IBM Tape History – Session 1: Tape Media
Bill Phillips, Ric Bradshaw, Andy Gaudet

Moderated by:
Tom Gardner

Recorded: October 12, 2015
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Also present off camera:
Joel Levine
Al Rizzi
John Teale

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Introduction

This is session one of five sessions held in Tucson, AZ, regarding IBM's tape storage history. The five sessions are:

1. Tape Media (CHM catalog number: 102737992)
2. Overview of tape products and product management (CHM catalog number: 102737994)
3. 3480 tape drive (CHM catalog number: 102738021)
4. Linear Tape Open (LTO) Consortium (CHM catalog number: 102738023)
5. Recovery of tapes damaged in Challenger disaster (CHM catalog number: 102738025).

IBM's tape development began in the late 1940s in the Kenyon Mansion, Poughkeepsie, NY, (later IBM's management training site)[1] and moved to the then new Poughkeepsie lab in 1954. The first production units shipped in 1952. In 1965 production and development moved to Boulder, Colorado, then from Boulder to San Jose, California in 1973 and then back to Boulder in 1977[2]. Its movement to Tucson, Arizona, was announced that same year and began in 1978. For additional history on tape products and technology see:

1. "History of Tape", IBM Corp., 1978 ca., in CHM lot X7677.2016
2. "Innovations in the Design of Magnetic Tape Subsystems," Phillips et. al., IBM JRD, September 1981, p. 691-99
3. "Data Storage on Tape," W. Phillips, in Magnetic Recording - The First 100 Years, Daniel et. al., IEEE Press (c) 1999, p. 252-69
4. "Fifty years of IBM innovation with information storage on magnetic tape," Bradshaw and Schroder, IBM JRD, July 2003, p. 373-84,

IBM Tucson was responsible for a number of tape innovations including the 3480 tape drive and cartridge and the consortium that led to the LTO standard. Employment in Tucson peaked in the mid-1980s at more than 5,000. Production was ended at Tucson in the late 1980s. New media product development ended in 1988. New tape drive development ended in the mid-1990s. As of 2016 IBM in Tucson continued to participate in tape standards development as a part of the LTO Consortium[3] as well as managing IBM storage products[4].

This session on media is primarily focused on the development of the chromium dioxide media first introduced by IBM for the 3480 tape drive; however it includes information on the earlier reel-to-reel tape media as well as the 3850 Mass Storage media. The following table summarizes tape media discussed herein:

Tape media code name	Approximate Date	Recording material	Binder	Used on
MST (Multi-System Tape)	1957 ca.	Iron oxide	Estane	Reel-to-reel

[1]See, http://pages.vassar.edu/casperkill/the-kenyon-estate-and-boardman-road/
[2]Source: "Celebrating Forty Years of Tape, 1952-1992," IBM Corporation, Tucson AZ, 1992 ca
[3]See, http://www.lto.org/
[4] See, "IBM Tucson Today" 2005 ca., downloaded February 22, 2017, Attachment 3 hereto.

MSS (Mass Storage System)	1975	Iron oxide		3850 Mass storage system
Mustang	Before 1978	Iron oxide		3480 development
Stallion	1978	Chromium dioxide	Estane 5701 polyester polyurethane	3480 development
Pegasus	1985	Chromium dioxide	Morthane 310N	Initial 3480 cartridges
Sonoita	1986?	Chromium dioxide		3480 cartridges and beyond

Extensive editorial changes from the video suggested mainly by Ric Bradshaw are shown in *italic times new roman font*. Changes made for clarity are shown in [brackets].

Interviews

Gardner: I'm Tom Gardner. I'm here for the Computer History Museum in Tucson, Arizona. It's October 12, 2015. For today's panel, we have three distinguished 3480 and IBM veterans to talk about tape technology in general, hopefully, from acetate through to Mylar and chromium dioxide, and about the 3480 media in general. But this really is what you guys want to talk about, not what I want to talk about or the museum wants to hear. We want to hear your recollections of the tape business with emphasis on the 3480 media. And now I'll let each of you take a few minutes to tell us about your background and what brings you to this great facility provided to us by West Press. On my left, first is.

Ric Bradshaw: I'm Ric Bradshaw. I joined IBM in 1978 out of grad school. And that's another whole story in itself. I was actually not intending to work for IBM ever.
<laughter>
My bosses were Joe Vranka in Boulder, and then in Tucson Dick Stacy, Bob Madeya, Lee Weaver, Ed Childers, Rick Meyers, Mike Liddicoat and finally John Teale. [Ric retired from IBM in 2007.]

Bradshaw: I was working on applied polymer chemistry. I was also interested in phenolic resins. And before that I got drafted, so my two years during the Vietnam War as a hiatus from my work in grad school. But in '78, a guy came through to see one of my professors, the head of the department, Dr. Monk. And he was on his way to Tucson for recruiting, and he stopped by and he said, "Do you know anybody in this college that actually does applied work?" "Oh, yeah. Talk to this guy. He's a nut job. He's upstairs."

<laughter>

Bradshaw: "But I doubt," and he said-- Anyway, so he comes up and he says, "I want to see you. Come over and fill out a resume thing." Well, I had already filled out a proposal to work for Los Alamos in fusion targets, and that's the one I was really working to get out. But anyway, so my boss calls me. He was then the head of the graduate fund, Dr. Burke [Dr Burke was the Dean of the Grad School at ASU and professor of Polymer Chemistry], He told me to take the interview as IBM had never come to ASU for students) tells me to interview this. They need to try and get IBM to do recruiting. They never did. They never came to ASU. It wasn't considered a "good enough" school to recruit from. So I go into this interview, and there was all these MBA guys sitting there with suits and stuff, getting ready to interview. And I came in my lab coat and my long hair. I didn't have a beard then. That's Bill's fault.

<laughter>

Bradshaw: Because when I went to Boulder, I had to grow a beard. It was freezing. Anyway, and he grew a beard every winter. So the point was that I really didn't want this job. So I said, "Look, you're wasting your time." And I hear this, "No, no. Let me get rid of all these idiots." And he's saying this in front of this room full of people in suits waiting to get a job with IBM. 'Cause I didn't know this, he was a chemical engineer, and he was working for IBM and GPD and he was there on a recruiting trip. I can't remember his name now. Oh, that's amazing, because I usually remember people. But so I just blew it off. I said, that ain't gonna happen. Well, about two weeks later, I get a call to call this guy in Boulder, John Slaten who was the professional hire lead. They want to have me go up for an interview. And that's when I went up and met Bill for the first time and my host was Dr. Robert “Bob” Haines, who worked for Joe Vranka I thought for sure I'm not going to get a job here but didn’t want to burn the bridge for others at ASU. Anyway, they made me an offer which was at that time they were hiring me as an engineer for I think it was $18,000 dollars a year. And this was in 1978. My wife, I had been married not that long. I got married just after I got out of the Army in 1973.

<laughter>

Bradshaw: But the point was, I really didn't want the job, but my wife said, "Take it. Take it." She was afraid, 'cause the problem was I was making money from my professor. He was getting me involved with all these other projects that had nothing to do with my Ph.D. But I was making him a lot of money. He had, like, five grants and stuff. And he was afraid I'd leave. So I had to get a job to get the hell out of school. So I said, "Okay." So we went and joined-- Well, Joe Vranka hired me and gave me a job in the Media Development group in the Tape Development function run by Bill Phillips. And I thought at the time that he had made a mistake, because he really thought I was a good liberal.

<laughter>

Bradshaw: And he didn't realize that I was about as right wing as, you know, Goldwater. And which is another whole story. 'Cause actually, in the seventh grade, I actually ran a campaign, a mock campaign doing it for Barry Goldwater. That's how back long ago. And that was in Dhahran, Saudi Arabia. You asked for some-- I was born in Denver. My dad was a World War II veteran. His father was gassed in World War I. Let's see, he was five years-old when his father died of pneumonia they called it in those days. And he was born in South Carolina then moved to with mother, his mother had a sixth grade education-- she was Welsh-- and went up to Rhode Island where he grew up. He got drafted in 1941, I believe, just before it was Pearl Harbor. Wound up joining the Army Air Corps
[00:05:00]
and was Mather Field in Sacramento California. And he was getting ready to get shipped over the Pacific. This was in May of 1942. He was flying B-25 Mitchells. And he had never had a date in his life. He never had any, and he was, this bunk mate of his, another pilot, was dating this woman, the blonde

named June. And she kept trying to set my father up with her office mate, Betty Jane Moyer, a long-legged brunette, a gorgeous woman.

<laughter>

Bradshaw: And my dad said, "I don't have time for this. I'm going to get killed," you know, and da-da-da. So he said, "I'm not doing it." So he's running down the stairs from this thing, before they're getting shipped out, and there's this June's coming up and there's this beautiful brunette coming up. And he goes, "Jesus." So the next thing my mom knows, she remembered it like this, is he's coming back up the stairs with flowers and candy. They knew each other for less than a week, got married and they were married for exactly 12 hours and he flew his plane over and then wound up in Nanda Airdrome in Fiji, to get used to navigating in the South Pacific. He flew 56 missions in 18 months. And my dad is 98 this year. My mother just passed away in August at 95. And they were married 73 years. An interesting story. But the rest of their story is even more phenomenal, 'cause my mother was in the Philippines and her father was a quartermaster for the Army. They were all born in cavalry posts. And she was born Fort Keogh, Montana.

My grandfather Preston B Moyer had an amazing collection of photos he took during the uprising as well as those early days in Manilla…some of them are not doing very well from the ravages of time. My mother's youngest brother, Alfred Moyer was born in Manilla and lives in San Jose. He has some of the photos and is trying to restore them. My sister has the originals in Mesa but will not release them…..

<laughter>

Bradshaw: So it was, like, and this is what we ought to learn. But anyway, my grandfather was offered a job to be the quartermaster of Corregidor in this November of 1941, okay.

Gaudet: Wow.

Bradshaw: And so but a friend of his in intelligence said, "Well, get your family out of here, Preston." And they got on the U.S. S.S. Sutter that left from Manilla, and in those days, I think they're what, they did 8 knots, those--

<laughter>

Bradshaw: But, you know, they really didn't go very fast. They left Honolulu for San Francisco on December 5th, 1941.

Philips: Phew.

Bradshaw: So, and when the ship went back to Corregidor, it was torpedoed by the Japanese. So they were in the last bunch of civilians to get out of there. So they're interesting here, and you'd never believe any of this stuff. And then his job at Dhahran, though, but we wound up going to Saudi Arabia. But anyway, there's a whole bunch of things that were totally happenstance that really influenced my interest in things and the way I wound up. But my job with IBM was totally accidental. But I've got to admit, you know, it was a good career. But the really amazing thing, and we used to hear it all the time, but in reflection, it was probably the biggest truth was it is the greatest collection of innovative, diverse, argumentative -- stubborn, pig headed, but great group of people. No, I'm serious. They were absolutely the best, if you got over some of the personality things, we could form teams from all over the world. It was truly an international company, which is amazing. If you want to solve a problem, put people with different perspectives, ethnically and background in a room and let them have their way. I didn't say we didn't fight. In hindsight, there's all kinds of things I wish I could apologize to Bill for, 'cause the thing in hindsight. No, he left. And there's things that I didn't do fast enough to solve the problem. We could have saved ourselves a lot of money. And so, I had those regrets. But the regrets I don't have are the people I got to know and meet. They were the greatest team of people I have ever been associated with.

Gardner: Are you still consulting now?

Bradshaw: Yes, but nobody pays me. But I do it all the time.

<laughter>

Gardner: And you may be worth what you're paid, right? <laughs>

Bradshaw: Well, I haven't learned my lesson to charge people before I tell them how to fix things, so that's a problem.

Gardner: Where did you go to high school?

Bradshaw: I went to high school in the American Community School of Beirut, Lebanon from 1963 to 1965. And then I went to undergrad in New Mexico Institute of Mining and Technology. I had a full ride scholarship. And when I first arrived there, I asked them, "Well, how many credits?" They said, "Well, you have to take a minimum of 16." "Oh, do you charge me more for the others?" It's a boarding school, by the way, and it's the largest campus, I believe, in the whole world. They own mountain ranges. It's that big. It's a large array of radio telescopes is on our campus. We used to take geology fieldtrips and never leave the campus and drive for six hours. You know, it's just amazing. A great place. Six hundred students, 30 girls. Definitely co-ed, right?

<laughter>

Bradshaw: And every one of those girls went to get their Mrs. degree, and they usually succeeded, you know, whether they really looked like dogs or not. But a great school. I had a great education. And then I went to ASU for my Ph.D.

Gardner: Still married?

Bradshaw: No.

Gardner: Children?

Bradshaw: No, my marriage, basically, was a victim of my career at IBM, because I was gone too long in the nineties when we were downsizing, and my wife decided to get a boyfriend. So, anyway I learned my lesson and I'm not doing that again.

Gardner: Okay. By the way, I never worked for IBM, but I experienced the IBM culture through IBM San Jose.

Bradshaw: Oh.

Gardner: And I really have to agree with your comment about the breadth, depth and variety of skills.

Bradshaw: We used to joke about it. That I literally believed that most people at IBM on the technology side of the house knew more-- or forgot more stuff than the rest of the industry combined remembered or knew. I mean, it was that good. I mean, there was the depth was just phenomenal. And it was, if you just unravel how many products we invented that IBM didn't do anything with.

Gardner: But I have to add that only IBM San Jose could do a strip file. Nobody else could build that beast.

Gaudet: Or try it. Amazing.

<laughter>

Gardner: An amazing product. Some of my friends worked on it.

Bradshaw: Actually, some of those other things they did, the floppies. When you're coming down to it, I love that whole story about the guy that invented the liner for the floppy disk out of Boulder. You remember that? He went home and you asked his wife for a bunch of different materials, and then by accident he grabbed one of those things for slips, it's a viscose rayon. The only thing that worked for a disk liner, <laughs> and--

Gardner: You might get a disagreement with that story out of IBM San Jose. But this is about tape, not floppies.
[Editor's note: US 3,668,658, the flexible disk media patent was issued to IBMs Ralph Flores and Herb Thompson, both from San Jose CA. The patent discloses 3M 550, generally known in the art as "pink wipe."]

Bradshaw: Okay. And the other thing was the hole that they punched in.

Gaudet: We can just drive there and get into the floppies if you want. <laughs>

Gardner: We could.

Bradshaw: No, it was fun. But that's, they're related because unfortunately, that's one of the things when I joined IBM about media, they still approached tape completely wrong. And I think it was, we went to a meeting when I hadn't even been there a month. And we went to Bethlehem, Pennsylvania to Lehigh

University for a symposium on coating technology. And I said, okay, this will be interesting. Like, I didn't know anything about coatings. I knew about polymers and syntheses. And they went on with this thing. And so and they kept calling it ink. Ink! This isn't ink. Wait a minute. The whole purpose of a magnetic tape is totally different than paints or printing things. Printing things haven't got anything to do with durability and stuff, but not the pigment. You want to minimize the pigment because the pigment costs money. In recording, the pigment is the money. It's the thing that stores the information and everything else is garbage. You put it in there just to keep it from screwing up the read-write head or having the coating come off. So my approach from the day one was to question why are you doing it this way.

Gardner: Which is really the subject we're going to get into.

Bradshaw: Okay. I'll shut up and let them get on with it too. <laughs>

Gardner: Now immediately to your left, to my right, in the center, we have Andy Gaudet.

Gaudet: Okay. Well, I have a biography three pages long. I'll just sort of sift through it. But for starters, I've been married 50 years-- 51 years now. And I have two kids. Both of them are doing phenomenally well. My son was born in 1967. It kept me out of the draft. That wasn't intentional. At the time, I was going to right before that to Stanford and for my master's degree. And the wife and I decided to have a child. And it turned out to be a boy, Brian. And he came along just in time, though, to where I didn't have to go in and be drafted. And then I went to work for IBM and it was in 1966 in January. And it was considered a critical employment whatever, to where they weren't drafting out of IBM. So I didn't get drafted. But that's the name of that story. And it was nothing intentional. I would have gone. I had my bags packed one time. I knew what time to catch the bus. But I got my deferment just in time before I went down to the bus station.

Bradshaw: You didn't miss anything. It wasn't that good, really. <laughs>

Gaudet: So I never did serve in the military. So I am a graduate electrical engineer from Sacramento State, Sacramento, California. And then I completed 46 units of post-graduate study in electrical engineering in Stanford and the University of Santa Clara. About that far away from getting my master's and work just fully encumbered me. I was unable to complete the last two or three units that I needed. So anyway, I never got my master's. Also, my education includes two IBM executive management courses. One is International Management School, at La Hulpe, Belgium in 1982, and the other is Managing the Enterprise, Columbia University Graduate School of Business in 1985. My professional experience covers DASD, tape and optics, and then back to tape, back to optics, back to tape. And then I finally retired in May 2001. Now that's the short of it. Now if you want the long part of it, if I have the time, just tell me when to cut it off. <laughs> My professional experience on DASD., I joined IBM in January 1966 as a junior electrical engineer in San Jose. I was promoted to staff engineer in 1970, advisory engineer in 1972, development engineer in 1975, and then to senior engineer in 1977. During that time, I was involved with DASD product development for the IBM 3330 models 1 and model 11 (Merlin then Iceberg).

Then, the 3340 Winchester, the 3350 disk drives, and then in '75 to '79, I structured and formed the initial channel integration effort in IBM San Jose, where I had the responsibility for providing functionality assessment of the first thin film heads and disks and recording channels for the 3380 drive. And I did all this on a precision test stand that was a mechanical marvel. We had micro inch predictable motion. You could look at track mis-registration effects on the recording channel. Introduce noise. Change speeds. It had all kinds of capabilities. We were able to thoroughly wring out the film heads, the film disks that came together with the recording channel. Which was a real boon and that's what I basically developed, the first department in component channel integration, which were the heads, the disks and the electronics. And on a precision test stand, I established the major read/write head specification, the dimensions for the film head, the track width, throat height, pole tip shaping, and demonstrated that a modified particulate iron oxide disk with thinner coating and reduced taper, reduced alumina content formulation and modified buffing operation could achieve the 3380 recording density data capacity objectives, and introduced this particulate disk into the 3380 recording channel in the middle of product assurance testing where we were seeing nothing but crash, crash, crash, crash, crash, crash. And not to mention names, I better not.

<laughter>

Gaudet: But it was the lubrication. <laughs>

Bradshaw: It was the irreducibility of porosity.

Gaudet: You're right.

Bradshaw: The lube would puddle.

Gaudet: Yes.

Bradshaw: And then it would make the head unstable.

Gaudet: He's right on.

Bradshaw: I worked on a task force for that.

Gaudet: Oh, okay. But it wasn't resolved, and what saved our bacon there was the fact that the--

Gardner: We're sort of a little off topic. It's very interesting to me as a DASD guy.

Bradshaw: No, but it's related.

Gaudet: It is.

Bradshaw: And honestly, believe it or not, some of the things are involved with the tape.

Gaudet: It's my background. In particulate it’s disks that led me to be able to understand this wet noodle.

<laughter>

Gaudet: That I got into later, which I have here.

Bradshaw: It is really, the formulation stuff that we went into is actually something we were already chasing in Tucson.

Gaudet: Right, right. And so in 1978, I was promoted to read/write recording channel technology manager. In 1981, I received along with Jack Grogan an outstanding achievement award for my technical work in defining a high density magnetic recording system for the IBM's 3370 and 3380 disk drives. Then, tape. That's DASD. I don't think I ever went back to DASD. No, that was my initial introduction and it was only from 1966 through 1980 that I worked on DASD. Then I was transferred to Tucson in July 1980 as a magnetic recording technology manager. From 1983 to '85, I was responsible for pulling that technology together and making sure that it would work and it was integrated into the 3480 drive. We had a lot of woes. And we'll be getting into those later. You know, like hard bands and things like that.

Bradshaw: That was later. That big one was stick. That was the one that almost killed it. I mean, that was the thing that was delaying it, to tell you the truth.

Gaudet: We'll talk stick.

Bradshaw: And the other thing was head wear.<laughs>

Gaudet: That's the cart before the horse right now. But we'll get there. But anyway, and let me get up with my notes here. Okay. In 1986, I was appointed manager of technology development, responsible for magnetic tape and optical disk recording-- so now we start to bring in the optical disks in terms of my career-- and electronic technologies and worked closely with San Jose Research in developing this roadmap for the future of storage products for tape and optical disks.

And then optics. In 1988, I joined product management and a series of technical staff and program management assignments. The program management assignments included product development responsibilities for the IBM 3.5 inch optical disk drives, Top Cat 1 and Top Cat 2 called MTA 3128 and MTA 3230 respectively. The product development assignment was a real challenge. <laughs> It involved management in Tucson and internationally inside IBM at IBM Fujisawa, Japan for a systems attachment and microcode in the read write channel, and externally outside of IBM with Philips, Eindhoven for the drive servo. optical head and media. The product was developed, shipped in full volume production from Philips in 22 months. I was just talking about the two optical disk products that I was program manager for, and bringing it together in IBM Fujisawa, Japan and Philips Eindhoven. And we came up with 2X capacity six months after the first product, that was TopCat-2. And work was started on the third generation 5X capacity. So we were going to build a, you know, year after year, leading edge, push it, push it, push it. And that work was sort of torpedoed when IBM's, Ray Abuzayyad and Phillip's Jan Oosterveld got together and decided that the thrust for optical disks should not be in the MO technology, but in the phase change CD-ROM compatible technology. So we abandoned the work on the next generation TopCat product. I also had the responsibility at that time to support the termination of the next generation Erimo product, which was a 3.5 inch optical disk drive out of Fujisawa, Japan. With their product office, we brought all that to a successful conclusion. So that's the story of my first venture into optics. And now back to tape. In 1995-97, I was program manager for the 3570 Magstar. It was a novel idea, fast access to data, mid-tape load.

Bradshaw: Timing-based servo.

Gaudet: Timing-based servo. Thank you. But a lot of whistles and bells, novel. And this product had a history before I joined up in product management and I got that responsibility. It had started up and stopped. Started up, stopped. A lot of false starts. But we restarted it in-- I restarted it in 1995, and I coordinated the internal IBM development effort with the activities in NEC, Yonezawa, Japan where they were doing the tape path work, and they were also the manufacturer for the tape deck and the tape cartridges, they sourced it. Oh. Wait a minute. The tape cartridges were designed by 3M in Minnesota and manufactured by Imation in California, as I recollect.

Bradshaw: But which was, you know was 3M.

Gaudet: Which was a spinoff. Imation was a spinoff from 3M. And the 3570 was shipped in full volume production in September, 1996. While I was over there at NEC in Yonezawa, around midnight I got this call from Larry Eisham (an ex IBM'er) working for Phillips out of San Jose. And at that time, he made me an offer to come to work for Philips in their CDRW area. I could head up the projects and be a contributor in optical disks because he had heard of the demise of the optics and I was, you know, back on tape again. And he knew all about me and what I was doing. And so I said, I'll consider it. I'll ponder it. And I finally did.

I formally retired from IBM on March 31, 1997. And in September 1997 I accepted an offer from Philips as director of CDRW projects. I managed this assignment reporting to Philips Optical Disks Headquarters in San Jose, California with development resources in Eindhoven, Holland and then Hasselt, Belgium. Hasselt, Belgium was where we were translating the technology into a product and getting it into manufacturing. And under my direction, for the two years I worked with Philips, we shipped a CDR that's a read only CD, the CDD 3610, and the first Philips CDRW optical disk product drive, which was the CDD 3800. And they were developed and introduced into the market where they were very well received as OEM products with reliable sourcing. Hasselt was a mainstay in being able to produce product and make it happen. It was highly cost competitive and provided extremely high product reliability and data integrity. I was also responsible for and established the advanced technology roadmaps for CD rewrite follow-ons and into DVD-RW optical storage products. That was more of a roadmap, looking at the technologies. What can we do and what can't we do, some of the initial testing, et cetera. And it went pretty smoothly. And I was having fun in optics at Philips. Then I got a call from John Teale and I came back to tape. He offered me a job as a contractor but in a development management capacity for the LTO product that they were getting their arms around, and it excited me.

Gardner: Did you mention who hired you at Philips?

Gaudet: Yeah. Jan Oosterveltd.

Bradshaw: Philips Eindhoven has got a wealth of data on their sites, too. I do peer review papers for them. *I have done some peer reviewed papers for the Journal of Applied Polymer Science and others for authors at Phillips since I left IBM, but always anonymously through the editor. It allows me to follow technology in a number of companies.*

Gaudet: But anyway, Philips is a very well founded-- were very well founded in CD disk, DVD recording technologies, the whole shooting match, from micro code through the media and everything in between. I mean, they were a good team. A very, very good team. So anyway, in early 1999, I hooked up with John again in IBM in my contractor role, and assumed the development project management responsibilities for the IBM LTO tape drive, 3850. And we finally cranked that one out, and it was the first to market LTO product. And in this capacity, I coordinated the read write channel development effort in Tucson, IBM Fujisawa, Japan for microcode development. Oh, microcode was in Yamato in Japan. It was the recording channel that was in IBM Yamato.

Gaudet: But then the actual recording channel, I think that was the last thrust they did out of Fujisawa, 'cause I can remember making trips down to Fujisawa and I don't know why else I would go there in that time frame.

Teale: It's possible it was the same crew, because they ended up moving to Yamato.

Bradshaw: Yeah. That was it.

Gaudet: Later, you're exactly right.

Bradshaw: And Zurich was starting to get involved then too with the mathematics.

Gaudet: Because what you saw was, it was starting to look like, an empty dungeon over there. Not too many people around.

Teale: And there's a back story on that which we'll talk about on the LTO section.

Gaudet: Okay.

Bradshaw: There's a lot of back stories in LTO. <laughs>

<laughter>

Gaudet: And there was a lot of interactions there, all the way to Fujifilm in Odawara, Japan, Tucson, Arizona and then NEC for the tape deck. . Odawara was responsible for the media (Fuji film). So we finally shipped that in, it was September, 2000 is what I have here from my notes and my memory bank. I don't know, John, is that correct? That's as close as I can peg it.

Teale: It sounds about right.

Bradshaw: It's close. The announcement was in May.

Gaudet: To reiterate, then, my professional experience was in the DASD, tape, optics, back to tape, back to optics, back to tape. That's what I just took you through. And I completely retired, completely, and I never had a job since May, 2001. Awards, recognition. There were several IBM Informal Awards, and four IBM Formal Awards. August 1980, contribution to direct access storage recording technology. October, 1981, definition of high density recording systems for the 3370, 3380 disk drives. March, 1985, management excellence of the 3480 technology. And December, 1996, 3570 program management award. And I have three U.S. patents, all-- a couple of them to do with optics and one of them in some sort of a routine you do in an optical disk drive with data.

Bradshaw: Data management.

Gaudet: Not data management. I forget what, exactly what it was, something to predict failure. So that's it. So that's it.

Gardner: Okay. Did you mention your parents?

Gaudet: Edward and Genevieve. And they were both from Texas. That's where they were born. Oh, no. My dad was probably born in Louisiana. But I know my mother's side of the family. I remember growing up in Bay City, Texas and riding horses out at Grandpa's and Grandma's place. And when I was about 12 years-old, I think seventh grade, my family moved to Lodi, California. My dad was a petroleum engineer, and he worked out in the Rio Vista area. Gas wells, primarily. He was in oil wells before.

Bradshaw: In Bay City, yeah.

Gaudet: Yeah, from Bay City-- **a**nd in Louisiana. When I was a youngster, my dad was hopping from job to job to job, and I changed schools from the first grade-- I never went to kindergarten-- <laughs> first grade through about the sixth grade, I think, about 15 times. It was always bump, bump, bump, bump, bump. So I got around when I was a youngster. The family was always on the move. And then boy, did I have a Texas accent when I moved from Bay City, Texas to Lodi, California. My dad was working for Dow Chemical at the time, and then he transferred to Brazos Oil & Gas Company, That was one of their operations in the Rio Vista area, out in the Delta in California, over by San Francisco where the Bay sort of seeps in there.

Gardner: Mother's maiden name?

Gaudet: Richers.

Gardner: Grandparents all born in the U.S.?

Gaudet: Yes. Yes. They were all-- they weren't immigrants, no. And, but their parents were, from Germany and England, I think. Yeah.

Gardner: What do you do for fun now that you're retired?

Gaudet: Today? I was trying to remember something about my early childhood. Oh, yes -- then I had this very strong Texas accent. And I was into this grammar school in Woodbridge, California. That's just right around Lodi. And I could not understand anybody. It took me weeks. And I'd have to say, "Slow down," in my drawl. <laughs> "I don't understand." My teacher also. But I overcame that and I adapted fairly well. And then I ran for student body president and won-- <laughs> election <laughs> in grammar school. And I went to high school. And then Sacramento State. Right to it, no gaps. And then Sacramento State, I went right into Stanford. But then, the wife and I started thinking about having a kid and she was a social worker. And if she was having a kid, I couldn't be at Stanford. So that's when I started looking for a job and I took the IBM offer. And the other one that I interviewed was Lockheed and there was one other one. I forget what it was. But anyway, I liked the IBM management that I interviewed with, and I was sold.

Gardner: Did you go to high school in Lodi? Did you mention that?

Gaudet: Lodi Union High School. Yes.

Gardner: Okay. Anything else you'd like to add?

Gaudet: Well, I was a Little Leaguer. Baseball's my sport. I played it through into high school. College, no. Well, except for fraternity baseball. You know, when the fraternities get together and we'd have this organized, you know, schedule and-- We'd play ball against each other. Phi Kappa Tau was the name of the fraternity.

Gardner: We ask you what made you choose engineering? Actually, I should go back and ask Ric the same thing.

Gaudet: Engineering, you know, I got in, I was always going to go to college. My parents said, "Thou shalt." And so I did. My first year I studied, I was commuting. So I was commuting back home from Sacramento State, about a 30 minute drive one way. And I was doing famously in all of my courses, but I still didn't know what I was going to be. You know, a mechanical engineer, an electrical engineer. I was taking all of these engineering courses, you know. Calculus and all that. And so then I started the second year and I joined the fraternity. At the time, it was a local fraternity, Phi Kappa Tau came later, a year later. We went national with Phi Kappa Tau. But the second year, all I did was party. I did not study. I did not go to my classes. I got an A in logic but flunked the rest.

<laughter>

Gaudet: French. Oh. I wanted to convert and be a doctor. So I was going to study medicine. So I went to, you know, biology and went to-- You know, it was about-- it was a full curriculum. And the night before the logic final, I decided to read the book.

<laughter>

Gaudet: So I stayed up all night. <laughs>

Bradshaw: As Spock would say, "That sounds logical." Yeah.

<laughter>

Gaudet: Anyway, took the test and that's the only course I got an A in. Obviously. The others I didn't go to class, so I flunked them. So I was way down on the end of the totem pole. I was a, you know a point 000 something GPA. But my first year, I got As and Bs. Then I met my wife. And she was in a sorority. And so we were-- we got pinned. Pinned means this fraternity guy and a sorority gal, and I gave her my fraternity pin. And so now we're pinned, sort of like engagement. But then we were married a couple of years later. And that really-- she really shook me up. And I said, I've got to do something with my life. So I went back in. I said, I'm going into electrical engineering. I made up my mind. You know, Linda, my wife, helped me make up my mind. And for the next three years, straight As. The Dean's Honor List, the whole thing. So it was a success. And I got accepted into Stanford and all that sort of stuff. But, you know, trials and tribulations. And I don't know if you want that kind of story or not, but it was fun in the fraternity for that one year. <laughs> I stayed in the fraternity through graduation. But I did not participate as vigorously.

Gardner: Pulled its GPA average up, though.

Gaudet: I graduated with a 3.6 or something like that -- I think it was a 3.2 GPA that I had from my freshman year and my second year I got a 1.000 something GPA

Gardner: Did you mention your wife's maiden name?

Gaudet: Vaccaro.

Gardner: And where her parents are from?

Gaudet: Her parents were both born in the U.S. Chicago and Louisiana, New Orleans area. Their parents came from Sicily. So my wife's 100 percent Sicilian. And a nice lady.

<laughter>

Gardner: Great. I think that's pretty good. I've got a couple of questions that I should have asked Ric, but we'll go back to Ric later. We'll go to your left, my right.

Philips: Bill Philips.

Philips: Hi, gang. <laughs> I'm an only child, born in Chicago, Illinois in the mid-thirties. My mother, father and grandmother came from Southern Illinois. And in Southern Illinois, everybody has two names. My cousins were Lorne Ray, Billie Jean, Lorne, and I was Billy Burl.

Philips: Burl was my grandfather's name. He was head of Consumer Ice, and I helped deliver ice to small places in Mount Vernon, Illinois when I was a teenager. I grew up in Chicago, and my dad was a steel salesman. My mother was a secretary. And my grandmother was-- raised me. And I remember getting up at 6:00 in the morning every morning, and getting ready for school, and the crossword puzzles were already done by my grandmother. She was wow. And I went to Southern Chicago Grade School. I went to Hyde Park High School for about three months, and my dad was transferred to Carmi, Illinois. So I went down to Carmi, and my mother said, "The orchestra director wants you to play." I was a clarinet player. For ten years I studied at Wurlitzer in Chicago. And she said, "He doesn't want a clarinet player. He wants a bass player." So I thought I was going to be boom, boom, ba-boom-ba-boom-boom-boom. It turned out he wanted a tuba player.

<laughter>

Philips: So I was converted from a clarinet player to a tuba player. And my dad got transferred to this big town in the middle of Illinois called St. Elmo. And I went to my first year of high school in St. Elmo and played the tuba in the band, and played tuba. All my college career, I marched. We transferred back to Chicago where I graduated from Austin High School. I played in the band. Voted most successful-- most likely to succeed. And a wonderful date, a girl named Shirley Rogers, who we still correspond with. I marched in Soldier Field many times when it was freezing.

<laughter>

Philips: Yeah. And when I was growing up, I had a knee problem and I went to Gompers Crippled Children's School at about 10 years-old. And I read a lot since I couldn't walk or run. I was in a wheel chair. And I read a book called, "Dignity: A Springer Spaniel." And it was about an electrical engineer who had this dog who was a marvelous, marvelous dog. And I made up my mind when I was about 10 years-old that I wanted to be an electrical engineer like this guy. So that's where I got my desire for electrical engineering. And when I was registering for the University of Illinois in engineering, my mother was very dubious about whether I would be good in engineering. So we did an aptitude test in IIT [Illinois Institute of Technology]. And at the end of it they said, "He's very good at math, very good at spatial relations, very good at timing. He'd be a good engineer." So that verified my desire. So I went to the University of Illinois in Electrical Engineering. And in those days the electrical engineering in Illinois was 17,000 students. And I went to fraternity rush and met a lot of my high school buddies from St. Elmo at a fraternity called Tau Kappa Epsilon. And I met my wife through a social, my fraternity and her sorority in my sophomore year. I wanted to marry her in my junior year, but her dad said no. Her dad was a men's clothing store owner in Oregon, Illinois near Rockford, 90 miles west of Chicago. And he said, "You're not getting married until you're both out of college." I did it in four years there. I did 18 to 21 hours every year. And now they do 14 to 16 hours and wonder why it takes them five years.

Bradshaw: And they're in debt.

Philips: Yeah. And the University of Illinois had no admission. It was $40 fees for semesters if you were a high school graduate in the State of Illinois in the upper half of your class, you went free. So I went four years of electrical engineering free at the University of Illinois.

I had met my wife and we married about a month after I got out of school (August 1957). I had already made a commitment to a job. I wanted to work for Bell Telephone Laboratories in New Jersey. And when I went out there, I stopped in an aircraft company in Baltimore whose name I forget. And I went to interview Bell Labs at West Street in New York City. And I added IBM to my list of interviewees up in Poughkeepsie, New York, and they told me at Bell Labs I would work on West Street in downtown New York. And growing up from Chicago, I see this pastoral laboratory across from Vassar College, away from all the muss and fuss and cars and smoke and noise. So I went to work for IBM in 1957. Starting salary was $5000 dollars a year. You got to work engineering hours, which were dawn to dusk and Saturdays and Sundays when you missed your schedules. And I won an IBM Ph.D. Fellowship in 1962. And I had my choice of universities and I picked MIT, Purdue and Illinois. MIT wouldn't let me in because my undergraduate grades weren't over a 4 point, which Illinois had a 5 point system. I was like a 3.8, just under a B average. So Illinois rejected me.

Gaudet: Their loss, Bill.

Philips: There's a story here.

<laughter>

Philips: And Purdue said, "Come on out and see us. We like you." So on my way to Purdue, Joan, my wife, and I decided to stop at the University of Illinois and find out why an IBM Ph.D. Fellow was rejected from his bachelor's degree university. So the Dean of Engineering met with me. And he looked through my files and he says, "Here's why. It says 'conduct unbecoming a university student.'" I said, "No kidding." Well, let me tell you the story behind that. I was living off campus with Rudy Siegert, who was captain of the football team, Al Johnson and me. And Al got pinned to a Delta Gamma. And we got a non-drinker from the TKE House to drive us. We were all drinking gins and gin and tonic at the time. We were half drunk and we threw pebbles at the windows of Delta Gamma to get the girl's attention and the house mother called the police. And so we sang our songs and the police showed up and found an open bottle of gin in the car, and we were thrown in jail for the night. And the only non-drinker was allowed to go. And Rudy Siegert, they wanted a $25 dollar Bail money. And none of us had $25 bucks to our name.

<laughter>

Philips: That was a lot of money. So Rudy told Bob Haymaker, who was the driver, "Go to this bar downtown, 'Champagne.'" Rudy knew every bar. He was a member of the drinking club of the Illinois football players.

<laughter>

Philips: And was captain of the football team, so they all knew him. So the bar owner gave Bob Haymaker $200 dollars in cash to get us out.

<laughter>

Philips: So we were bailed out, and eventually the charge was dropped. But it got into my records.

Gaudet: On the record? Didn't you get it thrown out? They didn't expunge your record?

Philips: No.

Gaudet: Ah, that's really not nice.

Philips: So we went over to Purdue and we loved it a lot. They wanted us. And I get a call from the Dean's secretary, and she says, "The Dean has changed his mind, and he's going to accept you." And I said, "See ya."

<laughter>

Philips: So I finished four years of Ph.D. work and left Purdue. Oh. I called back to my manager in Poughkeepsie, and he said, "You can come back to Poughkeepsie or we're opening up a new facility in Boulder, Colorado." And my wife heard the name Boulder when I was talking to him and she said, "Take it."

<laughter>

Philips: So we moved to Boulder in 1966 and stayed there until 1979, 13 years in Boulder. And my mentor there was Wayne Winger, who was lab director for a while. And I ultimately became manager of the technology group there. And when we were moving down to Tucson, to tell you what IBM people management they were, we moved in two waves, 1978 group and a 1979 group. And my group was 1979. And the housing prices were starting to move up from the IBM building going up and people coming and buying houses from California and Endicott and Boulder, those that were in the first year. And I had a lot of pissed off employees that weren't-- who were going to have to pay a lot more money for housing because they're going the second year. And I let it be known to the lab director. And Watson personally okayed a special deal to give you, if you were going in the second year, they would give you an interest free loan for the equity in your house to purchase whatever you wanted to in Tucson. So everybody went down. We bought a lot and went through the process of building a house with an architect. But to tell you, it was amazing what a people-oriented company we had.

Teale: A lot of changes today.

Philips: Yeah. And so we moved to Tucson in 1979. And I stayed there and ran the technology group there. I worked for Bob Mazza I worked for Carmen Rosato. I worked for all of them. And Wayne Winger also. And I had a lot of interaction with the supplies sales people in Dayton, New Jersey. And they were on our back all the time with tape stick issues. "Why can't you make it cheaper? We have to sell more." And one of them invited me who-- I'm a golfer. And he invited me to come to Colorado Springs to a new company he was vice president of sales with. And he wanted me to play golf at the Broadmoor. So how could I not go out to this new company called Brown Disk [Colorado Springs, CO]?

<laughter>

Philips: And I really fell in love with the whole environment and the new product was going to be floppy disks, both a 5.25 and 3.5 inch. We made the first U.S. 3.5 inch. But I wasn't sure about the commitment. So I had my wife come up two weeks later to meet Ben Brown. She has a fabulous ability to judge people. And she says, "Bill, Ben Brown is A-OK. Go with him." So Ben Brown treated me like a son. And we had a great four months, and then we were bought by a French chemical company, Rhone-Poulenc. And Fritz Meyer, our Chief Financial Officer, who's now a well-known stock and bond advisor out of Denver, came in one morning and said, "Bill, sign this." I said, "Fritz, you know I don't sign anything without reading it." He says, "Bill, sign it." I said, "What is it?" He says, "It's an offer to buy all of your stock options for $6 dollars a share from Rhone-Poulenc." -- "Where do I sign?"

<laughter>

Philips: But with it came a two year commitment to stay on as Vice President and General Manager of Brown Disk. But every three months, I would have to go to a quarterly meeting in Paris. So my secretary said to me one time, "Bill, you have the greatest job every quarter."

Gardner: That does sound like a rough life.

Philips: You would go to Rhone-Poulenc executive offices in Paris. I would leave on Saturday and get there and come home on Tuesday. So it wasn't a very long time in Paris. And I retired, I had to go to Albi, which is in Southern France near Toulouse. I don't know, they had another floppy disk company from-- of Rhone-Poulenc's. And they decided to shut down the Brown Disk, Colorado Springs and transfer all the equipment and people they could get to Albi, France. I came home one afternoon and I said, "Joan, how would you like to go to France to work for a couple of years?" And she said, "See ya."

<laughter>

Philips: She wanted no part of France. She couldn't speak the language. But I was fairly good at French. And so we decided to retire. So I taught school at the University of Colorado in Colorado Springs for two semesters. And one of my best friends was David Reese, who was an IBM-er in Tucson and Boulder and San Jose. And he called me and said, "Bill, we want you to come up and run the technology business for Storage Technology." So in 1987, I went up to become Vice President at StorageTek, running their technology business. And I did that until 1992, and retired and came back to Tucson where my daughters were going to school at the University of Arizona. And I continued to do work for StorageTek in a recruiting. I would say I was a college recruiter with IBM StorageTek for 40 years. I loved recruiting at college schools. And I started out in Poughkeepsie working on the 727. And my mentor was George Rudy. I have no idea what happened to George, but George was, his goal was to make me an acceptable electrical engineering by IBM's ranks. And I had a couple of patents. Got my Ph.D. Fellowship. Went to Boulder, worked on tape. Went to Tucson, worked on tape. Went to Colorado Springs, worked on disks. So I've been in magnetic media all my life in all forms of it, from the moving coil actuator on the 727, to the Prolay[5], Herb Baumeister's Prolay. You remember that name?

Gaudet: Yes.

Bradshaw: Yeah.

Philips: I was in mechanical analysis for a couple of years with my mentor there was Paul Batem and my buddy was Vladimir Neshleb. And somehow, I did not like chemistry.

<laughter>

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[5] A Prolay assembly has three positions; a neutral position, one to push the tape against the turning capstan to make the tape move and one to push the tape against a braking capstan. See: US Patent 3, 007, 086 and http://ibm-1401.info/Prolay64Parts.html

Philips: I had a terrible time with chemistry at the University of Illinois. I barely made it through chemistry. And I was put in charge of the new tape business. We're gonna go make our own tape and build a plant in Boulder and later, a plant in Tucson. Well, Boulder had their own manufacturing facility. And the manufacturing guys did everything in the new building in Boulder for making tape. And the engineers were sort of in the engineering side. There were a lot of the manufacturing engineers, very talented. But we had very little to do with the actual facility in Boulder. And but then when we started in Tucson, and we went down to survey the facility and we noticed planes flying off the end of Davis-Mountain Air Force Base. So we went to see the commander, whose name I forget, a lieutenant colonel. And we told him we'd have four 20,000 gallon volatile organic storage tanks sitting off two miles to the northeast of your runway. And I wanted to know if your planes went over that. And he says, "We never go over that facility where it's going to be." So my first visit to their, to look at the ground breaking, I'm standing there and here comes a fighter plane right over my head.

<laughter>

Philips: Another part of the story is we're up and running, building tape, doing well. It's a Saturday morning, I'm playing golf at Forty Niner's golf course out east of town. And it's a Saturday morning and I hear this, harrumph. I said, "Oh, damn. We just blew up the building."

<laughter>

Philips: And I looked behind it and I saw white. And I said, "Phew!" Volatile organics burn black. And a guy with a big rig had broken an interstate gas line and was killed in the explosion. And fortunately, it wasn't our facility. And on a Saturday, it wouldn't have been as deadly as it would, 'cause it would have killed a couple of thousand people if it was during the work day. And what I remember most about tape was how to get fast start-stop times out of a moving coil.

<laughter>

Philips: And a pinch roller moving back and forth. And the aggressiveness of product tests. We had the greatest product testing facility known to man. Except they were always trying to break our products. And we had what we call 90-80 [degrees F - % relative humidity] was the hot and wet temperature and humidity that we had to suffer through for our stick programs. And it would aggravate the stick. And cold-dry was never a problem. Mid-70-50 was never a problem. But 90-80, the stress test, was a big problem. And if you made it through that, you had a solid program. And we had ongoing relationships with the product test people. Some good, some bad.

<laughter>

Philips: Very aggravating, although we made up at parties and drank with them. What else can I add?

Gardner: Did you state your wife's maiden name?

Philips: No. Joan, the original Czechoslovakian pronunciation was Lebowich, but when they came over, they changed it to Lebwick. We've been to Czechoslovakia and seen her parents.

Gardner: So her parents were born in Czechoslovakia?

Philips: No. Her parents-- Her grandfather was born in Czechoslovakia and her father and mother were born in the United States.

Gardner: Okay.

Philips: My family all came out of Welshmen that came in through South Carolina. The Philips and the Edwards and the Smiths. All good English-Welsh names. Her grandfather was 6'2", 280 pounds, sheriff of Ogle County. You didn't mess with him.

<laughter>

Gardner: Did you say when you started at Brown Disk? I don't remember if you said the year.

Philips: 1984.

Gardner: Did you say why you became an engineer?

Philips: I became engrossed with the book, "Dignity: A Springer Spaniel." The owner of Dignity was an electrical engineer, and I just liked the way he thought. And the process he used.

Gardner: Okay.

Philips: My mantra was, "Don't reinvent the wheel." And that has saved me and my engineers and my family tons of money. But I cannot tell you how many people want to discover and make the same mistakes other people have made. So whenever I go on a project, my first instruction was, "Has this ever been done before? I want to find out who's done it, what problems they had, how they solved it, what the key ingredients were, what the key technologies were, and how do we avoid those problems and learn from them."

Gardner: You said at Poughkeepsie you worked on the 727. And then you went to Boulder. And did you work on the tape drives there at Boulder. How about the 3850 Oak? Were you involved with that at all?

Philips: Yes.

Gardner: Mainly on the media side?

Philips: Well, in Boulder I was technology manager. Media was one of my assignments.

Gardner: Okay.

Philips: I had electronics, media, mechanics.

Bradshaw: Microcode.

Philips: Yeah.

Bradshaw: That was just brand new then. But you supported MSS, didn't you?

Philips: Yeah.

Bradshaw: Yeah, that's what I thought. I was involved with that too.

Gardner: So what was your first activity on a 727 when you were back in Poughkeepsie?

Philips: Well, high speed rewind was always a problem.

Gardner: Okay.

Philips: Tape stick was a very minor problem in those days because we were using an acetate binder system, and it was relatively stiff and the heads were very sharp.

Gaudet: They were laminated too.

Gaudet: Yeah.

<laughter>

Philips: And didn't have this large, flat surface to stick to. You were trying to take a relatively stiff product and bend it around a V-shaped head. And the problems were head wear.

Bradshaw: And debris. **T**hey cleaned heads every eight hours, as I remember to keep it running.

Philips: Yeah.

Gardner: Okay. Did you happen to work with either, I'll probably mispronounce the name, Weidenheimer or Buslik?

Philips: Both.

Gardner: Both. And you may be the only person that can tell us any interesting stories about either of them.

Philips: Well, they were famous for inventing the product. <laughs>

Gardner: That's for sure.

Philips: And they came out of New York, as we all did in the early days. Yeah. I knew Walt Buslik better than Jim.

Gardner: Buslik has an interesting career. I know of his accomplishments at IBM San Jose. And most people give him credit for the work that ultimately led to the Winchester disk drive.

Philips: Yeah.

Gardner: But nobody seems to know much about what he did at Poughkeepsie. This may be the opportunity.

Philips: Well, I knew him only casually in Poughkeepsie, so I can't remember.

Gardner: There's a rumor currently floating around that the first vacuum column vacuum was generated by Walt's personal vacuum cleaner.

Philips: <laughs>

Bradshaw: It was. **T**he reason I know is when they did the 40 years of tape, which I've got a copy. I gave it to you. One of the things that's been an asset or it plagues me a lot is that I am an absolute history buff, okay. So when I joined IBM, after we published "Celebrating Forty Years Of Tape" in 1992 [IBM Corp, Tucson, Carl Schroeder Editor, CHM catalog number ????], and I was involved in that peripherally, although I didn't have, my name didn't show up anywhere on it, pulling stuff together. Then in 2002, it became the 50th year. And I'm very proud of what I did. My point was I started digging through some of these things. Wayne Winger was still in Tucson I believe and I was able to contact him and all these names started coming up now. Unfortunately, we didn't publish this stuff. This is what's really a shame. There's an IBM Journal of Research and Development article[6], which I'm very proud of, that we put together. I actually talked the IBM Journal into doing this full thing on tape, technology. Pulling teeth, I got some very *good contributions from the IBM Technical community.-- Like Bob Biskeborn, an STSM in Head Development in San Jose, along with other members of the head development team to write a paper about thin film head development.*

But it wasn't very good when he first wrote it, but it took him a lot of work to put it back together. But it wound up becoming one of the most cited papers in IBM Journal history on the heads. Because, quite honestly, that's how much leadership IBM had in head technology and it still does. But in the process of doing that, I wrote a paper that I've got to get you the draft. I don't know if I-- Yeah, they don't own it, I don't think. But anyway, I tried to put together a history of tape from IBM. And it was really fun, because I was, I think I'm the last person to actually touch some of these people that have gone, because the pickle factory from Poughkeepsie where the original tape, the whole piece was that people forget that the original tape drive, part of the problem you had to solve was all the software used 80 character punch cards. So the tape actually mimicked 80 character punch cards. So it thoop-thoop-thoop [they literally stopped and started in a jerking motion to mimic card usage]. If you think about it, John, and when we started looking at doing really fully streaming and stuff, one of the things we had to do is realize that the whole legacy of IBM tape was being strangled of using the technology, because we had to emulate punch cards. And you think about it, that's really what killed us. A lot of the problems that you guys dealt with, now you've fixed them. But the other thing we found out is we have the original picture that was taken of

[6] IBM Journal of Research & Development , Vol 47, No 4, July 2003. A special issue dedicated to Tape Storage Systems and Technology.

them holding a sheet up, standing there with you guys taking the thing, and his vacuum cleaner. The problem is, this is what always irritated me about engineers versus science, okay. Science, you understand things and then you build things based on what you understand. Engineers turn the knobs until something works that that's the solution that is put into the device which I guess is okay but it drives me crazy.

Gardner: <laughs>

Bradshaw: But I'm telling you, they literally had this GE vacuum cleaner that they had built the pneumatics around. All the plenums and everything. It turns out when they decided to make a product, the thing was obsolete, and they could find 50 of these vacuum cleaner motors, the pumps and the whole thing. And they already configured it to fit this thing, all the pneumatic. So they bought every one of them. Thank God, I think they sold 100 drives, something like that. So they managed to get away with it and give you guys time to make the mod 2 or whatever it was, where they bought another vacuum. So these are the kind of stories that are really fun. And then the other thing is, IBM didn't make media originally. They bought it all from 3M. And 3M had people with under a microscope scraping the defects off the tape with razor blades. And thank God the production of the tapes wasn't cut necessarily, either. And I think the original 5 inch tapes, which we found in Paul Hu's office. He had one in his desk in his office.In preparation for the publicity around the 50 years of tape, and we were able to recover the data off that. In LTO Gen 1, we could put more data on one inch of tape than the entire 727 tape. *When we were trying to generate comparative images of the bit patterns on tapes we wanted to get a sample of the 727 tape but at first could not find one...but one of the tape engineers, Paul Hu actually had one in his office file drawer and we were able to develop an image of the huge bits on it with a fine dispersion of magnetic particles, tape developer, that allowed us to image the written bits and compare them to the 3480 and LTO*.

Teale: This is actually a great segue into the next section.

Bradshaw: Okay.

Gardner: Let me-- let me make a point right here. Right here is a real good section for Ric to talk about the recovery of the data with the Challenger. [ph?]

Bradshaw: No, that wouldn't-- that's something else.

Gardner: No, really. Off the Challenger that crashed.

Bradshaw: Yeah, but that's way, that's--

Teale: That is a good story.

Gardner: I need that--

Philips: I have one more thing I want to--

Bradshaw: Yeah, let him.

Teale: Okay.

Bradshaw: I'm sorry. I didn't mean to--

Philips: That I remember very clearly from Poughkeepsie. Vacuum tubes.

Bradshaw: Yep.

Gaudet: Oh, God yeah. Vacuum tubes. That was, no, back in the day--

Philips: At the University of Illinois, we studied vacuum tubes.

Gaudet: Yeah.

Philips: Four or five courses on vacuum tubes. And I took one side course on solid state technology. In Poughkeepsie, we had all vacuum tubes in the 727 and the 726.

Gardner: I'm actually a few years younger than some of you. My EE course at Brooklyn Polytech was the first class where they taught solid state first. And then vacuum tubes were taught as a transistor with no leakage.

Gaudet: And mine was just the opposite, It was emphasis on vacuum tubes. And right at the end, we got into a little bit of diodes and transistors and all that, you know, solid state stuff. It was wild.

Teale: Vacuum was first then transistors as leaky vacuum tubes.
We really don't want to have a lot of people speaking, because it does make the translations difficult. So I think we've, the first phase which is kind of your personal histories; it is a perfect segue into the section on history of tape--

Bradshaw: I've got to get you this paper. Because there's a lot of quotes in there from people that were alive then, so I'll give it to you.

Gardner: I had one more biographical question for you, Ric, you're a Vietnam veteran?

Bradshaw: Yeah. But that doesn't count. I was in the country 48 hours. I trained as mortar man at Fort Polk, Louisiana; 92 millimeter mortars. Yeah, but. And the guy that took me into, and the other thing is they took me out to night fire.

<laughter>

Bradshaw: And I loved weapons and stuff, but I never owned a gun, you know, and I'm very good with a long bow. That's what I went as a kid, I had an English long bow made of whalebone.

Philips: A shot gun.

Bradshaw: Yeah. Straight up and down, yeah. But then I could still turn it. I doubt if I could even bend it now. This was, yeah, but anyway. So the point was, that thing I could fire it 50, 60 yards and put a shaft clear through a board that thick. I mean, that thing was a lethal weapon -- those long bows. But anyway, when I went to night fire, they gave me this M14, and you're supposed to shoot these little disks -- It's dark. It's November 1971 in Louisiana, a little red light goes on and you're supposed to shoot it. And when the lights go on, you shoot. So I'm sitting there and I'm waiting and waiting and waiting. Everybody else is done, and I've still got the 8 rounds, 16 rounds in the magazine. And the guy comes up and he says, "Bradshaw, what's this?" "Well, there are no more lights." It turns out I shot all the bulbs out.

<laughter>

Bradshaw: In the 50 yards, 100 yards and the 150 yards. And one shot, one bulb. One shot, one bulb. So they said, "Mmm." Next day, they take me out to the course to qualify for a sniper. And they hand me this beautiful rifle and everything else. "You should zero it in." Two hundred yards, and I zeroed it in. It's like popping around. And the guys in the in the trench under the target had the little poles with the little red optical like this to show where you hit. And this guy holds this thing up and he doesn't move it. So the guy's got his binoculars. He said, "Do that again." So I fired another two rounds. And I put them right on top of the other two then. So he said, "Okay, we want you to be a sniper."

<laughter>

Bradshaw: I said, "I don't know. You're drafting me out of college. I was working on my Ph.D. And first of all, another friend of mine who was over in 'Nam, who I went to school with since the seventh grade, John McGowan, he had told me, he's 6'2". I was 6'4", okay. And he said, "Tall guys in Vietnam do not live long."

<laughter>

Bradshaw: So he said, "You need to decide another career path." <laughs> "And don't be a sniper." "And don't get in tanks, 'cause you can't get in one, either," so he said. And then they, I told my mortar man. And he said, "You're not gonna survive this." But anyhow, it turns out as typical if anybody was then in the military, and I think it's probably gotten worse, they are so screwed up. When I was going through basic, and before you even get in, you take all these tests that tell you what your aptitudes are and all. So I took these and I thought, well, you know, what am I gonna do? Apparently, my records popped up to a thing called Science and Engineering Program. And the guy at White Sands Missile Range, Col. Bell, saw my name and put in a requisition to get me to go to White Sands Missile Range as an S&E on the nuclear reactors handling all the isotopes. It took them 16 weeks to pull my butt out of Louisiana. So I went to all that training in Tiger Land in North Fort, Fort Polk, Louisiana-- it was a swamp, okay-- getting you ready for Vietnam. And they caught up with me when I was getting off the plane in Vietnam. So I mean, it's just ridiculous. And so and then they said, "You. Who do you know?" I said, "I don't know," you know. So you go over with beers and ammo in a KC-130. And there was rocket fire. This was in '72, so I mean, we're already getting ready to pull out. And then I was the last draftee out of Phoenix.

Anyway, they run you over. They hand you this thing that says-- And they call up two other guys' names. And they said, "Get out of here." We're sitting there, and it took them another-- Going over, you got orders. You get on this plane, you get on this plane. Going back, it's next available, you know. And then so, anyway, the plane coming back was nothing but aluminum coffins with flags on them. And a bunch of guys with stiff, looking straight ahead. I mean, these guys were combat veterans going home. And when we landed, it's a different reflection of where it is now. We couldn't get fed. People called us names. Threw shit at us. I landed in San Francisco, you know. So it was horrible.

Philips: Hanoi Jane.

Bradshaw: Oh, that-- don't get me started on that bitch. Pardon me.

<laughter>

Bradshaw: Then I took a bus to New Mexico. And then they reassigned me to White Sands Missile Range, but I was attached to McAfee Army Hospital, which is a field hospital. And I had to be retrained as a medic. This is how silly this whole thing is. So they retrained me as a medic. I go, then, I go to Montgomery, Alabama to learn Nuclear Materials handling and safety technology and be qualified for nuclear materials exposure and handling ----in. It was the Atomic Energy Commission, by the way at that time. So then I went to White Sands Missile Range, attached to the field hospital, and had some amazing jobs. 'Cause I was in charge of over a thousand radio isotopes and I had a top secret clearance. Now that's a whole another story. Remember, they do all this, then they realize that I grew up in Saudi Arabia and went to school in Beirut, Lebanon. And they're trying to give me a top, super top secret clearance. 'Cause I'm handling things on the upstage, which wound up becoming Star Wars, by the way. This is 1974, and it worked, by the way. Anyway. So the point was that when I got out, they showed me this stack of records. They had my second grade teacher, all my people. They had to go interview these people, the FBI, to find proof of who I was. So it was really, you know, like, what's this file? Are these people alive? I didn't even know they were still alive. Anyway. And they had my teachers from ASU and-- And, so this was really a phenomenon. That's how I wound up in there. But I used to pick up radioactive materials and pick it up and stuff, and it taught me a lot of things about warheads --- and my first interaction with IBM-ers. It was in the Nuclear Weapons Directorate test facility at White Sands-- In fact, there were these guys, they were testing circuits for warheads that had to fly through a near nuclear explosion. So there's redundancy. They had all these circuits. And in Nuclear Weapons Effect Directorate they had a U235 source that was on a piston, and it would come up and it would go off and send out a flush of neutrons. But obviously, you didn't want it to stick around and blow the building up, so it would go up and down on the ground again, about 80 feet down into barite concrete. And they had these guys looking through a blast center through windows, all looking with oscilloscopes watching these circuits. And these guys were all in suits. I mean, <makes tongue in cheek sound> they all looked like they were pretty much the same. Some were bald. Some weren't.

<laughter>

Bradshaw: And the thing goes off and it goes into going le-le-le-le-ding. And I'm standing way out side it but I’m the guy that has pick it up if anything falls out, and it happened once before where the rings broke off and the uranium was rolling around on the floor, well, I'm the idiot that's going to pick it up, you know.

Gaudet: Oh, geez.

Bradshaw: [Fortunately nothing fell out] Oh, no, I-- dosimeters and stuff. That explains a lot, by the way. I got a lot of radiation doses, so.

<laughter>

Bradshaw: But anyway, these guys start cheering. And they're going, "Yahoo!" And they're smacking themselves and they're this-- And I'm like, "What the heck's this?" So well, I didn't have to go, because it went down and nothing happened, so I was getting ready to leave. And they said, "We're going to go and get a beer. Where can we get a beer around here?" They said, 'cause, you know, at IBM in those days, you didn't drink on the job. But these guys were going to get out of there, go have a beer. They had just successfully had managed to fly a telemetry device circuit through a near nuclear explosion -- the neutron flux would be essentially like flying through a nuclear bomb, okay. So which, remember, that's what the whole idea was. To send up a nuclear warhead, radiate it and now the guidance systems go bye bye. Well, this was in 1974, they had perfected a way. And it was just multiple redundancy with gold films between each one of the chip sets.

Gaudet: Is this this top secret information?

Bradshaw: It's not anymore.

Gaudet: Oh.

<laughter>

Bradshaw: The point was, it was a really phenomenal thing. So then so that's my first introduction to IBM was those people.

Gardner: And like Bill, I have an aversion to chemistry. So I really have to ask the question. How did you decide to become a chemical engineer or a chemist?

Bradshaw: Synthetic chemistry. I actually started-- it's a long story in a sense, 'cause my father when-- he was very poor and he really was interested in photography. And he went to Brown University before he got drafted. And he was working on photography and a couple of other things in his field. But he was taking chemistry. But when I was a little kid, he had these jars of potassium bromide, acetic acid and that, because he made his own developers and own things for the photo film. Well, I was at a very early age, I realized that you could take potassium bromide and add chlorine to it and it would precipitate bromate. And silver nitrate, and you could make these things. And so I started playing with it. And then by I don't know, I was seven, I started making my own photographic plates. And I was taking pictures with a little pin camera. You know, the old kind of boxes?

Philips: A pin hole, yeah.

Bradshaw: And then I discovered that you could make your own lenses. So I made lenses. So but early on, I loved history and I loved making model airplanes. My dad was a bomber pilot, God, I could kill him for the stuff he threw away. But I had his original jacket and all of his books with flying to Mitchell. I made that airplane many times. Broke a few of them 'cause I tried to fly them. You know, but little kids. Pfwt. Oomph. Crash. But and then ships. I made the U.S.S. Constitution model at least five times. Every time I made it and got it all done, I couldn't move it, so I'd have to leave it behind. I did that more than once. When I was eight years-old, my mom and dad bought me for Christmas a Gilbert chemistry set. I had every experiment in that thing done in the two weeks. Okay. Then I started, I cut my mom's geraniums down and extracted them and made perfume. I made furniture polish and I called it Bradshaw Chemical Company.

<laughter>

Bradshaw: And I made her all this stuff. I made her cold cream. She told me, oh, it was really great. And so she threw it all out, because she was afraid it would kill her, you know, if she put it on. But so that was my introduction to my interest in chemistry at a very early age. But I always-- then I got interested in geology. And so I wanted to do extractive metallurgy and stuff. So when I went to New Mexico School of Mines, New Mexico at Tech, I had when I left, I was two credits short of having a degree in geology, two credits short-- 'Cause I got started to say, they told me that you didn't get charged any more for credits over 16 there. But I had to have a 3 point to keep my scholarship. And it was a full ride. I paid $600 dollars for my room and board and tuition. Room and board, out of state. So and I'm in Arabia, for God's sakes. I either go with, you know, someplace like that or it's going to cost me a fortune. And my sister was going to Trinity and my dad was paying $3200 dollars a semester for her, so he couldn't afford to put me through school. I said, that's it. There's nothing to do there but study. I think I never took less than 22 credits and like Bill. You know, where am I gonna go? There's no girls. You're in Socorro, New Mexico, which means "help" in Spanish, okay. For a good reason. There is nothing to do there.

<laughter>

Bradshaw: And I didn't drink until I was 21. And I didn't know how to drive, so I learned to drive there. And we'd get these trucks and drag all the guys down for a beer bust down by the river, and I'd drive them home. And we'd have bodies hanging over the side of this thing. New Mexico Tech, a great school. Anyway, I really loved chemistry. And then when I got in action, I had a job as a research associate at the end of my summer year with a guy who just had left out. He was a Mormon guy, Melvin Hatch, who had over 190 patents with Dow Chemical in ion-exchange resins and synthetic polymer chemistry. And he came to Tech because he wanted to get back closer to Utah. He's one of the Hatches of Utah. And when he got there, I was the ace student in organic chemistry. So he took over the second semester. And we're taking Cram and Hammond, which is nobody but Cal Tech and Tech still taught Cram and Hammond, because it was just a brutal textbook, okay. He said, "Well, you guys have already done the first thing, so I'm not repeating any of that. So now we're going to do the rest of the remaining chapters…and he was serious he really intended to finish the rest of the text--" And every day's lecture would be at another chapter. He said, "We're going to finish this book this semester. We're going to finish this thing." He was a brilliant guy. He worked for Donald Cram, so that's one of the reasons why. He got his Ph.D. for Donald Cram. The net was that the first test, I had gotten As, I mean like 100 percent on every exam that the prior professor to Dr Hatch, Dr. Brower had given us. He gives it back, and he's saying, he's like, "I don't know what's wrong with you guys. You're supposed to be so good at chemistry and stuff, but you guys don't know much"

<laughter>

Bradshaw: And that's his words -- he's a Mormon. He doesn't usually say things like that.

Philips: Scata.

Bradshaw: Yeah.

Bradshaw: So he comes out and he hands me mine. And I looked at it and it was a 64. I had never gotten less than 90-something percent on an exam. And I said, "What the--" But I couldn't finish it. Everything on the exam and to be described from the basics, you couldn't just say use this to make this synthesis or whatever. You had to make everything from inorganic or natural sources but as a reagent before you did it. So you fermented alcohol to make alcohol, to make ketones. But so you learned-- but you had to do it all on the site. Well, I did them all and then realized that half the time was up. So I'm scrambling to go-- Anyway, the point was, the next highest score was 20, okay. And two of my best friends got up, took their tests and left the room. And he said, "Whoa, whoa, whoa. What I'm gonna tell you is let's do this exam over again." But I really didn't know. What did I do wrong, you know. I said, "First of all, there isn't enough time to do this." And this test was a comprehensive test of organic chemistry. The bad news is we all rebelled, and so-- And so he took me aside in his office, and he said, I'd really like you to come work for me. $1.20 an hour, by the way. That was 1967.

And the best thing I ever did. Within six months, we made three patents on thermally reversible ion exchange resins[7]. And by the way, he's the brains. I was just the guy running this. And this guy was really creative. He made-- It was a good lesson working with you guys in Boulder, because he was one of these guys that took cheap things, like we had an automated cycler for these ion exchange columns, using a crock pot that he bought at a yard sale to boil the water. And he had a little kitchen timer. Everything was Rube Goldberg. And it looked like it too, which if you remember when we did the Challenger, it looked just like that in my lab too.

Gaudet: <laughs>

Bradshaw: But the point was that I learned so much from this guy. And we wound up making the first thermally reversible ion exchange resin. Saudi Arabia bought it, too, desalinized salt water. Dow made a fortune on it. The first time I'd ever met patent attorneys -, -- I had my Road Runner then. I'd just bought my first car in '68. I went and picked up my '69 Road Runner. Dr Hatch had to meet the attorney's and management from Dow at the Socorro Airport. he had me drive, because he was really cheap. He had a Rambler. So he wanted me to take him out to meet these guys at Socorro Airport from Dow. The lawyers

[7] *Normal exchange resins pick up either cations or anions (positive or negative) acid or base species and are "regenerated" by washing with strong acid or base and then distilled water to reuse the resin. The simple but brilliant idea that Dr Hatch successfully pursued was to put both species into the same polystyrene porous bead…which when cold had both acid and base exchange sites…heating the resin caused the matrix to expand and the exchange groups would then form internal salts, displacing the ionic species pulled out during the cold extraction phase…thus regenerating the resin for reuse. The initial demonstration resin achieved ten bed volumes of deionized, pure water for ONE bed volume of 90 deg C rinse water. I believe later variants and improvements got way better than that. [Added: R Bradshaw]*

and some executive had flown down. I don't know who, to make us sign these patents. We literally, the plane's sitting there, a prop plane, but we've got this short airport. To sign these applications and they gave me a $50 dollar bonus for what turned out to be a $40 million dollar patent.

<laughter>

Bradshaw: But they didn't have to give me a thing. But I signed all these things saying I have no claim to this and all. But anyway, it got me into grad school. But that was, it's a thermally reversible ion exchange resin. It was a very neat idea. It was a cage-cage macroreticular resin, whatever. But made of styrene where you expand it and because of the expansion, thermally, the bonds that would form to extract ions out of salt water would pop open and out would come a 50-fold increase in-- when as soon it got cool, salt just fell out of this stuff, okay. But what came out was almost pure water on the other end. Now, see, Saudi Arabia had plenty of energy, but they didn't have a lot of drinkable water, The Arabian peninsula is surrounded by water The Persian Gulf and the Red Sea are extremely saline. And the other thing is we were involved in before was ion exchange resin capture for mines, for extracting trace amounts of very expensive nickel, cobalt, cadmium ions that were the waste. It was throwing it out. Well, we developed a resin that was specific for one ion by this whole method of trapping. It was really neat stuff. So that was my first patent. But my name is down as a sign off, not, my name's not on the patent. It's just a contributions by Richard Bradshaw, who has disavowed any claim to this patent.

Gardner: That is chemistry.

Bradshaw: Yep.

Gardner: Which for me, like Bill, was not my favorite subject in college.

Bradshaw: See, I like making things. I like making things. And one thing about synthetic chemistry, you have something in your hand when you're done with it. That's what I like. I still like. I work on cars. I work on machines.

Gardner: Yeah. So for the next hour, perhaps, we'll talk about tape technologies other than the medium itself, unless it really gets into it, and focus more on the history of these things, such as let's start with the transport from vacuum tubes to direct drive, But I'm a disk drive guy, so why don't you tell me about it.

Gaudet: You can get a technologist's point of view from Bill and Ric. That's not what counts in the end. In the end analysis, a lot of the problems, the design, the development of the tape path, the vacuum columns, reel to reel servoing, all that sort of stuff, those were changes that were made from the old 3420 and prior tape drives, tape decks. The whole intent, IBM said, that's not really making us leaders in the tape storage world. We're losing out. Reliability, customers, you know. It's just not hacking it.

Bradshaw: Footprint and energy.

Gaudet: Footprint and energy. On and on and on. There's a lot of factors there that just weren't cutting it. So IBM reached deep in their pocket and said, "Here's a bunch of money. Go build a plant site in Tucson. Now how they selected Tucson, I think the university and, you know, the environment's neat, nice.

Gardner: Or maybe it wasn't where Jesse Aweida was.

Philips: <laughs>

Gaudet: Maybe we were trying to hide from Jesse, but whatever it was, IBM built the plant site that included a development facility, a manufacturing facility, a manufacturing facility for the media, a manufacturing facility for the film heads and a manufacturing facility for the tape drives.

Bradshaw: And a huge tape test floor.

Gaudet: Yeah, and a huge test floor.

Bradshaw: Remember, that our attitude was getting up a lot of tapes and a lot of drives (tape deck prototypes) and throwing everything we had at it to find out how to break it and then fix it.

Gaudet: And the lab itself. The lab in development was also very, very state of the art, able to replicate problems, do analysis. I almost want to say let's talk about the Challenger tapes, but you know, that's an example of the capabilities of the instrumentation we had.

Bradshaw: That was much later, though.

Gaudet: The instrumentation that we had in the tape lab. And so I'm, if Bill, do you want to talk about vacuum columns, or Ric, you want to talk about vacuum columns, I don't think you're going to get anything from this audience. And if I look over here, Joel's the only one old enough to remember how to spell it. <laughs>

Philips: Vacuum columns were very simple.

Gaudet: Okay. Okay, good. <laughs>

Philips: They had typically two transducers staggered down and when the tape passed the transducer, the vacuum went to air, and it knew where the tape was with these vacuum transducers. And so you would load it up until it got air in the first transducer, start running it until it dropped below the second transducer, and it would-- the reel would pull it up. And so you had a rum-rum, rum-rum, rum-rum, rum-rum, rum-rum.

Off Camera: It makes for good movies.

Philips: And the original tape drives were 75 inches per second. And then we went to 112. So that meant if nothing else changed, you would have to go to roughly 50 percent more length than the vacuum columns because of the speeds involved. But because of we had high torque, better motors, better sensors, we could use the same length vacuum column at 112 inches per second as we could at 75. And then we started to get rid of vacuum columns, because they were just energy eaters. We got rid of vacuum tubes. They were energy eaters, because the torques required on the big motors.

Bradshaw: And the other thing is when we downsized the weight of the reel. See, the other thing is, remember, these are big 10 inch reels.

Philips: Yeah.

Bradshaw: The other thing is in the cartridge. And they, to make them stable, the most of the reels that were stable for storage were metal, okay, and not plastic. Now the cheap ones, they were plastic. That was an interesting thing. And IBM admitted with that auto load, where it could have had a little thing and it was sucked through and you pull it off, and it had a little pop up. That was another patent that was really useful then. But it was also changed the way people entered into tape drive selection for data storage and processing. Originally, all of the stuff had a lot to do with marketing, too. That people managed their data centers with boxes of cards and a guy who would roll it down on a little thing and bring it out. So when they did tape, they did the same thing, except now instead of boxes of cards, there were reels with a little loop on them hanging on a rack and they were moving them around. Well, the 3480, I remember that debate very well. Do we need an auto loader or a robotic library? StorageTek decided, and we got rid of our guys that went and did Elias, okay. We didn't want to do a library, because we're going to do an auto loader. And that's all you'll ever need. An auto loader of 10 cartridges I think it was, Joel?

Joel: It was five on the 3480[8] and seven[9] or ten[10] on the 3490.

Bradshaw: And that's with it hanging on the front. The other thing is the original design was one deck about this high [about 32 inches]. Well, it turned out one of the things that I remember very early on from some of the problems we were chasing-- These are anecdotes that are fun, okay. Product test was constantly running these things with the covers off, right. 'Cause the drawers were out people would put their sodas and their coffee on top of these things 'cause they were desk-like And I was constantly doing failure analysis and finding Coca Cola and things like that on it.

Philips: <laughs>

Gardner: You're talking 3480 now?

Bradshaw: 3480. and 10 inch reels, too. The same thing's true. They'd open the vacuum column and somebody would put his drink on there and you'd wind up with coffee all on the inside of this thing. And so we were doing failure analysis. This is what chemists are good for, right. You know, forensics.

<laughter>

Gaudet: This is Coke. This is 7-Up.

Bradshaw: No, but I got cola, because I went to the product testing guy, and I said, "Well, what was it?" He said, "It was Coke." He said, "It wasn't me, then," he said, "Because I don't drink Coke." And I said,

[8] "IBM Adds Five Cartridge Autoloader to the 3480 tape subsystem," Computerworld, June 9, 1986
[9] 3490 Model C22, announced February 18, 1992, source: IBM Archives
[10] 2490 Model Fx1, announced February 11, 1997, source: IBM Archives

"Ah, God." So we literally had to go prove what it was. So I had to get Coke and Pepsi out of the thing to do the IR, verify it and overlay it, and show it to the guy, and he said, "It's Pepsi."

Philips: True science.

<laughter>

Bradshaw: Because nobody wanted to take credit for that. But the point was, and then we finally got off our butts in 1990 when we did the 3490, where we stacked it straight up. And now it solved a whole bunch of problems. Now there are two drives. First of all, it had a better footprint. And people couldn't put things on top of it. So it was really amazing. So and then we did that dang Growel library. 'Cause we weren't going to do it. You guys [i.e., Phillips and StorageTek] had already beat us to it with taking basically, Elias. When you guys had left IBM. We gave them money. FAP'ed [Financial Assistance Packaged] them, okay.

Philips: <laughs>

Bradshaw: A Financial Assistance Package, where they got two years' salary and $25,000-- I had volunteered for that and a lot of other people did, but they wouldn't let me have it.

Gaudet: In the 1980s?

Bradshaw: 1988.

Gaudet: Yeah. We didn't let you go. <laughs>

Bradshaw: No. But and then 3M offered me a job to come, because we sold the tape manufacturing plant and media technology to them. And they wouldn't let me do that either. But anyway, I wound up working for 3M essentially for nothing, because I wound up having to solve their problems for them while I was working at IBM. But the point was, that we had all these opportunities but because of the floundering in '87 and '88 within IBM about the whole upper focus on the technology side of the house, I think we really paid a price. Because we could have made a library. We could have had an automated product. *But the Growel Library was what we could pull together with off the shelf robotics as we didn't t have time design one in response to the STK library. Instead we adopted a manufacturing robot made by Growel in Germany to move cartridges around. It was kludge at best. It was often called "Conan the Librarian." As it was huge robot to carry these small cartridges up and down a rail from slots into drives. It was very cumbersome and loud but it worked and was all we could do on short notice and almost no budget.*

<laughter>

Bradshaw: And some guy, the first one is it's a Growel Library. German, and it was made for warehouses. It was a big thing. It was yellow and it had this big counterweight on the back. And, well, somebody put eyes and a mouth on it so it looked just like Bart Simpson.

<laughter>

Bradshaw: And it was down on the test floor, and you see this. And everybody, they moved it. Remember, they originally had it across from the lobby -- But it made so much noise that we put it down in the basement so it wouldn't. And it would go, "Rrroarr. Rrroarr." And before they fixed the code and they put that little engine stopper on the end, we had one go off the rail and right out the back of the library. This thing was that big. And the other one was when they got the code wrong and they took a cartridge and crammed it right through the bezel and shoved the thing right in. It just smashed the cartridge, the whole guts and everything. "Krrrrrhh." And so we called that Conan, because remember in the movie where he yanks the heart out of the guy? That's what this thing did.

These are all anecdotes out of product testing. And my office was in those days was above that library, and I could hear them. "Brrongg. Brrroarr. Rrroarr." So we had to work on quieter wheels, quieter belts to make it quieter.

Gardner: Now this was not a product?

Bradshaw: We sold what, a hundred of them? [It was called the 3495 and announced in 1993.]

Gaudet: Tape library.

Bradshaw: Our answer to theirs. They were killing us, StorageTek. I'm pointing to him [Philips] 'cause when he went there, he took a lot of things he knew better *and understood not only the technology but the market better than most at a time when IBM senior management wanted to bail out of tape drives…*--

Philips: <laughs>

Bradshaw: I knew of these people. I had met a lot of them. And a lot of them left from Boulder, IBM Boulder and went to work for Jesse Aweida and Dave Weiss, okay, Weiss by the way, was a neat guy.

Gaudet: Yeah. I thought that.

Bradshaw: I thought he was a sharp guy. Dave Weiss. And the StorageTek team, there was some guys who came out of heads that worked for him [Marty Schmalhorst and Lamar Nicks]

Gaudet: John Marshall.

Bradshaw: Yeah. John Marshall. But anyway, the point was there was a lot of technology and we kind of floundered. We had so much technology, so much leadership, and we just floundered. It was a shame.

Gardner: This robot that would shove this stuff around, it's not a 3850, this is some other robot?

Bradshaw: No. The newer one -- That's a whole another discussion. And John will spin in a little bit. But when LTO came out and did their thing, they [the LTO consortium, Seagate, HP and IBM] wanted to do an independent cartridge [with no similarity to either the STK or IBM 3480 format]. And I fought that. And I was, I should have known by then I writing my own death warrant by arguing this. But the point was, why would we get rid of an asset base with all the libraries of STK and IBM data cartridges. We (the LTO consortium) should make the cartridge compatible with the existing automation. IBM finally did it with the

E cart (Jaguar), the enterprise timing based servo product the 3592 tape, J, JB and now JC tapes) announced shortly after LTO,

Before the 3592 was the 3590 -- we only had six months to do it. We used the 3480 deck, put a new head in it and a crappy servo. And were you involved with that discussion then? There was Chapman, I think was the program manager then.

Joel: It was Ed Chapman. I wasn't.

[Editor’s note: The following three paragraphs summarize a complex overlapping dialog on the tape.]
Bradshaw: Yeah, Chapman. But and I remember telling them. But they were convinced we had to do field format. And I kept telling them, "You can't field format in a cartridge. It's just not precise enough for the edges, for the guiding. So you don't do it." But we did it anyway. And we had this compromised servo pattern. And then DLT came out, Quantum put optical servo on the back, so they'd get precision. And that was why they took over, okay. And LTO was technology that was invented by a very bright guy in San Jose on disk drives, okay. Tom Albrecht invented timing-based servo, okay, in the 1990s. It was his first patent. [US 5,689,384, issued November 18, 1997]

The 3570 had a timing-based servo and we wanted to do it in the 3590.

When Vanderslice showed up, he gave-- we had this weekend meeting. And he sat there and said, "What can we do, and I'll give you six, seven months for getting your product out." What are you going to do? You don't start from scratch. So we basically took the 3480 deck and stuck a head on it and things like that and a newer--

Gaudet: I want to make a clarification. The 3580 was the LTO. And the 3570 was the midpoint load, code name Coyote. It was the one I did..

Bradshaw: But it's [3570] a time-based servo. And it was great. By the way, you know that that was the most reliable product we ever shipped?

Gaudet: I know.

Bradshaw: And we never had any field returns at all.

Gaudet: I know, but we didn't have a marketing team that could sell it.

Gardner: And what product was that?

Bradshaw: The 3570. Piggly Wiggly, Circle K,etc., and a lot of retailers used these point of sale systems. They loved the 3570 tape drives and cartridges..they were a perfect solution for that business-- But then things were changing, too. By then, let's face it, things were changing at the point of sale registers. So now with the internet and that kind of stuff with connections -- so we had a niche. But StorageTek took that technology and made the single point cartridge for quick access too.

Philips: Yep.

Bradshaw: So it was interesting how we cross-pollinated ourselves the whole industry -- because of the people that left. It's, but great teams. And but the library, see that's a whole another piece of next-- right now, the thing that is really keeping tape alive is virtualization, which people forget that the first virtualization engine anywhere in the world was MSS, where you did it ass backwards. Tape virtualized disk drives.

Philips: <laughs>

Bradshaw: That's how, see, people don't remember this stuff. I remember when there was a debate about it, because StorageTek wanted to file a thing, 'cause they had a virtual storage management offering (VSM) while we had our VTS (Virtual Tape Subsystem), and they thought they had a copyright on virtualization. So there was a patent war about whether we could use the word "virtualization." Well, I dug up the document. I literally did this. Found out the thing, because I kept all this crap. There was a field announcement for MSS, the 3850. Okay. So there was the big library, okay. With the cylindrical honeycomb. A lot of things I don't know-- By the way, you know it was the first rotary tape drive? Do you know that? Within the MSS? And it had "servo" written on it on for helical scan.

Gardner: Right.

Bradshaw: Sony used those patents to build the helical scan VHS. Anyway, then the point was, that was the first [tape subsystem] that had embedded microcode[11]. It was the first thing that had, it was, and it was way ahead of its time. But it virtualized 3330 drives. It was a basically, a huge thing.

Gaudet: Yeah.

Bradshaw: And then what they did, conceptually, it's a very wide tape, 19.5 meters long and 2.7 inches wide. Most people don't understand how disk drives-- you do, but most people don't. That data on a disk drive is a spiral around. It's not, it's sectors. But when they did the virtualization, they literally took the same format as the disk drive and laid it out on tape. In other words, the thing literally is a direct copy of the random thing on a disk drive and put it out on tape. And then they loaded it back to a disk drive. Well, there were a lot of problems with that, because from a media standpoint, it was Mylar-based. It was iron oxide, 500 Oersted. It used the same tape coating, Stallion, I think that was the name of the thing, the Stallion formulation as used for the reel to reel 3420 tape drives.. And they were going to try and mimic that and carry it into chrome dioxide and I said, "No." What was chrome dioxide? Chrome dioxide was a particle that DuPont and BASF made in the late 70's for VHS tape, BASF had licensed the use of CrO2 from DuPont as it had superior magnetic properties in the VHS formats than the gamma iron oxide pigments which dominated both tape and disk at that time.. It was also a very interesting particle. It was very interesting because of its shape and magnetic properties. The crystalline axis typically was 7 degrees off the magnetic axis so it had very good shape and crystalline anisotropy for a tape (linear

[11] Editor's note: The 3851 Mass Storage Facility includes a number of controllers which are microcode controlled, including a data recording control for one to four pairs of data recording devices (i.e., tape drives). Use of microcode for processor and disk storage control was established well before the development of the 3850 MSS as for example with the IBM System/360 beginning 1964.

recording format). So and The CrO_2 crystals grew in nice acicular particles. And they weren't like iron oxide. Iron oxide is full of holes. The magnetic form of iron oxide, magnetite, is not acicular. If you-- Anyway, I'm getting off track. The actual crystallography--
[Paragraph substantially rewritten by Bradshaw]

Gaudet: That is very good information. And what we should be taking about is the 3480 Pegasus tape.

Bradshaw: Which was the second generation. The first one was not. It was the Stallion with chromium which is what Tucson inherited from Boulder when we came down.

Gaudet: Okay. Stallion, then it was changed to Pegasus using chrome dioxide.

Bradshaw: And by the way, that whole story of that, we were late. I think the original plan was '82 we were supposed to announce and ship, okay. But we were late. And then they were scrambling to get the plant up and running by '80 and '81. We had the first-- I remember. And then in building 61, was the lab for the media development lab that we were in. [Buildings 21 and 22 in Boulder were] before we were in [Tucson Building 61]. Was at the end of the spine, there's this spine connecting all the buildings. And at the very end, because of, believe it or not, the same thing you were talking about, about flammable tanks and airplanes flying over and the thing. It was literally at the end, it's called Building 10.

And I was there when the coater and a lot of the unwind and rewind hardware for the 24" coater line was installed.. before they put the walls up.. The exterior walls of Bldg 010, the media production facility were meant to be blown out if there was an explosion so as to minimize the impact on the personnel. No, I'm not making this up. They're literally designed to blow out in an explosion so people could live through it. The plant was fitted with a Halon fire suppression system as well. The plant also had solvent recovery. This is how the world works. I carpooled with Earl Takanaka, a chemical engineer who Charlie Parker, the engineer in charge of the solvent recovery system for the tape media manufacturing plant in Tucson had hired.. Earl Takanaga carpooled with me. Another guy that was an understudy, basically, for Bill Phillips was Mark Warne. He was out of Montana, a chemical engineer who started the same day as I did in Boulder working for John Parker on drive integration. Once he arrived in Tucson he went right into the integration group working directly with product test. and wound up going to Rochester after in '88 to work on IBM for disk drives. So that's how the small world works. But we carpooled during the bring up of the Rita Rd site in 1979..the official site dedication in February of 1980.

During our daily rides together into work and back home each night we would share the horror stories from all the things going on. We worked in different buildings doing different things. He was actually an engineering interface, Mark Warne, with the test group. And at that time, the Product Test Group was an adversary. It wasn't a partner in development. A big mistake. But during that timeframe, Boulder had the formulation expertise. Also they were inventing a new type of coating, which quite honestly, once we got things figured out, it was really a Godsend. It was the pneumatic extrusion.

Phillips: Yep.

Bradshaw: Instead of using the usual gravure roll printing process. Gravures have a real problem. And the thing is, you tweak your rheology of how you coat these things based on what happens to the nip (the interface between the gravure roll (steel roll with precision groves in it to carry the "ink" to the substrate running over another compressible roll surface so as to squeeze the ink out onto the substrate) NIT and at certain times you can't change the speed. Now, speed -- think about a web coating of making tape. You're printing money. The faster you print this stuff for a given footprint, the cheaper it gets. Our base manufacturer (DuPont made our PET base film) and they knew this problem very well doing melt extrusion on Mylar.) goes-- I don't know if this is confidential, but I don't-- right know I don't think [DuPont] Kyron cares.

Gaudet: I don't think it is. It's too <inaudible>long ago.

Bradshaw: When I originally got involved with this, our base cost to manufacture a single cartridge of 3480 tape was estimated to be around 12 dollars.. And by the way, the first five years-- I think that was the way we capitalized then, was over five years you depreciated the equipment. And so here we were starting in '78 and '80 buying this equipment, and we were supposed to announce in '82 -- well, we didn't ship until '84, right?

Gaudet: We shipped the 3480 in late 1984

Bradshaw: Well, I remember the panic – by 1981 we were paying for installed manufacturing lines but there was no money coming in. The budget problems got us a lot of corporate attention. We were just throwing money at this thing, and it was-- and that's when we got Gus[12] and we got some changes in management, because we were way, way late. Well, there were problems with the head. There were problems with the drive, because you remember, we didn't have a flange on it at first, on the machine reel, and the tape would spiral off and fly off, before we put that little finger on it-- we called it the Froehlich finger.[13] It looked like a comb after cycles of product test--

Gaudet: Fred Froehlich's finger.

Bradshaw: Finally we put a vented flange on it. Because the problem was, originally they had the choo-choo train to do the loader. You remember that? We called it the choo-choo train because it was literally a belt track that carried the *tape through the tape path loading the leader block into the machine reel to complete the threading operation*. Thank god for the team you had over in building 71, that wound up working for you-- I mean, in that building with you-- that did the mechanical redesign. *Paul Bareman was one of the new hires that worked in the group. And he is still at AIBM in the Tucson lab working in the Product Field Engineering Group (PFE).*

Gaudet: Oh, yeah.

Bradshaw: But there was a-- oh, I can't remember this guy's name-- but they said, "Why are we doing this? We don't need this." They made a simple *Pantocam, a cam following arm that was above the machine*

[12] *Gus Vassiliades, Tucson Manufacturing Manager and Site General Manger. He was highly instrumental in keeping development and manufacturing key technical personnel focused and coordinated during the development and release to manufacturing and shipment of the 3480 [R Bradshaw]*
[13] *It was replaced with a special vented machine reel flange and the addition of the decoupler. [R. Bradshaw]*

reel and feed the tape through the tape path from above. It was cheaper, faster and didn't have the problems of the belt. The only thing that worried me was the debris was always above, and it could fall down the tape path. There was also some concern about damaging the head guides which were compliant ceramic buttons on stainless steel arms mounted on top of the head guide bearings which were air bearings.

Phillips: Yeah.

Bradshaw: So that was one of the things-- I think I said that on day one, is, "This is not good. We want to do something." So one of the things we did is worked real hard to make the material with impregnated Teflon so it wouldn't wear and make debris. *This effort was carried out in Fran DeCormier's Materials Lab with Dave Strebbe the polymer materials expert, Bhim Sharma and Bharat Bushan in the tribology group in the Materials lab under John Gniewek eventually although it was initially under Ron Russel who moved down to media Manufacturing around 83 and John came down from Poughkeepsie, NY I believe. He initially came to Tucson on one of the many Corporate technical audits and so impressed site management that they convinced him to move to Tucson to help out.* It galled but it wouldn't dump debris. We solved that problem before we even shipped it. But the other thing is the--

Gaudet: <chuckles> What do you mean you solved it before we shipped?

Bradshaw: No, we solved it. In other words, we did it in a-- before we actually built the prototypes, we put that thing in --and made the-- because they were asking-- Dave Streebe, downstairs, where Fran DeCormier and Bob Madeya (managers of the Materials Lab under John Gniewek who took over the materials lab function, it was in `83 or early '84

Gaudet: Yes, I remember, 1984.

Bradshaw: But the point was, there were some things we solved early in the engineering phase, but we weren't lucky most of the time, as Joel and others will remember. We had many times where we'd think we were close, get it into test, and get kicked out almost immediately. And he was right-- as soon as we hit hot/wet-- cold/dry-- now, admittedly, cold/dry had a problem earlier with static and stuff, zapping.

But chrome is conductive. So the chrome media never had the problem. We never had the problem. Because you used to have to back-coat, and back-coating in those days was totally artsy-craftsy. They changed the type of carbon black they put in the formulation and the thing would go all over, so they had specs on gloss and--

Gardner: So for those who are not tape technologists, what you are talking about is the 3480 tape process.

Bradshaw: Yes, and what it was

Gardner: When you say cold/dry or hot/wet you are talking about ambient temperature and humidity.

Bradshaw: Those are test environments. Yeah, they're-- you're right. When we had it inspected, they called it normal office environment but the thing is, because of shipping and storage, we had this thing that-- and by the way, it wasn't just IBM came up with it. There was a guy called Cuddahy [Dr Edward

Cuddahy at CalTech and JPL], and the National Bureau of Standards had this really thick thing on office products and how to ship it, what it could-- magnetic-- how much stray field-- you could set it on a magnet, how strong it could be. There was all this guidance, and they had things for storage and shipping. Operationally-- I always thought it was funny. *Early on in my introduction to tape in IBM I asked the tape development team in Boulder where I started why the normal office operating environment was chosen as 75/40 plus or minus which was the operating environment we were expected to run at for years.*

Gardner: Seventy-five degrees Fahrenheit, 40 percent relative humidity.

Bradshaw: Yeah, 40 percent level of humidity, and they said plus or minus so much. That was it, because it was an office environment. And the irony is, if you coated tape at that environment, why was it magical that none of these problems showed up when you did it? Because I'm totally-- was approaching this thing from science. If you make something in that environment and it's a rubber band, plastic, and you never move it from that environment, it'll never move. But if you move it, it's going to change. So what does that tell you? Learn what the hell the goddamn properties are and design it that way. This is how stupid I was when I first made that comment to Joel and he just broke up laughing because John Carlson, who was running the pilot line in Boulder and his team were totally knob-turners, Edisonian experimentalists, and I'm not. So I really didn't go over big with them. So anyhow, but Lederle[14] just wanted to fix the problem. So Lederle would sit there and pick my brain and he'd sit there He'd play Three Coin with me, beat me, and then have me buy him coffee.

Gardner: Ric, are you saying that the production environment in Boulder was so much different than the production of Tucson

Bradshaw: Totally. But they had inherited it. The other thing I love-- there's a lot of anecdotes that really make-- show you something about they came from-- IBM, when they got in the tape business, they originally started with 3M. Then they had Sony make their tape for them, because 3M couldn't make stuff-- they weren't in that business, of computer tape. Sony had a better formulation. Then IBM bought the formulation, decided to make it themselves, and this is the interesting thing, because when I first--

Gardner: But 3M until when?

Bradshaw: I think it was 1957, I think that the Sony formulation took-- '57 to '58 that you wind up getting Sony, and then Boulder was built to make MST.

Gaudet: Yeah. Right.

Bradshaw: And that was an IBM formulation.

Gardner: And MST is?

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[14] *George Lederle was the tape development process manager in Boulder working for Bill Philips. He ran the pilot line coater in Bldg 21 in Boulder and his team was charged with the tape production process. [Bradshaw added]*

Bradshaw: Multi-system tape.

Gaudet: Iron oxide.

Bradshaw: VAGH, a vinyl alcohol copolymer with an Estane[15] polyurethane binder, and it used Mylar rather than acetate. The earlier ones were on acetate, which-- he's right. Acetate films are stiff and rigid, but they're not very strong. Now, Mylar is extremely flexible and strong, but it has its own properties. The other problem is nothing dissolved very well in Mylar. You extrude it, okay? So it's not soluble. So adhesion was a problem.

Phillips: And then there was one and a half mil and one mil, two different sizes.

Bradshaw: Yep. And we learned the hard way about slip agents. Slip agents in there could-- they had to put something in it or all these films would-- literally you could never unwind them. They would wind them-- DuPont would make these huge roles of this stuff, wind them up, and then try and peel them off. It's just they would-- they'd rip. And so they said, "Well, let's put the slip agent in." Well, the slip agents were defects. So originally what Boulder did is coat them thick, coat over the defects. Well, that's money. Chrome dioxide was not a cheap pigment. Iron oxide is basically rust. I mean, it's a special type of rust-- I won't talk about the chemistry of that-- but it's full of holes. It's also not a nice clean particle. Chrome *dioxide is a needle shaped (acicular) particle which is similar to sapphire in hardness and crystal structure. It is a uniform composition except for the surface which was "supposedly passivated" with the formation of a layer of chromium hydroxide, but it was in fact a mixed hydroxide layer containing both Cr+3 and Cr+6, so chemically a strong oxidizer is on the surface. Chromium dioxide is a very unstable chromium oxidation state (+4) so very reactive when exposed to water. It wants to form Cr+3 and Cr+6 and not stay in the +4 oxidation state….hence a lot of our degradation and binder interaction problems…which were resolved once we understood the surface chemistry and used these properties in the design of the binder.*

Gardner: What do you think when you say full of holes?

Bradshaw: You can't make a solid crystal of gamma iron oxide and so-- to make the shape. It was not vertical recording like disk drives today, okay? Where you can stand them [particles or domains] up. They're lying in plane. Well, ideally what you want is a log. Say like toothpicks in a box, where they're all aligned perfectly and they all have the same length. But magnets don't do that. If they have an inherent magnetic field and there's a pole north and south, they're going to do this [gestures: pole tips staggered side by side]. They're not going to go like that [pole tips aligned side by side], because they're going to want to repel each other, so they do this. So you'll always get a stagger. Well, that means the resolution of the bit between a zero and a one is clouded by the length of the particle. So this has become a mantra for 30 years: Make the particles smaller. Make them denser.

Gaudet: Lot of media noise, read signal. After you write it, magnetize it and you're reading it back, you get this noise because of the non-homogeneity of the particles that you want all lined up perfectly right on top of each other [along the in-plane tape direction]

[15] Estane is a BF Goodrich trademark for the polyester polyurethane resins.

Bradshaw: By the way, the magnetic field coming out of the head is circular. It's not straight up and down. You have shields and stuff that try and define that. *The shields serve many functions in tape heads since we write several tracks at a time with both writers and reader elements very close to each other. Cross talk in the readers and stray fields from adjacent writers interfere with the head signal homogeneity and unless "shielded" or "shunted" with nickel or other non-ferro magnetic but permeable materials, high track density writing and reading on tape would not be possible*[16].

Gaudet: So what you get when you magnetize it is from that misalignment you get signal back from that, which has nothing to do with the write signal. So it's a signal to noise detractor. One of the signal to noise detractors. There's many more but that's one

Bradshaw: The problem is if you make a thick coating it's hard to read at high densities -- the thing about the MR head too was it was totally breakthrough technology, because the MR head had so much more sensitivity and you could tweak it by the number of coils you put into the reader,

Gaudet: No, no, no. No, no, no. The amplitude of the MR head, the sensor, is magneto- resistive, and it's a changing flux field that changes the resistance--

Bradshaw: I understand that. I'm talking about the writing depth.

The quality of the written bits, the number of switched domains in the bit as well as the resolution or separation of each bit from the ones leading and following it determine the quality of the signal presented to the read head But the write field is not straight up and down at the bit wall and actually curves as it moves away from the write gap. It is only "vertical" to the tape surface (which would be the best bit wall position) right as the field exits the edges of the pole in the write element. As the flux lines move deeper into the coating the field drops in strength and departs from a vertical angle of passage through the particles. This results in a lower exchange with the particles and a poorer orientation with in the field box which is the written bit presented to the read element.

Gaudet: Oh, now you're on the write half of the head. Yes. <chuckles>

Bradshaw: The point is that the media's role in this is a number of things. First of all, you want the thing in contact with the head because as it moves away from the head it becomes less straight up and down. Right at the contact point it's coming out of the gap and it's going like this, [flux is down almost vertical to the tape surface]. So I'm talking write, and read is a little different but it's the same thing in a sense *that I am talking about …that is the construction and quality of the tape recording surface. What you are able to leave behind during the write process is what the reader element will see and its amplitude, resolution and frequency response are all determined by the design of the head and the construction of the medium.* You're looking at a residual magnetic flux, and below it, within the subject, is noise. So ideally, what we did with LTO and everything else, we got thinner, thinner and thinner. We put keeper layers on tape media just like they did for disk drives.

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[16] See e.g., "Hard-disk-drive technology flat heads for linear tape recording," R. G. Biskeborn & J. H. Eaton, IBM JRD, July 2003

The recording layer of the tape is very thin now, with a much thicker under layer to cover the substrate defects and allow the write flux to pass through the recording layer cleanly with less media noise than characteristic of a thicker recording layer with no under layer. This is what disk technology has used for decades now although for HDD the under layer is an anti-ferromagnetic coupling layer to aid in bit resolution for very thin recording layers.

Gaudet: Yes, exactly what made disk drives work.

Bradshaw: So it goes straight down. Straight up and down.

Gaudet: The disk drives would not have worked with the tape coating

Bradshaw: That's correct, it's too thick. And they used to-- but my point was that getting those things-- the top layer, when you take them out and you coat them and they had-- these things would rotate because of turbulence in drying when you make these things. So the tapes weren't flat. *So then we would compress or calendar the tape coating just after the magnetic layer was applied to the substrate in the coating process. A calendar is a device with one or a number of very highly polished rolls which contact the moving web of a tape or film between another roll . The tape calendar we used was initially "compliant" but eventually another hard roll was used. This resulted in a nip or squeeze point between the two moving rollers, which could be running against the tape web direction to produce a very high sheer gap. This resulted in compression and to some extent orientation of the particles in the surface of the tape coating. This was so much trial and error during the process development that it was a nightmare until we realized that there were so many things that affected the condition of the magnetic coating before it reached the calendar that would alter the result or actually cause defects in the final tape.* If you calendared tape one way and then flipped it end for end, it didn't give you the same output, if you designed it the old way, and what they used to do is burnish the tape. Remember MSS? You actually had burnishers to knock all this crap off. It was stupid. You're pre-damaging the tape, breaking the coating surface and generating debris...

Gaudet: You burnish disk.

Bradshaw: Yeah, but you can get away with it. They're married for life. The biggest problem of tape is you got miles of this stuff going over a single tape, interchange. That's the thing. You think about miles.

Gaudet: Well, the poor DASD head is spinning almost all of the time.

Bradshaw: And remember, that's the other thing we used to test, is long-length durability. We had to do 2000 full file passes. Well, now we don't, but LTO, because they were on so many trips up and down, they do a thousand passes to fill it once. So it's a totally different animal, and it never leaves. See, the other thing we used to get away with is you could unload this and clean the head. So the tape-- I'm talking about the old tapes. With chrome, when we started we couldn't make that. I mean, we used to run and it'd stick to the head. *You'd turn the drive off, at the 87F/85% RH Hot/Wet operating environment test corner which is where stick was the worst since water would condense between the head and tape and cause it to adhere to the head and result in either a broken tape in some severe cases or a motion problem which resulted in write or read errors…regardless of what happened it was a data error. —Mark Warne was in the integration group working for John Parker and he was running prototype drives in the Hot/Wet to evaluate a number of "fixes"* *coming from the head, media and drive teams….ultimately a "puffer" was put in between the write and read modules of the head in the FRU to allow a burst of pressurized dry air to blow just before start motion to lift the tape off the head. We also changed the tape formulation to further improve the mechanical properties and water wetting (meniscus) properties of the magnetic layer in contact with the head..and the head group modified the head contour and cross slots. Lynn Wilson was the head of Tape Media Manufacturing and responsible for the bring up of the tape coating line in Bldg 10. He really looked like Kenny Rogers and was a very bright Chemist who went to school at the University of Colorado in Boulder with Dr Dick Stacy who was my manager in Tape Development in Tucson working of Mick Marchese who worked for Bill Phillips.*

Phillips: Yep.

Gaudet: Oh, I remember him.

Bradshaw: The guy that looked like Kenny Rogers.

Gaudet: Yeah, Kenny Rogers, yeah. It was his cousin. I told him that.

Bradshaw: And he always hired gorgeous women. Yeah. He always hired gorgeous girls. We called it "Wilson's Harem," because out of Building 10 there were all these nice-looking girls down there. They were all bright. Mary Levardo [later Chesher], Kim Albright and many others Mark Warren was in his shorts in the product test chamber running "stiction" test at 87ºF/85%RH in '82, trying like hell to get this thing to pass, and he's dragging these tape drives around with the tape, just pulling it around on the rollers in the test floor showing you how bad it was stuck to the head. I remember you went over there with Carmin Rosato (the site general manager then) to look through the glass windows in test and-- Mark told me this[17], I wasn't there-- and he said you guys came up-- and he knew who they were, obviously-- and so he's in his shorts and he's sweating. I mean, it's hot in there, and he's-- and he doesn't know they're there, and he's pulling this tape drive. He's trying to get the tape un-stuck and he's dragging it on the floor, and apparently Bill says, "Well, I don't think we're fixed yet," something like that. And so he heard about it after the fact, and then when I'm riding home with him-- we went in at six in the morning, came home six, seven, eight o'clock at night-- it's not unusual, everybody did that.

Gaudet: Those were the usual hours. What do you mean? That's daily office hours.

Bradshaw: Yeah. Well, it was not helpful if you were trying to keep a young family, but anyway.

Gaudet: I had a young family.

Gardner: Bill, do you recall that incident, tape drives being pulled around by their stuck tape?

Phillips: No. But I can't recall what I had for breakfast. <chuckles>

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[17] *Mark Warne and I car polled along with Earl Takanaka who worked for Charlie Parker down in Bldg 10 (solvent recovery) so during this very crucial time I spent half an hour or more each day, coming and going with a guy doing testing and a guy embedded in the media manufacturing plant. As a result, I knew in great detail what was really going on every day. [added, Ric Bradshaw]*

Bradshaw: It's true. It's really one of those things that happened.

Gaudet: But let me bring up something here though. A figure of merit-- if you look at the 3420 drive, 3420 model 8, -- they had to clean the tape path at least three or four times a day, and it'd take them five minutes or more to clean it at a time, whereas the 3480 tape drive, you had the cleaner cartridge. You'd mount it and use it once per week and it would take one minute. So a heck of an improvement.

Phillips: You had to take it electrically offline to clean it[18].

Bradshaw: Yeah.

Gaudet: Yeah.

Gaudet: Right, the old 3420. But you could do this in situ with everything working. You had to run the tape path and so forth.

Bradshaw: And it wasn't even that long of a piece of tape.

Gaudet: The 3480 was a big productivity gain for the customer. So it was a much cleaner media, is what I'm trying to say.

Bradshaw: Once we fixed it.

Gaudet: It should be obvious because of the cleaning that's required.

Gardner: So the 3420 was a conventional 10.5-inch reel-to-reel tape.

Gaudet: Right.

Bradshaw: Prolay and capstan driven tape with large vacuum columns to allow stop start tape motion, yeah.

Gardner: Iron oxide?

Gaudet: Yeah.

Gardner: And in the customer environment, they were required to clean it?

Gaudet: Several times a day

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[18] *What we were all talking about was the routine maintenance and cleaning required of the older reel to reel drives. Ideally cleaning was once a shift and when it was more we (IBM field support) would hear about it as a problem ... a big impact to performance and operating cost ..and since then tape was used for transactional processing and not just back up or archive it was a big impact and a strong marketing claim if you could improve your up time and maintenance schedule versus the competition. [Added, Ric Bradshaw]*

Bradshaw: With good media.

Gaudet: And the vacuum column and so on. You had to clean that for sure.

Bradshaw: And by the way, not all tapes were the same. Some of them wouldn't even go that long.

[Editor's Note: Beginning of substantial clarifying changes made during edit review]
Gaudet: That's why sometimes cleaning would be three or more times a day. The operator soon understood that what was bogging the system down was a throughput degradation since the system could detect an uncorrectable error, but could not correct it so the system would retry (reread) again to attempt to recover the data. When the operators became aware that cleaning would reduce the number of reties they started cleaning the drives more frequently. Didn't have to do that in the 3480. The reliability of the 3480 tape drive was less than one permanent (uncorrectable) error over one trillion bytes processed and this was consistently validated over a six-month period of time in the test lab. It was a tremendous improvement. And what contributed to that improvement was less noise from the read head (reduced cross talk (shielding) between the parallel write to read elements), the error correction code used (adaptive cross parity) and the write equalization used where for a given pattern you precomp the position of the write transition to reduce the read back inter symbol interference.

Bradshaw: And it can be tweaked on the fly.

Gaudet: Tweaked on the fly, and a big improvement in terms of increasing signal to noise (

Phillips: A lot of that improvement was electronics, error correction coding.

Bradshaw: The 3480 was not NRZ and that adaptive cross parity code and the thin film head construction, the shorter head cables to the pre-amp greatly improved channel electronics, low noise motors, low mass reels and a shorter tape path all contributed to a remarkable improvement in performance and reliability. We had a very significant head wear problem with the chrome media initially, but once we encapsulated the pigment in a tightly bound binder the coating improved mechanically and actually was now used to do the final lap of the head. So running in the drive the head actually got better! Also the packing of the particles and dispersion was so greatly improved with the Sonoita formulation that we got almost TOO MUCH amplitude and the signal resolution went up significantly...while head wear (the initial wear was a "baby butt" profile due to cupping, which went away with Sonoita) became a non-problem...for all but poorly slit, "green media" which showed up in premature failure of the heads consumed in the testers in manufacturing.

Gaudet: But all of the noise contributors were reduced to a large degree and the tape itself was much better in terms of continuity, consistency, in terms of the recording surface, not as many abrupt abnormalities, and the adaptive cross-parity error correction code, which was used to correct "on the fly" the errors, which was not available on the older tape drives. What they'd have to do is just retry it. You'd write it, read it, get an error, you'd have to redo it again. Adaptive cross-parity was the correction code used. This run (error rate verification testing) that I'm telling you about had all of those improvements on the final drives that were run extensively over a long period of time. I think it was up to six months, but I remember building up to it and it kept going and going and going. I think it was several months, Joel-- I don't know if you remember but it was enough data to make the claim that there was less than one detected permanent error in one trillion bytes transferred.

Bradshaw: It's unheard of. And everybody thought we were lying too.

Gaudet: That is 6 orders of magnitude improvement (1E6 to 1E12)

Bradshaw: Well actually, we didn't quit till at least 1988. We ran that same drive and we never had an error. Richard Greco kept running four drives in the extended verification test with Sonoita (single sided tape with the optimum binder which IBM owned the exclusive rights to!) well into the late eighties up to the time when the decision to "downsize" Tucson was made in 1988....so the number Andy used was actually conservative.... but those drives ONLY used IBM media and were never exposed to Pegasus or the competitive media which was giving us headaches in the field...only our tapes ran optimally on the 3480! In fact beside the efforts on Ajo and the longer (thinner tape),Eagle/Aquila, I spent most of my time doing competitive media analysis and field problem forensics and resolution.

[Editor's Note: End of substantial clarifying changes made during edit review]
Gaudet: Did you? You kept doing it?

Bradshaw: Yeah. It ran 10 to the 12th.

Gaudet: I know it did. That's a trillion. <chuckles>

Bradshaw: No, but I meant-- no, but we changed tapes, ran another one. So we just kept going. But, by the way, that was our tape.

Gardner: So what was the raw signal-to-noise ratio, and how did that compare, say, to the 3420?

Bradshaw: I think it was like 30 dB was what we-- our target was.

Gaudet: Yeah.

Bradshaw: But with Pegasus, we had some-- remember, we had to roughen it up-- and then the thing got more-- we got down to 24 db. But we soon went to Sonoita. That's a whole other thing. Single coating Sonoita.

Phillips: We had what we called surface recording, make it look like a thin film.

Gardner: Tell me what surface recording was.

Bradshaw: Write deep, read shallow.

Phillips: We have a big magnet like this. We would only record on the surface

Man 1: The edge of it.

Gardner: So the field of the head didn't penetrate through the media. It was only recorded at the surface.

Phillips: Yes, exactly.

Gaudet: Of what device now?

Bradshaw: Talking about the 3480. But it wrote deep and read shallow, is what it really was. **A**nd the coatings got thinner. We also took them down from [initially about 250 microinches of dried magcoat on 1 mil substrate but went down to about 180 microinches for the magcoat on 0.96 mil substrate for Sonoita]

Gaudet: It was not saturation recording.

Phillips: No.

Gaudet: Saturation recording, like you have on DASD, because of the coating thickness. But it was a shallower write field than for the 3420, but when you read it back the flux at the transition is still there, and so you pass the head over it and the ferrite gap would pull that in, and it would get coupled through the magneto-resistive element, and it would change its resistance and you'd get a signal output.

Bradshaw: There was this thing-- the unsung of that whole piece he's talking about was in the ASIC that IBM developed and designed-- Larry Tretter and people like that, that group-- because the preamp tuning-- I mean, he developed this thing with unbelievable design features making it adjustable and with very high noise rejection and minimal signal loss.

Gaudet: The electronics did have a phenomenal amount of noise immunity.

Bradshaw: Because our other problem was we couldn't make enough media. When we shipped it-- this was one of the things-- I remember when Art Anderson came down and we had all the new hires, with Brent Beardsley, an MSS microcode engineer, and younger, new hires from each of the product areas all sitting at the table in one of the Cafeteria conference rooms. Art Anderson was already there at the head of the table when I got there. He's sitting there-- guy with a white beard, long hair and white coat. He looked like Jesus Christ, except--

Gaudet: Art was a neat guy.

Bradshaw: Physicist. PhD in physics. He's sitting at the table, and he had everybody introduce themselves, and I was the only there from tape media. Well, there were others from tape manufacturing I believe. And then Brent Beardsley, who was a MSS micro-coder when he started in Tucson-- sitting at the end of the table says, "Why are we building this tape plant at the back?" And I started coming out of my chair, and Art said, "No, no, anybody else in the room besides Ric want to answer that question?"

Gaudet: Besides Ric. <chuckles>

Bradshaw: Well, *the whole story is that he invited me to the meeting that morning in my lab; he had walked* into my lab and I told him to get out because he had no business being in my lab with a white shirt on and stuff. He's the division president and he owned us all -- he said, "No, no, this is my lab," and I said, "Uh." He said, "I'm Art Anderson." I said, "Oh. Oops." I knew who he was. I had never met him. I said, "Okay, I better start packing." Now he was wondering around the lab and looking at my note book. My second level manager, Mick came into the lab looking for Art -.

Phillips: Mick Marchese.

Bradshaw: Yeah, Mick Marchese, I thought was going to smoke another pack of cigarettes right then and there because he was so afraid that this guy was going to find out something from me that was not the party line.. because we were still dealing with the tape stick problem and other program delays. Anyway, back to the original story in the meeting with Art in the cafeteria, he asked, "Why are we doing this?" and nobody said anything, "Well, I guess"-- so he said, "Wait a minute, what is the purpose of this site?" And I think this is relevant to this whole thing about 3480. "What's the purpose? Why is IBM investing [hundreds of millions of] dollars?" And he said two things. He said, "Well, to make tape. That's it. We're in the business to sell tape drives. The tape drives then support our software and our operating systems and microcode and business things, and we sell computers. We need storage. We sell big DASD." He said, "We need tape drives to offload some of that stuff to tape." But why did we have to do that tape plant? And nobody said anything, and finally he said, "Okay, Ric, why?" I said, "To sell tape drives." And he goes, "Bingo." He said, "Without the media, it's like having a fast car and trying to drive it on a sandy beach."

Gaudet: That's good.

Bradshaw: And he goes, "You guys better wake up. That plant has to work or we don't have a product." And you could have heard a pin drop. At the time the tape media people were just the poor relatives on site that stunk the place up. Think about it. People used to stop in my lab, say, "Get out of here, it smells." Because the guys in Boulder had decided by trial and error that the dispersant they were going to use was lecithin, soybean lecithin. Yelkin[19], remember? And they had bought the entire development batch. They had one 55-gallon drum in Boulder that they bought about 1970 -- and they were using it on MST, and MSS. Well, chrome dioxide turned this stuff into putrescene [which is a generic name for rotted fats… specifically aldehydes and alcohols from fatty acid ester oxidation].

Phillips: <chuckles>

Bradshaw: Human beings are not supposed to eat rancid meat. Now, some people do in certain cultures, but you can smell that stuff at parts per trillion, okay -- it makes you nauseous. The other one is sweat, the smell of gym shorts and things like that. It's valeraldehyde. This is all chemistry you don't need to know. But Building 10 smelled like valeraldehyde and putrescene. You'd go in there, you'd <sniffs>, "Jeez, what's that smell?"

[19] Yelkin is ADM's trademark for its soybean lecithin surface-active agent

Gaudet: But you'd get used to it once you were in it for a while.

Bradshaw: Yeah, "What smell?"

Gaudet: I remember doing that every day.

Bradshaw: Every morning I'd walk down and there-- it kept me in shape-- I think it was almost half a mile one way and half a mile back, down from 61 down there. After a while, when I left and walked back, I could smell it, and then we figured out how to fix it. But anyway, the point was, we had a reputation of being the guys that stunk up the site, because everything stunk. And fresh tape, when it was first slit, just smelled like this stink.

[Editor's note: The following section substantially rewritten by Bradshaw for clarity]

And then we started back-coating it. Pegasus-- we had a problem with the surface-- it was too soft. And Bill, I was telling him, that when we signed off and solved the stick problem, that was chemistry, but the mechanical properties, that's a whole 'nother story. IBM basically was the first company that I'm aware of since or during to do DMA, Dynamic Mechanical Analysis -- because now I have access to the histories from other people, Memorex, 3M, BASF ,SONY, Fuji or any of the other manufacturers of tape at the time did mechanical analysis on tape. At the time, 1978 – 1981, techniques available to measure the mechanical properties of polymers were pretty limited and actual measurement of tape mechanical properties by the methods available gave pretty useless results. There was no reliable method to measure the coating(s) contributions to the overall tape properties which became increasingly important as the substrates got thinner and the areal densities increased.

There was a lot of effort underway on the mechanical properties of polymers using some novel approaches but most were applied to fibers or relatively thick samples cut from cast sheets. None of the methods were applicable to coatings….except for a few devices in research labs at DuPont and in the UK..the DuPont 980 Dynamic Mechanical Analyzer was made available by DuPont Instruments in late 1979 and Dr Bruce Prime at IBM in San Jose in the Materials Lab working for Dr Ed Barrall had managed to secure what I recall was one of the first DuPont 980's sold outside of DuPont. He was using it to investigate the particulate disk coatings that IBM San Jose was working with…and ewe (terry Martin and I) heard of it at a Polymer ITL (Internal Technical Liaison) meeting we attended in San Jose and got to connect with Bruce and actually see and use the instrument. Terry Martin convinced my manager, Dick Stacy to allow us to buy one and within a few months it was in Tucson and Terry and I went to work trying to see if we could get this new tool to give us a better look at tape mechanical properties of tape

The DuPont 980 used two parallel arms on very low friction pivots fitted with transducers to measure the force on one arm in response to the push-pull of the driven arm which was in resonance with the trailing arm. This produced a direct measurement of the stress and strain as well as the phase (lag of the trailing arm with respect to the driven arm) as a function of temperature.

The instrument was initially designed by DuPont to evaluate relatively thin (less than a few millimeters thickness cast films such as Mylar or other sheets of metal, composites or plastics). A rectangular sample of a solid material is clamped horizontally between two parallel arms which are then enclosed in a heating/cooling chamber and then the samples are heated slowly while a force is exerted on the driven arm so that the passive arm is placed into *resonance with the applied force and oscillation frequency altered by the properties of the sample clamped between them.*

The early DuPont 980 DMA was not sensitive enough to give reproducible results for tape samples or even some of the free films we were initially able to prepare….later an updated model the 982 was available in the late 80's which gave us some very good data.

[End of rewrite]

The 980 was a-- vibrating two arms that would clamp-- two clamps-- and DuPont developed it, and this is how IBM's technical capabilities in the '70s and '60s really were world class, like Bell Labs. They had the very first prototype ever given to anybody else was in the San Jose materials lab, Erma Barlow and a guy named Bruce Prime and we -- we being my tech, Terry Martin, who came from Boulder-- nice, great guy, but he's one of these people that couldn't talk in front of a crowd and every time I'd try to get him-- I don't like taking credit for other people's work. That's another thing that got me in trouble, because you're supposed to let other people take credit for the thing. Anyway, the point is, he wouldn't get in front of a-- I'd constantly put his name on the papers and say, "You give it, you give it." So he wouldn't-- he'd do it. But anyway, this guy was really a hero in a lot of ways because he was unsung guy who'd just keep working and do this stuff, and he was very-- he wasn't just your normal tech, he was my partner in this stuff. Because we were <inaudible>-- remember, we were staffing everything up, buying all new equipment. So we ordered a thermogravimetric analyzer, differential scanning camera-- all the normal thermal stuff-- and a TMA, a thermomechanical analyzer, which in those days is not the same. It's a probe that penetrates. That's not what you need. You need to have a device to measure coatings as function of frequency and temperature. And we started off doing tape because we couldn't make direct measurement on the coatings-- then we learned we could actually coat the inks when they were stable. This is in hindsight. Bill wasn't there by the time I realized this to go tell him that we finally had an epiphany that if you coat something out of a solvent and it cracks, why would you make tape out of it? I mean, think about it. How simple is that? And yet here I am dealing with all these other companies <inaudible>. We poured it on a Teflon plate into-- now, admittedly we got away with murder. Tucson has a very unique atmosphere in the sense it's dry. If you try and dry a solvent like THF [Tetrahydrofuran], which sucks up water, in an air with <inaudible>, water goes in it. Now, most organic materials don't like water. That's called latex paint, things like that. They go-- they just skim up. So we were constantly making free films. As soon as we tried to work in Germany with Emtec[20] and somebody, they couldn't make film. So we went to all the trouble of-- this was really fun-- trying to take it through an airplane, a thing loaded with THF, solvent. I'm not kidding you, how many times I snuck them in-- sounds like, honest to God-- we actually had cans of Burma Shave that we stuck this stuff inside the can to get it through customs, so we could bring these flammable things on an airplane. You didn't hear any of that.

Gaudet: <chuckles> You might want to censor that.

Bradshaw: But the Germans got even better at it. They actually put it in beer cans.

[20] EMTEC spun out of BASF Magnetics in 1996, see: http://www.emtec-international.com/en-eu/company-profile

Gaudet: <chuckles> Until they drink it.

Bradshaw: But were able to duplicate it and show them that if they got a dry box with nitrogen, we could coat the films. Well, we pioneered that, we being Terry Martin and myself. When I first gave the first paper with Bharat Bushan, Bhahrat wanted to put an absolute modulus value on the y-axis for the paper. I didn't have any faith in the calculated values Measurements of multiple samples would give 20 percent variations-- well, you can't do comparisons with 20 percent error, unless you're in the government. But the point was the thermal transitions-- where this thing turns from a solid to a soft thing is absolutely crucial to design of a tape, can be reproducibly measured. Another critical bit of useful information not previously measureable for tape coatings is loss modulus plot. It's a peak that looks like this [drawing a upward curve in the air] from which can be calculated the rate of change in modulus or tangent of the phase angle (delta) . These are mechanical terms for the mechanical response of a material to stress and strain. The tensile modulus is how a material stretches under an applied load or stress and at which temperature it begins to move or stretch under the applied strain. . Polymers should be tough. They should elongate and for an elastomer or rubber, it should return to its initial shape and position when the strain is removed. goes back. What do you want on a tape coating? You want it to go back. The last thing you want it to do is have it stretch and stay there. That's called injection molding, right?

Phillips: But you get more tape that way.

Bradshaw: Yeah. You said that. No, was it you? Who was it that said that? Tom Geist in Boulder said, "Well, you're making more, because you stretch the bits."

Gaudet: Doesn't work that way. <chuckles>

Bradshaw: Then Ron Ferddie did *some very detailed finite element analysis model runs on tapes using some of our DMA data and validated some of our observations at a time when we needed some support for our interpretation of our results which were so new that we were having trouble getting support for using the information to move forward and replace the binder*. Fundamentally, if you want to solve something, it isn't just one person that thinks of these things. It's teams of people that have insight, but they have to talk to each other. The one thing I found early on is that if you don't listen-- and it's not like I never listen to anybody because I'm always talking-- but I had an amazing number of people -- in San Jose, in - the materials lab in Mainz, Germany,- Sindelfingen-- my god. And then the people in all these different locations -- Jarfalla, Sweden, and the guys in Yamato, Japan -- it was an impressive group of people. I finally got to meet them in Hursley -- Hursley was off doing disk drive stuff, and they were great. English -- well, I'm English ancestry, but we're American.

Gaudet: I thought you were Arabic.

Bradshaw: No, I just grew up there. But anyway, the point was that when we got involved with the tape program, the heritage was the old iron oxide. Chrome dioxide was totally unique. DuPont had been making Crolyn tape, a video tape based on chrome. So they thought they understood it, but they did the same thing that everybody else did. They took this particle and stirred it into conventional iron oxide binder. Well, it was falling apart. Remember? They tried to send us their tapes and they died, okay? I mean, they were horrible. They were worse than ours. No, because the way they were milling it and doing the dispersion. Crolyn tape. Remember? It just-- You could literally iron it on and make it stick to the head. Just one pass, and off would come the coating. But we learned early on that the tape was hydrolyzing and some of the solution-- and then you guys[21]-- we went up-- you paid for it, because you sent us up to meet with BF Goodrich and we met with Shollenberger in BF Goodrich in Ohio. Shollenberger was the inventor of the polyester polyurethanes, the guy had all the patents. And so we asked him a dumb question: "How do we improve the hydrolytic stability?" And he looked at me and said, "We have no problems with hydrolytic stability." because "Estanes" were used for example in raincoats, boots and stuff like that."

Gardner: I think we're getting a little too deep at this point.

[Editor's note: Detailed and confusing dialog beginning at 02:17:42 omitted from transcript. In summary, Bradshaw points out that the application at the chromium particle level in tape is more complex than the normal bulk reaction.]

Bradshaw: No, I'm just telling you what the problems were, because in order to have the fix, you had to fundamentally understand the surface of the particle, what it did. Once we understood that, I went off and that's when you gave me the thing, "Go do it. Just don't tell"-- because we were supposed to get this product out. We did it under the table. It was basically a skunk works project. Sonoita.

Gaudet: Wait, Ric, you did a lot of stuff. Okay, you're talking Sonoita.

Bradshaw: Pegasus *was the formulation we were trying to scale up in Tucson from the development formulation & process developed in Boulder using Estane 5701 polyester-polyurethane with DuPont chromium dioxide. Once the "plan of record" POR tapes began to come off the manufacturing line in Bldg 10 in Tucson we started doing design verification tests (DVT) and failed….for tape "stick" which was soon proven to be degradation of the polyester by water (hydrolysis) to produce sticky materials which would contaminate the head and tape path.*-- then there was a task force and we solved the stick problem.

Gaudet: Pegasus had chrome dioxide.

Bradshaw: All of them were. The entire 3480 was predicated on using chrome dioxide. The SNR needed by the thin film head and channel had to have chrome in it. The other problems that we had, conductivity. *We were not going to back-coat the initial tape target since magnetic coatings using the chromium dioxide particle were actually more conductive to heat and static than the conventional carbon black filled coatings used to back coat the existing iron oxide tapes to resolve static as well as handling problems..*

Gaudet: But why the problem?

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[21] *Bill Philips had the tape formulation team leads form Boulder and Tucson meet with Dr C.S. Schollenberger of BF Goodrich who was one of the "fathers" of polyurethane chemistry. [R. Bradshaw]*

Bradshaw: *It was the chemistry of chromium dioxide which increased the hydrolysis of ester groups in the polyester segments of the polyester-polyurethane co-polymer used as a binder to hold the chromium dioxide pigment on the tape surface.. In the process of making a dispersion of the magnetic particles in the binder, the pigment is mixed in a very high shear environment with the binder, a polyester-polyurethane, swollen with a good solvent in which the cleavage of the ester groups into acid and alcohol groups effectively cuts the polymer chains into smaller fragments which are no longer rubber binders but sticky contaminants of the tape head and tape path surfaces. The molecular weight (which reflects the length of the chain of the binder)* would go from 120 thousand down to 20 thousand. So what happened, instead of being this rigid plastic, ooze would come out, and it would stick to the head.

Gardner: Pegasus was the third iteration of 3480 tape?

Bradshaw: Not yet. The initial formulation used Estane 5701, and we tried a bunch of different Estanes trying to fix the problem. We then, almost by accident we solved the hydrolytic degradation problem -- Bob Price had asked for samples from other companies. We got this thing from Morton Chemistry, Morthane, and there were a couple of them-- 300, 310, 320, 330-- and we didn't know anything about what they were. But of course the first thing Andy asked me was, "What are they?" So we started analyzing them. And we made small runs, tested them. Turns out they didn't stick. They didn't hydrolyze. First thing we did was do GPCs, [Gel Permeation Chromatography] did extractions to prove that the molecular weight didn't degrade while we're milling it or coating it, and we put it in 125º F, 30 percent relative humidity to age these things and run them again, and we didn't get a significant decrease in the molecular weight.. It was hydrolytically stable.

[Editor’s note: Substantial addition by Bradshaw:
Then it took me a while to figure out why. Cyclohexanedimethanol was the polyester used to construct the soft segment portion of the polyester polyurethane rather than the butanediol adipate used in the BF Goodrich Estanes. This particular polyester is very resistant to hydrolysis and greatly improved the resistance to chain degradation during mixing with chromium dioxide or aging at hot and humid conditions.

This binder was then used in a second iteration of the IBM chromium dioxide magcoat formulation which was then called Pegasus. It was better but too soft and had a “stiction” during testing at warm wet conditions on the drive. No sticky debris but the tape surface would become smooth during running and the friction at the head and on the bearings would increase such that if the tape stopped running or tried to change directions the tape would lose tension, mis-position or even break the tape.

By then we knew from the DMA measurements that the Pegasus formulation had a softening point, or glass transition temperature,(Tg) at 22-24 deg centigrade. Early on after the initial Morthane 250 was chosen to solve the stick problem, our development team in Tucson recognized that the Tg was too low and needed to be above normal operating temperatures and began looking for ways to move the Tg of the coating higher. We got one sample from Morton Chemical, from Dr Charlie Amirsakis, the developer of the Morthane resins that was very difficult to make a coating off as it did not want to dissolve in our solvents which we were committed to use in production due to the restrictions on the solvent recovery system already in place. But it did not stick and gave us a coating with a TG as measured by our DMA method of over 45 deg C.

We now knew what we needed and signed a joint development agreement with Dr Amirsakis and Morton Chemical to build a custom resin for the 3480. Once Charlie and I were free to talk openly about what we knew we literally made a batch of a few high hard segment resins in his lab near Lake Geneva Wisconsin over a weekend and cast it from the melt reactor onto cookie sheets, froze it with liquid nitrogen, broke it up into chips with a hammer and I carried it back to Tucson in my suitcase. We made several lab scale coatings and made some pretty marginal quality tapes with these small samples but were able to produce good free films of the dispersions to allow good DMA measurements. The higher hard segment resins all gave very good Tg results with 80% CrO2 by weight but they were still very hard to give good solution properties that were needed for the process already in place in the tape manufacturing plant in Bldg 10.

Charlie Amirsakis of Morton and I talked over the phone and it was agreed that I should fly up again and talk about a possible fix… Charlie had made some mixed polyols with cyclohexanedimethanol (CHDM) with adipic and azelic acids. These acids are of different chain lengths so they don't fit well and crystallize ... so they are more soluble.
[End of substantial enhancement]
We staggered the polyester so it wasn't just one polyester chain and easily crystallized -- the things aren't the same length. If you want to have two things that don't crystallize, don't let the blocks line up, okay? So what we did was increase the length of the chain. Now we could raise the amount of the hard segment, the thing, encapsulate chrome reactively with-- and we got a patent on it, by the way -- the last I heard we made 56 million dollars off of royalties. I never saw any of it, and it never came back to Tucson. That's the other thing. It all disappeared in corporate. But anyhow, what I'm trying to say is when we started there were 16 manufacturers of computer tape in the world, and everybody thought our formulation stunk. Memorex came out with one that stuck almost immediately. They had the stick problem worse than we did. 3M had their Blackwatch, which stuck like crazy. BASF actually came out and said, <in German accent> "We are better. We are German. We know everything." And so theirs was almost as bad. But pretty soon, within a few months, Anacomp and Rhône-Poulenc paid IBM to use our formulation. Our problem was we couldn't make enough tape. That plant was designed to make 10 million cartridges. You remember, we had people in the warehouses redoing this stuff and rebuilding because they completely canned all the automation to make these things and move them around. Remember, they paid all that money for the robots to move the stuff around -- the throughput was too low -- we could not make enough boxes. You remember the heads? We'd go through burps every once in a while with the thin film line, and we'd lose head production. And not only that, early on we were eating heads in the field because of the stick problem. Not that stick, but the Pegasus problem with the debris from the back-coat sticking to the front coat.

Gaudet: I don't remember. Well, I wasn't around in the field at that time.

Bradshaw: That's right. But Joel, you remember-- we did. And I tried. I said, "Don't ship it." But boy, that was not popular with Jay Hassan. And you remember that. I think I told you [Andy] that, and you said, "Ric, just keep at it. Keep doing it." And we ran it at midnight. The run was labeled 3346, which is Julian dates. It was run in late November 1983 and finished in early December. We snuck this couple of jumbos through the line and it had no hard bands, dead flat. It had an orientation ratio of four right off the bat with the standard orientation magnets installed at the coater head as used on Pegasus to get an OR of 3.0-3.2. -- because if you design the thing right and the polymer is around the particles and you put it

through sheer, they go "pop" and they line up, and not only that, because of the way I designed this thing to be totally insoluble in the high boiling solvent used in our process (75%THF and 25% MIBK) so that as the wet coating dried the last solvent was increasingly MIBK which forced the hard segments out onto the pigment leaving the soft segments in between he particles resulting in a hard coating around the particles and rubber between them, MIBK [Methyl Isobutyl Ketone] We had a plant that was designed to use only THF and MIBK. It made no sense that when you flash off the THF that the second high boiling solvent then is left behind as the dominant solvent in the drying coating. Everybody else in the world used cyclohexanone because it made it look shiny. Cyclohexanone never dries. You ship a jumbo with half a gallon of cyclohexanone in it, you can smell it-- sweet smell. I said, "Wait a minute, if I have a polymer and it's swollen, what's going to happen over time?" It's going to shrink, which is cupping,
[02:25:00]
which was killing us.
[Editor's note: Additional material inserted by Bradshaw]
The thing would go like this and run against the guides on the tape path which would scrape the edges of the tape when the tape was "cupped" toward the guide surfaces … that is the edges of the tape would run against the head and guide surfaces with the rest of the tape running above the surfaces…we called this positive cupping with negative cupping having the edge of the tape pulled up from the tape bearing surfaces.
[End of additional material]

Gaudet: I remember the cupping problem.

Bradshaw: Yeah, I know. You asked some very good questions too, without patronizing, about, "Tell me why this fixes it." We had engineering data showing it. I said, "Well, if I don't have any swelling-- if the swelling is reversed of-- if I can swell this stuff and it doesn't swell"-- that's how we tweaked the binder. The binder that we-- I went up with Charlie to Lake Geneva, Wisconsin, and we poured this shit out on a cookie sheet, and then hit it with liquid nitrogen, hit it with a hammer, and I flew back on Monday with a sample of four resins-- 371, 370-- they were all different ratios, and what we were trying to do was optimize the wetting of the particle and the length of the polyester so we'd get toughness. What I wanted-- you can't just make this thing brittle, hard as a rock, because it still has to bend. So we wound up making this thing, 371, where we designed-- the polymer length was 22-- there's a whole bunch of things that are in the patent that never tell you exactly what works. We described it, but not everything.

Gardner: Of course.

Bradshaw: The point was, you wanted enough of the hard segment-- it's MDI, methylenebis diphenyl diisocyante to interact with the particles to completely encapsulate the pigment in a hard non-hydrolysable shell with the flexible polyester dominating the space between the dispersed particles and holding the particles together in a cohesive film. Chromium dioxide reacts with the hard segments, specifically the benzylic groups in the MDI to make a ketone, and when it does that, the thing segment bends and it cocks the chains around the chromium dioxide particles it wraps around it to make a very tight barrier. chrome dioxide has a very unique crystal structure, where it actually has a helical spiral to it on the surface of the long needles formed during growth in an aqueous reactor. if you can get those all wrapped around, you wind up coating the particle -- and the SCM bears this out. You look at the particle gold coated, and it looks like a hot dog. You take the gold off, you look through it, and all you can see is the particle and there's this little thin shell of binder. All the binder is the hard segment and all of the rest of it is polyurethane ester. It's soluble in MIBK. The hard segment isn't. So when it starts to dry, the two soft phases do this and tangle and they don't go apart. [Editor's note: Paragraph substantially rewritten by Bradshaw]

Gaudet: And that caused?

Bradshaw: The glass transition goes to 40 degrees C, so we never got above it, and we had a long rubber regime that made it tough, you could bend and do things and it didn't cup, because all the stress was relieved when you dry it. So our tape was dead flat. We had better signal to noise. Thirty-five db -- remember they (the tape manufacturing plant in Bdg 10) once had a "blip" in the process control charts where the OR [Orientation Ratio] dropped down from 3.6 down to almost out of spec at 3.0… They had left the orientating magnets out at the coater head after a routine clean up and restart. They were cleaning them because they had crap all over it from a web break, and it still got 3.0 orientation, because of the effect of the rheology.

Gaudet: Yes, that solved the cupping problem and the head wear.

Bradshaw: The other problem is we used to wear one part of the head because of the compliance of the coated tape and Pegasus made it worse because now we had a back-coat that was not calendared or compressed like the a front coat was, and it was a disaster. And I remember saying, "Don't ship it," but we had to. The thing was so late, everybody was pissed, and Gus came in basically demanding, "Get this product out, period." But anyway, the good news is that that really was a breakthrough, and to me, after I started talking about this in the chemistry world it became clear to me just how much more we in IBM knew about making tape than anyone else in the world! Unfortunately, we wound up getting out of the tape business, making tape, very early on, but for the longest time, for a while, especially when Rick Myers [ph?] wanted to listen to us we were actually fully engaged with the rest of the world in the design of advanced tape formulations….. we had a very small group but we were telling everybody else in the world how to make tape.

Gaudet: Ric, talk about the hard bands.

Bradshaw: Well, hard bands -- when we were back-coating it, it was a nightmare. The other problem is rheology. When you coat these things in an HPC-- it's a pneumatic membrane, -- it's not a gravure, -- gravure rolls have grooves in them. The inks sit in the grooves and there's a little blade that comes and knocks the excess ink or dispersion off the gravure roll which is then pressed against the moving web to squeeze out the ink onto the web surface. So the grooves lay down-- like printing, and what Joel's company does. Now of course nobody does that anymore, do they?

Gaudet: Gravure printing?

Bradshaw: Yeah. But they would always "smooth" out the gravure pattern with a "smoother film" or another roller and you'd smooth it out.

Bradshaw: When you make them really thin though and you put a light like this, you can watch it, you can see the ripples, just like corduroy. In fact, there was a name for that, it was corduroying, that you'd get because of standing waves. Now we take everything for granted; you can go on a computer and model these things in a few hours because of the amount of MIPs you can do, but-- and IBM spent a lot of money modeling these things. But anyway, then it was all trial and error. Well, HPC used a membrane, a pneumatic air membrane which was patented and it didn't have gravure. You could tweak the pressure and they'd have a feedback for the coating thickness as a function of line speed and membrane pressure, but the rheology had to be tweaked for that nip [the area between the membrane and the moving web] pressure. We spent a lot of time optimizing the solvent blends and resin to pigment ratio to give the existing tape coating process the best possible dried coating properties, mechanical, chemical and magnetic performance The fluid ink rheology was the other critical formulation piece. When we went to Sonoita and I got rid of this erratic behavior of drying and characteristics of tape, the rheology was dead stable and we could make this thing dead smooth at a fraction of the cost. We cut the coating thickness down. In 1988 we were down to five dollars in manufacturing cost, including the plastic.

Gardner: Five dollars per what?

Bradshaw: Per cartridge-- media, everything. But when we shipped it, it was 12, and that was partly because we were also trying to pay off the capital, and the delay. But the other thing is when 3M became Imation-- my nephew worked for 3M and ran the coater-- in 2001 they did a final build to supply the world. They said-- by the way, this is interesting. The 3480 finally went end-of-life I think effectively in -- I don't know when StorageTek got rid of it-- but it was in the 2000s[22], and I was still getting calls from people in Asia that had pallets of 3480 cartridges they bought for 10 bucks and they wanted to know which ones they could use, and I told them, "Throw everything out that doesn't have an IBM logo on it." And I meant it, because it was the only thing that was stable for 50, 60 years. Everything else-- Memorex? You were lucky-- you remember the old days of "blocked tape" on 10 inch reels when you'd take the thing off the reel and go like that and it would be stuck together like a solid disk ? You'd take the flange off and if you hit the side of the solid disk of tape it with a downward strike it would just fall apart. Well, Memorex, you may not recall -- we'd call it hockey puck. Memorex 3480 tape, you could take the spool out of the cartridge and throw the spool on the floor and watch it roll around-- nothing would come off. It was just glued. But they weren't the only ones. Graham Magnetics - remember they fought us in the marketing press saying chrome tape was unstable and a customer would lose their data. "You don't want to use chrome dioxide. It's not stable and you want to use geologically stable iron oxide." So Graham went-- but we had already optimized the transfer function for the recording channel around chrome media... We said, "To extend the media, we have to stay with chrome because of the transfer function. We may be able to adapt iron oxide eventually for the 3480 if needed but right now, it won't work. Which wasn't really true Well, we never did change it. But the argument was you had to stay with chrome, so that we convinced the industry-- and the standard-- good old Paul Sager, who went to the standards industry at IEEE and we wound up getting that standard in. So pretty much within, what, five years, everybody made chrome.

[22] IBM withdrew 3480 A22 and B22 from maintenance effective December 3, 2012
http://www-01.ibm.com/common/ssi/rep_ca/6/897/ENUS911-106/ENUS911-106.PDF

Gaudet: But net, net, net, -- what I call reformulation, but it was actually the process, the formulation and chemistry that all changed.

Bradshaw: No, the process was fixed.

Gaudet: Didn't you change some feeds and speeds?

Bradshaw: They just went faster and faster. In fact, I love it. When 3M bought the plant, they said, "This line"-- because all they made in Building 10 was one product. They had one coater. And they could never go faster than 300 feet per minute. Within two months, we went to 600.

Gaudet: The chemistry, the formulation, the processing finally evolved where you had the glass transition temperature at the point where you wanted it. The stability and uniformity of the process from the formulation resolved the isolated areas of cupping, hard-banding, adhesion and head wear. That's what I was asking about.

Bradshaw: Head wear dropped like a rock. Why? Duh! We made a flat tape that didn't change from the inside of the hub to the outside. See, those or the things-- remember, you wrapped this thing up, you compress it, so the inside gets smoother and the outside gets rougher, unless you back-coat it. If you back-coat it, you emboss crap on the front coat.

Gaudet: Right. And that's no good. <chuckles>

Bradshaw: The other thing is in this video I showed you, that we showed to customers-- because a couple times-- Bank of America was a classic example. After the 3480 introduction and the release of Sonoita I found myself spending a lot of time in front of customers explaining IBM tape. That's a whole 'nother anecdote that's funny, the how I wound up getting involved with customer briefings, which I don't believe anybody did that at the time. I remember one I went to with other people that were retailing media that Kitsey talked to in Boulder. He was telling them about the MST formulation, how interesting it was, and difficult. That was my only previous involvement with customer or sales rep briefings

So I always brought my lunch to work because I never got to go to the cafeteria. It was in the early morning, so it was dark. We had two cats and I would scoop the cat box and put it in a bag and go out the door early in the morning. I'm driving and I have Mark Warren and Earl Takanaga in my car pool in my orange truck that I bought in Boulder, my Dodge. I made my lunch, my sandwich, in the dark, and I grabbed these bags and I'm driving-- I go in the garbage and I throw the cat litter out, get in my truck, except I'm driving and Mark gets in and says, "Gee, something smells like crap!". So then we get Earl. Now, he has to get out because there's only two seats and you have to tip it forward—my Dodge Ramcharger has two doors. Earl gets in and sits down and he grabs this bag in the back and he goes, "Jeez, what the hell is this?" At which time I now knew where my lunch was since the cat litter box deposits were now in my back seat.

And I said, "Oh, well, I guess I'm going to have to eat with you guys in the cafeteria-- because I threw my lunch out and grabbed the cat litter and drove to work with the cat litter. This was the days when we had to go down Pantano and Haughton to get to the Rita Ranch entrance to IBM. there was no bridge and you had to go all the way around to the freeway if you hit rain--

Gaudet: Yeah, through the wash.

Bradshaw: --you had to go all the way around, so then we did that, so it was a longer drive than normal, so this thing really stunk. So I remember this because we got to where the thing was in the water. Earl hands Mark the bag, they roll down the window and toss it out the door, which in Arizona you just don't throw litter on Colorado-- you get shot throwing litter in Colorado. So I go to the cafeteria and I'm in my coat and I'm sitting there--

Gaudet: Your lab coat.

Bradshaw: My blue lab-- with chrome black-- anybody that worked in media in those days had black robes, okay? Shoes were black, everything. So I'm sitting there trying to eat and get back to the lab..-- and I can't even remember what I was eating-- but this guy comes up-- who was it? Oh, Mill Cochran You remember Mill?

Gaudet: Yes.

Bradshaw: Mill was the guy that involved with the marketing team talking about tape management, stuff like that. Very interesting man. Anyway, Mill Cochran comes up and he says, "Rick, what are you doing here?" I said, "Well, you'll never believe this. I threw my lunch out and I hauled the cat litter to work, so I'm having to eat here"-- he started laughing at that. And so he disappears and the next thing I know I hear this raucous laughter at these tables behind me, and this guy walks up-- Johnson, from marketing-- he said, "I want you to come talk to these guys about what's different about our tape." Before he even got the rest of the question, "What do you mean tell them? It's patented. We own it. Nobody makes tape that works on this drive but us." "We can't say that." "Well, tell them. That's why they should buy IBM media." So I go to this meeting. I had no time, to prepare or dry run this first interaction with customers…-- no briefing. This was the old days of foils. You remember those things? [Andy's secretary] could do all the color stuff.

Gaudet: I did my own, every once in a while.

Bradshaw: Okay. Well. All I know is mine were typed and looked like hell because they were all typed and hand-drawn. But I never did the hand-drawing because my writing is horrible.

The point was that I went and gave this briefing and told that, "This is why IBM media is unique," and so after that they decided that it really worked. They wanted me to talk to customers, which I thought was risky at that time given my penchant for saying what I knew to be true. So they made this videotape that I gave you those two reels of that goes through the excruciating detail. Well, a couple of these guys weren't buying it. They thought it was all propaganda. It was Bank of America, -- anyway, he showed up and he had this folder, because I was showing him slit edges. The other thing I was trying to talk about-- what Andy was talking about, some of the problems-- if you make this coating where the binders are encapsulated and they want a string, when you go to slit the tape, you're not cutting a cookie, you're essentially ripping like down a sheet and you get the warp thread and you go right down and just strip like that, it's called-- especially if you have a below-the-glass transition, because now you're cutting a hardened material and it cracks rather than tearing. I had SCMs that were done by the Lee Randall in the materials lab downstairs of our edge and every one of the competitive tapes. And you took a look and you'd say, "Why"-- because the ones like the 3M and the others, they cookie-crumbed. They looked just like a piece of gingerbread, because it's crushing, it's not tearing. Then there were the ones that were really bad and you'd see those little strings, like taffy, because they're that soft. And I said, "Would you want to run that on a tape drive? And if you don't believe me, here's what the heads look like when I run this stuff," and I had pictures of them -- so after they left that meeting, some of them were really convinced but others thought I was giving them a pile of BS. well this guy showed up about two months later and I recognized him, and he has these pictures-- he had Carnegie Mellon take pictures of tape, and he didn't tell me which ones-- he said, "Tell me what these are." "Okay, well obviously your contrast is a little different, the magnification, so I'm comparing-- but that looks like 3M, that looks like Rhône-Poulenc, that's Anacomp, because that looks like ours but the edges aren't good. This is ours." And I said, "And this one I believe is Graham." And the guy flips them over and he says, "That's it, I'm done." He calls his guy in his procurement office on the phone in the briefing center (a hard line not a cell phone), "You ever buy anything else again I'll fire you." [Not making this up…I was with the IBM northeastern sales rep when this happened, Larry Apperson, and he told me about the conversation and the huge order that he closed that day!]

<laughter>

Bradshaw: No, because the thing is, this guy had told him-- they saved 50 thousand dollars by buying these tapes from 3M and he got them into his library, and the whole library is now contaminated.

Gaudet: Let me close out with this. 3480 wouldn't have been a good success overall, long-term, unless it was for Ric's personal expertise and contributions.

Bradshaw: No, that's not fair.

Gaudet: That is true.

Bradshaw: No, without-- I had the advantage of having access to Almaden's materials lab and things. Thor Smith, Terry Martin--

Gaudet: Cut all that out and just use what I said. <chuckles>

Bradshaw: No, I'm not being humble, I'm just saying that's a fact. It was a team, and without Joe Vranka -- think about it. How many iterations did we turn around every week?

Gaudet: I remember.

Bradshaw: We used to turn eight or nine tape iterations.

END OF PART ONE

[00:00:00]
Gardner: During this morning's conversation we- heard a number of acronyms and names that are unfamiliar to me and probably unfamiliar to other people, so I'd like to take a few seconds to clarify. As I understand it the medium for the 3480 was developed under a series of code names and starting perhaps with Mustang. Would somebody like to elaborate on that series?

Bradshaw: When I joined IBM, there was a formulation that was based on iron oxide -- we call it MSS, mass storage system.

Gardner: That's another one of the names I wanted explained. MSS.

Bradshaw: Mass storage system and it was virtualization of disk drives on tape, two 50-megabyte cartridges in a round cassette. The program started from that in Boulder. Then they started using that formulation and the decision was made to move to chrome dioxide and a thin film head. Okay? So, the head technology is being developed in San Jose, the media was being developed in Boulder, and the drive, I think, was being built and designed two places, right?

Gaudet: It was being done in two places. But I don't recall an MR head development effort in San Jose.

Bradshaw: The Boleyn head, Charlie Swall and Lee Weaver told me-- maybe that's the guy you need to talk to.

Gaudet: I remember Charlie Swall.

Bradshaw: Swall. Manufacturing. He had Weaver working on-- what the heck is the name of that head. They did the Boleyn head, which is the first MR head-- the point of sale register. This is how things evolved, how you take technology and put it together. But Weaver was brought to build the head line in Tuscan and that's where I met him and first met Charlie Swall. My point was that some of these things kind of morphed as the move to Tucson and certain groups didn't move, some did, and there's some residual technology being done in San Jose. Some was being built in Tuscan and then Lamar Nicks and others were coming to Tucson, bringing refinements to it. The masks for the thin films were all built in San Jose--

Gaudet: But, so net this out: We're talking about a point-of-sale wand.

Bradshaw: It's the first implementation of MR head technology.

Gardner: Okay, let me inject that Chris Bajorek is a good friend of mine and my understanding from Chris is he did the wand for IBM.

Gaudet: He did the wand, but he did nothing on tape heads. He was focused on DASD, which was very sensitive to track widths, the narrower track widths that they had to use, Barkhausen noise, other aspects that they couldn't control, which were not factors in the MR tape head. The MR tape head requirements suited a tape drive.

Gardner: My understanding from Chris, and we all have different recollections is he physically came to Tucson and worked on the MR head here and then went to San Jose and worked on the MR head in San Jose.

Gaudet: Did he?

Bradshaw: That's correct. Yes.

Bradshaw: That's correct. It is true. I met him.

Gardner: Now this is my understanding from Chris and he worked with Shelledy on the MR head in Boulder and here and then he went to San Jose and did MR head again.[23]

Gaudet: Here's your patents on the MR head. It's got a lot of names.

Gardner: Sure.

Gaudet: And here is Chris Bajorek's paper -- it's the first four pages. I didn't copy the whole thing. Where he states, "Challenges of MR heads for HDDs," he said, "The ferrous shield at MR heads were first commercialized in IBM in '84 for storing and reading data in the IBM 3480 magnetic storage system. There are two key requirements-- for HDDs, however, there are two key requirements for the read head element of the MR head." GMR, he calls it. "Grand--" okay, let me finish. It's very important. "For HDDs you've got a biasing sensitivity; you gotta bias the device very carefully-- much more carefully than you do because of its dimensions than on tape-- to operate in a quasi-linear response mode. And, secondly, operating the device in a single domain mode-- if you don't, you wind up with Barkhausen noise. The narrower the track widths that you have to have, the higher the Barkhausen noise. So, all of that is what Chris Bajorek focused on. The actual manufacturing design and release of the head, MR read head and coil-- plated coil write head, is in that-- those patents right there. That's not just one patent. There's other references.

Gardner: We're not necessarily disagreeing.

Gaudet: And it was done by people like Frank Shelledy, Neil Robinson--

Gardner: I don't want to get into a debate.

Gaudet: All I'm saying is I don't understand Chris Bajorek's role-- I worked with Chris in other areas on DASD, but I don't ever remember him talking in terms of MR heads on tape products in Tucson or Boulder. That's my recollection.

Gardner: Okay.

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[23] IBM's Dr. Chris Bajorek first at White Plains Research and then at San Jose Research made multiple visits to both Boulder and Tucson to work with Shelledy and Swall among others on tape heads. [Source: Bajorek]

Bradshaw: Lamar Nicks is still around. You can get him to clarify some of that. The point is he was involved with the manufacturing line. Chris came down with it and was involved with manufacturing -- Charlie Swall[24] owned it, I think.

Gaudet: Yeah, Charlie Swall -- the guy that finally had a heart attack.

Bradshaw: The disconnect here is the overlap between head development and manufacturing. The manufacturing line, Chris had pretty much a piece of that -- Weaver's another guy you can use for that information. He worked him.

Gaudet: Lee Weaver.

Bradshaw: Yes.

Gaudet: Lee Weaver came out of research?

Bradshaw: No, no. Always in development. He worked for Charlie. But that's a whole other story.

Gaudet: Lee Weaver came through manufacturing.

Bradshaw: That's right. That's correct.

Gardner: We did get as far as MSS.

<laughter>

Gardner: There was MST mentioned.

Bradshaw: That's "multi-system tape", which when IBM decided to make a tape-- by then they had, like, five models of the reel-to-reels that were supporting the Mod-8, the 10, the different tracks. The old upright drives and they also made a smaller one, that was to be manufactured in Tucson- it still used ten inch reels but they were no longer in vertical columns but laid almost horizontally in a more compact drive still capstan drive.

Gardner: 3410?

Bradshaw: It was [the 3410].

Bradshaw: And they were all very interesting drives. They had very interesting features, 'cause they were trying to shrink the tape path and stuff. Tom Kitsey owns the patent for that out of Boulder. It was called multi-system tape. That was the one tape that would work for all of the iron oxide reel-to-reels -- not quite all the way back-- it didn't work on the old ones, of track widths and speeds. And they also had some design things were they did the autoloader, where they had a little leader that would suck out, vacuum

[24] See: http://www.nytimes.com/1989/01/24/obituaries/charles-swall-executive-46.html

and re-thread the drives. ‘Cause in the old days it was all manual. But the later ones that were done in the 70s-- you literally laid the thing in, closed the lid on it, button it, threaded it, and did it all.

Gaudet: MST-- you wanted a definition of it. Do you have that answer?

Bradshaw: Multi-system tape.

Gaudet: And you understand it’s application design--

Gardner: I understand half-inch, reel-to-reel iron oxide and-- but the MSS was the 3850, iron oxide in a round cartridge.

Gardner: So, at some point the team decides to go to a square cartridge.

Bradshaw: Okay, that’s where they learned a lot of lessons. But problem with the original [round MSS cartridge.][25] You had to un-shuck it to read the thing. It had a number on the side. It could-- so, the real problem was mis-loads. Remember that, Joel? <points off camera> ‘Cause these things-- it was an automatic library, and the whole thing was made to look like DASD

Gardner: So, these things were problems in the 3850?

Bradshaw: Architecturally. There was an architecture of--

Gardner: With a round cartridge?

Bradshaw: Yes.

Gardner: So the next generation tape drive--

Bradshaw: And, by the way, there is an older cartridge tape-- there’s-- remember?

Joel: <off camera> 7840.

Bradshaw: Bingo! See--

Gaudet: Wow, Joel! I didn’t know you want back that far.

Bradshaw: No, there are a lot of attempts at different cartridges’ design. The thing that was really unique about the 3480 was one-- first of all, it was the leader block, which-- and that was, again, another thing.

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[25] *In this rather unique cartridge the tape was about three inches wide and about sixty feet long and was in a bullet shaped shell. The tape spool had a metal base which could be grabbed by a magnetic picker arm and loaded into the library of honey comb racks or placed into the load mechanism to pull the spool out of the shell to thread the tape into the drive. So there was no way to read the cartridges to verify the tape ID until it was removed from the shell and the header read off the tape in the drive…they referred to this as “un-shucking” the cartridge. [Bradshaw addition]*

There was a leader block where the tape could not get loose on a reel for-- so that was one of the problems.

Phillips: Yeah.

Bradshaw: ‘Cause we were trying to get quick start without a Prolay device -- you could feed it through, take it to the back, and get a header and lock it and now you could time it. But this had to get up, load and get going. So, we did a leader block.

[Editor’s note: Beginning of section of clarified overlapping dialog]
Gardner: I’m still trying to get some of the terminology. So, then we somehow get to the horses’ series that has been brought out. And the first one was--?

Gaudet: Stallion.

Bradshaw: Then Mustang.

Gaudet: And then with Wings, you get Pegasus.

Gardner: That’s the three -- these were all square cartridges.

Bradshaw: That’s correct. This. <hold up gray object> This thing is called the leader block.

Gardner: And they were all chromium dioxide?

Bradshaw: All of them.

[Editor’s note: End of section of clarified overlapping dialog]
Gardner: Okay.

Bradshaw: The very early Mustang was iron oxide.

Gaudet: We shipped a little Pegasus, but the major volume ship was Sonoita.

Gardner: Oh, and, so, for the last version-- and the primary changes were?-

Gaudet: Rick’s reformulation saved our bacon.

Gardner: So, the primary change was fundamentally to the media formulation. The substrate remained the same.

Bradshaw: Yep. No, actually, it got thinner.

Gardner: It got thinner.

Gaudet: It did get thinner.

Gardner: The backing was changed.

Bradshaw: We got rid of it. The bad news is that the original backing was the front coat. That was the dumbest thing-- it was expediency. Again, we coated with chrome.

Gardner: Okay--

Gaudet: That's not what he asked <pats Ric on the back>

<laughter>

Gardner: All right. So, I'm still trying to summarize -- then the primary improvements from Stallion through to Sonoita--

Bradshaw: Major changes. There's a bunch of things.

[Editor's note: Beginning of section of clarified overlapping dialog]
Gaudet: Sonoita is about thirty miles south of T Tucson.

Bradshaw: Yep. That was the code name. You'd say-- wait a minute. We just broke from the horses. That's another whole story.

Gardner: Okay

Bradshaw: Sonoita has horses! It's a huge horse farm. There's grasslands down there that you wouldn't believe that live in Arizona, I mean, the amount of rain they get. And one of the people that was in charge of trying to figure this out had horses down in Sonoita. And they just said, "Let's break it-- let's call it 'Sonoita'." That's how it came out.

Gardner: Did the drive itself have a code name?

Bradshaw: Saguaro! That's right. Then it was SAG1 and SAG2. SAG1 was the low speed, cheap engine. [It was announced but very few were bought and all were upgraded within a few years] we converted everyone onto SAG2. SAG2 was the high speed 3480[26].

Gaudet: The cactus.

Phillips: Don't sit on one.

Bradshaw: It's that big cactus. In fact, for the longest time our badges had a saguaro on them.

Gaudet: Yeah, remember that.

[26] It was announced but very few were bought and all were upgraded within a few years to the full 3480 model, SAG2

Gardner: Oh, okay. We have them in California, too, I think, but not as many, I think.

Gaudet: They're only in the Sonoran Desert.
[Editor's note: Only in found in Arizona and northern Mexico]

Gardner: Was there a separate code name for the controller? I think it became the 3803?

Gaudet: Al, do you remember the code name for the controller? 3480..

Rizzi: <off camera> Uh.. god.

Gaudet: There had to be!

[Editor's note: Beginning of section of clarified overlapping dialog]
Gardner: But we had an interesting discussion of the technical problems overcome as you guys went from Stallion to Sonoita.

Gaudet: Now, do you remember what they were?

Gardner: Would somebody like to summarize just what the problems were?

Bradshaw: Chrome dioxide is an acidic particle. The acid will cleave the binders systems and instead of being a rubbery and non-adhesive, it would turn into an adhesive. *This degradation of the binder thus produced contaminants that would cause material to stick to the tape over data as well as along the tape path and on the head causing errors both temporary and permanent errors. This was the stick problem. Then after winding under tension and shipping at elevated temperatures (above the Tg of the binder) the coating would become smoother and the friction across the drive and head would increase and in too many tests cause tape motion to go out of spec and cause read as well as write errors on the tape and sometimes data integrity problems as you could over write previously written data and destroy blocks and headers.*

Gardner: For those who are not tape technologists, tape usually consists of a substrate on which is coated a thin layer (the recording layer) with a binder and a pigment, a lubricant and possibly an additive for wear.

Bradshaw: You had to have a lubricant.

Gaudet: But that caused stiction.

Bradshaw: Chrome didn't need it. *See, iron oxide had to have aluminum oxide or silica particles added to the recording layer formulation to try to control debris collection on the head as well as head wear…although the actual mechanism of head wear in the early heads and the new thin film heads was still not completely understood and a lot that was believed to be true turned out to be dead wrong!)*-- by the way, it's head wear. When you put the-- and then there are defects. These things-- I'm a taker-out-- my whole approach to this thing was, "I want the maximum pigment and the minimum of everything else."
[Editor's note: End of section of clarified overlapping dialog]

Gardner: I think Bill would agree with you on that.

Gaudet: Yeah.

Bradshaw: That's why you put up with me for so many years.

Gaudet: What Tom is trying to understand is what was Mustang-- Stallion--

Bradshaw: Stallion was iron oxide--

Gaudet: Just "what was it"! Not, why, where--

Bradshaw: There was a formulation used to make a rotary head interface tape. Okay?

Gardner: Now that, for those who would not IBM experts, what Rick is holding up is the cartridge that was used in the 3850, also known as the MSS or mass storage system.

Gaudet: Right.

Bradshaw: And the actual data cartridges were actually a brown clear plastic. These were alignment cartridges.

Gardner: Oh.

Bradshaw: Different colors.

Gardner: It had a part number, too. A model number.

Bradshaw: Yes, they all did.

Gardner: But I don't remember what it was. Anybody help me?

Bradshaw: The cartridges, you mean?

Gardner: The cartridge itself -- you could buy them.

Gaudet: I don't think we sold those, did we?

Gardner: Sure, you did, -- you buy the mass storage system and then you load cartridges into them.

Bradshaw: What they would do-- the PFE, the guys who installed it, they would put the red, the blue and-- in the corners, because they had to let this robot calibrate to figure out where the heck you were. And you had to have it human-readable, so that's why they're colored. But the actual drive, itself, worked-- it had a magnet on the base. It would pull this thing out, hold it, and a little thing would come out and shuck it. It would push these little pins on the very top in, it would collapse [ph?], and out comes the cartridge. *The media itself is a three-inch span, a big, long (60 feet I believe strip of tape coated with iron oxide on the inside (recording layer) and a carbon black filled, conductive coating or back coat on the outside of the tape as it was* *wound onto the spool All the tape was made in Boulder by IBM and it had to be servo written at the factory. Nobody ever made the tape besides IBM as it was not a widely sold product . I believe less than 100 were actually built and shipped. It had a leader/cover on the outside of the spool which was picked up by a "hook" in the drive to pull the tape through a convoluted tape path across a rotary head at an azimuthal angle. It ran very fast and each cartridge replicated the sector pattern of a disk drive in a linear representation of the initial circular data layout. Remember the 3850 MSS was attempting make tape data look like disk stored data to the host. The data was still laid out as it was on the disk ... in a random sector format. Each tape had a mirror image of the disk it had copied and all it did was restore that image to a new disk when needed. It used an array of slots looking like a honey comb of octagonal slots in a wall across which the robot arm would move to insert or remove a cartridge. There was no way to read the cartridge or know where a cartridge slot was until the robot was calibrated using mechanical reference points and counting cog rotations during movement of the arm so a technician had to carefully align and calibrate the library ... and anytime a cartridge "fell" out of its slot or got misplaced it had to recalibrated manually.. had to calibrate and if it ever dropped one*, it was a nightmare, because you had to shut the library down and some guy had to go and pick them all up and put them back and find out where they went.

Gardner: And you didn't ever want to get into it when the two robots were moving.

Gaudet: We're talking about the genesis of the 3480 now, right?

Bradshaw: No, -- the problems of that box are what led to the re-design of the cartridge. That's what I'm getting at. They wanted it so you could hold it up, look at it in the back-- so, that's why it's square and had a label on the back.

Gaudet: Okay, that's the reason, but we went through various coating formulations.

Bradshaw: Tell me about it.

Gaudet: Where we punched in the stuff.

Bradshaw: That's right -- like, four or five iterations a week!

Gaudet: Now, there were-- there was a Stallion, there was a Mustang, and there was a Pegasus. And then there was the Sonoita.

Bradshaw: Pegasus was back-coded. Before we got--

Gardner: Right, we've established that.

Gaudet: It with Stallion! Stallion had problems. What were they?

Gardner: Just in summary what were the problems? Like stiction, cupping, edge wear.

Gaudet: Stiction, edge damage, cupping. Whatever.

Gardner: Whatever the problems were.

Bradshaw: Bill, correct me if I'm wrong, but we didn't have one-- we weren't lucky enough to get one problem at a time.

Gaudet: No.

Bradshaw: The primary one is-- when we first started, when I was in Boulder it had nothing to do with stick. We saw the writing on the wall--

Gaudet: What was the problem?

Bradshaw: 'Cause we hadn't gotten the right environment yet. It was amplitude and SNR. We were working with the prototype heads, okay? And the tape was too rough.

Gaudet: Gotcha.

Bradshaw: They solved that from some really nice work that Lederle's team did.

Gaudet: Does this take us from Stallion to Mustang?

Bradshaw: <laughs> During the transition to Tucson a whole bunch of things happened. That's what I'm getting at. We got a different iteration of the head. We had a different thing in the channel, the pre-amps, okay?

Gaudet: Okay.

Bradshaw: So, we got-- now so-- and the other thing was the drive noise. We had a problem originally with the cards. Okay?

Gaudet: Yeah, yeah. They were read-write--

Bradshaw: There was a bunch of noise in the cards. And one of the sounds-- it was cables! I mean, I love-- we had-- there was so many-- remember, we're trying to design these things from all these-- and put them all together.

Gaudet: Yeah, but we're talking about the media now.

Gardner: And the cartridge.

Bradshaw: No, but it-- they're all related, because we had a test system for the media that relied on cards and we were always downloading from the ones that they were doing for the pilot.

Gaudet: But you gotta distinguish when you're testing the noise, where it's coming from--

Bradshaw: That's what-- and that's what we had a whole independent group doing the channels, as you know.

Gaudet: Yeah.

Bradshaw: Andy was involved with the hardware and stuff.

Gaudet: Yeah. I managed that.

Gardner: So, with Stallion was the cartridge decided by Stallion time? Was Stallion, the cartridge, essentially unchanged from Stallion through Sonoita?

Bradshaw: No. First of all, the thing is, originally, they weren't welded. They were snapped together. Remember? They kept falling apart. If you dropped them, they'd fall-- there's a bunch of-- this is typical of when you start with a clean sheet of paper and start from nothing. 'Cause we'd ship them from Boulder and we'd get-- half these were out of their cartridges and tapes were loose.

Gaudet: There were major, major problems that manifested itself in the tape and/or the cartridge, okay?

Bradshaw: And it all added up, okay? We constantly under delay.

Gaudet: Stiction!

Bradshaw: Stiction was a big one to try to fix. It started in seventy-nine from binder hydrolysis.

Gaudet: All right and that was the Stallion.

Bradshaw: Actually, every formulation had it.

Gaudet: Wait a minute. Let me just carry it through then.

Bradshaw: All the old tapes had [stiction].

Gaudet: It was Mustang also, right?

Bradshaw: It just took longer.

Gaudet: And it was Pegasus also, right? I don't remember too much on Pegasus (re: stiction).

Bradshaw: Pegasus was the right binder. We got rid of Estane. Estane was a hydrolysable binder system. It means it could react with acid degrade the long polyester polyurethane chains needed to hold the particle in the coating into small fragments more adhesive in nature (glue) than a rubbery binder. Chromium dioxide pigments were not a=only acidic but oxidative particles, very powerful chemistry which was not well understood or appreciated when I joined IBM and took us years to fully understand.. the GPC-- gel permeation chromatograph, allow you to measure the molecular weight, size, of a soluble polymer. We used this tool extensively to get a handle on what was happening during mixing of various binders with the chromium dioxide pigments ... not even as tape coatings.. Typically the Estane 5701 binder as received form BF Goodrich in tetrahydrofuran (THF) solution would give you 120,000 MW average for the binder. The molecular weight (MW) is the length of the binder chains in Daltons--

molecular units. Okay? We mill it and it goes to eighty. Wait a minute, something's happening. Okay. You age it, 125 degree F and 22% humidity for twenty-two days. That was our magic number for shipping it, right? Twenty-two days? It's down to twenty thousand. Twenty thousand, you might as well use it as grease. Okay. So, why shouldn't it stick? Okay? Morthane's 310N was a non-hydrolysable (actually it was very hydrolysis resistant but not NON-hydrolysable, but it was much better than any of the Estane PU binders, but it was too soft. It had a 23-degree glass transition, which meant--

Gaudet: And which formulation was that?

Bradshaw: That was Pegasus.

Bradshaw: And to make it pass, we back-coated it.

Gaudet: Yes.

Bradshaw: And because we didn't have a back-coat formulation, the expediency was to coat chrome on the backside. And I said, "Why would anybody do that?" "We don't have time. We have to get this product out." That was the honest-to-God-- from Raj Rahejia and the manufacturing team.

Gaudet: Okay.

Bradshaw: So, we made one coating, chrome, and coated two sides. One side we calendared, the other side we didn't. And guess what happens when you take two magnetic-- one's compressed and one's loose, you pull the stuff out-- <claps hands>! So, it passed,. What? Nine million of them.

Gaudet: What fell out?

Bradshaw: The back coat would pull off and stick to the mag coat.

Gaudet: Yeah, I don't recall that.

Bradshaw: That's exactly what happened -- you remember how many task forces we were in, showing-- I could track it in the field, because we put a "1" on the cartridge for Pegasus and a "2" for Sonoita. And we shipped the Sonoita and everyone in the field showing growth in errors had "1"s in them. As soon as we got rid of them and put the "2"s, problem gone.

Gaudet: We were able to ship Pegasus given that we pre-conditioned them against Ric's recommendations and demands that we don't do it..

Bradshaw: The burn-in, they called it.

Gaudet: -- But we were able to show that under a simulated ship environment-- temperature and humidity, that's all we were stressing these cartridges to, it would manifest in predominately hardband problems.

Bradshaw: That's the first time you fired me.

<laughter>

Gaudet: Right.

Bradshaw: And pullouts.

Gaudet: Stiction?

Bradshaw: That was the other point-- no, the smooth part near the hub would stick. Okay? Then we put the puffer on the head! Remember?

Gaudet: That’s right, that’s right. We did add a puffer.

Bradshaw: We had a little puffer that blows air to get it off the head.

Gardner: So there’s another term that just got thrown out: hardband

Gaudet: I’m trying to get to hardbands--

<laughter>

Gaudet: --because we had a stiction problem that was predominately resolved with the back coat.

Bradshaw: No, with a binder change.

Gaudet: Stiction is what I said.

Bradshaw: No, no. To me, stiction and stick were related initially, because we called them the same thing. But then, we got rid of the one problem from aging, but then we set the 87-85 in the humidity and we get stiction.

Gaudet: Right.

Bradshaw: Okay, that’s what you’re talking about.

Gaudet: Right. And we resolved that one with--?

Bradshaw: Back coating.

Gaudet: Okay

Gardner: If we did a Pareto analysis--

Bradshaw: Well, at first it was stick.

Gardner: Stick as opposed to stiction. -- stiction is an engineering term. What’s “stick”?

Bradshaw: By ’81 we had that resolved.

Gaudet: Glue. Stick.

Bradshaw: Stick.

Gardner: Stuck together.

Gaudet: Yeah, stuck together.

Gardner: Okay, as opposed to stiction, which is increased friction when starting.

Bradshaw: You couldn’t move it even if you had a back coater. You couldn’t move it. It was--

Gardner: Okay, so we have stick and stiction.- they’re different.

Bradshaw: Yeah, adhesion from water condensing interface. And we put a puffer on it and it blew it off.

Gardner: Is that stiction between layers in the reel?

Bradshaw: No, on the head.

Bradshaw: You could wring it in by shoe-shining it and it would go “Whoop!” And it would lock up.

Gardner: So, Bill, is that your impression?

Phillips: Yeah.

Gardner: Stick and stiction as the top of the Pareto analysis? The one that gave you all that gray hair?

Phillips: It all depends on if you bring in cupping or not.--

<overlapping conversation>

Gaudet: He didn’t have to worry about stiction and stick.

Bradshaw: No, I did.

Gaudet: We haven’t done cupping yet.

Gardner: We also have hardband. We have cupping. We have edge quality.

Gaudet: Stiction was predominately resolved with the back coat and the puffer to keep the tape off the head, okay?

Bradshaw: But then we couldn’t pass long-term ship. That’s when we started doing burn-in, right?

Gaudet: Let me just finish.

Gardner: Okay.

Gaudet: So, now, that is primarily how we solved the stiction problem, which is, again, resolved with Sonoita. Okay?

Gaudet: Now, I don't want to get into another thesis on what Sonoita is, because we had that this morning. But Sonoita, the reformulation, the increase in the glass transition temperature of the chemistry--

Bradshaw: Complete re-design.

Gaudet: Complete re-design of the binder.

Bradshaw: Solved everything.

Gaudet: Solved everything -- we didn't need the puffer.

Bradshaw: Didn't have cupping.

Gaudet: And the hardbands went away. Now, hardbands, the localized-- big areas, you could see them on the jumbo.

Bradshaw: Ridges.

Gaudet: Ridges.

Gardner: On the jumbo -- "jumbo" is another term.

Bradshaw: A jumbo is-- before you set the tape down to half-inch. It's a big ass roll. Okay? It was twenty-four-inch wide and these things weighed about two hundred pounds.

Gaudet: I could bench press them every day. <laughs>

Bradshaw: And they were run that way because it's cheaper. But the way some companies-- and everybody had them. If you stacked the stuff where it's a smooth edge, the edges were all on top of one another, it looked like a tin can with the little ridges in them. The reason that you-- when you're doing a coating of a thing and you're squeezing it down, you run it with a hydrostatic wave, depending on speed. One of the fixes was to slow it down. You slow it down, you're printing money at a slower speed. So the next thing-- we'd get it all resolved-- in Boulder they could only go one hundred fifty feet per minute, I think, because of the length of the ovens, so they didn't have hardbands. They sent it to Tucson and we're gonna go two-fifty. And, all of a sudden, ding, ding, ding <wags index finger in the air>. So the first engineering solution is move the rewind back and forth so these bands don't line up.

Gaudet: Guess what? It didn't manifest itself--

Bradshaw: Till you put it on the drive!

<laughter>

Gaudet: Well, until you went to temperature and humidity testing.

Bradshaw: But if you run it in the dry and then run it in the humidity-- see, remember, this is the problem with the way we did testing, It was all functional. And we'd pass on test environment and then go to the next…and hit another problem. This is what happens when you don't understand the fundamental requirements and just throw things against test requirements and tweak things to pass. we were cheating and as we'd get a problem we'd go resolve it. That's stupid! Okay? So, the point is we got a lot smarter. [00:24:36]

[Editor's note: Removed unintelligible overlapping conversation about "hardbands"

In summary, hardbands revealed themselves as ripples in the coating of the 24-inch wide web ("jumbo") which when slit into ½-inch tape caused differential flying height of a head over the medium leading to HTI (head tape interference, "head crashes') and data errors. It was a show-stopping problem]

Gaudet: How do we ship the product? We ship the product by going through an environmental stress test of the cartridges which Ric was against and in the end analysis he was right on. But, because we saw this during environmental stress testing-- and I'll raise my hand. I'm the culprit.

<laughter>

Gaudet: I said, "Why don't we get some trucks together, because it's in the summer and run those around the loop of the plant site, because that's what's gonna happen when they're in a customer-simulated environment. Because we couldn't get a hold of large-size ovens at the time. We finally did. And so we did that and then we took them back in house and we loaded up the manufacturing floor in Building 10, the tape area with tape drives. And we ran each reel for data reliability. And those that passed we were able to confirm both by failure analysis and by data reliability that there were no hardbands and the ones that did fail were due to hardbands. And so we kept that up and that's how we were able to get sufficient quantity-- our yield was damn low. Twenty percent or something?

Bradshaw: Yeah, nineteen, I think it was.

Gaudet: But it was low!

Bradshaw: Yeah.

Gaudet: I remember that. It was a nightmare. And at this time the only way I could get to sleep at night was I knew Ric was working on a reformulation and we had our Glass Transition Temperature (T sub g) tutorial. We sat down and talked about it-- hours! Days! "How in the hell are we gonna get out of this?" And we finally, finally-- Ric was able to show the results in Sonoita, show that it not only resolved stiction, it also got rid of the hardbands.

Bradshaw: The yield went to ninety percent.

Gardner: And it solved stick, too.

Bradshaw: <shakes head> There was no--

Gardner: Stick wasn't there.

Gaudet: Stick wasn't there. That was the Estane

Gardner: Gone.

Bradshaw: The other thing is hardbands and cupping-- see, cuppings another--

Gardner: Well, that's Bill's problem, right?

Bradshaw: Cupping happened after Bill Phillips had left to manage the Brown Disk venture for IBM in Colorado Springs..

<laughter>

Gardner: That's the one that gave Bill all the gray hair.

Bradshaw: No, I did.

Gaudet: It was Ric that gave him the gray hair.

Phillips: Actually, it was your tape drive.

<laughter>

Bradshaw: But the hardband things-- see, the other thing is when we started doing this screening, one of the things when you burn it in, if you-- luck of the draw-- if the hardband is near an edge and you slit-- the way these slitters are done-- there's multiple ways, but the way we always had a supported edge and an unsupported edge. In other words, there's a thing that's half-inch wide and two knife blades like that <spreads index and middle fingertips on table>. The side that's supported, the blade's not going up. It's going down. Okay? It's cut cleanly. The one coming up is smearing this way. You want it with a lip. Now, if there's a hardband there that edge is running against the-- and it turns out it's the luck of the draw. We proved that-- it was an interesting experiment that Mark Warne did, where he flipped the cartridge that had-- was walking on one guide, he flipped it end-for-end, ran it, and flipped it on the other guide. It was all engineering data and yet as soon as we relaxed it-- that was Paul Dosier he made that little fixture in an O-ring that he'd stand a piece of one-inch tape-- he'd cut it and drop it in the screen [ph?] and look at it end-down and he could see the cupping. What he did, he stood the tape on its edge-- unsupported, so it just barely touched the side of the thing--

Gaudet: He's doing "cupping".

Bradshaw: --so it was unsupported. But they're related. He-- we took a hardband samples, put them in this fixture and correlated hardbands to cupping as-- and then for a while we thought that was it, with this-- screen it-- we had the ROS, set the Reel Optical Scanner that Dennis Byrne[27] built.

Gaudet: Right. It was an optical raster that I'd used on a DASD substrates many years before--

<overlapping conversation>

Bradshaw: And that's how we inspected the jumbos to select "good" spools of slit tape prior to winding in a cartridge…it would scan the outside of the bulk slit "pancakes" of tape prior to winding into the cartridge That's how we shipped the product, but the problem is I was still very concerned because every time I looked at the cartridges after they'd been run, the inside was smoother than the outside, 'cause of compression. And, so, I was getting differences in stiction! In other words, so the back-- and then if you didn't use-- if you solved it, then you got it wrong [ph?], you peel it there was back coat sticking to the front coat. Remember, it's magnetic. So, it would go into the gaps of the head and-- "Plop!"-- stay there.

Gardner: Inside was smooth and the outside was--

Bradshaw: Every tape is a ribbon that's wound on a reel. And, so, it's pulled on a certain tension. We had one newton was our normal tension at that time. We went to eight and I think it was--

Gaudet: It was about eight-- yeah.

Bradshaw: But, I mean, the winding tension was always lower to prevent the tension induced hardbands on the jumbo roll, but on the dry side of the process where the jumbo was slit down to pancakes of ½ inch wide tape ready for winding into the cartridges the spools had to be wound under higher tension to stack well and run in the testers and tape drives. On that end of the process the tapes was wound to eight newtons, I think. Six to eight.

Gaudet: It was eight, I think it was, as I recall.

Bradshaw: In any event, there was a lot of really interesting modeling done. If you think of anything when you start winding it, there is a tangential force pulling it out and as soon as you run it on a hoop-- there's hoop strength, where it bends over, and now there's force going down. Well, the inside of the hub, the smaller diameter, there's more compressive force on the tape going into the hub. But as you go further and further out, there's less and less, the tension to elongate the tape dominates over the compressive tension into the spool and the tendency for the overlaying coatings to compress into each other and smoothen decreases until on the outer wraps they are essentially not in compression at all.
[00:30:00]
and actually we called we called it 'loose wraps". That's what the leader block was for, is to get this thing

[27] *Dennis Byrne worked for Clem Kalthoff in the Media Development mechanical team that was responsible for the dry process for the coated tape, slitting, calendaring, drying and physical testing. Dennis was a very gifted and hardworking, smart mechanical engineer who did a lot of the hard lifting in Clem's group. [R. Bradshaw]*

under relaxation, keep it tight, so it can't get any looser and looser and looser. Well, that fixed one of the problems of the thing falling off, but it meant that there was a differential relaxation. The outside would get loose. And we have this thing—ROS [sic UTS][28]. That was another thing that one of your guys <pointing at Bill> did -- it was Greco.

Gaudet: It was one of [Bill's] guys. <pointing>

Bradshaw: Greco did the thing that just took the motors and when "Dit-dit-dit," and he managed to see when the tension came up and he could read it on tension sensors and he said, "the tension's gone." And it was a major breakthrough! Saved our ass on that-- on the drive side, because the other problem is we could fix our media, but what about everybody else's? As soon as we ship this product, everybody and their uncle's gonna start through their stuff on it and saying, "It was easy, we can make it better, and none of it worked."

Gaudet: And a lot of it, the IBM product had very, very high reliability -- we went through that this morning. And even in the field, the field performance. Very high reliability--

Bradshaw: We predicated a twenty-five-year life and I can tell you what my analysis in 2002 for almost thirty-year-old cartridges? We had no IBM failures ever for a mechanical failure, chemical failure, anything. Every failure was overwrite, people overwrite the header. Stupid things people did. We had fires. I loved that. The one we had the fire that melted the cartridge but we were able to recover all I the data off the tapes.

Phillips: Yeah.

Bradshaw: And, think about it, remember I told you a hundred and twenty-five-degree Curie temperature is inherent for the chromium dioxide particle…if it goes over 125C for a few minutes it loses its magnetic domain barrier and relaxes so the alignment used to store the bit is lost - completely!

Gaudet: That's "C".

Bradshaw: Celsius. But think about it. A building fire?

Gaudet: Yeah, it's gonna get up there.

Bradshaw: And this is polycarbonate. It starts to flow at about one-fifty, okay? So, by the time you do this chrome is pretty much lost to -- "Oh.." <buries head in hand>this was mission critical data to a financial customer, we had to get the data. Turns out because of the reflectivity of chrome, the outer wraps are

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[28] *The ROS was the reel optical scanner used to detect hardbands; it was designed and implemented by Dennis Byrne in Tucson working for Clem Kalthoff at that time.*
The Universal Test System (UTS - Antero) was built by Rich Greco to do all the engineering verification testing in development…and which due to its heavily instrumented unique channel and drive component logging points it could measure everything that went on during stop start and data acquisition. [R. Bradshaw]

sacrificial, but they prevented inner damage -- but you had to have a sustained heat to get it to demagnetize -- so we got all the data off it.

In other words we (IBM and the customer) got lucky. The fire did not last long enough to completely destroy the whole tape The outer wraps were gone but the burn of the shell and the outer wraps absorbed enough of the heat so as to prevent the inner portions of the tape from seeing the Curie temperature long enough to erase the signal. We had to unspool the tapes onto new spool in a new cartridge and then retrieve the data on a special drive with very adaptable microcode controlling tape location and tachometer count; these tapes had no servo so there was no on tape reference marks to allow precise block or bit location.

Gaudet: It was a tough cartridge and what we shipped was reliable. Our Achilles heel was OEM cartridges.

Bradshaw: For the next three years that's what kept me employed.

Gaudet: They gave us a little black mark there. But, overall, it was high data reliability.

Bradshaw: And other people took that formulation and went further with it. For StorageTek, for his thing <points to Bill> Redwood, they actually got up to a gigabyte in the cartridge.

Gardner: Explain for our audience cupping.

Bradshaw: Curvature. The tape would shrink. You coat this thing on a flat ribbon, right? You dry something on it. Well, if it shrinks, it's going to pull it this way <bows a piece of paper>, okay? Well, if it shrinks the wrong way, okay, there are things that the Japanese did-- do you remember that? They tried to tell us that thing, too. That was SONY: Put a bigger coating on the back and pull it the other way. Are you nuts!? It doesn't solve the problem. Get rid of the stress, okay?

<laughter>

Bradshaw: And that's exactly-- when I designed the binder I remember the first time I pitched it as a test, I said, "I'm designing this binder so it doesn't swell in MIBK, Methyl Isobutyl Ketone." We used two solvents, Tetrahydrofuran (THF) and MIBK. MIBK is a high boiling solvent. The idea was if you flash all that stuff off, you won't get gloss. Gloss -- from the printing industry, okay? It's gloss. Reflectivity. People at that time still thought gloss was surface roughness. It isn't; it's a question of reflectivity.

Industry believed that the gloss or surface reflectivity was a good measure of surface roughness and this was carried into "expert experience" with tape. This is totally misleading when comparing formulations and processes and is only useful for process control of a fixed recipe and process.[29]

[29] *Magnetic tape coatings were initially formulated as in much of the paint and printing industry but at Tucson we realized that such solvent systems were not appropriated for tape coatings.*
A good solvent and hopefully one that is cheap and not hazardous is one which fully dissolves the binders and other additives is needed to allow wetting and dispersion of the pigments of a coating. Since you need to end up with a

[Editor's note: Beginning section of clarified overlapping dialog]
Gardner: So, in a laymen's terms -- you have this plastic substrate, you put paint on it. The paint has a pigment and it has a binder, which is going to hold it together and a solvent which make it a liquid and then as it dries it can cup[30]

Bradshaw: Mylar substrate, Chrome dioxide pigment.

Gardner: Like when you paint the wall.

Bradshaw: Your orient it. You magnetically orient. Without a magnet it's still oriented. So that's what was interesting about it. And then it's even better. And then you also have lubricants.

Gardner: So, the problem you were facing was during the drying process it would shrink, that would cause the shape to change.--

[Editor's note: End of section of clarified overlapping dialog]
Bradshaw: Think about this: The realities of making a coating is you coat this thing drying flat in an oven. Then you wind it up, okay? It may or may not be, quote, "dry". In other words, there's still solvent. And we knew that because we weighed the jumbos. Then for a while there we used to cook it. It was this idiotic idea about cross-linking -- where you put this isocyanine in the cross-link and cure it. Well, it didn't do anything. *What it did was react with trace amounts of water and a few small molecules always present in such polymers to make them insoluble but it never actually crosslinked or extended the binder chains as some believed. It only improved solvent resistance and altered the porosity of the final coating.*

Gardner: That is the binder would cross-link but it didn't really do that?

Bradshaw: And it didn't really do that.

Bradshaw: It's a holdover. In the old days of iron oxide they used a vinyl alcohol, which is hydrolyzed vinyl acetate. There's no such thing as vinyl. Anyway, so, it's called VAGH. It's a trade name from a vinyl chloride-vinyl acetate copolymer that's cleaved. It makes -OH groups. Then they put it on isocyanine; it causes the cross-link. This was the hardening resin for the urethane. It worked for iron oxide, because iron oxide's chemistry stunk, okay? From an interaction with a binder.

<laughter>

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dry coating, the solvent which is there for dispersion and application needs to be removed - so the majority of the good solvent needs to evaporate at low temperatures so the liquid coating will dry and not run off the substrate. If it dries to quickly the coating can crack and lose adhesion so other solvents which are higher boiling and good solvents for the binders are added to allow the coating to get tacky enough to stay on the moving web but dry enough to not crack and stay on the substrate.

[30] *The wet coating has a volume of material on the surface which is decreasing in height as the volatile solvent leaves. This means that the middle is dropping in height and the edges are moving inward due to surface tension as well as dropping in the height off the substrate; all cause lateral forces on the edge of the drying coating so that the edges are either pushed out (down toward the backside for backcoated tapes) or up if the coating is shrinking toward the middle of the drying coating… driven by surface tension and drying rate.*

Bradshaw: So it relied totally on being enmeshed in a matrix. Very similar by the way to the particulate discs. There you had an epoxy system, which really-- and they used isophorone for a solvent. And it never evaporates!

Gaudet: Yes, they used isophorone and it doesn't evaporate

[Editor's note: Beginning of section of clarified overlapping dialog]
Bradshaw: And cyclohexanone-- and you think of that smell. That's a real smell. You're in one of those plants-- oooh!

Gaudet: Building 10 made me woozy.

Bradshaw: No, no, that's sweet-- isophorone is sweet smelling. It smells like cherries. Cyclohexanone. smelled nice.

Gardner: When I was head of engineering at Memorex I used to joke with the engineers that if they screwed up I was going to send them over to the ball mills to work there for a month or so.

Bradshaw: It's a threat!

<laughter>

Gardner: And the ball mills at Memorex--they leaked and they smelled bad.

[Editor's note: End of section of clarified overlapping dialog]
Bradshaw: Well, the thing is-- one thing about the process that I haven't mentioned yet, one of the things that was state-of-the-art at that time is it started with SAG2, was the use of the sand mills, where they didn't use the ball mills.

Gaudet: Did you get your question answered, "What was cupping?"

Gardner: I think so.

Gaudet: All right, question! Question: What's cupping and how was it resolved? Simply.

[Editor's note: Beginning of section of clarified overlapping dialog]
Gardner: What was the failure mode that it caused.

Phillips: High wear of the guides, heads.

Bradshaw: *Cupping is an attempt to describe the curvature of the tape as it would appear across the tape looking at it down its length from the end…like a tape measure which is intentionally cupped so as to make it try to stay stiff when it is pulled out of its spool. What the multi- track recording head wants is flat tape so all the read-write elements across the width of the tape are at the same distance from the recording surface, In addition, guiding of this flexible ribbon down the tape path from the spool in the cartridge and onto the machine reel prefer to move the tape gently by interaction with guides that tap the edges, contacting them tangentially so that their response is lateral* *motion and not vertical bending which leads to debris and guide wear. Ideally the tape should be flat and have no inherent stress produced in it during manufacture so that it wants to curve or cup during its life as a spool of tape.*

If drying stresses try to make one coating shrink and pull in so as to cup the tape one way one "solution" is to put another shrinking coating on the other side and pull the tape back the other way. This was the idea of the balanced back coat which was being added to solve the stiction problem initially but was then being considered as a fix for cupping….a band aid not a resolution.

You couldn't stagger well either. Think about it. If you-- tell me which way-- if you do this? By the way, on 3570, you have--

Because it would lay down and roll over. But if you did this, it sits on the guides and does this--

<overlapping conversation>

Transverse curvature.

Positive ______ if it's towards the head and--

Of the front coat. The mag coat. That's exactly what we did.

But the initial thing on Pegasus was the attempt to balance the back coat thickness to make it--

Gardner: As a mechanical compensation.

Bradshaw: Yeah, and it didn't work. Does it change as a function of being compressed on the--

[Editor's note: End of section of clarified overlapping dialog]
Gaudet: You know about hard band, cupping, stiction and stick. And what else was there?

Bradshaw: In other words, nobody in their right mind would do tape for a living. It's really not as simple as you think it is, because of interchange. And we made our money off the tape drives. We really wanted everybody's tape to run on it.

Gaudet: There was some preferential MR stripe wear and I remember one of the solutions to that was to vary slightly, in terms of micro-inches the height of the MR stripe away-- distance away from the media so that the ferrite and the titanium and the interface, you know, wouldn't wear. So, it wouldn't have the preferential wear. That was Neil Robinson's contribution, I remember. I remember giving him a real pat on the back for that. And there was something else that was done--

Bradshaw: On the head?

Gardner: So, to put it in layman's terms?

Gaudet: I'm trying to remember.

Gardner: And you can put it in layman's terms. The reader in these tape heads was an MR stripe.

Gaudet: Right.

Gardner: There were actually eighteen of them reading the eighteen tracks.

Gaudet: Right.

Gardner: And if the MR stripe was coplanar with the face of the head--

Gaudet: You get preferential wear.

Gardner: It was perhaps softer or different material than the separators and the write element.

Gaudet: Right.

Gardner: And, therefore, it would wear more-- essentially increasing the spacing--

Gaudet: Right.

Gardner: --which would result in signal loss.

Gaudet: No. No, not really. We were afraid-- it could get carried away to the point where you get enough to bring it in there to continue to wear it. What we're able to show is we had end-of-life test and it was decreasing our end-of-life by about a year or two in terms of the head

Bradshaw: Replacing heads.

Gardner: So the head was supposed to last five years. It was lasting four.

Gaudet: I forget the exact duration, but it was longer than that.

Gardner: Unlike the heads in the prior reel-to-reel which did not last nearly as long

Bradshaw: Well, the other thing is the FRU, too, field replaceable units. *The heads were mounted and aligned at the factory into their bearing and guide assembly with the cables attached so that the whole assembly, or FRU, was replaced and not just the head*

Gaudet: Yeah, you can replace it. But anyway, the point was is that we worked on that and we were able to move the vertical height of the stripe somewhat.

Bradshaw: And there was some change in materials. The alumina-- remember the shield?

Gaudet: Oh, that's right.

Bradshaw: And the planarization of the ferrite. At first they were using DASD product -- some of this is just evolution moving from tape to disk and in a way back and forth.
[00:40:00]

Gaudet: It was a shield though.

Bradshaw: Yes, it was. And there was also that alumina-- the thing they did-

Gardner: So we're now talking about the shield between the MR elements and the thin film write elements

Gaudet: --They were Permalloy shields, soft magnetic material--

Bradshaw: And then there was the alumina layers that were put between them to isolate the things, and we didn't understand that. We did learn later. It's electrochemistry. And yet chrome hit it because chrome dioxide is conductive and it's abrasive and very hard. As hard as the sapphire. But it turns out after all was said and done and everybody bad-mouthed chrome, but if you did it right, we actually started for the next, what, four generations of drives to use iron metal particles (MP) tapes for later enterprise drives as well as LTO (Linear Tape Open systems)-- we used chrome to finish the heads. Now the problem is nobody makes it anymore.

Gaudet: <laughs> But, it was basically materials and positioning of the stripe and we were able--

Bradshaw: It's some really nice engineering.

Gaudet: We were able to meet our end-of-life objectives.

Bradshaw: The other piece I'd love to talk about is the cabling.

Gaudet: Field replaceable units.

Bradshaw: There's a real need-- 'cause think about it. We didn't-- it was a solid. But when we tried to do the actuator, the 3590, remember moved it-- what? We only indexed it.

Gaudet: I never worked on a 3590.

Bradshaw: Well, it was still the same number of things. And we had these *Aramid polyimide substrate encased printed cables. They were wider and more rigid where they go into the card on the drive and then neck down to narrower ribbons as they go into the back of the head modules. This results in differential stress concentration points in the compression fitting and at the pins used in the connection to the deck…which was a mechanism of failure in some environments and operations which were causing the replacement of "good" heads which when returned were logged as No Defect Found (NDF) charges against the drive maintenance cost ... so a big issue that was always being chased.*. Well, the LTO really pushed it, because <mimics tape sound>. But cable technology never got the attention it really deserved, because that closure-- it was a thermal-bonded thing. We didn't have to just make one track with it, we had to make them all work.

Gaudet: Right.

Bradshaw: *These cables come off the board where they attach to the preamps as flat ribbons that then wind their way to the head modules. In drives that moved their heads such as the 3590, 3570 and LTO, the cables attached to an actuator which needs to have a very low mass and stiffness so the cables need to flex with a predictable and minimal resistance…*

Over the range of operating environments needed for tape operations these very closely packed "wires" would see oscillatory strain and stresses that would allow water or mobile contaminants to wick between the polyimide sheaths and bridge the wire leads causing connections that could lead to transient or permanent shorts. We called the conductive deposits "dendrites" since they typically were metallic salts that under examination with the scanning electron microscope (SEM) looked like fingers or tributaries, dendrites. They were often copper, sometimes sea salt or even silica

Gardner: So, again, for the layperson.

Bradshaw: You get a short.

[Editor's note: Beginning of section of clarified overlapping dialog]
Gardner: No, but we're talking about, as I understand it, in the 3590 -- now we've gone from eighteen tracks to thirty-six tracks and now where the eighteen tracks were across a half an inch of tape, we're now have — what — two bands of thirty-six?

Bradshaw: Initially we turned on one eighteen track module on going one way, turned another module on going the other way. That's all it was. We designed that thing in six months! You remember *Andy Chapman and Jeff Fox were given the task by a new Division President Bob Van der Slice who replaced Ed Zschau*

Bradshaw: We're talking about the e-drive, the 3590E, [Condor] is what it was called, where we doubled *the track density and thus the capacity compared to the 3480.*

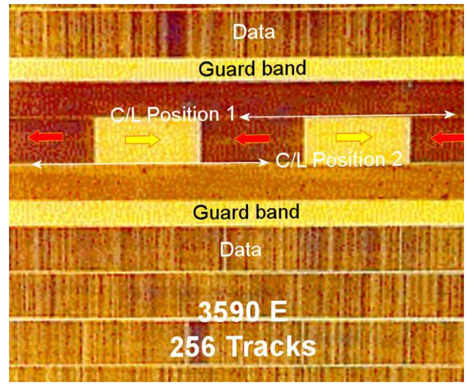
Gaudet: It was thirty-six tracks--

Gardner: Eighteen in one direction.

Gaudet: Yeah. And eighteen in the other direction.

[Editor's note: End of section of clarified overlapping dialog]
Bradshaw: We didn't move the 3490 head -- we put a servo on a 3590E -- that's that damn amplitude servo, you know? Remember that one? [Illustration at right]
Yeah, okay. You guys, you saw it and StorageTek just laughed, "Why are they doing this?"

a



Developed portion of 3590E tape.
Courtesy Ric Bradshaw

Gardner: So, again, and pardon my ignorance, but that sort of implies a seventy-two track head. Thirty-six in one direction, thirty-six in the other direction.

Gaudet: No, thirty-six elements.

Gardner: Thirty-six element and you indexed it.

Bradshaw: Initially, we didn't. What I'm saying at first all we had was there's a module here and module here that were all on the same head. Okay? When we went in one direction, we turned the lower on, coming back the other direction we turned the other one on.

Gardner: In that embodiment, the 3590E, when you're going one direction are you reading eighteen heads or thirty-six?

Bradshaw: Eighteen. You only read one at a time. But it just doubled the capacity--

Gaudet: Doubled the capacity, but the controller wasn't ready to accept the full thirty-six tracks.

Bradshaw: But buffers got cheaper and got us some time, too.

Bradshaw: There was some real magic being done by the code guys, too, that saved our bacon a lot of times, too.

Gardner: And back to the mechanical problems--

Gaudet: We talked about that. That was the Froehlich finger and that was important, too.

Bradshaw: That was a disaster. *The initial 3480 tape deck did not have a machine reel flange since the threading mechanism was initially a ribbon feed on a rail above the drive that threaded the tape from the cartridge through the drive an into the machine reel. It was just a flat piece of plastic placed over the machine reel hub where a flange would have been to push the edge of tape down to the lower machine reel flange to prevent the tape from flying off the machine reel hub during high speed winding or unwinding. Fred Froehlich was the manager of mechanical team when this fix was put on. However, after a few hours of tape motion the surface of the plastic in contact with the edge of tape was cut full of groves and loaded with debris…all of which could (and did) fall down into the tape. It was problematic and was eventually replaced by the Pantocam threader located above the machine reel which now allowed us to put a slotted flange on the machine reel*

Gaudet: Wow, but we shipped that,

Bradshaw: It looked like a honeycomb after you ran it for a while.

Gaudet: But it worked. The Froehlich finger worked

<laughter>

Gardner: I led us down this rat hole on the way to dendrites.

Bradshaw: If you think about it, it's current flowing through these things that if you get humidity and there's any kind of gap from the closure, you get wicking. And a single ion would move out and it would bridge and then now it could short. The bad news is it would short and the operator, they'd send it back to us in Tucson-- we put a current on it and test it across the lead and blow it open and the head's fine, we sent it back to them and a few months later, it dies again.

Gaudet: Same head.

Bradshaw: The one I love was the one who's in Hamburg in an old hanger-- they had the data center. It was a big bank-- Deutsche Bank. They had moved to the new data center. In the meantime, they took all their 3480 drives and put them in this Quonset hut built by the U.S. Army during the occupation and with the cooling being provided by fans drawing humid air in from the harbor.. So the humidity in there was near something like sixty percent. And all of a sudden things started going bam! Bam! Bam! We started getting heads back in boxes, you know. And they're sending them to us for failure analysis in our lab, because Mainz wouldn't touch it, because Sindelfingen had its own private disk drive lab at that time[31]. *This was a big customer and a very important account - enough that the IBM CEO was getting calls which got everybody jumping on it. Anyway it was a cable delaminating problem only showing up in places where water and sea salt could condense on the cable and wick between the leads and short the cables.*

<overlapping conversation>

Bradshaw: So, Mainz was sending them to us and we finally get a phone call-- we gotta stop this, 'cause they were replacing every day. And all of them were good. They had just shorted.

Gardner: And the perspective I was trying to bring out was dimensions actually shrunk by about a factor of two.

Bradshaw: That's right.

Gardner: I thought it was maybe a factor of four.

Bradshaw: Believe it or not though, it's interesting how we played games with that. we didn't actually shrink it that much.

Gaudet: A materials' type change and--

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[31] *IBM Tucson had a tape product FE team in Mainz that was supported most of the time by a very good materials lab in Mainz headed by Johannes Windeln whose primary mission was to support DASD in Sindelfingen as well as drive and mainframe support for Europe out of Mainz. If we had an urgent field problem many times the failure analysis and forensic work had to come back to Tucson which was the case in this instance. This meant a very long turnaround time.[R. Bradshaw]*

Bradshaw: We squeezed the space between the [leads]. So, the inter-lead spacing in the cable for us at that time got pretty spiffy. *The polyimide was made smoother and thinner and some very hasty and serious co-development went on with the supplier to completely change and improve their product capability…much of it was patented (very unique for that time)*

Gaudet: It got us out of the problem.

Bradshaw: We didn't cut them in half. We kept them wider because the signal noise wasn't good enough.

Gardner: So, I think we understand the dendrite issue. What others? Bill, you have any others?

Bradshaw: The other thing I remember is we went off on Keno. Do you remember that one? Keno was an attempt to make a low end 3240 drive.

Gaudet: Keno was a disaster.

Bradshaw: Yes and AMC was gonna make the heads for us.

Gaudet: What we tried to do with AMC was to use an old permalloy tape head.

Bradshaw: With our cartridge.

Gaudet: With our cartridge. And that didn't work out. And it turned out to be that to a first order when we did the failure analysis-- and John should be here now, because he did a lot of that work-- we found some alumina that came from somewhere in the process that was free, exposed, and chewing up the heads. So, it was really a head wear problem that kept us away from doing it.

Bradshaw: It was a low entry drive.

Gaudet: We couldn't meet our cost objectives if we put the Patagonia (MR) head in Keno

Bradshaw: That was the Patagonia-- that was the name of the head. Patagonia (used in the 3480).

Gardner: This was an all metal head?

Gaudet: This [the Keno permalloy head] was an all metal head, not an MR head, it had nothing to do with technology. It has to do with trying to pick things off the shelf

Bradshaw: Make it cheap-- glue them together and put them into a product and ship it. And it wasn't-- I don't know how we got off on that track.

Bradshaw: No, it was the mid-range. Remember, the one thing that killed IBM in the '88 and '87 is we basically were focusing on the big customer with big mainframe and this whole business went away from this. And the company went from what? A hundred and something dollars a share to thirty?

Gaudet: Yeah, well, there was too much knee-jerking--

Bradshaw: Yeah. No, I understand. But my point was that one of the things that bit us in the ass was-- who was the guy that was our boss -- he came in from San Jose -- Newman worked with him

Gaudet: Ernie?

Bradshaw: No, Ernie Newman was okay. He was a good guy.

Gaudet: Yeah.

Bradshaw: This guy was a-- reported to-- it wasn't Abuzayyed yet.

Gaudet: Oh! Somebody at that level!

Bradshaw: You remember him [Harries]? He would come in and he would rattle the cage about Keno, "You guys, make it work." And all this stuff. Remember him?

Gaudet: I remember him!

Bradshaw: What I'm trying to say is that really scuttled efforts that we were doing in Tucson for follow-on products. I really believe that Keno and Jerry Harries-- at the corporate level we looking like a bunch of clowns. No-- and I think it bit us in the butt. 'Cause we had all these plans: do a library, we wanted to do double density, we wanted to a track--

Gaudet: Bottom line this is what got us off that track and got us into the LTO-tape arena-- by trying to do it with the eighteen track head. The old tape head, -- the laminated head-- still had the data rate capability that we needed. The laminated head wasn't at its end-of-capability in terms of frequency attenuation(data rate sensitivity), but it did experience extreme head wear and I remember John (Teale) had head wear testers going and trying to understand what exactly was happening. Day and night, twenty-four-seven.

Bradshaw: We were using-- alumina, flame-sprayed heads. Remember that?

Gaudet: Yeah, we did everything to try to get the head to work-- but it turned out that it was some sort of abrasive and we finally identified it. At least, that's what I recall.

Bradshaw: It's too late.

Gaudet: But it was alumina particles from somewhere in their manufacturing process. It wasn't intended to be there. But it-- somehow or another it-- they were probably taking heads off of old tape drives and saying "Here they are! Use these!"

<laughter>

Bradshaw: No, no..

Gardner: So, alumina would up on the surface of the tape element and therefore it just ate the tape head because alumina's a very hard material.

Bradshaw: For a while the big debate was it coming out of the head or was it coming of the manufacturing?

Gaudet: Well, we have alumina in -- Even chrome dioxide and iron oxide in tape --

Bradshaw: It turns out it was electrochemical. And chrome made it-- see, the heads didn't have a problem with iron.

Gaudet: Didn't it? Didn't it have alumina added?

Bradshaw: The iron oxide tapes that they ran on their heads-- this is AMC. And who was it that was going to build the drives -- Cipher?

Gaudet: Yes, what a memory!

Bradshaw: Turns out the iron oxide didn't have the problem. So they were convinced it wasn't them; it was chrome! And, so, here I am, the chrome guy, and I was already in the middle of dealing with the State of California, because of disposables and the toxicity of chrome dioxide and that crap--

Gaudet: We proved that definitively.

Bradshaw: I know that, but it took us a while.

Gaudet: Well, it took a few weeks to do that damn testing, yes!

Bradshaw: It's a lot worse than that, because we were dealing with vendors who didn't want to listen to us, too. That didn't help. But the other one, at the same time, we were working on a really neat disk program, Ajo! *Ajo was a floppy disk project trying to see if we could use chrome coated 3.25 diskettes and a thin film single track disk head to put 120 MB on a floppy disk.*

Gaudet: Yeah.

Bradshaw: Okay? Bernoulli. And we had it in the back of our pocket -- the thing is what killed us is management didn't think we needed it -- *magnetic storage product options were viewed as dead end technology soon to be rendered obsolete by optical storage products*.

Gaudet: It was Ajo, we were able to prove feasibility. It was a very high capacity floppy disk drive, multi disc, and the servo was phenomenal. Don East was the one that created the servo system and we were running data reliability tests and, hell, every week, when Ray came to Tucson, I'd show him these charts. And I kept, you know, pushing it and pushing it, but we never got it funded. And then he was able to turn me off by getting me into optics. <laughs>

Bradshaw: Yeah, but what was the company that actually-- we did-- we don't want it again. These guys went on a one-hit wonder--

Gaudet: Iomega.

Male 1: <off camera> Our test guy went there.

<overlapping conversation>

Bradshaw: Yeah. That's exactly what he did and he did very well, by the way.

Bradshaw: The one that was done by Iomega was a Ajo follow-on using the Bernoulli principle.

[Editor's note: Deleted conversation regarding Iomega's later successful ZIP drive which does not use the Bernoulli principle.]

Bradshaw: And then, if that wasn't bad enough, a group took some of it back to Hursley, England, and we were involved with them on a disk drive product using chrome dioxide.

Gaudet: [A follow on by the Piccolo group].

Bradshaw: [This was a hard drive effort targeting Rochester's new midrange RISC 6000 servers; they were looking at using our chromium dioxide coatings for disk drives.] There's a lot of things that during that timeframe we were out looking for products because we had technology.

Gardner: When was Ajo?
[Editor's note: Iomega founded in 1980 began shipping Bernoulli drives circa September 1982 which would date Ajo in the late 1970s]

Joel: I was in Hursley Lab in the UK with Sprat in 1977.

Gaudet: Ajo was something that never saw the light of day, except for a couple of prototype devices--

Gardner: And that's A-H-O?

Gaudet: Ajo. Just like a small town to the Southeast of Tucson

Joel: It means "garlic".

Bradshaw: But it was a fun product. I understood a lot. We wrote a lot of reports on it.

Bradshaw: It led to TRX, which was a program that John carried into LTO.

There was a commercial tape product used in the consumer market with very impressive capacity called Travan and a series of products called TRX …..John Teale's Ad Tech group got some support from a wonderful innovative guru in IBM Research, Jim Eaton, (he died awhile back but left a great legacy to us all) who managed to get the ear of *the division president, Paul Lo to pursue a new tape product NTP. John assembled a pretty interesting team with some of the people who bailed out of optics to remain in Tucson and set up a project then called TRX which explored combining a bunch of rising technologies to really kick tape into the future, new media, new channel, new drive, new cartridge and servo. Even early on it was timing based to resolve the whole block and bit placement down tape issue and get rid of the tachometer based position method which was for the beginning problematic and unreliable. It never became a product although some of its technology wound up in the 3570 and LTO.*

Gardner: Sure. Hold on, let's go back to the 3480. You've gone through a progression. Any other major challenges solved?

Bradshaw: Well, we wanted to double the capacity, make it thinner. So, we took it to thinner tape and that sounded trivial, but to tell you the truth our problem was, again, nobody wanted to change the micro code. And we were chopping blocks. Remember, we didn't have any servo.

Gaudet: Oh, we forgot the glue dot embossment.

Bradshaw: Jeez, that was another one. Yeah!

<laughter>

[Editor's note: Beginning of section of clarified overlapping dialog]
Bradshaw: Manufacturing originally used a little glue dot to aid winding tape onto reels. They would go into manufacturing and hit it so it would stick to the tape and spin it up. And otherwise it would just keep slipping it over when you attached it. Well, when we went to thinner tape, it got worse, okay? The dot would emboss and so we'd get to the end of the tape and all of a sudden we'd start to see these emboss areas.

Gaudet: Errors.

Bradshaw: Printed errors, repeating once a round. They'd keep coming back around and around. Finally, it's-- obviously, it's easy failure management, on one hand: Here's this little thing, just the shape of the glue dot.

Gaudet: Oh, there was no problem finding that problem.

Bradshaw: So the first fix was to wind more tape.

Gaudet: Right! Buffer it, you know, so it wouldn't emboss after a number of wraps.

Bradshaw: But it passed at twenty-one days and then it failed at twenty-five. But the trouble is we started getting problem reports from customers-- unfortunately, people don't realize there are customers that will do everything you tell them not to do to a product.

Gaudet: But this tape is a wet noodle. It doesn't-- it'll sit there and not obey what you want it to do,

Bradshaw: One of our biggest customers was a geophysical company and they loved taking them out to ships.

Gaudet: But, anyway, we resolved the problem, I think it was a different attach.

Bradshaw: The water attach. We got rid of the glue dot -- squirt a little bit of water. This is what happens when you ask the engineers, “Well, what can you do?” Well, why don’t you squirt water with a little bit of soap? And that’s that thing that led to the water-based tape cleaner. Just put enough just to wet the surface so that it leaves nothing behind.

Gaudet: The wet attachment of the tape to the cartridge hub was an earlier method to initiate and allow the initial wraps on the hub. Extensive testing validated the wet attach process and we were able to get rid of the glue dot attach.

Bradshaw: At first they used to put a little double adhesive dot, which had thickness. So, after it started to relax, the return would make an embossment clear through the tape and you had this little bump. And you could literally see in a data type, if you looked at the error you could watch it circle..

Gaudet: But that took us probably a month or two to really get on top of.

Gardner: I mean, you probably didn’t see it till you got to the end of the tape and most tapes are not written till the end.

Gaudet: We saw it when we tested them

Bradshaw: Where we found it (embossments) again was at one of the corner environments where you had to do a ship store. You had to ship it at a max of one-twenty-five °F, which, by the way, as you know, when we did the burn-in in Tucson (for the detection of hard bands) we exceeded a lot of times in the back of the truck -- 140 °F one day in the sun in a truck.

Gaudet: But, otherwise, I said, “Okay, I want to simulate, emulate, a normal cartridge ship environment.” And those aren’t air-conditioned trucks we put them in. So I said, “If the test lab is gonna do their ovens, I’ll do my trucks. And I’ll be able to screen them out with these testers on the manufacturing floor and we’ll just ship good product,” until Ric came through with his re-formulation So, that’s the way we maintained that one.

Bradshaw: I was shocked. A hundred and forty °F.
[Editor’s note: End of section of clarified overlapping dialog]

Gardner: Hot, wet, what about cold dry?

Bradshaw: Yeah, what they are is they’re corners that-- by the way, these are not-- the National Bureau of Standards has these things for certain things.

[Editor's note: Deleted overlapping conversation about worst case temperature humidity testing. IBM Tucson, like many computer equipment vendors tested both in operation and as shipped at four or five points on a psychrometric chart, cold dry, cold wet, hot dry and hot wet at one or two points of constant humidity.]

Gardner: You were having some production problems that ultimately, I guess, got resolved by going to formulation that really didn't care much about the temperature or the humidity?

Bradshaw: By understanding what the heck was happening, yeah.

Gaudet: It was the glass transition temperature. It was pre-dominantly the hardband.

Bradshaw: *It was really hard segments in the resin.*

The original binder (Mustang and Stallion) used Estane 5701 which was soft when we started from Boulder. Later when I had a way to measure it I found that coatings made with it and CrO2 had a Tg of between 12 and 16 deg C…. way too low! I mean, it meant it was soft to begin with. But that's because it was already degraded by the time we started coating it. Morthane was harder at twenty-three.

Gaudet: Okay.

Bradshaw: Let me explain that. Metal melts -- it has a melting point, it has some temperature at which it is hard and then at its melting point it will become a liquid at some temperature and pressure (from its characteristic phase diagram, true of almost all solids that don't decompose upon heating). A thermoplastic is a type of materials that softens so that it flows like a liquid and then can be cooled to solidify to the shape it achieved as a liquid ... in other words it can be molded into a new shape. . Rubbers-- or elastomers, which we're dealing with for binders. Elastomers are tough -- rubber bands, they can stretch and then snap back.. If you freeze a rubber band below a specific temperature at which it is no longer elastic but glassy,(the glass transition temperature or Tg), it will shatter like glass-- okay?

[Polymers and plastics are a very complicated group of materials that can fall into almost all the other areas of material properties.] The glass transition in polymers is in general not a sharp point. It's one of these-- it goes like that <draws in the air negative slope> and the width of it tells you the range at which the material has resilience and toughness -- in other words, "How much can I stretch it?" And when it's glass, it's like pulling steel. Once it gets to rubber, you just start stretching and the tensile modulus just drops as temperature increases. In other words, it's got less force to take to stretch it. A true elastomer when you let go of it and it goes right back to where it was. If it doesn't go back, it's not a true elastomer -- it's called a thermal set. Right? Where you elongate it and that-- unfortunately, our tape products use co-polymers that once you melted them, they didn't always go back. So they got smoother and smoother --

Phillips: Skinnier.

Bradshaw: --and now you had stiction and all kinds of things. But the electronics guys loved it. They called it their reference tapes -- they'd run these tapes *a lot of times. All the defects had been cleaned off and* *the tapes were smooth and compliant – so they had low errors and good amplitude; just not durable or representative*.

Gaudet: Yeah, but we had HTI [Head Tape Interference] ramifications--

Bradshaw: But I loved that. I'd be in where these test guys were saying, "We have these tapes -- you can't have my reference tape. I've been running this for a year and a half."

Gaudet: Right.

Bradshaw: And it had thirty something decibel amplitude at that specific recording density across a reference head. – they said "You guys can't make good tape -- this is your target -- you gotta make this." So then we finally got a micro topographer to actually measure the surface roughness.

Gaudet: It was smooth.

Bradshaw: And they had knocked all the asperities off it. Nowadays we call— it's still rough tape, you know, because it was, I think, R-sub A, it was like nineteen? You know, it was ridiculous roughness by today's standards. Micron, actually, micron. We're down in angstroms now in LTO. Anyhow, in fact, if you believe the numbers, today they're reaching atomic dimensions.

Gaudet: Well, you have to.

Bradshaw: The point is that we were looking at these things reacting and meanwhile, in my lab, we were constantly going after the fundamental stuff. And, of course, my audience was getting very limited as you can understand from you guys after listening to me for an hour, people were getting awful tired.

Gaudet: I listened to Ric for about a month straight--

Bradshaw: You fired me twice during that month!

Gaudet: --during those discussions and then we kept having them, every day, and he would sit down and explain to me what he was going to do and I finally got a grip on what it was and he showed me test results and so on. And I told him, "Go for it! Do it!" And he was going to do that anyway. And we had a Band-Aid to ship it and we shipped I don't know how many cartridges--

Bradshaw: Nine million.

Gaudet: No, not nine million.

Bradshaw: Yes, it was.

Joel: Of Pegasus.

Gaudet: Nine million?

Bradshaw: Yes.

Gaudet: <whistle>

Bradshaw: Remember we also had PDM. PD Magnetics[32], which was a disaster. That's my fault, too. Because I was telling them, "Do Sonoita." And they didn't.

Joel: Didn't we replace them all?

Bradshaw: Every bit of it.

Gaudet: Yeah.

Gardner: So you shipped nine million cartridges and replaced nine million.

Gaudet: Oh, yeah, we replaced them once we had a--

Gardner: And prior to that you had twenty percent yield for every one of those nine million were shipped, you built five times that?

Bradshaw: Yes.

Gaudet: Well, the twenty percent yield--

Bradshaw: That's overall.

Gaudet: Wait a minute. Let's explain.

Bradshaw: We threw away a lot of the stuff from the jumbo.

Gaudet: The twenty percent yield was when we did a hundred percent tests, because we had the problem. Not all cartridges had hardbands.

Bradshaw: Everything that had a hardband didn't go to the winder or the slitter.

Gardner: Is there a dump somewhere in Tuscan that's full of chrome dioxide.

Bradshaw: Believe it or not a lot of them got incinerated.

Gardner: Incinerated.

Bradshaw: For a while there, remember, we had another whole challenge. We had to prove to the EPA that this wasn't toxic.

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[32] Philips DuPont Magnetics, now RMG International, see http://www.rmgi.eu/pdf/rmg_international_bv.pdf

Gardner: You are aware of the chromium six problem in California?

Bradshaw: Yeah. In California, you had the strictest rules in the world.

Gaudet: --after Sonoita. Then after we demonstrated--

Levine: ‘Scuse me. Just listening, there’re two of you talking at the same time a lot. That will transcribe into a mess-- a terrible problem for the two of you.

Gaudet: Okay. Other than that it’d be good, because of what we’re saying, it’s probably gonna be a little nonsensical. But I--

Levine: No, I think it’s all very interesting.

Gaudet: I wanted to clarify a point. The fact that we had these tests on the manufacturing floor of the final product before we shipped it to make sure that we weren’t shipping problems to our customers. After Sonoita I don’t think we continued that test. At most we probably did a sample.

Bradshaw: Eventually.

Gaudet: So, not only the yield-- and the yield when you said “yield” it was twenty percent, in that range, because of the hardbands we were finding. When it went up to-- you said ninety percent when we finally stopped testing all together, or small samples, there was hardly any fallout. The Sonoita tape didn’t require-- with the adaptive cross-parity and all the recording channel enhancements that we had: the adaptive cross-parity, the error correction, we didn’t have to worry about it (the infrequent occurrence of hardbands).

Gardner: You have a question?

Rizzi: I wanted to find out whether we did, like, a recall on the stuff that we shipped. And we basically have already got to that point as--

Gardner: With a recall and low yields you must have had a challenging disposal issue. Nine million-- if that was over a few months period?--

Gaudet: Few months.

Bradshaw: Actually, it was almost half a year. ‘Cause there was inventory in Europe. I’m sorry, I really don’t mean to contradict you but sometimes my memory is different. The other thing you have to understand after we announced this, everybody who was in the media business announced they were going to make a 3480 cartridge, okay? Rhône-Poulenc, 3M, Memorex, Ampex, Kodak even thought about it for a while, remember? And they made videotape out of some place in New York. It wasn’t Rochester. But anyway. Maxell, TDK, Sony—

Gaudet: <nods agreement>

Bradshaw: and then there was Rhône-Poulenc. All these kinds-- some of these I've never even heard of … And then Anacomp and Dysan. Remember these--? Well, and, of course, here I am trying to solve these problems and meanwhile guys marketing in the field are handing me these cartridges saying, "We need to know what's in this." And so Ron Rhodes , would go off in testing with Tom Reed-- go test them, see if they met *our interchange requirements and then try to evaluate them against Sonoita, chemically and mechanically ... a lot of effort which we had to do but didn't really count toward our as stated "job" in development*. Meanwhile, I did the chemistry on all these. We wound up with a database of everybody's data. It turned out that's-- when you said about replacing it, if that wasn't bad enough that we had bad product out there, within a very short period of time there must have been thirty million cartridges. That's-- the 3480-- and the reason you're talking about this-- was absolutely a home run. I mean, from all the bugs and everything we beat ourselves-- it was such a leap forward. People couldn't get enough of them and the geophysical industry just jumped on them because it was costing them so much money to haul reels of tape and half-- they had to buy two reels on every shot they took, because taking them off the boats by helicopter or whatever, they'd bang the wraps and they wouldn't get all the data off. And this cost them millions to do the shots off these exploration rigs. So, when they got the 3480 they went-- I think that was the first standard, Joel, that they went just like that. <claps hands> If you wanted to do interchange and geophysics it had to be on the 3480. So, we couldn't make enough just for that industry sector demand.-- think about it. These guys don't buy just a lot of drives, they buy ten drives and thousands of cartridges, so we were bottlenecking the program, which I remember that meeting, 'cause you were there, so was Raj Raheja from manufacturing and he was saying--

Gaudet: Abuzayyad was our Division general manager.

Bradshaw: No, no, no. I'm talking about Raj Raheja.-

Gaudet: Ah!

Bradshaw: Raj was sitting there saying, "I cannot make more tapes unless you give me more money. I can't start another production facility….not just a coater but slitters, winders, testers and overseas distribution points. I need another--" and we had no time to build another line anyway. That's the reason we were working with PD Magnetics. They made chrome media for DuPont. The problem is we stuck it to them, really, quite honestly, politically, because we were already working on Sonoita and they wouldn't let us get it to them. You were gone then <points at Bill>, so it's not your fault. You wouldn't have let it happen. But the management of Tucson really wanted to make sure that all our product made money and NDD[33] had something to do with that, the sales team.

Gaudet: Right.

Bradshaw: Because they wanted a proprietary tape product. And it was. It truly was. And I think the target was twenty-five bucks a cartridge retail price? Do you remember what it was--

[33] *National Data Devices sales and distribution team of salesmen that sold everything from tape, typewriter ribbons, punch cards, everything except systems. [Bradshaw addition]*

Joel: That was starting out, yes.

Bradshaw: The point was not only did we have to recover all the ones in our production of Sonoita-- even with ninety percent yield, we were having a hell of a time making ten million, okay? But by the end of the year though the cost of making a cartridge dropped -- thank god, because the price was dropping like a rock because we weren't throwing all the tape away. We went down to, like, five bucks a cartridge and selling them for twelve. I'm not sure how much it-- but by the time-- by the way, when Imation got done with it and then I think it was down to a dollar sixty. It cost more for the plastic than it did for the media.

<laughter>

Bradshaw: They literally sold everything but the squeal out of the pig. I mean, they made everything. And the other thing is they used to scrap ink when filters. Remember, in the old days the longer the process that as we got smarter and down the road we did things right, magnetic tape-- we used to filter to get the lumps out. But that's not filtering. Basically, you're collecting good stuff. And these filters are not cheap, like sixty to a hundred bucks. And they'd plug up. What do you do with them? You throw them out or you incinerate them? And we had another thing of incineration, remember that?

Gaudet: Oh, yeah, I remember that.

Bradshaw: It was a nightmare. Well, with Sonoita, we didn't have lumps and the filters lasted forever. And they literally said, "That can't be right. Something's wrong here." Duh! Anyway, we learned a lot of lessons the hard way and we went MP, magnetic particles after the 3480, and we tried to use that with our partners, but that was such an uphill battle. That's really what caused us, I think, a lot of our delays then in the media. I'm talking about the media side.

Gardner: Okay. So, I think that does a nice job on 3480 and media.

Gaudet: In the end we shipped a very quality product.

Bradshaw: And none of our tapes ever failed. Thirty years later.

Phillips: More compact-- the drive, small, very hardy cartridge. It was a great product.

Gaudet: And we had technology that was extendable and we validated that extendibility if you look at what happened-- 3490, double track, so on.

Bradshaw: And those drives are still up and running all over the world. You'd be surprised.

Gaudet: There's a lot of headway--

Bradshaw: There's a lot of STK drives as well as libraries all over the world based on the 3480 model..

Gaudet: Even DASD started using the MR element. They resolved their Barkhausen noise problems and non-linearity problems -- bias linearity. But they were able to get it into DASD drives. So the MR element is a mainstay for magnetic recording and we were the first to come up with it and put it in a product, a successful product.

Bradshaw: So then the other thing we did well is RAS, using field data to-- the RAS was the reliability and service--

Gardner: Availability, Serviceability.

Bradshaw: And in the old days it was a lot of lip service, in my opinion. But as we started getting more field data we were really rolling that into our code releases and our dry fixes. We fixed our remaining small impact lot to lot material problems, which would have never shown up in tests, which were statistical not really long term high volume lot variation tests. Again, customers will do things to drives that nobody in their right mind would ever do. But if you solve them for them, guess what? They don't call anybody else. They call you: "I need you to make this drive work in our environment not a test lab."

Gaudet: But sometimes the test lab does things that the customer won't do.

Bradshaw: Yeah, yeah.

<laughter>

Gaudet: So, there's two sides to that coin!

<laughter>

Bradshaw: Like the jelly donut.

Gaudet: Yeah!

Bradshaw: The other one was the peanut butter sandwich -- a guy was being laid off on the test floor and he stuffed his peanut butter and jelly sandwich-- think about the size of this cartridge. He stuffed it into the front of the cart-- let it sit, then ran a tape in and ran this crap all the way through the head, pulled it out, did it again-- about four drives on the test floor and we had all these things were failing. And, remember, they would run the tests all night.

Gaudet: We were able to diagnose that one <laughs>

Bradshaw: Yeah, they sent it to me and I said, "This is peanut butter and jelly. How the hell did it get in our tape drive?"

Phillips: It was a digestive.

<laughter>

Bradshaw: But, so, we had a lot of interesting-- and I haven't told you about *investigations to chase down things that were of human origin and not design or process problems…..anecdotal stuff*. People used to put their coffee and stuff, knock it over into the drive. We had that and we had the soda-- Coca-Cola-- "I don't drink Coca--" okay, fine. So, you had me go analyze it, find out if it was Coke or Pepsi. Turned out it was Coca-Cola and the guy who just said he didn't drink Pepsi he was the one that given the <slaps wrist>-- fired.

Gaudet: But, to answer your question, that's the bottom line of the development cycle, implementing it, the cartridge, the tape, into the 3480 drive. We took you through all the trials and tribulations, taking you through the technology and what that consisted of in terms of the MR head, the chrome dioxide media, and the ramifications, and the iterations we went through. The recording channel was using state-of-the-art technology from vendors and internal IBM. And there were some-- you know, read-write coupling-- noise problems, coupling problems, but we were able to detect them fairly readily. We had a cable problem because of the eighteen tracks and getting that all isolated and insulated and--

Bradshaw: We also used tubing, 'cause there's pneumatic air system. On the tubing originally they used was blowing oils into the tape path, which took us a while. Then we wound having to fix that with silicone tubing that were rinsed and pre-baked *to prevent silicone oils from being slowly accumulated in the tape path or on heads or tapes*. So, we changed a whole bunch of materials problems that you only find when you build enough of these things. So, we did-- and most of the customers never knew it. We fixed it all.

Rizzi: You were shipping product based on Pegasus, implementing Sonoita. How significant was the phase in? Because you're in production and shipping product that you have a lot testing that you're doing to ship and at the same time you're using the same processes to bring in the new Sonoita. How significant was that problem?

Gaudet: How did we switch from [Pegasus to] Sonoita?

Rizzi: Just that-- the logistics of that has to-- my mind says it must been a big problem.

Gaudet: The serial number of the cartridge, it'll tell you that.

Rizzi: No, but I mean you're running process-- you have manufacturing process--

Bradshaw: I know what your question--Let me tell you how we did it.

The decision was made to stop coating Pegasus but to turn all the already coated bulk media into cartridges.. which was a waste of resources, materials and caused a lot of expense to recover, but that is how Sonoita was phased in. We stopped coating Pegasus and scrapped most of the Morthane 310 N binder used to make it. All production after June 1985 as I recall was Sonoita media -I believe but have the actual date and implementation plan somewhere in my Tucson Lab files.

Gardner: Okay.

Gaudet: Well, he developed it in his lab.

Bradshaw: He's asking the right question. Tell you the truth, we did it--

Gardner: Let me rephrase the question, because I think that the question is you have a manufacturing process with one line building jumbos and you need to make a fundamental change to that line.

Bradshaw: That's right.. And we couldn't make enough as it was.

Gardner: So how did you manage that transition?

Bradshaw: I'll answer the question, because I did it. Okay, some of this is all accidental. I carpooled with the people down in Building 10 who were making the product, okay? And I knew them. I was down there all the time. I brought in donuts on third shift and I said-- we made the mix in Building 41-- 'cause we couldn't take their line to make the binder and mix it up. We made it in Building 41. Okay? *The Lederle team that was in Tucson Frank Plant, Tony Candelaria, Bob Brown and several others ran a pilot scale coater similar to the one originally making all or 3480 tape in Boulder. We literally rolled this big stainless steel cart with a pressure tank blanketed with dry nitrogen down from the Bldg 41 pilot line mix room,, down the spine to the media manufacturing plant ,Bldg 10, took it in the back door through their mix room and hooked it to the filter and pump station at the coater head in between the second and third shifts as an unsanctioned (no Engineering Work Request, EWR) and the manufacturing lead team under Kim Oldright and few real great line operators (Kim's best people) ran two jumbos using up all the ink that the development team in Bldg 41 had made from the very limited supply of full scale Morthane CA 371 resin (the morthane resin we co-developed with Dr Charlie Amirsakis) that we had that November in 1983.*
[01:15:00]
And the jumbos all have Julian dates. It's 1983, 3354. I remember that-- day one. And then we snuck it through the slitter Well, I went down 'cause you have to let it sit so many hours-- it had nothing to do with cure, but that's what they thought it was. But, anyway, so it was gonna be first shift in the morning when they did this. Well, in those days we were still chasing the hardbands and everything else. So they're down there getting ready to do on the reel test and this engineering jumbo *of Sonoita covered with a plastic trash bag and with no EWR number assigned to it is somehow on the floor next to the hardband tester… It had been slit as early as possible as we were trying to sneak it through the process before the alarms went off by the process police! As I recall this all happened around 8 AM the morning after we had coated it (which started before midnight).*

Gaudet: Now is this your final Sonoita?

Bradshaw: This is it. I had already done four runs under the table in Building 41 with six-inch coatings.

Gaudet: Oh. Okay.

Bradshaw: What he said is the real question: How did we sneak production-level coatings into this plant?

Rizzi: No sneaking. I thought you would have had permission

Bradshaw: Oh, no, no!

<laughter>

Bradshaw: Raheja threw me out of the meeting. He said, “This is the stack we are given and you will do it that way.” You know, to hell with you. And then my boss, Mick Marchese, nice guy but he would not fight the battles. Okay. Mick was a nice guy, but he just-- and Dick Stacey was my manager then. Nice guy, but he’d just there and stress and wrap more tape around his filter on his cigarette.

<laughter>

Bradshaw: That was one of his quirks. But my point was I basically got it *through by using my connections with various people in the tape manufacturing plant. Lil Lackett was one of the lead techs in the process control inspection team and she collected the samples and ran them without paper work.*. Kim Albright was the manager of the mix room, he had really good lead engineers on the coating. [Chuey Perez was one, they all got "FAP'ed" in 1988 when IBM closed down the manufacturing line and sold it to 3M ... only a few of them got hired by 3M.] But we snuck this thing on an-- you can’t get any of that. You have to have it approved, because you’re interrupting production. We had what they call engineering run.

Gaudet: Yeah.

Bradshaw: But you could only get so much time in engineering runs. So they managed to wait till a coater was going to go down for the back coat. Remember, Pegasus had to be back coated. So they had to shut it down. That meant I could coat the front coat, but I couldn’t coat on the back coat line- they’d have to re-web so it didn’t go back through the other coater. So, I said, “Okay, we have a window: One hour.” So I get down there. I had two dozen donuts. I went to everybody in that plant, brought ‘em coffee-- outta my pocket. You know, but, believe me, it was a good investment. The point was we ran it through it and the next morning I went down there-- ‘cause we’d carpool, I went in at six. I’d been up all night. But I went home to say hello to the wife, pat her on the head and say, “Okay,” then went back to work. Get there and here’s this jumbo and everybody down there who worked on third shift knew what was going on-- well, as luck would have it, Raheja was walking somebody from San Jose-- may have been Jerry Harries. Anyway, it was an audit, they were going through the plant and here’s this jumbo -- right in front of them – it’s all slit. There’s forty-eight of them. Twenty-four-inch wide jumbo slit to half inch wide. And the ones on the outside they threw away then in those days. But there were no hardbands on it and they were putting it in front of the ROS, the tester, and all the other production ones in front of it got stripes and bands and things like that-- hardband looks like a tin can, you know, corduroy road. And “What’s this?” Raheja said. “Oh, this is our standard one. These are rejects over here.” And the guy standing over there -- what was his name?

Gaudet: Jerry, probably.

Bradshaw: Kim Albright was the manager of the mix room, he had a really good technician on the slitter. *He was standing there in front of the bulk media rolls (jumbos) waiting for hardband (ROS) testing I’m behind them all some distance away as I walked in not expecting this audience….with a cup of coffee or two …I think I actually had a cup in my hand for the slitter operator to try to sweet talk him into running our Sonoita jumbo quickly before it got discovered by the process police or management*. And, by the way, you had to suit up in those days and you didn’t bring cups anywhere near the dry side. So I was out and looking through the window just going, “Ah, shit.” Because they are looking at it and this is all illegal -- everything had been forged. The document to do the engineering tests was all fudged. The signatures were all copied from other people's memos. It was totally illegal, okay, from an IBM standpoint. And we originally had it covered with plastic bags. You remember the plastic bags to keep the dust and dirt out them?

Gaudet: Yeah.

Bradshaw: Garbage bags! You know the black-- cut in half. Well, this one had "Engineering"-- what did we call it? We didn't call it Sonoita then. What was it called?

Gaudet: Pilot line

Bradshaw: No, no. -- we had a name for it.

Gaudet: Oh.

Bradshaw: And it said, "Ric Bradshaw, engineering". And Raheja just saw that and said, "What the hell's that?" The tech said, "Oh, it's an old jumbo that Bradshaw had there and we just kinda get it in front" He says, "Well, why is it so flat?" "Well, he'll tell you that when we get rid of all the data." Jerry Harries, who knew me for another reason-- and so I get a phone call in the lab, Mick's [Marchese] nervous, It was upstairs --. across from your office <looking at Bill>. Bill was on one end and MIck's office was across from you-- remember, in '61, upstairs?

Phillips: Yes.

Bradshaw: Okay. And I go in there and you could tell how stressed Mick was. He smoked-- chain-smoked. This was the days when you could smoke in your office. He had a big glass ashtray and the whole thing was full in the middle with cigarettes all the way around and it was only noon. You know, so I said, "Uh-oh, this is not a good day." You remember?

Gaudet: I remember. I used to smoke four packs a day. Mick (Marchese) smoked eight packs a day.

Bradshaw: The reason I'm saying that is I was in trouble! "You're impacting production." This is the same thing they were saying. "We can't make enough tape." Well, that afternoon they had the engineering status meeting. You have the thing where production and then the engineering runs come up and they give you status. Kim gets up-- and I'm down there and Mick's in the corner, "Oh, my god." And this is Raheja's meeting, down in Building 10. And they're going through the day's yields and so on. "First shift yield, 19.2." By the way, they had all sorts of yields: ink yield, soot yield, ROS yield, cartridge , amplitude, etc.. We had things for things for-- and, then runs were pulled off the cartridge. They weren't spun right. We had a little bug sometimes on length, but anyway. Then this other jumbo shows up and it says, "EWR 3356", Amplitude: 39db." Okay. "Orientation: 3.9".

Gaudet: <laughs> Jeez.

Bradshaw: "Defects: Zero"! Okay. "Yield: 98.7"! Dat-dat-dat-dah. And Raheja says, "What the heck's that?" And Kim says, "Oh, that is the thing you didn't want to hear about. That's the engineering run we ran two nights ago." And that did it. They closed the meeting, called me and Mick said, "I didn't know anything about this." That's all right. Plausible deniability. I just said, "Nope, it's mine. I did it and if you want to fire me, fine. But you shouldn't be shooting this product, you should be shipping this one." And they said, "Okay." Then Lynn Baker of product test calls a meeting for Monday. He said, "I want you to pitch what you did to my team," 'cause they're living with the day-to-day realities of what they're trying to do to test this. And he's saying, "I have a window," because we were on some regression testing--

Gaudet: Now, this is where I found out about it about that time, but I still don't know why you didn't see me first. Because I would've given anything to be a part of it

Bradshaw: Well, I knew you did, but remember Gus has his own battles.

Gaudet: Gus and I were like <brings thumb and index finger together closely>

Bradshaw: <laughs, pats Andy on shoulder> Okay! I love it. All I know is, Al, to answer your question, we did it under the table, but once we had the numbers, then it was a question of why are we making Pegasus? With those kind of yields we could repopulate in four days. And that's exactly what we did.

Gaudet: Yeah. But that was in '83.

[Editor's note: Beginning of section of clarified overlapping dialog]
It was January 1984 when we started getting production Sonoita. But we continued shipping Pegasus until we had the inventory of Sonoita built. I'm pretty sure we started doing-- what do they call it? Early ships in early 1984?

Gaudet: Yeah.

Bradshaw: And beta tests was something. This is where I go back to what I recall about geophysical. They got the beta test and they went "That's it we want ten thousand." We didn't even have the product announced and they started buying these. I mean it was that big of a home run.

[Editor's note: End of section of clarified overlapping dialog]
Gaudet: Exactly.

Bradshaw: But we were building an inventory, because we knew after it was announced, the volumes of our stuff that was coming back from the banks, geophysical, the government was potentially huge -- they didn't want just a thousand drives and ten thousand cartridges. Remember we thought we could ship them all with a hundred cartridges per drive to get them started, I think it was? Do you remember, Joel? It was a hundred, I think? Which was, by the way, it was packaged in thirty packs. You remember?

Gaudet: Yeah, I remember.

Bradshaw: And so a hundred seemed like-- that was a big stack about <draws large square in the air>-- well, that's this week's production. Well, these people wanted thousands of cartridges. Well, we couldn't make it at that time.

Gaudet: Here's the point. Ric's initial experiment was a booming success. He did hit a home run with it, but you can't take that and ship it. We went through extensive product testing.

Bradshaw: Nobody believed it! <laughs>

Gaudet: We went through extensive product testing. We went through extensive stress testing. We even overdid the limits to make sure that there was nothing that was going to flare up on us. And nothing did. And it took us the better part of-- I don't know-- I'm not gonna say a year, but it must of been a least nine months or so. And then we had to convert the line over. 'Cause you can't just start on one jumbo, convert the line! You gotta go through testing! We ran more engineering runs. It wasn't just one engineering run. We populated lots of cartridges. We did a heck of a lot of testing.

Bradshaw: The other thing is there was no commercial source for the binder. The one that was made in November I made with Charlie Amirsakis in his lab in Lake Geneva, Wisconsin.-

Gaudet: That's right.

Bradshaw: And we poured the molten resin on to a cookie sheet, poured liquid nitrogen to freeze it hard enough to hit with a hammer and shatter it and I had a bag and I got on an airplane, flew back to Tuscan and that was the world supply of Sonoita.

Gaudet: Yeah, we had to get that also. I mean, there was a lot of work that needed to be done-

Bradshaw: So then we had to get an agreement with the people in Morton-Thiokol to scale up. They wanted to come in and "How much you gonna buy?" So, now the chemical engineers get involved-- first of all, we're gonna cut the volume in half just because we're not doing a back coat, right? And we're gonna coat the coating in half the thickness. Whoops! You just did all the wrong math. You said the wrong thing. But we think we're gonna double the production. "Okay, now we're listening." And "What if we gave you joint patents on the use of the resin?" So one of the things that's interesting is it's my name is on the patent[34] IBM owns totally for the formulation for chromium dioxide for the tape drive. But the joint patent[35] for the binder device that I was involved with Charlie; we both jointly designed the molecule that worked-- is owned by Charlie]. So he now has a license to be the only supplier of that resin to anybody else in the world and that's where they made their money. 'Cause within six to nine months of Sonoita hitting the world everybody bought his binder. He couldn't make enough of it. His total capacity was forty kilograms a day and he wound up being absolutely stressed making just enough for us.

Gaudet: There are so many horror stories you can tell. My "fondest" memory of the test lab-- and generically-- is the 3380 and I was up for twenty-four hours straight for about four days. Same clothes, wasn't shaven. Nothing. I just stayed there in the test lab and watched them crash (the film heads and film disks) and tried to understand, look at the read signal, try to determine what had happened-- I mean, it was just a booming disaster. That's what I remember and then on the 3480 we were running these

[34] US Patent 4,525,424, Bradshaw. June 25, 1985
[35] US Patent 4,568,611, Amirsakis, et al., February 4, 1986

extended long-term data reliability tests and I would move myself up to an oscilloscope and take a look at what was happening to make sure everything worked right and so on. And I spent better part of a month in there.

Gardner: Okay. Bill?

Phillips: Product Test's job is to break it. The question is what does it take to break it? Our job is make it unbreakable and so <bumps fists together> it was a constant war even when we were partnering with them.

Gaudet: Yeah, it had to be legitimate.

Phillips: And they did their job as they should: Try to break it, find out what the problems are.

Gardner: Did the tape folks do product tests the same way with disk drives, ABC tests, system ABC tests.

Phillips: Yes. ABC in the beginning.

[Editor's note: Beginning of section of clarified overlapping dialog]
Gaudet: Yeah, it became EVT, Engineering Verification Test and DVT, Design Verification Test.

Rizzi: We dropped the one between <inaudible>

Bradshaw: Yeah, that's because it costs us time. But he's right <pointing at Bill>-- there was this in between-- because we used to give them a snapshot before they went into full drive development tests so they didn't waste time, because, unfortunately, in '81-'82 we did that too many times.

[Editor's note: End of section of clarified overlapping dialog]
Gaudet: There was manufacturing verification.

Bradshaw: The final one.

Gaudet: So we used the first two and that's where we really got hit in the face with all this cupping and all that. And some of that we saw in the lab, but far out from there-- the hardbands, all that sort of stuff. But we had to be all ready and go through-- got it-- I mean, MVT used to last at least six months as I recall. It wasn't a quick snap of the fingers, ship it. And it was during MVT on 3480 that we were doing our data reliability testing. And less than one error in a trillion bytes transferred. So, it's very extensive testing. So Ric went through with his first jumbo and it was phenomenal! And going in and really understanding the data and the results that he got and the follow-on testing that was done with that small sample size. I got very comfortable with it. But now you gotta go through the steps.

Bradshaw: You have to scale up, but also don't impact the product! I mean, we couldn't just turn the line off and switch over.

Gaudet: Because we felt fairly comfortable that we were stressing it, doing our testing in house, twenty percent yield-- at least it wasn't gonna keep us from shipping the product, but we had to get Sonoita in as soon as possible because we weren't gonna let that crap stay in the customers' areas, because we wanted the good stuff. We don't want, you know, some customers to have Pegasus and others to have Sonoita.

Bradshaw: But IBM also didn't want to bad mouth Pegasus -- we wanted the product to be universally accessible and shippable. So we did the right thing.

Gaudet: Exactly. So there was a lot of hurry to get this into manufacturing and Raj Raheja finally vanished from site. S-I-T-E and S-I-G-H-T. He was gone!

Bradshaw: Flemming Golden took over.

Gaudet: I think I had a long talk with Gus Vascilliades on that. Because when Ric unloaded on me that war story, I remember going to Gus and Gus was our ally.

Bradshaw: Well, I guess he was once the data was in ... but nobody in the media development ever got invited to his evening meeting that I heard of….-- it amazed me, anyway. The other thing, relative to his question about the management of this thing, one of the things I would say that came out because as Andy just said, the following Monday when we did this run and Lynn Baker and Tom Roy in Product Test wanted a complete data dump…on that Monday meeting and understand why Sonoita was so different….if we indeed actually knew!

Gaudet: Oh, yeah. He's a great guy.

Bradshaw: Okay, my empathy for all of you people listening to this tape-- sitting through three hours of me describing Sonoita, the clinical formulation--

Gaudet: You guys were lucky! <laughs>

Bradshaw: These guys were really super, 'cause what they were trying to do was get a fundamental understanding of why this stuff does what it does. Because they're trying to commit to an accelerated schedule without all this data that he's talking about. Because we're under the gun! This product is a home run. We can't turn the spigot off, okay? So, I was exhausted, 'cause these guys were asking a lot of good questions. And what happened is I think a major breakthrough that I think did very well in the future was instead of this adversarial relationship with Ken Ouchi's Product test organization as it had been for years ... we had to change that, they became an extended team of development. In other words, instead of doing this "Throw it over the fence; tell us what doesn't work," you do it while we're doing this. So, send us the data; we'll find out what's wrong. Some of it was code! Well, you don't break the code and then send it back for a fix and restart ... not time and very inefficient discovery and response to problems -- if you find out there's a bug, let's work on it this night and keep going! So, we did this and our time to data--like, when we did 3590, we did it in six months.

Gaudet: Yeah.

Bradshaw: And you think about it that's-- we would never have done that in the old days. The reason is Tests was our ally. There were not in the tank..-- by the way, they didn't fudge anything.

Gardner: Was there a organizational change that resulted in this change?

Bradshaw: There was, as you remember there was that quality assurance organization, too, for a while, that really went up and down.

Gaudet: It was Ken Ouchi that was managing Product Assurance here in Tucson and Mike Liddicoat was working for Ouchi, and I think it was Liddicoat--

Bradshaw: That was our ally.

Gaudet: And his team--

Rizzi: Liddicoat came out of development into the test operation, and had this empathy for development.

Bradshaw: No, he did, he drove it. No doubt about it, he did it.

Gaudet: Yeah, yeah, yeah.

Gardner: I think in San Jose, for example, for quite a while, the product test reported up to the site manager, development engineers reported up to the lab, right? They didn't have common management until much higher in the corporate organization

Gaudet: Yeah, you're right.

Gardner: And there was the tendency for adversarial relationship.

Bradshaw: Well, the other thing is the culture at that time. If you weren't doing your job, you rubber stamp would develop gave you. I mean, that was your job to find the holes. Like you said, "Break it!" Well, I was trying to tell them, "You guys keep working on breaking it, but I'll tell ya why it ain't gonna break. This is why." And by the way, in the meantime, I'm gonna keep exploring the weak links of this thing. We didn't know what the modules would be. What I was finding out, is it took us till '86. And this was the guy, I don't know if you remember when we got Sam Falcone, a PhD chemist, went to school at ASU, who was a urethane chemist, okay? He joined in and he did some really nice work independently to verify the chemical reactions. And it wound up being as a synthesis you use chromium dioxide (our pigment of choice) to carry out a very efficient but oddball reaction. And he wound up publishing the reaction in the Journal of the American Chemical Society and we both presented the paper at an American Chemical Society meeting in Las Vegas in 1987. My point was as we fundamentally understood more and more of this, we could then do predictive design. Now that is a huge breakthrough. Because instead of mix and stir and cook 70 things. We said, "If you do this, we do two iterations, run DMA." We didn't-- we could literally make useful tape coatings in a 50 cc Eiger mill. We would coat it in the lab on a thin five inch wide strip of Mylar and air dry it and test it. As well as cast a free film from the dispersion for DMA.

Gaudet: Yeah.

Bradshaw: That's what we drove the industry to.

Gaudet: Except for glue dots and hardbands, you wouldn't have caught that.

Bradshaw: No, no. No, that's manufacturing -- but by the way, Sonoita doesn't emboss like Pegasus. The modules is that much higher, and the glass transition is 42-- by the way, the more age, the harder it gets.

Gaudet: Hey, don't take that to heart, right?.

Bradshaw: No, I'm not. 50-year-old tapes have gotten better, not worse.

Gardner: I have a question for Bill. You were at STK by this time?

Phillips: '87 to '92.

Gardner: So you were the competitor to the 3480.

Phillips: No, no. I was at Brown Disk ‘84 to ‘97.

Gardner: Okay, -- then you went to STK.

Phillips: Yeah.

Gardner: And you were working on the STK equivalent product?

Phillips: Yep.

Gardner: Was STK was making its media?, or--

Phillips: No, no, no. We never made media.

Gardner: Right, so, what was your perspective of the media suppliers from an STK point of view?

Phillips: Bring it on.

Gardner: I beg your pardon?

Phillips: Bring it on!

Gardner: Bring it on? Did you see the problems these guys have been talking about?

Phillips: No. Didn't see any of those things.

Gaudet: But they didn't have the capability,

Bradshaw: Your media guy at STK was Lionheart, wasn't it?

Phillips: His name was Michael Linhart.

Bradshaw: Linhart, okay.

Gaudet: Yeah, I remember him.

Bradshaw: Okay. I get a call, I think, look, one of the things I've learned early on is you can be competitors in some ways, but sometimes for the good of the customers, basically you gotta stop this horse shit and tell people the truth, okay? But you don't give away the family jewels. It's mine to do. It's IBM-owned, right? But he calls me and says, "What is different about your tape?" And I said, "Well," we were already telling customers, so why can't I tell you? See that's my angle. I didn't ask for permission, -- what do you do? Don't ask for permission, ask for forgiveness, so that's exactly what I did. So listen, he calls me at night at my home. How he got my phone number, I think he got it from Lamar, because Lamar Nicks had left IBM and gone to STK, because he wanted to work with Bill. Okay, and so he gives me this call, and I told him, "Don't use anybody's tape but Anacomp, IBMs, 'cause they're all our binder and that is the only coating that will work with CrO2." So they didn't have the problem, but the big thing is that what hurt us was we stopped any follow on after the decisions of 1988 and the down turn at IBM.-- we did the long-length tape and that was it. We never did the thousand gigabyte that they did at Redwood. IBM never did a follow on while STK was still actively using chrome media and improving their drives and libraries…which we did not have. The product that burned me was we were working on a thousand oersted chrome -- small particle, that had a better output than MP, didn't need a back coat, and gave you a higher module and better coat packing and resolution than the best metal particle (MP) tape available at the time.. We should have never done MP, but I lost that to John, 'cause he was in love with Fuji.

Gardner: And MP is?

Bradshaw: Metal particle.

Gaudet: Metal particle.

Bradshaw: And I'm not picking on John. There were decisions being made, but we were much better off. Chrome dioxide was a really good-- but it got a bad rap, because people-- the Japanese had all the patents on cobalt modified.

Gaudet: And iron barium.

Bradshaw: Yes, barium ferrite. Don't get me started on Barium ferrite. Barium ferrite, we also looked at. Barium ferrite, mechanically is a horrible product.

Gaudet: But that's what Fuji used, right?

Bradshaw: I know, and the reason they get away with it right now is how many people actually reuse? Remember when we did tape, when they were doing, tape was actually used in data processing. It wasn't written and put away. *So a lot of the tapes were written and rewritten over and over and moved from site to site physically…so they had to withstand a lot of durability issues that most modern tapes never see since they are now almost exclusively used for archive and are filled to capacity and then put in a library. Many are never read again until they are copied to a higher density format and discarded*..

Gaudet: It probably happened at some of the big customers.

Bradshaw: Oh, all the time. Some of the tapes I got back from the field, they were anything, were jobs that were mounted over, and they overwrote data. Well, they'd write in between previous blocks and corrupt the headers,,, because we didn't have a servo. And if it slipped the wrong way you would chop blocks, things like that. Okay. Thing is, LTO, there's just so many strong things that came from just a stupid decision, but the only thing I think was wrong is IBM should have had-- this is paining me a little bit-- We should have been qualifying the tape. Period. We knew more about tape than anybody in the world. That's me bragging, but it's a fact, okay? But we gave it to MAC (Materials Analysis Corporation)ac in California that did video correlation, and he'll tell you about that. I think it was a mistake. I was trying to sell Liddicoat and John to let us do it. "Pay us to qualify. We'll be independent." You can say, "Look, we'll be very unbiased <inaudible>. Because we don't make tape anymore." But this way, IBM can drive the tapes in the optimum direction to support out head and drive technology which were leading in anyway…-- this was my motivation from Day 1. You want to design the media that doesn't damage your heads. Once you do that, you make one, people will copy yours, or buy it from wherever you qualify. So if we know this, we have the leadership in coating. We had the leadership in the heads. So there's absolutely no reason for us not to do the media! But he didn't want it. But by the time it went to committee, he kicked me off, and put Childers on it. And so I was off the committee. And another thing, in my original spec, I didn't want all this other crap. I wanted a functional test in the cartridge and DMA. I wanted the glass transition. I wanted the magnetics, and I wanted the chemical composition and mobile materials controlled and monitored..- but nobody else even want to measured it. I said, "Fine! We'll measure it for ya. Send us the tapes!"

Gaudet: Are you going to be here tomorrow?

Bradshaw: Not unless you guys are--

Gaudet: Well, John and I can talk about the same stuff for Fujifilm and so on tomorrow.

Bradshaw: And by the way, they won. They are the last company fully invested in tape and dominating the market.--

Gaudet: Oh, that's Friday! LTO is Thursday

Gaudet: Because there could be a real battle emerging, and it'd be better.

Bradshaw: No, it's not a battle. I mean, it's a different perspective . What I'm saying, give him the credit. There was a thing called TRX. We started working on, "What are we going to do with the next technology?" And [Jim Eaton] came out of San Jose, who pitched it to [Paul Lo]! Travan was an 8-

millimeter product, and we started working on [in the 90s] using our technology that we were working on simultaneously with 3M to do the 3570. Mid-point load tape.

Gaudet: Yes.

Bradshaw: Which was a really interesting little tape that was two reels in the cartridge, and fixed guides also in the cartridge which gave us some technical problems but which Fuji MP tape resolved … by accident not design

Gaudet: We shipped that thing.

Bradshaw: And I was dead wrong. I wanted it flat. I wanted the tape flat, and I was wrong. *It turned out that this fixed guide tape path needed cupped tape not flat tape to run straight off the two spools in the cartridge*.

Gardner: If I could take this conversation away from maybe some of these issues.

Bradshaw: My point was one of the things that's happening in the tape industry anyway, is parallel development. And we had a lot of it. And we really benefited from the fact that we weren't on an island with STK in that sense, or our competitors. Because we talked. People kept swapping.

Gardner: We made it pretty clear of the advance of 3480 over reel-to-reel. But reel-to-reel really wasn't that bad.

Bradshaw: No, no.

Gardner: No, and I'd like to hear a little bit maybe from Bill about some of his reel-to-reel experiences both on the drive and on the media side, more so than Travan or LTO.

Gaudet: Well, let me just give you a little lead-in to that, which is very important. The 3420, Model 8, wasn't cutting it. That was our mainstay. That was our tape drive. And there was a lot of money to be made on tape. A lot reason for Tape in the marketplace. But we were having reliability problems is my understanding. IBM gave John Carter, I think it was, a pocketful of money to come and build this plant site to produce a state-of-the-art leading edge tape drive. And so that was the real story. And I think you can understand that there were problems with the 3420. It wasn't measuring up. We weren't leaders in the tape area. And when we really focused in on 3480, we started to build our niche in the marketplace, which we'd almost lost altogether with the 3420, because it wasn't cutting it. That's my understanding. I don't know. You can add or subtract from that, Bill.

Phillips: No, I think that's a good summary.

Levine: Another piece of what Andy's bringing out is also we developed a lot of 3420 competitors.

Gaudet: Right.

Levine: And they be STK, or whoever it was, we had a lot of competitors at that time, and the name of the game was differentiate ourselves. And that was another factor in why the 3480 came about. Not the only factor. There were many of them.

Gaudet: Yeah, that's a good point.

Levine: But another, one more piece of that pie was, "Why do we want to be like everybody else? We gotta be a leader, and we have to be different." And that was the one piece of the puzzle of making 3480.

Hendrie: I'd like to understand a little bit more about the time when you had the 3420. And the competitors and what they were doing, and what sort of innovations they had that you, you know, they were giving you trouble in the marketplace.

Gaudet: Yeah, well, it was more market share-driven.

Gardner: Okay, one at a time.

Gaudet: Cost.

Gardner: I think Bill may have perhaps has the only experience going back to 727 and seeing the entire spectrum of things.

Phillips: Joel claims to be that old.

Gardner: We will get Joel tomorrow; this is our one chance with Bill.

Phillips: Well, tape drives are an incredibly mechanical, electrical-- oh, what am I trying to say? They're the inventions required to run tape from the very beginning of vacuum columns to the Prolay to the electronics that allow us to run slow and stream fast. Were hard to predict. I remember in my thesis defense at Purdue, I did a moon orbit. And one professor said, "What are you using to control your moon orbiting vehicle?" I said, "IBM 3090." He said, "How much does that cost? I said, "About three million dollars." He said you think it's practical to put that three million dollar device to do a moon shot?" And then I'll say-- tell him so he'll never forget it. And I says, "Well, I would imagine someday that'll be on a chip."

Gaudet: Good for you, Bill. Right on!

Phillips: And the pairing of the mechanical capability with the electrical capability with the electrical capability and putting those two together, because the error correction codes which came from the math guys, that head flying and MR heads came from the magnetic guys. And--

Gaudet: The media.

Phillips: Oh, yeah, there was media.

Gaudet: Yeah there was media, right? and it was phenomenal!

Phillips: Yeah, when we got to the high coercivity media and had all that data in a small block, we could run it into a cache and handle the media however we wanted to. I can remember when the 727s, these big hot motors in the back going back and forth. Vacuum columns that needed to be cleaned. It was just-- and the transition from vacuum columns to the 3480-type devices where there is no vacuum, allowed you small flow factors, take up-- well, you remember, there's--

Gardner: Isn't there still a vacuum in the guides?

Levine: No, no, All air pressure and then there is a slight negative pressure.

Bradshaw: Positive pressure. Well, actually, it's in the decoupler. You remember that?

Phillips: Yeah.

Gardner: We'll talk about that on detail on Wednesday, I believe.

Bradshaw: There is no negative side. There isn't a pressure side on the cleaner blade.

Gardner: The problem is these big massive reels with a big mass on them, that are hard to move, and yet you want the tape to move at a fast rate, but knowing where to stop. And so how do you do that cleverly?

Phillips: Well, it becomes much easier to do when you have high density recording.

Gardner: Because?

Phillips: Because you don't need to move as much tape to get that data. And when you have massive buffers that allow you to read forward, and not have to start fast, because we cached everything ahead of time. So when the computer wanted it, it came out of memory. And we could use a slow start time, cache more. So it was a marriage of every-- not every-- but many different engineering technologies. So it was a marriage of every-- not every, but many different engineering technologies. Mechanical, electrical, chemical.

Gardner: You know, arguably, the mechanism in the older drives was more challenging, because you were literally accelerating and deceleration at much higher rates, and moving things around, which, you know, buffering sort of made the engineering job perhaps a little easier?

Phillips: No.

Gaudet: High maintenance; high failure rates. You know, those were all the problems. There was a big piece of problem there that was resolved with technology.

Phillips: Well, error correction tools, double bit error correction.

Bradshaw: One of the things that happened later was he hit a key piece that I think is critical, tape has evolved, which is one of the things that it's been pronounced dead at least six times that I know of, okay?

But the irony is, as new technology opens up advantages in other places, we were able to use it in tape, to expand tape. So one of the things that happened in the LTO timeframe, and in the enterprise at STK-- Oracle now, and STK then, <inaudible>-- is people don't understand that we don't do sector correction or single tracking like that. The data that's written out of a modern tape buffer doesn't look anything like what you think you used to write. It just goes into-- because buffers are cheap. What he calls cache now is cheap. And we're going-- and tape, the data processing rate is unbelievably fast. We go at least three to four clock speed faster in the buffer than we do right on tape.

Gaudet: You're right.

Bradshaw: But we literally take all the data, throw it in the matrix. All things in the matrix. We don't write that data. We write matrix equations on each one of the tracks to rebuild the matrix. Which means you can literally blow a hole in the tape, and get all the data back. All of it. Not just some, all of it. And the thing is, you can have four tracks out of sixteen dead as a doornail and get all the data.

Gaudet: That's right.

Bradshaw: Because it's the matrix. Now we're already to ten to the sixteenth error correction. And you say, "Well, these are all funny numbers." In some architectures, it is. Okay, but in tape, because of the way it's written in the matrix-- and these guys in Zurich, IBM-Zurich, I don't know what they eat, but everybody else in the world ought to eat this stuff, because these guys are creative beyond belief.

Gaudet: Yeah, that's Arvin Patel that gave us the adaptive cross parity code for the 3480. And he was in manufacturing and research in San Jose.

Bradshaw: And one of the first members of the IBM Academy of Technology[36].

Gaudet: Yes, right.

Bradshaw: And I met Arvin. The problem is, Zurich has taken over that with a team in Zurich, which they're just unbelievable. Zurich is the leader in data encryption and encoding, led by Evangelos Eleftheriou who I believe is an IBM Fellow now at Zurich lab. and there's like six of them. And John will give you the rest of these things. And you see his papers all the time. But that error correction means we can use less media, less tracks, and get all the data back. And it means you can do it so much quicker. The other thing is, we can lose amplitude, and all the other pieces. A brilliant guy named Larry Tretter, who did the ASICs.

Gaudet: I remember Larry.

Bradshaw: Okay? Custom ASICs. Remember, we don't have a single channel preamp to work on like DASD (direct access storage device) I'm not picking on it. I mean, DASD has been an amazing

[36] IBM Academy of Technology was formed in 1969 as a society of IBM technical leaders organized to advance understanding in key technical areas. Ric Bradshaw was elected to it in 1994. See, https://www-03.ibm.com/ibm/academy/about/about.shtml

technology and innovations there have been slowly used to extend tape. we barnacled off their technology for a long time, okay?

Gaudet: Okay.

Bradshaw: But what he did is he made ASICs, a custom ASICs with each track could be independently optimized *from adjacent tracks and modules so each individual element could be optimized in real time. We could change a lot of the preamp and head parameters to optimize both the write and read while the data was still being put on tape and keep the head running while collecting diagnostics that allowed us to do a number of things to recover rather than just pull the head out.. So we could literally have heads going south, and figure out, okay, we'll keep in it. If needed a cleaner cartridge using chromium dioxide tape would be run to try to remove debris and lightly burnish the head….if this worked the drive would return to operation otherwise the head would be flagged as needing to be replaced. All this capability came from better ASIC and channel electronics as well as head construction and materials and deposition process improvements*.

Gaudet: Right.

Bradshaw: A quick pass of chrome, just for metal tapes, bink! Back it comes. Now we started figuring out what's going on? We're getting something collecting. It turned out to be a head design. I can't tell you how we fixed it, but it was a very subtle materials change in the ways we laid the films down, that something solved the problem. Selective chemistry.

Gaudet: Okay.

Bradshaw: So the net of it is we're learning a great deal. And tape today is nothing like it was even 20 years ago.

Gardner: Bill, given your, what is it, 50 years' experience in the tape industry?

Phillips: Fifty-seven.

Gardner: Fifty-seven. What do you think were the biggest breakthroughs? If you had to rank them.

Phillips: Thin film head.

Gardner: You mean the separate reader/writer MR head?

Phillips: Yeah, just thin films, in general.

Gardner: Thin films in general. Right, okay.

Gaudet: And that's because you could control the parameters, reproducibility, higher yield, …

Bradshaw: Production yields.

Gaudet: Lower cost, I mean, you know, less labor intensive.

Phillips: If you saw how we constructed 727 head - winding the coils.

Gardner: I at one time had head manufacturing and made 2314 and 3330 class heads on the floor. So I can sympathize with the winding of coils.

Phillips: And I'd say the biggest thing was the marriage of technologies. **S**omeone said, "What's that cache memory--?"

Gardner: Which liberated the mechanism.

Phillips: Yeah, which freed up the mechanisms, which allow us to build more powerful devices--

Gardner: And smaller.

Phillips: And smaller. So electronics had a lot to do with it, besides doing equalization and all the error correcting, checking.

Bradshaw: And there was microcode, too. Embedded microcode. We took the stuff out of the mainframe and put it on the drive, *so it didn't require host management and proprietary software to interface …at least eventually ... for a while the proprietary interfaces persisted and limited the market .. hence the aggressive move to open systems architecture*.

Gardner: How about Mylar? It seems to have been around the longest.

Phillips: Well, I can remember when there <whispers> "One mil Mylar."

Gaudet: Yeah, right.

Bradshaw: *One-and-a-half mil acetate was used on the earliest tapes, then polyethylene terephthalate (Mylar is the DuPont trade name) became the standard in the 60's…the 3480 started out at 1 mil which was 100 gauge but then was shipped at 96 gauge and then reduced slightly to 92 gauge with Sonoita. It was 57 gauge in the 3490E Aguila tape. The 3590 used 56 gauge then went to 32 gauge for the 3590E tape* . . Now were down to five micron PEN, polyethylene naphthalate.

Gardner: Well, we're going to start out with what was the thickness of that?

Bradshaw: Oh, the earliest one?

Phillips: Mil and a half.

Bradshaw: A mil-and-a-half **a**nd it wasn't tensilized. The 727 tape, the original one. Because I remember it was 3M Dynarange tape.

Phillips: It was acetate.

Bradshaw: That was acetate. -- it was acetate tape, which is crispy. The other thing is after it got old, and you had it in humidity, you could smell vinegar. Because acetate hydrolyzes and makes acetic acid which smells like vinegar. I walked into this tape library, and I said <sniffs>, "You got acetate tapes in here?" "How do you know that?" "Can't you smell that?!" Because it smelled like somebody just dumped vinegar on the floor.

Gardner: Smells like salad.

Bradshaw: And I said, "By the time that you can smell it, you need to get rid of this tape."

Gaudet: Yeah, yeah.

Phillips: And not last, nor least, was deciding to make media instead of purchasing media. That was key to a lot of the advancements.

Bradshaw: We should have never stopped.

Gaudet: But Bill's lead-in, his analogy is phenomenal about his orbit around the moon. And the power of the computer, and the type of computer you would need today. Tomorrow that's going to be on a little chip to do all that.

Bradshaw: Well, they know that, because I loved a display they had that showed that the 1999 [Computer History] Museum’s Fellow’s award.

Gaudet: No, no, really. That analogy is phenomenal. And that really, you know, form factor, capacity, data arrays, it's a new technology, a step in that direction.

Bradshaw: Energy consumption.

Gaudet: And right around the corner, we're going to have tape drives on little chips. <laughter>

Gardner: Anything in the channel area that stands out?

Phillips: Error correction codes.

Gaudet: And the write equalization was pretty key.

Phillips: Yeah, writing equalization.

Gaudet: Mm hm. And then the actual channel design itself. The circuitry. The ASIC modules, the use of higher circuit densities.

Bradshaw: Self-correction. Individual heads.

Gardner: What was the worst problem you encountered, gave you most of that gray hair? I probably mislabeled it earlier.

Phillips: Stiction.

Gaudet: Stiction. Back to the acetate and-- well, I guess acetate not so much. But we went to Mylar and stiction became a problem.-

Phillips: So we tested the hell out of them in product tests. And then almost every drive or media head, stiction of one form or another. And we just had to learn how to deal with it. And for each version of media, there was a different recipe for the solution.

Gardner: So every time you went through a formulation, or a head technology change, you rediscovered stiction.

Phillips: Well, think about it, you have a magnetic head, and you want the magnetic media as close as physically possible.

Gardner: To a disk drive guy, that sounds horrible.

Gaudet: Same thing in disk, you want it as close as possible, but don't touch.

Bradshaw: At least it's rigid media.

Gardner: But don't touch.

Bradshaw: But it's a rigid interface, that's a little easier.

Phillips: And we developed the air flows to reduce the head wear, but they were microns. So as soon as that tape settled down for any length of time, the vacuum column pulling on it, we had stiction.

Bradshaw: And it broke tape sometimes. I mean, really snap it.

Phillips: Yeah.

Phillips: And hot/wet environments, I hated them! <laughter>

Gaudet: I second that.

Phillips: I grew up in Chicago, which is hot and wet.

Gardner: I was at SyQuest for a while, which made a cartridge disk drive. And we hated Hong Kong and Singapore. It just was very hot and humid, very difficult environment for anything that's in a removable medium. The disk drive guys solved that problem. Fixed the disk.

Phillips: Our problem with hot and wet was that we made a portable product. Because in computer rooms, it doesn't get hot and wet.

Gaudet: Right.

Phillips: It's when you take this out, put it in a truck, ship it to your customer down the street. And he says, "It's sticky."

Gaudet: Well, like the data logging business, where the tape-drives are in the back of a van out in the middle of Oklahoma or--

Phillips: Or on a ship.

Gardner: Somebody once pointed out to me that, "God probably didn't like the oil industry, because he sure put it in awful places!"

Gaudet: There's a lot of oil to be had on land. My dad was a petroleum engineer.

Gardner: Well, Pennsylvania's not bad, Norway's not bad. But think about some of the other places that oil is.

Bradshaw: And that's where they do data logging. That was a huge tape business. And they don't throw data away. It turns out because of better operating systems-- remember it's all being reflection. They take things, they measure sonic wave propagation, well, as you get better and better knowledge of reflectivity of different kinds of geologic structures, with or without water, with oil and stuff, you get better resolution. You go reprocess data. But if you have to go back and reshoot the log, you spend millions of dollars. The data, if it's still there, and you take a newer thing and go through the granularly or the noise
[02:00:00]
before you filter it, up pop's a new prospect —Halliburton and Schlumberger were making a fortune by reprocessing old data. Especially in places where now, in Africa and the Middle East, that you can't do the logs anymore.

Phillips: I'll get to the best invention.

Gardner: Bill's best invention.

Phillips: The Prolay.

Gardner: I'm sorry, I don't know what that is.

Phillips: In the IBM 726 and 727, you have a moving coil that would actuate a pinch roller into a motor when you wanted to move it, into a stop capstan, if you wanted to stop it. That was replaced with the pro-lay, which was a magnetic gadget that had one position on one side, one position on the other side, positioned this way, and positioned this way. So you had coils-- opposing coils and a one, two, three, four position with how you energized the coils. And so you got rid of moving coil actuator and it boiled down to just a little tiny thing on the front of the tape drive.

Gardner: This was directing the tape?

Bradshaw: Literally stop-side motion.

Phillips: It was what pushed the tape against the drive motor or against the stop capstan. Of course, that all disappeared when we went to direct drive.

Bradshaw: Right, but that was a breakthrough. Because the other one had a real problem, the tape wore out. It literally would wear out, and they had to clean the capstans almost every other day, I think, or every day.

Phillips: Yeah.

Bradshaw: I heard those war stories from the guys who were in the field. They said, it really depended whose tape they used, too.

Gaudet: Yeah, exactly.

Gardner: I can probably tell you some Memorex war stories about tape wearing heads, or the other way around.

Bradshaw: Well, it always depended which wore -- like we used to get beat up by our suppliers, I mean, because our tape drive, was their tape works very well. And they played STK against, you know, "We don't have a problem with STK's, right? How come you have it" and so much truth. Their heads were different, some materials. And so things that hurt us were-- now we're talking about *wear in part caused by dispersants used to break up the particles and mix them with the binder. Once the coating dried some of these small molecules and their decomposition products would rise the surface, especially in humid environments and then actively attack the metal in the head elements or even the bearings and capstan surfaces, causing them to pit and then collect tape debris. Some of head materials are susceptible to alkaline attack and others are more sensitive to acidic attack. The chemical corrosion can cause pullouts or dislocation of material from the surface of the interface between laminates of films. The pullouts cause debris to migrate across the head surface to form a very thin haze sometimes the "grey cloud" or "brown stain" and in severe cases smearing of the tape coating across the elements or on the edge guides..*

Gaudet: Brown stain, yes, yeah, yeah.

Bradshaw: Which we used to call "management shorts," you know, but anyway.

Phillips: Well, one other thing, I'd already told-- talked about this, with the 726, 727 had "pluggable units."

Gardner: Pluggable units?

Phillips: With vacuum tubes.

Gardner: Oh.

Phillips: <laughs> Yeah.

Gardner: Transistors certainly changed our industry.

Gaudet: Yeah, you didn't plug those. Or unplug them.

Phillips: The movement from vacuum tubes to transistors to solid state circuitry to megabytes of cache data, and incredible electronic developments, which were all put in the drives as quickly as they became feasible.

Gardner: Yeah, I haven't tracked tape, but I can tell you that disk aerial density since 1957 has been exceeding Moore's Law. But probably next year will fall beneath. As of today, if you plotted the aerial density of disk drives from the first RAMAC of November of '57 to today, it exceeds a Moore's Law rate; the current aerial density is slightly above a doubling every two year line since November 1957. I think the tape guys cost per byte you'd see similar progress.

Bradshaw: Oh, we've always been there.

Gardner: You've blown Moore's Law away also.

Bradshaw: And that doesn't include the energy. The one thing when we do these days is costs of ownership, the real things is energy, because tapes, literally, you have a huge capacities that you only power up and use electricity to read or to write the first time, and then you put them away. The other big innovation that we haven't mentioned at all is automation. Because what's becoming different, and which is not good for tape drive manufacturers-- in the old days, tape management wanted to sell lots of tape. But drive management want to sell lots of drives. Well when we actually moved from data processing and backup to archive, the number of physical volumes relative to a tape drive has gone way off the charts. *So where the money is now is in the management of the data both physically and logically in the software "cloud". Fewer drives front end a lot of tape volumes stored in ever expanding automated libraries so fewer drives and lower profit margins make on-going investment in tape less attractive … even though the expectation and demand for archival storage on tape is now firmly established well into the future. When digital check imaging was first being developed one of the problems that became immediately obvious and a major performance hurdle was reconstruction of the check images into data sets that reflected a logical arrangement of the data in sequential order and not as they would occur as stored on a disk array and backed up on tape. Recall of the images from the tape backup of the disk array required reconstruction of the random files on a number of disks so multiple tape shad to mounted and the individual files pulled into the logical data set that one would expect in a check registry ... the solution was not disk back up but collection of all the related data into a logical collection and then send that file to a single tape which then could be sequentially recalled quickly in logical order as determined by the characteristics of the data.*

Because that is a classic example of why you don't just backup up data from a disk drive. Because if you back up data and it's all randomly put back on the backups, and if you want to reconstruct a check image of your account, Bill Phillips' bank account, they have to go mount 40 or 50 different drives to reconstruct the sectors that goes all down the disk drive. So it's called co-location of data, where you take it all out into a massive array, and write it to tape. Now when you call that tape up for your check imaging, it comes-- why don't you just think about it. How do you look at checks? It's serial. What does tape do really well? Serial! Okay? And reliability. So when now, when you look at these libraries, they're huge. By the way, think the deep slot libraries IBM did in 2005 holds one in the door, one in the front, six deep. They get 60,000 cartridges in, I think about the size of this table. Or not even that wide, it's about this--

Gaudet: Sixty-thousand cartridges in a library.

Bradshaw: Cartridges. Library! And now they're ten terabytes per, okay?

Gaudet: Yeah, oh, I know.

Bradshaw: And the thought was, well, it's gonna be time to data, because the ones in the back-- so these smart code guys-- I love it. You give the guys a problem and let them solve it. They put-- they keep track, because buffers and cheap computers are all over the place. They keep track of the inventory. When was the last time you called a disk cartridges? Andy's been called up, and you can do a protocol, daily, monthly, whatever, goes through the front door and the thing. And it's kept near the drives. So they're getting-- the mount time is like this. It's unbelievable. While you're doing the query, the thing's being loaded. So these things look like they're a virtual tape drive. I mean, disk drive. They're that that fast. Now I'm not talking about random, I'm talking about sequential. Once you load and say, "Okay, now I want the check," "brrrrrrp" it's there. Okay. So it's unbelievable what tapes are doing. But it's really architecture now and management of data. The other thing is archive. What's the real challenge of archive? It used to be seven years, 'cause of the Federal government and things like that. And then it became ten, depending on some-- then you talk about medical. Hundred years, because people live longer, and you're liable for a long period of time. The other thing is, "Do you want compression?" No, you want loss less compression. Because what happens in 50 years, if you look at an X-ray, and you look-- now you have better resolution, they want to get that data, you wanted loss less compression. So you can't just can't enough storage capacity. Remember we used to think it was megabytes was a huge amount of storage, and 500 MB was all that would be needed on a PC…Now users of tape expect high data rate and reliability but always want to know what is the uncompressed capacity.

Gardner: There are lossless codes.

Bradshaw: Yes, there are, but nobody trusts them. And I'm telling you, the people who do archive want every bit of the data. Especially, music. They don't want an MP4, they want all the noise, everything recorded. So the bandwidth is necessary but tape is cheap, so they make one copy here, and now with fiber, they make another one across the Atlantic someplace.

Gaudet: Well, tape and DASD are two different animals.

Phillips: The best separation of DASD and tape is, you only have one way to change the capacity of your drive. Jack up the areal density. We could slim down the tape, jack up the areal density, put more tracks. But of course, you had a track density, too.

Gardner: We also made thinner disks.

Phillips: <laughs>

Bradshaw: Well, the other thing you did that we hadn't done yet. There is a one-shot thing which I've said about many times, and STK did when they did their enterprise drive, they put two heads on the drive, in case of data rate thing. Now what does it show you? If you get-- buffers are cheap. So you get enough buffer, you don't have to do these things in sequence. You can read and write both sides of tape at the same time. Because you don't have to sequentially looking at data, or reading/writing data. If you do that, you double the density of a cartridge in one fell swoop, okay? So 100 terabyte cartridge is now 200. Now after a while, you say, "Who cares?" You know, think about it, I just told you, we're talking about zeta-bytes in a library without compression. Now the bad news is that the world is taking a lot of pictures, they don't ever erase, and they store them up-- and they call this big thing about the cloud right?

Gaudet: The cloud, that's where the 3480 is and the LTO.

Bradshaw: Well, no, by the way, have you ever talked-- now this is fun. Because two years ago I was at a conference hosted by Fujifilm[37] for over one hundred big data storage users, academic, broadcast news and TV, sports, education, science and government…..-

Gardner: We're getting way off track

Bradshaw: Google was talking about their problem. They have a huge disk farm. They're talking about archiving. And guess what it's going on? Tape.

Gaudet: Yeah.

Bradshaw: Their concern? Who is going to continue making tape? Because we had that discussion in the car. I think data will be there, but what if there's no drive or software to read it back.

Gaudet: And you can't afford to archive in DASD, that's why tape will be there. And it'll probably be there for a long time.

Gardner: I was going to ask Bill, and get his 57-year view. We spent an awful lot of time on the transition from iron oxide to chromium dioxide. Any things about the growth of iron oxide from the original 727 formulation to the 3420 that you think is memorable in either way? Great or terrible?

Phillips: Mylar. Chrome itself being able to tame its wear properties. The chemistry of lubricants.

Gardner: When did lubricants get introduced?

Bradshaw: Oh, Day 1.

Phillips: Yeah.

Gardner: Day 1?

Bradshaw: First of all, you wouldn't believe, I think they used shark oil originally in some early formulations for the 727 tape.

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[37] Fujifilm 5th Annual Global IT Executive Summit. Houston TX, October 23-26, 2013

Phillips: Yes.

Gaudet: Oh, my god.

Bradshaw: Sony used whale oil until that was politically incorrect. So they did rid of that. Sharks were fine. Nobody likes sharks. Then they went to tridecyl stearate, which was what was used in the MST. And then again in the Chrome Stallion. And MSS used isocetyl stearate.

Gaudet: Did they use RSS [Rick's Secret Sauce]?

Bradshaw: No, they never got into it. Contaminated tape drives. That was my crap. Anyway, RSS is my number entry for a lubricant that I made that worked really well, but it was a total disaster, because it contaminated the tape drive, and nothing would run on it, it'd just slide all over the place. But the isocetyl stearate was used in MSS. *Another anecdote about lubricants in tape from my first days at IBM in Boulder in 1978. I had joined the media team in IBM Boulder and I car pooled with a fellow Terry Lux who was a manager in the MSS tape cartridge manufacturing line in Boulder. One morning he told me they had a strange problem with wax collecting on their servo writer heads and causing serious yield and through put problems…so I looked into it and worked with the materials analysis lab (Fran DeCormier's people as well as the manufacturing materials lab, Tracey Rold) . I collected some of the material from the servo writer heads and found out it was n-cetyl stearate one of the isomers of iso-cetyl stearate which was the lubricant that was supposed to be used in the MSS tape formulation. To save money and not buy rectified or purified isocetyl stearate as called for in the formulation recipe, a manufacturing engineer had decided to buy a lot of un-rectified isocetyl stearate.* Rectified isocetyl stearate is a liquid. But really it only is a liquid when the isomers aren't pure. So some guy decided he'd get a cheaper one, and save, I think it was a dollar a pound, or something like that. So they put it in and suddenly it started clogging up the servo writers with crystals of n-cetyl stearate, the linear form. The n-cetyl stearate would separate out and crystallize on the surface of the tapes during their cure at 125F prior to servo writing.. Now rectification means you chill the liquid down, and the stuff that solidifies (crystallizes) can be filtered off. You paid extra for that. *So this guy, to save money put this stuff in on the line. I had to convince their management what the problem was and they had to clean the servo writers with mineral spirits until all the batches prepared with the un-rectified, out of spec lubricant was gone from the line ... but rather than scrap the contaminated MSS jumbos and cartridges, they decided to warm them in the cure room over night to melt the n-cetyl stearate crystals and let them soak back into the coatings (MSS had an iron oxide magcoat and a carbon black back coat) These reclaimed cartridge and jumbos passed their final tests if given enough "cleaning" passes so they shipped them all…naturally all those reclaimed MSS carts failed in the field as I told them they would..* This taught me a lesson about burn-in.

I'm talking about the manufacturing building that made MSD and MSS using ball mills.

Phillips: It was Building nine.

Bradshaw: Nine, it was nine. I keep saying ten because of that. Building 11 was where they had the cafeteria in their offices and stuff, isn't it?

Phillips: Mm hm.

Bradshaw: Yeah, okay. Anyway, my point was that they heated it up, and melted it, and they thought it was all fine. Guess what? They shipped it, and every one of the drives had got one of those heads up with this dang waxed. It would slowly come back to the surface and crystallize. N-cetyl stearate is waxy solid that melts at around 50 deg CI and is a white waxy leaf like crystal. you could melt it and it would go back in the tape, but it'd come back. So this taught me a very big lesson -- and I mean one of the challenges Bill Philips gave me was to work on lubes. As well as, in my spare time, work on binders and water-based systems. And the lube thing was interesting, because at the same time DASD was working on new and novel lubricants -- and there was the Zedol[38], okay? There was an interesting property -- we could have another whole discussion. Because one of the things I love is that getting connected with the disk development team got me engaged with the amazing Materials Lab in San Jose run by Dr. Edward M. Barrall, and Barrall under Dr. Ermala Barlow the second level. God bless them! Bruce Prime, Gordon Maul [sp?], Vatherine Albright, Bill Moreson and so many truly gifted chemists of all disciplines. and just amazing people. Brilliant, bright people. Well, we collaborated. We talked. Phone, you know, over the phone and sometimes using VM the old desk top electronic mail system that IBM ran.-

Gaudet: Oh, gosh.

Bradshaw: they learned a lot the hard way about f interfacial lubricants under high shear on disk drives.. And one of the things that was interesting about the free radical reactions on a disk drive that caused the fluorocarbons, normally very stable materials, to breakdown to gaseous fragments that would slowly build up little crystals on the back of the slider. And they would literally change the slider flying -- it would make it pitch and yaw-- depending on whose slider it was by the way. Seagate, because of their design and suspension, collected it on one edge. So it crashed outboard. The IBM one crashed inboard. Guess what the solution was? I love these things -- it had nothing to do with engineering. Somebody asked, "Well, gee, why does this stuff stick there?" Well, because there's oxide on the back, and oxide acts like a catalytic support for the fluorocarbon radicals." "Then why don't we just fluorinate it to start with?" So they fluorinated the back and the problem went away. We never told the world how to do it in San Jose. Because how do you reverse engineer with fluoro lubes looking at a slider and find fluorocarbons on it, and say, "It's just contaminated. They did a crappy job of manufacturing." What they did was treat the clean slider rails and some areas of the suspension assembly in later designs with a fluorocarbon gas to react with the oxide surface of the metal slider and form a very thin “Teflon like layer” and nothing stuck to it.

Gaudet: What machine was it?

Bradshaw: 3380.

Gaudet: I never knew it (that you were involved).

Bradshaw: You see, that was *allllll* under the table.

Gaudet: Oh, you worked on the film disk?

[38] A random co-polymer also known as Fomblin Zdol

Bradshaw: No, no no. *I did not work on the film disk and only indirectly on the particulate disk. I was pulled in by Joe Vranka who was invited to join the 3380 task force by Jack Harker who was the lab director. In San Jose at the time I believe. This was the big one when the disks were crashing and they had to delay ship after announce ... I think it was in the early 80's*. And both, the sliders they started with-- the original lubes on the particulate disk were not. But remember the 3380 pore problem was that they were cooking it, and the pore structure was totally erratic. And they would do the glide test and put the lube on in front and kind of smear it around. And they passed-- this is what taught me another lesson about engineering solutions, rather than science. Okay, we *[that is, mainly Ed Barrall's group]* did an infrared map. We made a fluorocarbon, which glowed in the dark, just for these experiments ... essentially okay? And so we'd shine infrared light on it, and we'd do an after test and see these nice little streaks, a little photograph record around it, right? Then wait a while, spin the disk and watch the [lubricant flow into pools and rings]. Okay? Do you want to ship the product like that? See? What you want, is you want to make a lube, that when you put it on, you spread it out, you spin the hell out of it, 12,000 RPM, I mean, what in those days, I think we were running seven or eight-thousand RPM then? It was a big disc.

Gardner: That's 3600 RPM on a 14-inch disk.

Bradshaw: That's it, 3600. It was the next one, the little one that we went to higher RPM -- okay, but it was flat, and we started seeing these little things like bow waves. There's some really neat crap that the old San Jose research site found. God, they had some neat cameras. You know, those high-speed cam-- you can watch these things setting up these little waves, and you send a disk head through it. Watch these bow waves flying. You know, we're talking nanometers. Now atomic force microscopy (AFM, MFM, etc.) , everybody's got one, you know, but at that time it was just awe-inspiring. My point was, once you identify the problem, you can solve it. Not just engineering fix-it by trial and error.

Gardner: I think we're pretty much at the end of our day.

Bradshaw: I really appreciate you guys asking me.

Gardner: And I'd like each of you to say, give a one minute, two minute wrap up.

Bradshaw: Why don't you go first?

Gardner: Each of you except Ric. He's already given his wrap-up.

Bradshaw: No, I'm done.

Gardner: Of your perception on where tape has been and going. We'll start with Ric, and I'll cut him off at two minutes.

Bradshaw: There's no end, in my opinion. Except for the lack of investment by people who want to continue in that business. I think the demand is there. The real challenge is metadata management, and migration. Because it's gonna be deep archived, it's going to be hundreds of years lifetime, and you need to be able to read it.

Gardner: Andy.

Gaudet: I agree exactly with what Ric said. And the only viable storage for archiving, the kind of storage that's taking place today, all the data that's being stored-- cost effectiveness, you're never going to get that out of (from) DASD. There will be tape until, and if, and only if, holographic or something like that comes about. Which is somebody's wet dream, at this date. Okay? Ten years, fifteen years from now? We don't know.

Gardner: Okay.

Phillips: Keep your eye on the rearview mirror. Somebody may be gaining on you.

Gardner: Any idea who?

Bradshaw: Flash.

Phillips: No.

Gaudet: No, not Flash.

Bradshaw: They think they're going to, though.

Phillips: There needs to be continuous improvement, because otherwise, you're going to lose.

Gardner: You've seen 57 years of continuous improvement.

Phillips: Yeah.

Bradshaw: But what happens when you go static, too? Take your off the ball, and somebody will pass you on line.

Gaudet: That's right.

Gardner: Thank you guys very much. It's been a great day. I appreciate your taking the time.

Bradshaw: Well, I thank you. This has been a great reunion. I haven't seen these guys in a long time, and I miss them. One of the greatest team ever. They're unbelievable.

Gardner: Yes, thank you.

END OF INTERVIEW

Attachments:

1. Dictionary of names and uncommon terms in session transcripts

2. IBM Tucson circa 2005

Editor's Notes:

1. First pass editing by T. Gardner began in late April 2016 and was concluded on June 12, 2016. Many overlapping conversations had to be summarized or replaced with reconstructions. Copy was provided to all interviewees.

2. Suggested changes were received from Andy Gaudet on August 9, 2016 and incorporated into the working copy dated September 3, 2016; it was provided to Ric Bradshaw for his comments,

3. Suggested changes were received from Bradshaw on October 29, 2016 and after several exchanges and telephone conversations with Bradshaw incorporated into the working document dated December 11, 2016.

4. No feedback was received from Bill Phillips

5. The first final draft was provided to all participants on December 11, 2016. Subsequent feedback incorporated on January 13, 2017.

6. Transcript renamed from "Evolution of Tape Technology & 3480 Media" to" IBM Tape History – Session 1: Media." Associated files name prefix including all prior versions renamed from "102737992-05-01_3480_Evolution … " to "102737992-05-01_IBM_Tape1_Media". Similar changes made to video file names. Introduction substantially revised.

7. Memorabilia offered by interviewees and accepted into the museum's permanent collection have CHM Lot Number's X7617.2016, X7620.2016, X7677.2016, X7678.2016 and X8091.2017.

8. All unknown or uncertain names, dates, places, products and other facts were verified to the extent possible. A collection of more than 100 pdf documents collected in conjunction with editing this transcript was provided to CHM as Incoming Receipt A2017.5820.

Attachment 1. Dictionary of code names and acronyms terms in transcripts

Acroynm	AME	Advanced Metal Evaporative - Sony media technology
Acroynm	ESS	Enterprise Storage Server
Acroynm	HPC	
Acroynm	HSM	Heirarchical Storage Manag(er)(ment)
Acroynm	LZ1	Lempel Ziv compression
Acroynm	LZ2	Lempel Ziv compression
Acroynm	MIBK	Methyl Isobutyl Ketone
Acroynm	MSS	Mass Storage System
Acroynm	MST	Multi System Tape
Acroynm	RABF	recursive accumulating backhitchless flush
Acroynm	STSM	Senior Technical Staff Member
Acroynm	THF	Tetrahydrofuran
Acroynm	TWGs	Technical WorkIng Group
Code Name	Accelis	Alternate format For LTO
Code Name	Ajo	A double sided 3.5" floppy disk drive, 16MB. Never shipped.
Code Name	Brewers	Code name for LTO Consortium, each company was a beer brand
Code Name	Hydra	The follow on to VTS - a large disk cached virtual tape library for the Enterprise.
Code Name	Intrepid	Code name of 3480 when it came from Boulder to Tucson, started in 1997
Code Name	Ironwood	3880-11
Code Name	Jaguar	IBM Model 3592 tape drive; current IBM enterprise version of LTO
Code Name	Linden	The technology set that later enabled 3590 and 3570
Code Name	Mustang	3480 media - ver 2
Code Name	Ocotillo	3480 Drive - ver 2
Code Name	Pegasus	3480 Media - ver 3
Code Name	Prospector	Array of large floppy disks on a spindle emulating an HDD array
Code Name	Saguaro 1 (SAG1)	Entry level 3480 shipped second, all were upgraded to SAG2 3480 boxes within a few years,
Code Name	Saguaro 2 (SAG2)	3480 Drive - ver 3, final--this was the code name of the first shipped product
Code Name	Sawmill	SJ hard disk drive
Code Name	Sheriff	3880-13
Code Name	Sonoita	3480 Media - ver 4, final--yes but pegasus was shipped initially
Code Name	Stallion	3480 media - 1st version that came from Boulder
Code Name	Summerton	Maybe related to Linden
Code Name	Sunfish	3430 non- vacuum column compatible reel to reel drive

Attachment 2: IBM Tucson circa 2005

IBM Tucson today

Fast forward 25 years from the official dedication ceremony in 1980 to the first decade of the 21st century, and IBM Tucson's profile today both resembles what it was a quarter-century ago and differs somewhat from it. The facility still develops all of IBM's storage products but it now has other IBM organizations in residence (the General Products Division was phased out in 1990). Among the site's more than 2,000 IBMers are employees from:

IBM Systems and Technology Group

- TotalStorage hardware and software development and support.
- TotalStorage brand management.
- MVS (Multiple Virtual Storage) storage software development and support.

IBM Software Group

- Tivoli storage management software development.
- Tivoli storage management product support.

IBM Global Services

- Storage hardware level 2 support.
- Storage hardware service planning.
- Groupware services.

In addition, IBM Tucson is home to one of two IBM TotalStorage briefing centers in the Americas, and IBM is the managing operator for the site's University of Arizona Technology Park.

Key products in IBM Tucson's current line up include:

- IBM Enterprise Storage Server.
- IBM DS4000 (formerly FAStT) midrange product line.
- IBM TotalStorage DS6000 and DS8000 data storage systems.
- Linear Tape Open (LTO) drives and automation.
- IBM 3592 Enterprise Tape Drive.
- Virtual Tape Server.
- NAS Gateway.
- SAN Volume Controller.
- TotalStorage Productivity Center.
- DFSMS (Data Facility Storage Management Subsystem).
- Tivoli Storage Manager.

IBMers at the site received 95 patents in 2004 in such fields as disaster recovery technology, data storage optimization, data consolidation and server/storage communication technology.

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