BASF

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The Inventor's Notebook

TECHNICAL BULLETIN #3

The Technical Argument for Chromium Dioxide

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BASF has continued research and development of chromium dioxide as a magnetic pigment for a number of technical reasons. While some companies have switched to cobalt-modified ferric oxides for reasons of cost, licensing, or politics, the fact remains that, in terms of the physical uniformity of particles and in overall magnetic properties, chromium dioxide is still the best magnetic pigment available. It is for this reason that BASF remains committed to chrome.

The greatest single advantage of chromium dioxide lies in the shape of its particles. E.I. DuPont, an American company, discovered the process by which chromium trioxide decomposed in the presence of water at a temperature of 900° F and under a pressure of 30,000 psi to yield a synthetic mono-crystal of chromium dioxide. These particles are very small, very long and thin, and very similar to each other in size and shape. They are also totally free of the physical deformities that plague gamma ferric oxides. Gamma ferric particles not only vary a great deal from each other in both shape and size, they also suffer from physical flaws such as dendrites and holes. Dendrites are branch-like imperfections that stick out from the trunk of the ferric particle. The holes are created when gasses escape from the particle in refining stages. Under a microscope the ferric particle looks like a spongy rod; a CrO_2, particle looks like a smooth glass rod because it has no deformities (Fig. 1).

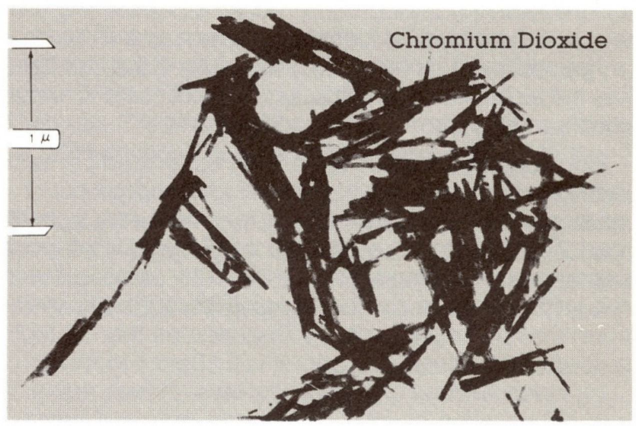
Freedom from physical imperfections and uniformity of particle shape and size provide chrome with electromagnetic properties that are essential for good audio and video tape and that are unmatched by any other formulation. The most important characteristics are:

I. LOW NOISE

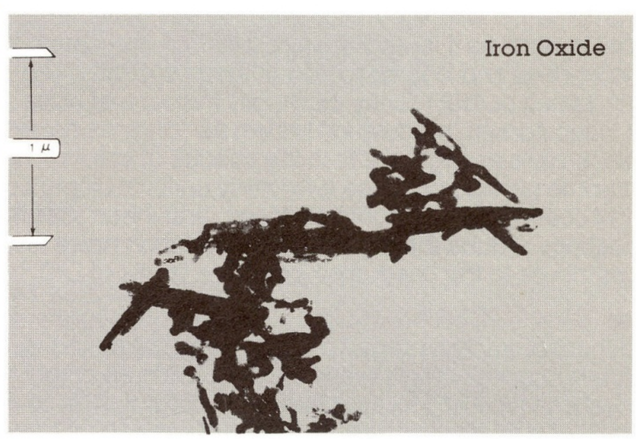
The most significant benefit of chromium dioxide is its low noise. In audio tape, this means less background hiss mixed with the recorded program and less "muddying" of the sound. In video terms it means less "snow" effect and truer colors on the picture screen.

Tape noise is composed of bias noise and two kinds of modulation noise, AM and FM modulation noise.

Figure 1: Chromium Dioxide and Gamma Ferric Oxide Crystals



Above, the uniformly long, needle-like chromium dioxide particles have no short, off-shooting branches or dendrites. In the photo below, however, you see much shorter, less needle-like iron oxide particles with dendrites.



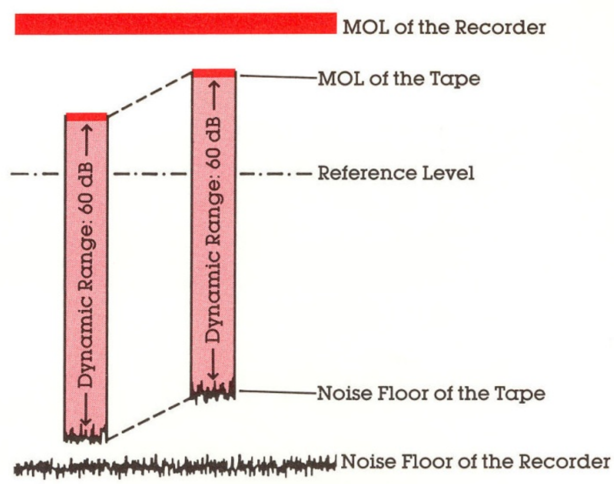
A. Bias Noise — Bias noise is the noise added to a tape as it passes under a rapidly alternating bias signal from an erase or record head. The bias signal makes the tape noise slightly greater than that on virgin blank tape. The amount of bias noise added depends chiefly on particle size: the smaller the particle, the less the noise. Uniformity of particle sizes and freedom from physical imperfections are also contributing factors. Chromium dioxide particles are not only more uniform in size and shape than cobalt-modified gamma ferric oxide particles, they are also considerably smaller. The advantages of smaller size and greater physical uniformity result in lower levels of bias noise. In fact, no other magnetic pigment can match the low noise levels of a good chromium dioxide tape. The difference is easily audible when a recording with no audio signal is made on a ferric-cobalt chrome "equivalent" tape and compared with that of a true chrome tape; the chrome tape measures about 2.5 4db lower in tape hiss.

Video recordings do not use a bias signal for the video portion of the recording (although the audio track is recorded by a stationary head using bias); the very high frequency of the luminance signal, the 'brightness" on the screen, acts as a pseudo-bias. Low levels of audio bias noise are analogous to low levels of luminance noise in video; so just as chrome audio tapes have less hiss, chrome video tapes produce less "snow" on the video screen. Chromium dioxide video tapes produce cleaner, clearer video pictures because of less luminance noise (video "bias noise").

B. Modulation Noise — Modulation noise is due to irregularities in the oxide coating, either on the tape surface or within the coating. Modulation noise is different from bias noise in that it is only apparent when a signal is present (assuming the A.C. bias is not a signal). AM modulation noise is tested by recording a direct current signal (0 Hz; AM modulation is also known as "D.C. noise" because of this test method) on the tape and measuring playback. If a tape were ideal, there would be no output; but slight irregularities in the tape will cause amplitude variations somewhat similar to dust causing "crackle" noise on a vinyl record disc. The noise occurs as amplitude spikes in either a positive or negative direction. The level of AM modulation noise can be reduced somewhat by carefully adjusting the bias current. Good tape coatings do not seem to vary significantly in terms of AM modulation.

FM modulation is due to varying tape/head contact because of minute imperfections in the magnetic coating or to varying frictional forces between tape and head. FM modulation noise can be distinguished from bias noise by altering tape tension or by altering the frequency of the recorded signal. (FM modulation is much less perceptible at low frequencies than at high frequencies). These alterations will affect FM modulation noise without changing the level of bias noise. FM modulation noise causes a fuzziness in sound reproduction that is visible as fuzziness on an oscilloscope display of a recorded signal. This type of modulation is a "muddying" of the sound caused by a very slight but continuous altering of tonal sound as the tape moves imperfectly across audio heads. FM modulation noise in combination with AM modulation noise creates a noise that sounds as if it were always "behind" the signal. The noise rises and falls as the signal rises and falls, and increased output merely increases this type of noise. On a video screen, modulation known as "chroma noise" is discernible as slight shifts in the shades of colors. The chrome particle provides extremely uniform dispersions and coatings with smooth surfaces, and these superior coatings reduce the level of FM modulation noise and contribute to the unequaled low noise levels of $Cr0^2$ tapes.

Figure 2: Comparison of Dynamic Range



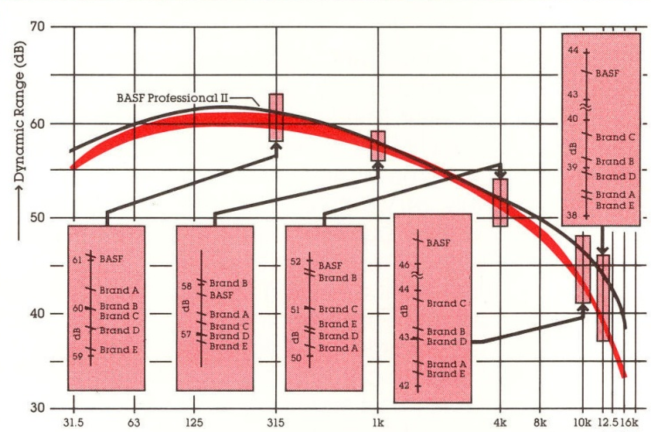
The total dynamic range of a tape with a given MOL and a very low noise floor can equal that of a tape with a very high MOL, but an equally high noise floor. There is no audible benefit to either tape if all else is equal; but a higher noise floor often includes higher FM modulation noise which "rides" the increase in output. In that case, the tape with the lower noise floor will sound quieter.

II. DYNAMIC RANGE

Dynamic range, or signal-to-noise ratio, is defined as the difference in decibels between the maximum output level of a tape at 3% third harmonic distortion (or, in the case of high frequencies, the point of saturation) and the noise level, either weighted or unweighted. The "signal" in signal-to-noise ratio is usually measured at low frequencies. It is important to remember that a signal-to- noise ratio or dynamic range of 60 dB can mean either a given level of output and a very low noise floor or a greater level of output and an equally greater level of noise (Fig. 2). The audible effect of different tapes with the same S/N ratio may be different, however, depending on the S/N ratio at higher frequencies, on the noise spectrum, and, to a degree, on the amount of modulation noise.

An examination of the dynamic range of chromium dioxide tapes at high frequencies shows why so many supporters of ferric-cobalt tapes state dynamic range at low frequencies only (Fig. 3). Improvements in the high frequency sensitivity of ferric-cobalt tapes have historically been at the expense of increased noise. Improvements in high frequency sensitivity of chromium dioxide tapes, on the other hand, have not changed the already low noise floor except, in some cases, to further reduce it slightly by reducing both bias and modulation noise. An examination of the frequency spectrum of the noise shows why the difference is audibly significant (Fig. 4).

Figure 3: The Dynamic Range of BASF Professional II Chrome and Its Cobalt Modified Competitors

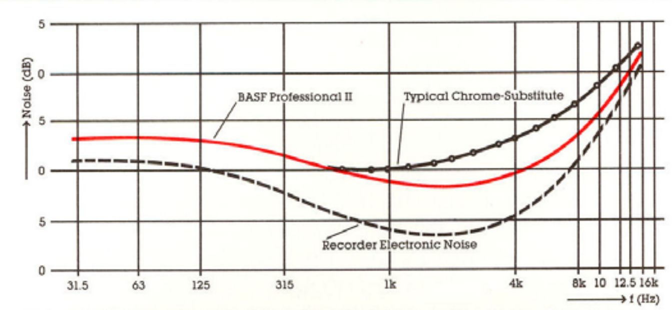


The Dynamic Range of BASF Professional II Chrome and its Cobalt-modified Competitors

Up to 8 kHz, the dynamic curve of all tested products is so close together that an individually drawn representation would be difficult to read. Above 8 kHz the dynamic ranges of the competitors compared to BASF Professional II clearly drop off but move closer together underneath each other. The dynamic staggering of standard test frequencies shows the "magnified representation." Note the considerable spread of the dynamic scale inside the "boxes."

The lower noise level of chrome lies precisely in the "presence" region (1 kHz to 8 kHz) where the ear is most sensitive to sound. Not only does chrome provide a lower noise floor, but it also changes the "sound" of the noise to a "softer" or "less aggressive" disturbance than that of chrome substitutes. The use of noise reduction systems will reduce many of the noise problems and some of the differences between magnetic pigments. The argument that high output levels will mask higher noise levels also has some validity, but both arguments overlook modulation noise. FM modulation noise "smears" sound clarity in audio and color sharpness in video. Noise reduction systems and high output do not help alleviate this type of noise; only a superior coating can. It is significant that some critics of analogue and digital systems find the most audible superiority of digital not to be in frequency response or dynamic range, but in the lack of FM modulation, both tape modulation and wow and flutter. Chrome tape is a step in the right direction.

Figure 4: Frequency Analysis of Tape Noise



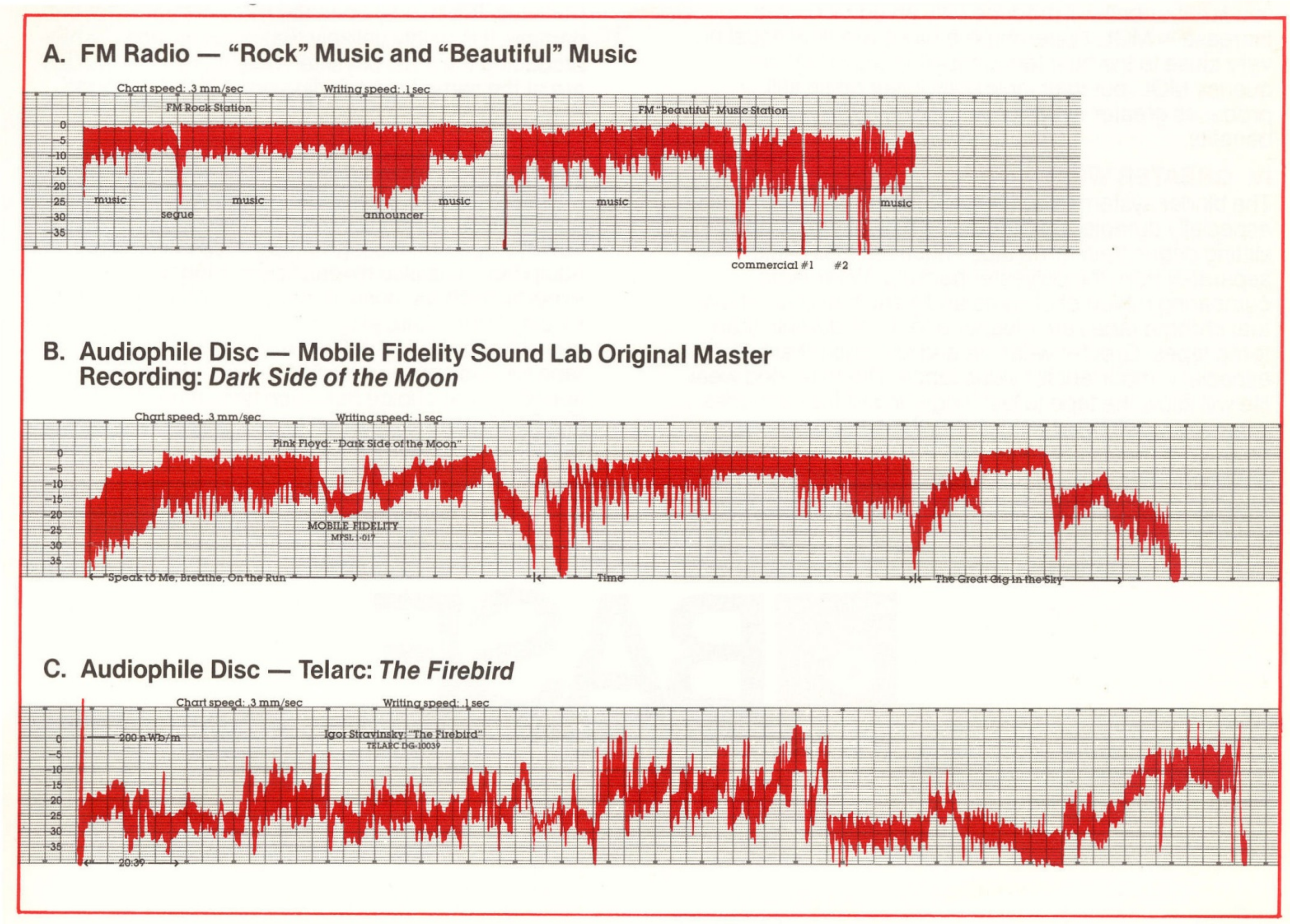
FREQUENCY ANALYSIS OF TAPE NOISE. The difference in noise level between a true chromium dioxide tape and a typical high bias chrome imitation is at its greatest in the "presence" region (1-8 kHz). Since the human ear is most sensitive precisely in this area, a true chrome tape sounds significantly quieter than a ferric cobalt imitation.

III. MOL

Maximum output level is the first half of the signal/noise ratio. The chief claim to superiority that ferric-cobalt and metal tapes make is that of greater output, which, unfortunately, is accompanied by increased noise. The net effect is that an increased MOL at the expense of increased noise results in the same -dynamic range figures as a low-noise chrome that has slightly less output. It is questionable whether or not it is beneficial to sacrifice noise for increased output when that noise also includes more modulation noise. Increased output can mask increased bias noise, but it will not mask modulation noise. Modulation noise, in fact, will increase as output increases!

Audio experts expect the digital revolution to be significant in increasing dynamic range not by increasing sound levels but by *decreasing noise interference.* A comparison of the practical application of dynamic levels is given in Fig. 5. The output levels of various program sources were charted over a time span. The 0-db level in the charts is equivalent to a tape flux level of 200 nW/m on a cassette deck's

Figure 5: Dynamic Range of Musical Sources



meters. The output from the vinyl record discs was fed through the electronics of a three-head cassette deck and fed to a Leader LFR-5600 frequency analyzer. The pen was placed in its fastest writing mode, 0.1 sec., to measure the output levels from the disc. The pen was not as fast as the meters in transient response, of course, but it was fast enough to read + 6 db at the striking of the kettle drum at the end of Telarc's *Firebird.* What are more important are the relative differences of output levels over a span of time.

The program with the least dynamic range was the FM rock station with a mere 10-dB difference between loud and quiet. The announcer's voice was more dynamic than the music. Next was the "beautiful" music station with a 15-20 dB dynamic range, including the two commercials. The Mobile Fidelity Sound Lab Original Master Recording of the Pink Floyd album averaged 20 dB, but the reliance on quiet disc surfaces was obvious at several spots for dramatic effect: the opening heartbeat and the sudden alarms at the beginning of "Time." The digital recording of the *Firebird* had the greatest dynamics. What is significant is the number of times the output reached within 1 dB of the 0 reference or exceeded it: 27 times in 20 minutes. An increase in MOL was an advantage for only thirty seconds (presuming each peak lasted a full second). That means that for the most demanding music where dynamic range is most advantageous, low bias noise was beneficial for 20 minutes or for 96.9% of the time, low modulation noise was important for the full 20 minutes, 39 seconds, and the "big" advantage of increased MOL was useful for 2.4% of the time.

The emphasis on MOL as an important criterion of tape must be considered in relation to noise; and, in the case of the *Firebird,* MOL was relatively less important. Some tape manufacturers continue to emphasize increased MOL as the major asset of their tapes; but if a ferric-cobalt tape can receive a 1-dB improvement in MOL, what guarantee is there that the end user can fully utilize it? The slow VU-type meters probably will not allow the user to set the difference precisely on his or her meters; neither will the popular fluorescent-type meters that often move in 2-dB steps in the critical range. It is far more likely that reduced noise will benefit him or her more because no exact settings are needed to take advantage of it. Increased MOLs are often wasted by conservative settings on poor meters; reduced noise is *always* beneficial to the user.

Improved formulations of $Cr0_2$ have led to the development of Superchrome formulations with increased sensitivity at both high and low frequencies. Increases in sensitivity of $Cr0_2$ formulations result in equal or greater increases in MOL. Increasing sensitivity in a ferric-cobalt will produce only an equal or less increase in MOL. Double-coated, Superchrome tapes are now equal or very close to the best ferric-cobalt tapes in low frequency MOL, but their inherently lower noise still produces greater dynamic range and more practical benefits.

IV. GREATER WEAR LIFE

The binder system used for BASF chrome tapes is especially durable because the binder surrounds each perfectly shaped particle better. Chrome tapes typically show less slitting debris than ferric tapes because less oxide separates from the polyester backing. Wear tests comparing rub-off of chrome and ferric materials show that chrome tapes are cleaner and more durable than ferric tapes. Greater wear life and less rub-off are especially important for video tapes. The extended wear life will allow the tape to last longer in still frame modes when the video head is scanning the stationary video tape. An internal quality check at BASF requires that a tape show no increase in dropouts or decrease in output after 60 minutes of still-frame scanning on the section of tape. Less durable formulations will wear away because of the physical contact. Less rub-off reduces the amount of video noise caused by debris on the video heads and increases the life of the heads. A cleaner tape means cleaner heads for greater lengths of time.

V. GREATER PRESSURE STABILITY

Ferric-cobalt tapes were once notoriously subject to magnetic losses caused by physical pressure on the oxide, a phenomenon known as the “magnetostrictive effect.” This problem has been reduced to insignificant levels in audio tapes, but the pressures exerted by rapidly rotating video heads do cause some signal demagnetization on cobalt-activated ferric video tape. Chrome video tape, on the other hand, seems to be immune to this type of signal loss. A recording made on chrome video tape played over and over again will retain the original picture quality that would have deteriorated if the recording were made on a ferric-cobalt tape.

Ironically, in spite of all its unsung technical benefits, chromium dioxide has suffered from a charge still widely accepted, that chromium dioxide is very abrasive to recorder heads. Particles of chromium dioxide are harder than ferric oxides, and their frictional characteristics are also different. Tapes coated with the magnetic powder of CrO_2 particles produce less wear on mu-metal heads, which are the softest type and most likely to suffer wear damage. On these heads, ferric oxide tapes produce more wear. On sendust and ferrite heads, which are much harder and very resistant to wear, the CrO_2/ferric wear ratio switches. Chrome tapes show more initial wear on these types of heads as the hard, smooth surface of the tape polishes the grainy structure of the head material and wears down the rough surface. In fact, in the first one hundred hours of running virgin chrome tape on ferrite heads, the amount of head material worn away is shocking when compared to that of ferric or ferric-cobalt tape. However, for the next three thousand hours, the rate of wear decreases dramatically. More importantly, the integrity of the gap edges remains intact, unlike the edges of ferrite heads running ferric or ferric-cobalt tapes that erode.

This phenomenon is critical for video duplicators. As the gap edges erode over time, high-frequency luminance signals decrease in output. In those cases where a ferric-cobalt video tape has extra lubrication added to reduce head wear, the gaps become fouled with lubricant and also gradually lose luminance output. In order to bring luminance signals back to their original levels, after 800 to 1,000 hours of duplication time, technicians use lapping tapes to polish the video heads of machines running ferric-cobalt tapes to clean and restore the integrity of the gaps. The lapping procedure reduces the protrusion of the heads to the same wear level as that of heads that have seen only chromium dioxide video tape and saw the worst wear in only the first 100 hours. The chrome-only VCRs, however, do not need any down time because the heads remain clean, the gaps are intact, and the luminance stays the same. At two thousand hours, ferric-cobalt VCRs need relapping. Chrome VCRs do not. The largest VHS duplicators have learned that alternating ferric-cobalt and chromium dioxide tapes on their industrial VCRs extends the life of their equipment and reduces down time for maintenance.

The great headwear scare that dogged chromium dioxide tape is likely to have been based on measurements over only fifty to one hundred hours when the tape polishes hard heads the most. Measurements taken over the next three thousand hours indicate that total wear of head surfaces is nearly identical to that of ferric-cobalt tapes, and the gap wear is far less.

When particles are coated on a tape, however, other factors, such as the binder system, coating technique, surface finish, and environment are far more significant in determining the amount of abrasion likely to occur than is the particle used. Several tape manufacturers using exactly the same particle may have greater differences in wear factor between their tapes than one manufacturer may have in a number of different tapes using different particles. It is mainly up to the manufacturer, not the particle. It is highly unlikely that chrome tapes, while producing the least physical modulation of all oxides, are at the same time grinding down head surfaces at a rate that destroys equipment.

The technical arguments for chromium dioxide would remain merely theoretical if it were not for some hard practical facts. When professional recording engineers choose a tape for audiophile recordings, the choice has usually been chromium dioxide. The basis for choice is not only rigorous testing with sophisticated measuring equipment, it is also extensive listening tests. When the experts, such as those at the uncompromising Mobile Fidelity Sound Lab, A&M Records, Deutsche Grammophon, American Grammophone, CBS Records, Windham Hill, Polygram, RCA, Vanguard Records, and Connoisseur Society choose a tape for audiophile recording — in real time or high speed — that choice has been chromium dioxide. They, like BASE have chosen CrO_2 for unarguably sound technical reasons. They, and we, feel that any other reason is a compromise.