -- finally solving all of our problems. The media is important; and tolerances are important on tracking--very important.

And I don't know where we are going to stop, you know; maybe with barium ferrite, we can do half-mil write tracks.

MS. CARLSON: You are still going to be on polyester; you know, that's the driving thing.

(Inaudible discussion)

MR. ROBINSON: So, I think you media people should advise the recorder people to make the tracks wide enough so these guys won't have the problem.

PARTICIPANT: (Inaudible)

DR. REAGOR: And from my user's standpoint, we would like to have as much data as you could put in a square inch of media that will be there 20 years from now; and I don't care if I put it under water; I don't care if I burn the building around it or whatever--it's there.

With the phone system we have right now, if there is lightning and your power goes out, you pick up your phone and it works. So, the phone company has this attitude that what they use to work with their system should be the same.

So, from a user's standpoint, I agree with what you said. I can't tell you what to do; I'm just telling you what I want.

MR. ROBINSON: What we should do is be conservative in design.

PARTICIPANT: (Inaudible)

MR. HADAD: Your statement is absolutely correct. 1 percent is something like 8/10ths of a dB, and that doesn't bother an ECC system at all.

DR. SPELIOTIS: But on the other hand, most of these tapes are for real high density environments; they operate at an error rate of 10^{-5}, with no correction. And 10^{-4} is about the limit for error correction to get you to 10^{-12}. In other words, you have an order of magnitude roughly and degradation narrows the safety margin.

PARTICIPANT: I think that is an incorrect statement.

DR. SPELIOTIS: Why?

PARTICIPANT: Why?

DR. SPELIOTIS: Well, of the typical Reed-Solomon error correctors used require tolerate input error levels of about 10^{-4} , or maybe seven times 10^{-3}, before they fall off the edge.

MR. CORCORAN: If you allow us enough overhead, we will bust it through to any level that you want. Okay? On a terabit memory system, they used double recording and then record over it. And I believe on one of the audio systems, they do the same thing. They double record and then they record over that.

And they can get 10^{-15} or 10^{-16}. In fact, it becomes very difficult to measure it.

DR. SPELIOTIS: Right, but what do you start with and what is the limit?

MR. CORCORAN: I just gave you two examples, and I know that we can get up to almost any number you want; it is just going to take more overhead. Most of the time, we are not allowed 100 percent overhead.

We have seen recorders where we were only allowed 10% overhead, 5% for ECC. The lady in the back said: Well, you have all these different problems; and it winds up being a trade-off between the different alternatives, and you are squeezed in almost every direction. And you have to make a good judgment.

PARTICIPANT: (Inaudible)

MR. CORCORAN: Yes.

DR. KRYDER: Other questions?

PARTICIPANT: I would just like to make a statement. I'm surprised somebody up here hasn't already done so; and that is that the care and feeding of magnetic tape is not a new subject.

I know that Ampex has brochures that they make available to customers that say: Here is how you treat magnetic tape. And there is no mystery to that. You don't mistreat it, folks; that's the basic problem.

I'm afraid the old iron oxide tape has been forgiving enough that you may have been misled into thinking that you can mistreat them.

PARTICIPANT: I would suggest that you go back to your friendly dealer and pick up their recommendations on how to treat the stuff. (Inaudible)

When IBM first came out with their 3480 tape, they shipped that stuff in refrigerated cars

MR. HADAD: Well, we are pushing the edge. People's requirements are greater; that's true, and there are materials out there to make more robust tapes. But I don't think anybody wants to pay for them; they are between $1,000 and $10,000 a reel. Yeah, we can probably make a tape that is stable to everything; but nobody is going to buy it.

DR. MALLINSON: I have a question for Dennis. (Inaudible)

DR. SPELIOTIS: The recording performance is equivalent?

DR. MALLINSON: Yes.

DR. SPELIOTIS: The recording performance is superior. Barium ferrite is far superior to MP at very high densities (above 80 KFCI)

(Inaudible discussion)

DR. KRYDER: Does anyone have anything else?

MS. CARLSON: To expand on what Dennis is saying, just think about barium ferrite particulates. If you go into Target or K-Mart, you can see VHS all over the place. The industry is scaled up for particulate media. So, the cost per package is going to be much lower just because there is an industry that is all scaled up to manufacture, at very reasonable cost, particulate media. With ME, you have to put the capital investment in in order to get your manufacturing up to even 1% of the worldwide capability that we have now in particulates. So, that is going to be a huge investment for the manufacturers, and they don't want to go out of business. It has got to make very good business sense in order for that to happen.

(Inaudible discussion)

DR. KRYDER: Any other questions? Comments?

(No response)

DR. KRYDER: Okay. I want to thank the panel and thank the audience for all your participation.

(Applause)

(Whereupon, at 6:25 p.m., the conference was recessed, to be reconvened on Thursday, July 25, 1991 at 9:00 a.m.)