CHEMICAL HERITAGE FOUNDATION

GORDON E. MOORE AND JAY T. LAST

Transcript of an Interview
Conducted by

David C. Brock and Christophe Lécuyer

at

Woodside, California

on

20 January 2006
(With Subsequent Corrections and Additions)

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GORDON E. MOORE

1929	Born in San Francisco, California, on 3 January

Education

1950	B.S., chemistry, University of California, Berkeley
1954	Ph.D., physical chemistry and physics, California Institute of Technology

Professional Experience

	Johns Hopkins Applied Physics Laboratory
1953-1956	Research Chemist, Physical Chemistry
	Shockley Semiconductor Laboratory
1956-1957	Member, Technical Staff
	Fairchild Semiconductor
1957	Founder
1957-1959	Director of Engineering
1959-1968	Director of Research and Development
	Intel Corporation
1968-1975	Co-founder and Executive Vice-President
1975-1979	President and Chief Executive Officer
1979-1987	Chairman and Chief Executive Officer
1987-1997	Chairman
1997-present	Chairman Emeritus

Selected Honors

1975	Distinguished Alumni Award, California Institute of Technology
1978	Harry Goode Award, American Federation of Information Processing Society
1979	Frederik Philips Award, Institute of Electrical and Electronics Engineers
1980	Computer Society Pioneer Award, Institute of Electrical and Electronics Engineers
1988	Founders Award, National Academy of Engineering
1990	National Medal of Technology

1993	Medal of Achievement, American Electronics Association
1993	John Fritz Medal, American Association of Engineering Societies
1996	Excellence in Achievement, California Alumni Association
1996	Elected to Horatio Alger Association of Distinguished Americans
1997	Founders Medal, Institute of Electrical and Electronics Engineers
1997	Alumnus of the Year, California Alumni Association
1998	Fellow Award, Computer History Museum
2000	D.L. (honorary), Princeton University
2000	D.Sc. (honorary), University of Illinois at Urbana-Champaign
2000	Lester Center Lifetime Achievement in Entrepreneurship and Innovation Award
2000	PricewaterhouseCoopers Leadership Award for Lifetime Achievement, The Smithsonian Institution
2001	Othmer Gold Medal, Chemical Heritage Foundation
2001	Vollum Leadership Award, Oregon Graduate Institute School of Science and Engineering
2001	World Technology Awards: IT-Hardware
2001	Millikan Medal, California Institute of Technology
2002	Presidential Medal of Freedom
2002	Order of the Golden Ark, The Netherlands
2002	25th Anniversary Lifetime Achievement Award, Semiconductor Industry Association
2002	Bower Award for Business Leadership, Franklin Institute
2003	Elected Foreign Member of the Royal Society of Engineering (UK)
2003	L.H.D. (honorary), Johns Hopkins University
2004	Perkin Medal, Society of Chemical Industry
2005	Lifetime Achievement Award, Marconi Foundation at Columbia University

JAY T. LAST

1929 Born in Butler, Pennsylvania on 18 October

Education

1951 B.S., optics, University of Rochester
1956 Ph.D., physics, Massachusetts Institute of Technology

Professional Experience

Shockley Semiconductor Laboratory, Mountain View, California
1956-1957 Senior Technical Staff

Fairchild Semiconductor, Palo Alto, California
1957-1959 Senior Technical Staff; Co-Founder
1959-1961 Head of Integrated Circuit Development

Amelco Corporation, Gardenia, California
1961-1966 Director, Research and Development; Co-Founder

Teledyne Technologies, Inc., Gardenia, California
1966-1974 Vice President, Research and Development

Archeological Conservancy, Albuquerque, New Mexico
1980-present President

Sierra Monitor Corporation, Milpitas, California
1980-present Director

Hillcrest Press, Inc., Santa Ana, California
1982-present President

Think Outside, Inc., San Jose, California
1998-present Member, Board of Directors

Honors

1999 Hutchinson Medal, University of Rochester

ABSTRACT

This oral history with **Gordon T. Moore** and **Jay T. Last** focuses on the years 1956 and 1957, during which time Moore and Last worked at Shockley Semiconductor Laboratory and Fairchild Semiconductor was founded. This transcript is about the life of ideas and the people who brought those ideas to fruition; Moore and Last reflect on their experiences during these years while flipping through an old notebook that documented various aspects of the meetings they had over an eighteen month period. In order to fully understand this oral history, the reader must consult the Supplement to Gordon E. Moore and Jay T. Last Oral History, oral history number 0327S, which is also part of the Chemical Heritage Foundation's collection

INTERVIEWERS

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Christophe Lécuyer is research historian at the Chemical Heritage Foundation. He holds a Ph.D. in history from Stanford University. He has published extensively on manufacturing districts, university-industry relations, and the history of electronics and scientific instrumentation. He was a fellow of the Dibner Institute for the History of Science and Technology and taught at MIT, Stanford University, and the University of Virginia.

INTERVIEWEE: **Gordon E. Moore and Jay T. Last**

INTERVIEWER: **David C. Brock and Christophe Lécuyer**

LOCATION: **Woodside, California**

DATE: **20 January 2006**

BROCK: Christophe and I had a discussion where we wrote down a list of topics and events that we hoped that by going through the notebook it would spur the two of you to talk about, to reflect on, and to sort of share your experiences. One way that we can begin the discussion would be to talk a little bit, Jay, about what this notebook is, what it's a record of, and what you used it for? I seem to recall it was a record of weekly staff meetings? And then perhaps we could talk a little bit about what that weekly staff meeting was like, who was there?

LAST: Well, it was more than that. It was a hodgepodge of every meeting that we held. We had weekly staff meetings. Sometimes I wasn't there, or sometimes we didn't hold one, or sometimes I didn't write anything down. In addition to that there'd be a special meeting once in a while reporting on one thing and another. And it runs the whole gamut from how we're going to have the coffee committee work, [laughter] up to long-range planning of building a new building and all the stuff in between. But it does list people and their tasks, and how far along they were, and what the bottlenecks were and things like that. But a lot of it's pretty cryptic of course and that's why if we sit and look at this stuff we may find some of it will come together.

BROCK: So it covers the period from the formation up until the time you left, which was in late 1961?

LAST: No. The meetings stopped after about a year and a half. And then they got pretty scattered. We didn't have the formal meeting of the group of us after about the first year. So, I think the value is, really, answering how in the world did we, in forty weeks, [laughter] scoop the industry?

MOORE: The dates go from October 1957 until 14 May of 1959.

LAST: But it's scattered. I think if we focus on the first year, the first year ends with the balance sheet of what the company was like after what we'd done and what we'd spent in the first year. The way this [notebook] survived, I just didn't think much of it. I created it because I

like writing rather than just sitting. Later, I just threw it in a box with some other stuff when I left Fairchild, just odds and ends of historical things, and that box—I lost track of it, and when I moved to Southern California it was with my Teledyne [Teledyne Technologies, Inc.] stuff and I didn't pay any attention to it for several years. It was down in my cellar and I just never threw it out. Then I started looking at it, and then as the years have passed it looked more and more of historical interest. I know Christophe spent a lot of time going through it.

LÉCUYER: Yes.

BROCK: In that early period was there anyone taking more formal notes of the meetings?

MOORE: There's no sense of history at all in these startups. Everything is about getting tomorrow's job done.

LAST: As a company fails that's the last thing you do. When they're hauling it off, when the Sheriff is auctioning it off, [laughter] they ask you to write a good history. [laughter] But if it succeeds you're too busy. So it was just a fluke that I kept this.

LÉCUYER: So what was the atmosphere of these staff meetings?

MOORE: You know, the weekly staff meetings were kind of just to get everybody brought up to date on where we were going. We went around the table and told about the problems rather than the progress. That's the way it usually goes.

LAST: And the area that I know very little about was the whole diffusion side of it, and that's the area that you—

MOORE: That's the one I—

LAST: That's the one you know.

MOORE: That I was involved with.

LAST: So, I was in one half of the building and you were in the other half.

MOORE: Well, you got involved in the lithography, right, over there?

LAST: Well, I got involved in lots of odds and ends. The first thing I did was crystal slicing and polishing. From my optics background I know how to polish things. So I came down to Southern California and bought some American Optical lens polishers, and that was the start of the polishing.

MOORE: That was a trade secret of somebody's.

LAST: I did that, and I worked with Bob [Robert Noyce] on the photolithography. As Bob spent more and more time outside the company selling things, I spent more and more time doing that. But looking at this notebook, we had the processes all set, that we said "We now have to write process spec manuals." We can look at the data, but that wasn't that far along.

MOORE: That was after we let Baldwin in, though. He was the guy that kind of told us you had to document these things. [laughter] Building them in the laboratory wasn't enough.

LAST: One of the things I like best in here is I recorded Baldwin's first talk to us about what we had to do to run a company.

MOORE: That was his major contribution to the whole deal.

LAST: Well, that and pointing out that we needed a new building very fast. That was before we had ever built anything. He said, "You need a new building," and he pushed for that.

BROCK: For what reason, just more adequate for production? Or—

LAST: Oh, he said, "These devices are really going to take off."

BROCK: Capacity?

MOORE: We had no idea of the magnitude of what was necessary. There are two examples I may have told earlier. Initially I laid out the diffusion furnaces so there were six tables, so we could make twelve furnaces. We made half for development and half for production. Jean Hoerni showed that by staggering the tables you could get a seventh table in there, so we put that one in for future expansion. [laughter] On our gas supply, we went all the way to having a manifold with two cylinders on each side, expandable to four cylinders on each side if we needed more gas. And that was the magnitude of which we were looking. We were figuring to build one in the laboratory and I guess ten in production. We had no idea the scale-up that was necessary. Baldwin did bring that to us.

LAST: Yeah. And he just flabbergasted us. He said, "You need this 100,000 foot square building as fast as you can build it."

MOORE: Well, when we were initially looking for a building we looked at one that Varian was getting out of in San Carlos, and it was 40,000 square feet and we looked at that and couldn't imagine ever needing that much space. [laughter] We went into one that was about fourteen, as I recall, and that seemed a lot more comfortable. [laughter]

LAST: I've recounted the anecdote of how packed we were in that building before the new building was built. I remember hiring somebody from TI [Texas Instruments] and he was going to be the big shot, and running things, and he came up here and I said, "Well, this is your desk." I took him out to the annex and said, "This is your desk and you're sharing it with seven other people." [laughter] "This is your desk drawer." [laughter] But Ed was right on that.

BROCK: What was the date of the first staff meeting documented in the notebook? I'm sorry, I have it right here.

MOORE: Yeah. The first meeting is actually the Buffalo Electrochemical Society meeting in 1957.

LAST: I didn't copy that stuff.

MOORE: It's even got my initials on that one.

LAST: Yeah.

MOORE: I must have gone with you. I remember going to—that's the kind of meeting I would have gone to.

LAST: The thing that's weak in here is that I didn't write down what I did is because I knew that. [laughter] So, it starts—here's a book that'll make it easier to look at.

MOORE: Okay. It's easier to read?

LAST: Yeah.

MOORE: It's easier to read, from looking at that, "The gold in silicon." I remember that paper.

LAST: Yeah. [turning pages] So, it's meeting notes up to page—reports on various meetings up until page twenty-one which is where the notes of staff meetings start.

BROCK: In this period of late September and early October, as you're signing the agreements with Fairchild, having your final meetings with [Arnold O.] Beckman, and officially starting Fairchild, were you also at that time talking about some of the major technological decisions? That is to say, you know, "We're going to go with diffusion. We're going to go with photolithography. We're going to make our own crystals." Or was that assumed?

LAST: It was pretty much assumed. The big change that came in, I think, was photolithography, which we had.

MOORE: We decided that we wanted to do that, which hadn't really been done on silicon before. We knew generally where we wanted to go, but there was a lot of specific development that had to be done to make it work.

LAST: And the photolithography was sort of an iffy thing. We didn't know if it was going to work. It didn't for a while. But that also turned it into a batch processing thing, being able to step and repeat it. So that laid the groundwork for the later integrated circuit, because we had the idea.

MOORE: This comment on the final meeting with Beckman is interesting. I hadn't realized he had taken that hard a—well, I'd forgotten he'd taken that hard a position.

LAST: Oh yeah. So, we started 1 October. I remember very distinctly the eight of us meeting in my apartment, and I didn't have any chairs. I just had all the wooden boxes that I had shipped my books out in, [laughter] and we all sat around on those wooden boxes. And, then we were just saying that we obviously had to get a building, and talked about things like that. We rented the building by the next week.

BROCK: Were part of those discussions in October coordinating who would tackle which aspect of the work once you had the facility?

LAST: It must have. I'm not clear.

MOORE: I don't know. It was fairly straightforward and divided up, I think. It wasn't a matter of a lot of discussion. I had been working on diffusion mostly at Shockley. Jay was generally involved in a variety of things.

LAST: With the group of us, there was practically no overlap of talents. The only thing close to an overlap would be you and Jean on some diffusion things?

MOORE: Well, in the beginning Jean was still our theoretician. We wouldn't let him touch any equipment in those days. [laughter]

LAST: No.

MOORE: None of the setup of stuff. He didn't get involved in that.

LAST: When I laid out the half of the building on the other side. A third of it was for Sheldon's [Roberts] crystal growing, and I had the center third for assembly, and the bottom third was Jean and he put in diffusion furnaces right away. I have pictures of it.

MOORE: Boy that's something I don't recollect.

LAST: Yeah.

MOORE: I remember having to build him a glass jungle when he wanted a furnace. He wanted the ability to mix everything in any proportion. He wanted to be able to mix hydrogen and oxygen in any proportion in this furnace. It scared the heck out of me [laughter] but I built the glass jungle so he could do it.

LAST: And the wall at the end of his furnace there, those two supplies came shooting out right into the wall, and you could see the hole in the cement there where those tubes had blown up time after time. [laughter] But the other key person in here, I think, was Dave Allison. He brought a lot of help into the diffusion. You worked closely with Dave?

MOORE: Yeah, I did. And, you know, Dave would have been the ninth member of the group of eight if he'd only come to the meeting we had at my house before we left. He and Jack Clifton, I think, both were invited and neither of them came. He was in Canada on business.

LAST: I just see references steadily through here of dates, diffusion comments and dates for them.

BROCK: Talking about the division of the space, maybe we could return to that a little bit because I think I was getting a little bit confused. Half of the entire space was devoted for setting up for production and half (Last: Oh no.) with development? Or you were talking about the whole space?

LAST: The building had two bays to it. There was the bay where Gordon was working with diffusion and evaporation and all those things. The other bay was the one that I laid out, which had Jean working. I had gone to Sears and bought a bunch of cabinets, for assembly of devices. Sheldon had the bottom end.

MOORE: I don't remember Sheldon's crystal growing in the same bay as the diffusion.

LAST: Well, no.

MOORE: He may have done it in both places.

LAST: No. I've got a blueprint someplace of the thing that shows all of this stuff. Because I remember distinctly Jean and Sheldon were—they had this competitive, quirky nature and I just told each of them, "I laid this out and I gave you a little more space than the other one." [laughter] I told them both that.

MOORE: I'm surprised they weren't both out there measuring it.

LAST: I think Sheldon was getting ready to measure it. They didn't bother, but I'm very clear on where they were laid out because I went through and did that. And after we'd been in business about a month or two, I took a picture and it shows those furnaces that Jean was going to use. He did get into it whenever, whatever the timing was he did get into it.

MOORE: Oh yeah. He became the wild man of diffusion.

LAST: Yeah.

BROCK: [laughter] What do you mean by that?

MOORE: Well, I remember a particular—we used to have to do what we called alloying, and heat everything up for the aluminum to melt. Jean would go up to the diffusion area, look for any furnace that didn't have anything in it and then zip it in and zip it out to do this quick alloy. [laughter]

BROCK: So that's the division, the tripartite division of one bay? What were the activities going on in the other bay where you had your diffusion operation?

MOORE: Well, my recollection is not the same as Jay's blueprint. [laughter] So, you know, I guess I'm not quite sure of that.

LAST: I know there was a room over there where we were doing evaporation.

MOORE: Yeah, there was a room on your side where the evaporators were, or my first evaporator anyhow. And it probably evolved over time.

LAST: I know a lot of—we had some rooms full of microscopes looking at things.

MOORE: And Sheldon always had his metallurgical microscope set up someplace. There was a kind of a double row of rooms down the middle, not quite completed yet. That separated these two bays.

BROCK: Did you have individual offices as well?

LAST: Yeah.

BROCK: At that point?

LAST: Well, there was a bay in the front, a double storage bay and we each had offices and I shared one with Jean. And then there was a little conference room down at the end.

BROCK: Is that where you would have these meetings?

MOORE: That's where most of these meetings were held.

LAST: Yeah.

LÉCUYER: So then the first production was set up in these bays too?

LAST: Yeah. I can draw the picture of my recollection of it. So, after a month, on 29 October—

MOORE: "Seven furnace benches," you know. [laughter] We discussed Jean's contribution to get the other one in there.

LAST: And small rooms for optical testing, wafer lapping, wafer polishing, photoresist emulsion, evaporation.

MOORE: Those are the rooms down the center.

LAST: The crystal growing area, which was up at the end, and this device development area which was over on your side, where they were putting in all the gas lines.

LÉCUYER: Sheldon then built his own crystal grower?

LAST: We built it. Gene [Eugene Kleiner] and Julie [Julius Blank] did a great job of building a lot of stuff.

MOORE: In those days you couldn't buy equipment. A machine shop was an important part of the whole deal.

LAST: And Gene and Julie had some good machinists. We had to build some pretty sophisticated stuff on short order.

BROCK: Was their machine shop on the site?

MOORE: It was a little annex right next door.

LAST: And we kept gradually getting more offices, across the street and things like that. On 6 November, we'd been in business five weeks and see there's a staff discussion of products.

BROCK: So, was this—

MOORE: That was quick.

LAST: It was five weeks.

BROCK: Was this people pitching essentially their choice for a first product? Do you recall? Or did these represent a range of options that you could go for?

LAST: Jean was intrigued with boron diffusion I think, and that got him going on PNP.

MOORE: I don't know what we were discussing at that time, but eventually we started with the development of both an NPN and a PNP. And, in addition to the process stuff I was doing I was, I guess, the project manager for the NPN and he was for the PNP.

LAST: And that went through until—in March there was a decision made. That comes in later.

MOORE: I had an opportunity to choose between my child and his child. [laughter]

LAST: And he did it in a—

MOORE: Mine was the most beautiful by far. [laughter]

LAST: Well, it was beautiful from the standpoint that it worked. [laughter]

MOORE: It was easier to do. It was a better transistor and easier to make, but it was a tough decision. [laughter]

LAST: But at the 18 November meeting—

[END OF AUDIO, FILE 1.1]

LAST: We were really learning on the job, because when we were approached by Hayden Stone we didn't have the idea of starting our own company and we were just getting used to it, and none of us had any managerial experience. We were both learning how to be managers, and doing the technical stuff, and running a company. We were having hourly and monthly payroll discussions. People would get paid by the month and by the hour, and I remember I gave everybody a raise by not converting weeks to months properly. [laughter]

MOORE: Where are we?

LAST: We're at the top of page two, we're talking about—we were doing all of this without electricity. I'm just amazed. We didn't have the power in and Gordon was making a commitment to do the PNP in a couple of months. And you were also doing the evaporation. You were in charge of both of those.

MOORE: Uhm-hmm.

LAST: And Jean was—

MOORE: RB is Bob Brown, I presume, on the assembly?

LAST: Yeah.

MOORE: [laughter] I snicker. I remember him up there working on this gold ball bonding for a while. I deemed that eventually an operator would be able to do a hundred transistors a day. That was another example of our view of where the technology was going. Now it's just like a sewing machine. [laughter]

LAST: Making how many contacts?

MOORE: These days we've actually gotten away from that, most of the stuff. We put on a bunch of bumps and turn them over and solder them down. But we used to put on 408 that way.

LAST: So, at week nine we finally got the power in. [laughter]

LÉCUYER: The plumbing too?

LAST: I know we didn't have plumbing because the gas station down the street was getting very irritated with us, [laughter] this whole company using their facilities. [laughter] I remember one day there was sort of a field across the street and a rabbit ran right out of that field into the plant.

MOORE: Yeah. It got into the women's restroom. Anyway, Murray Siegel had to chase the thing out of the women's restroom. [laughter]

LAST: So, by week nine it was that long until we had facilities in.

MOORE: Yeah, it was a bare shell when we went into it. It took a while. Had to design it and get it done and it's only a couple months.

LAST: And build every piece of equipment.

BROCK: What sort of hours were you keeping in those days? When would you typically arrive and when would you typically leave during the day? Were you working weekends? Do you recall?

LAST: Well, sometimes.

MOORE: It was nominally eight to six, I think.

LAST: Yeah. Well first we had to quit when it got dark. [laughter]

BROCK: Yeah. That settled it.

MOORE: It would get dark earlier and earlier at that time of year too.

LAST: And so we put an ad in the paper.

MOORE: That's when the ad ran. It took us that long to get an ad out at the time.

LAST: And I don't know what discussions were—I don't remember discussions with Bob on why he didn't want the role.

MOORE: Well, at that time our conclusion after Shockley was that none of us had enough experience to do it. We had to bring in somebody from outside.

LAST: We interviewed, I remember, somebody from Varian, and a few others.

MOORE: We interviewed several people.

LAST: It was a tricky kind of an interview, us young kids interviewing somebody to be our boss.

BROCK: Was that before you—

MOORE: Every salesman in the country thought he could be a general manager.

MOORE: In fact, Tom Bay came in as one of the candidates. We hired him as sales manager.

LAST: At that time he started the first of January. And—

BROCK: I'm sorry, Jay, can I interrupt with one question going back, and forgive my ignorance, but what is a PNIP device that you were suggesting that you were going to make by June?

LAST: Oh, this was something that never happened. It was just a device with an extra layer of an intrinsic material in it. But nothing ever happened with that.

MOORE: Yeah, it was presumably a way to get higher frequency performance.

LAST: Something that startled me—all through here we were still thinking of the four-layer diode.

MOORE: Were we?

LAST: That goes on for a year.

MOORE: No kidding?

LAST: Where we had a preproduction line on four layer diodes after a year.

MOORE: I didn't know that.

LAST: I didn't either until I saw that. At week ten we still didn't have our sinks in. [laughter] And, putting that in perspective, that's now thirty weeks from the time we delivered our first [laughter] product, or had the Wescon Show in August. And so we—

MOORE: We applied for the security clearance for the facility.

LAST: Which we never got, I don't think. Probably—we were dealing with the military, but I think we were far enough away from the actual use, that we didn't—maybe we did have one. I don't know.

MOORE: I don't remember.

LAST: I did have a security clearance there.

BROCK: Personal?

LAST: They really check into all the stuff that you've done in your life. And then I had, when I was at Teledyne then I really needed one. That was the happiest day of my life when I handed it in. [laughter] I was never suited for that.

BROCK: Did other—

LAST: I got some vague remarks from somebody in Washington once that said, "When you're in Europe would you sort of look around at some of this stuff and follow up on that?" [laughter] But here, at week twelve, we had spent seventy-five thousand bucks, in a month.

MOORE: A high number. Wow.

LAST: And week thirteen was recorded a meeting by Noyce with IBM.

BROCK: So Noyce was traveling around talking to potential customers before Tom Bay came on?

LAST: Yeah, or with Tom, but Bob steadily did that from then on. He was Mister Outside.

BROCK: Were either of you involved with any of those potential customer calls?

LAST: No.

MOORE: No.

LAST: By then Gordon and me, neither of us had ever seen a transistor. [laughter] So the first ones we ever saw were the ones we made.

MOORE: Well, I had made a couple of them with Shockley, but no two alike. [laughter]

LAST: But you said that we learned from our mistakes [at Shockley]—were there mistakes in those first transistors that you saw that could be corrected?

MOORE: Oh yeah. There were a lot of things that we had to do differently.

LAST: Remarks were made at the time and later we just took all these processes from Shockley and put them into practice, but they were all changed or greatly modified.

BROCK: Was part of the reason that you were convinced early on that you needed to hire your own general manager, was really saying, "We need some professional management expertise," in contrast to the management difficulties at Shockley?

MOORE: I'm sure that was probably it, yeah.

LAST: Also, while our thoughts were fairly vague, we knew we needed all kinds of systems put into place—personnel policies and things that we had no inclination for or knowledge of how to do.

BROCK: Right.

LAST: Gene [Kleiner] picked up on a lot of that stuff. We did know the company has to have a—

BROCK: Administrative structure?

LAST: An administrative structure.

MOORE: Well, we needed an organization.

LAST: Which, looking back on it, was a difficult role for Baldwin, who was both our boss and wasn't part of the group of us that were doing stuff. A key thing on page three was that they [IBM] needed matched NPN and PNP, and that was a key thing because we were the only ones with our processes that were going to be able to do that on short order.

MOORE: But the one we ended up making was this core driver, a 150 milliamp 2 megahertz device. That was the product that got us going.

LAST: Yeah. That's the one that—

MOORE: They'll pay a hundred dollars each for the first five hundred.

LAST: It was a vacant area in transistors. We never questioned the idea that we were going to use diffusion, but here we, on page three, we had thought it through. We were saying why diffusion was going to be able to do things. You can make complementary devices. We had flexibility in the structure we could make. We could keep capacitance as low as possible.

BROCK: When IBM was saying they needed a matched NPN and PNP, could you explain what that means? Matched devices, the NPN and PNP?

MOORE: Oh, it means they handle about the same current. I think they wanted to use a kind of push-pull for the server drivers.

BROCK: I see.

LAST: One's on and one's off. When the polarity is one way one of them's on.

BROCK: And then they would have similar electrical characteristics all the way down?

LAST: There's a seesaw kind of a thing here.

MOORE: Complementary bipolar, if you want to look at it that way. [reading] "Hard to make contact with low saturation resistance in diffusion."

LAST: And so we, [laughter] we're still debating doing the core driver. But whatever IBM had wanted I think we probably would have. [laughter] But we ended up with something we could make. "The smallest island possible, five mils." [laughter] That looked awful small then.

MOORE: It was.

LAST: In week thirteen we finally got—

MOORE: A poly sink, a good old plastic sink finally delivered.

LAST: So in this first twelve weeks, you were busy building furnaces?

MOORE: I was building furnaces and then things like the poly sinks are things I did. I was building a lot of the equipment, doing my glass blowing. In those days, all of the diffusion furnaces were equipped with glass jungles.

LAST: And you were the only glass blower in there?

MOORE: Yeah. Well, when Bob Brown got into it. Oh, Art Lash. Art was a technician that got into glass blowing. He was the one that we set up on the side to make the little capillaries for the gold-ball bonding, [laughter] and that became Electroglass.

LAST: But you changed the furnaces completely from what we had at Shockley?

MOORE: Oh yeah. I had made a horrible blunder at Shockley building platinum winding furnaces. I didn't realize that there was a volatile platinum oxide. The platinum just left the elements and deposited it all over the ceramic and it burned out in about two weeks. So we had to design something completely different. We got good furnace elements from the company in Sweden. I think it was called Kanthal?

LAST: Kanthal.

MOORE: Kanthal. And while I didn't know what I was doing, I had to design the control system for the furnaces. It was a kludge but it worked. We designed the transformers. We designed saturable reactors. Good chemicals problems.

BROCK: And Jay, in that initial twelve-week period you were—we talked about the crystal sawing and polishing, the photolithography set up?

LAST: Noyce and I were building the step and repeat camera.

MOORE: I don't remember which one, or both, went up and selected the lenses for the first step and repeat camera.

LAST: Well, Bob and I went.

MOORE: You went together?

LAST: We went together.

MOORE: And you selected the three best-matched lenses—

LAST: Yeah.

MOORE: —out of the collection that they had in San Francisco.

LAST: So the high point of the use of my whole undergraduate optics education was picking those three lenses. [laughter]

MOORE: I've always maintained that's the reason it took so long to try Jean's planar device, because that took four masks. [laughter] We only had three lenses. [laughter]

LAST: Well, I bought a bunch of lenses.

MOORE: Yeah, but the camera only used three at a time.

LAST: It used three but I think we bought a dozen of them or something. The camera store obviously couldn't make very good tests on them. I sort of eyeballed the thing so I could match them up. I worked on that with Noyce. Then we started working with photoresists that were not nearly capable of doing what we needed. We worked with Kodak and they really cooperated.

BROCK: Were you working directly with Kodak or with a distributor?

LAST: Well, probably somebody in between, but it was a pipeline right into their—because they were looking for guidance for resists that were going to be a step beyond what they were using in printed circuit boards. We were providing the input and they were providing us stuff. They must have been very fast.

LÉCUYER: So was the issue purity then?

LAST: Oh, it was everything, purity and how do you get the layer to stick and still be able to get it off later on without having to scrub it.

LÉCUYER: Okay.

LAST: It was getting it off that was more of a problem than putting it on.

MOORE: These were a lot finer features than any of the printed circuit boards and we needed a lot thinner layers of photoresist to mask against the etches.

LAST: And it was an awful lot of witchcraft. I remember when we wrote the process manuals—which will come into play in a couple of months—if you followed the manual you never could do anything. [laughter] There were just enough decisions that you had to make that you couldn't even write down, which meant that when the thing got into production there was a lot of work to straighten those things out.

BROCK: Right. How did that contact with IBM Oswego happen? Do either of you recall how Noyce got in the door there?

MOORE: I think Tom Bay was shaking the bushes to see who wanted to buy a transistor, even though we didn't have one to sell quite yet, and dug out the thing.

LAST: Well, Christophe came up with something in our files about Sherman Fairchild?

LÉCUYER: Yeah, actually I talked to Dick Hodgson once and he told me that Sherman Fairchild contacted IBM and that they went together to see Tom Watson and told him that they were interested in selling transistors to him.

MOORE: Oh, okay. I'm kind of guessing. I don't really remember specifically.

LAST: I had nothing at all to do with the sales activities. Even allowing for gross inflation, these numbers are awful low. [laughter]

BROCK: In evaluating, in early January, your financial burn rate or whatever you want to call it, was that a cause of concern when you saw that? With going by your estimations that you had run through your commitment of 1.3 million dollars by March 1959, or did that seem on track? Did that seem okay?

LAST: It seemed okay to me. I didn't think about it that much.

MOORE: I don't remember feeling any special pressure.

LAST: But here we were still had a year's money. At week thirteen we were still talking about Baldwin.

MOORE: If we wanted him.

LAST: And week fourteen—

MOORE: [reading] "The photoresist has worked once." [laughter]

LAST: And now, on the diffusion, who was doing what there? Some of this you were doing. And some was Dave Allison?

MOORE: Yeah, I was looking over all of it I think.

LAST: Who else was involved in the diffusions?

MOORE: I remember it was mainly Allison and me and a couple technicians.

LAST: The technicians had to learn on the job, because obviously nobody knew any of this stuff we were doing.

LÉCUYER: Actually on 13 January there's an entry called "Educational Summary," and there's lots of things about education for technicians.

LAST: "Technicians, inside education, outside education, orientation, reimburse expenses." People came from all kinds of backgrounds.

BROCK: The technicians?

LAST: Yeah.

BROCK: Any particulars come to mind?

LAST: I think [Robert] Robson was pressing me.

MOORE: Robson was working across the street with—

BROCK: Farnsworth, I think.

MOORE: They were into some kind of electronics and he came from there. But Murray Siegel was the first technician who arrived. He was actually on his way out to go to work for Shockley, and Gene Kleiner knew him. And Gene called him on the way out and he came to Fairchild instead. [laughter]

LAST: They worked in [Victor] Grinich's garage for a while.

MOORE: Yeah.

LAST: It must have been a shock. [laughter] He hung in there for years.

MOORE: Yeah. He did.

LAST: So we were doing all of this. No wonder we were having trouble making stuff—we didn't have distilled water or hoods.

MOORE: Yeah. Right.

LAST: Dave Allison reported, he said, "We can make the devices quickest with antimony and gallium."

BROCK: In terms of production time?

MOORE: In terms of which things were farthest along.

BROCK: Okay.

LAST: Reproducibility.

MOORE: Gallium diffusion was relatively easy.

LAST: Antimony really wasn't that bad. But I wasn't doing it.

MOORE: I don't think any of them were really that bad.

LAST: Boron chewed up the tubes pretty bad.

MOORE: Yeah, you really had to cook them in those days.

BROCK: And, "for encapsulation the cold welder is to seal the cans." Is that right?

LAST: Yeah.

MOORE: Uhm-hmm.

LAST: We knew that a lot of these were going to be long lead-time items and, that was the stuff Gene and Julie were focused on.

MOORE: Okay, and here's the first discussion of our crystals.

BROCK: The week, on 13 January?

MOORE: Uhm-hmm.

LAST: So, we were—

BROCK: It says "side freezing out."

LAST: I kept some of Sheldon's first crystals. They looked like acorns. [laughter] I have all these nice looking little acorns. But he got it straightened out.

MOORE: Yeah, and, [Dean] Knapic got into business about this time too, not much later.

LAST: With crystal growing?

MOORE: Well, selling crystals too.

LAST: Oh.

MOORE: But it must have been a little later.

LAST: But our diffusion furnaces were all built inside?

MOORE: Yeah.

LAST: Art [Lash] went into the business.

MOORE: Yeah he did.

LAST: Later. And we bought them—I don't know. When I went to Amelco I bought crystal growers, and furnaces from him.

MOORE: The whole industry did, except Fairchild for a long time.

LÉCUYER: Were these crystal growers induction growers, or were they resistance heating growers, that were the first ones at Fairchild?

MOORE: Well, Knapic built crystal growers that he sold as well, I guess, and crystals. I think that's right.

LAST: Sheldon, not too long ago, was talking about what he did on switching from one to the other and I don't remember what he was talking about. This was just a good example of people working independently and doing their part of the thing. Because Sheldon, that was his responsibility and he did it.

MOORE: I had to tell Tom Bay not to give out data sheets yet. [laughter] We hadn't made a transistor yet. [laughter]

LAST: Yes. So Tom was doing it mainly and Bob, I think, was very involved in this a lot. He was getting specs from IBM, and were very cooperative because I think the original spec was something we couldn't meet, and needed to reduce the specs enough that—

MOORE: The 150 milliamps were right where targeted, and amazingly came out that way.

LAST: And then on week eighteen we hired Baldwin, and he came in and made an organization chart. [pages turning] Yeah, here's what Ed told us we had to do. That's page—

MOORE: Page fifty.

LAST: I sort of understood what all these words were but I didn't necessarily see how it would fit into the grand scheme.

BROCK: So, he's defining the necessary functions and the organization?

LAST: And, under R&D [research and development], which is headed by Noyce, I see Gordon's name penciled in for Device Development.

MOORE: Sheldon for Materials. Grinich for Device Evaluation. There's Blank for Engineering Services.

LAST: Engineering, it's not very clear, E.K., Kleiner for Manufacturing.

BROCK: Then this spot blank.

LÉCUYER: Actually, Kleiner appears both for Engineering and Manufacturing.

LAST: Yeah.

MOORE: Yeah, actually, the way things shook down I actually took that Engineering job, with Preproduction Engineering, Instrumentation, and Applications Engineering. So, I took the job here as soon as Kleiner left, after the first transistor was built. I moved with the NPN from Device Development to Engineering.

LAST: I think in the last page there, someplace there, there's an organization chart that shows Gordon. It's in there someplace. Where is it? Oh, it's probably the last page of the thick book.

MOORE: I know I did that. Although I'm just not quite sure when. When we switched to NPN.

LÉCUYER: It's after page ninety-six.

LAST: Oh yeah. That was your empire.

MOORE: My empire. [laughter] That's what it was. There's a bunch of names there I haven't thought of in a long time. Some of them I don't even recognize.

LAST: But Ed had hired a lot of his cronies from Hughes [Hughes Space and Communications Company]. Like Weindorff. These were guys where that had been their job, preproduction engineering.

MOORE: Weindorff and Elbinger [Bernie Elbinger] are both in here.

LAST: Yeah. And, Robson was in there as a—

BROCK: As a foreman?

LAST: Foreman, technician. He had his assemblers. In addition to this, in R&D I had hired Jerry Lesard. He's an ex-Navy chief who ran—if you wanted experimental devices put together Jerry would, it was his group that did that. At this time the assemblers, a lot of these girls had college degrees and were really a skilled bunch of ladies. And that was beyond my capabilities of running that bunch. But Lesard, an old Navy chief, he was just perfect at it. [laughter] So this organization chart was August of 1958, so that was just at the time we shipped our first devices to IBM.

LÉCUYER: The company had grown very fast? It's just amazing.

MOORE: Yeah, well, once you—it's a complicated process and you've got to have several different things working, so you can't do it with just a few people. Like Intel, we got up to a hundred people right away. The minimum we needed to cover the bases. I see in week seventeen, 7 February 1958, single metal for contact resistance was still a problem.

LAST: Yeah. That was something that bugged you for—

MOORE: Oh, that bugged me. [laughter] I had all kinds of complicated solutions, and Noyce suggested I try aluminum that everybody knew it wouldn't work, but I'd never even thought of that before.

LAST: What do you think he was thinking about?

MOORE: I don't know. If anybody would have been against it, it should have been Bob. But the only thing I can think of is, you know, with his thinking on tunnel diodes back at Shockley, had this idea that if something was doped enough it essentially became a metal. And he may have recognized that if the emitters were heavily enough doped it might be okay. He never gave any justification for it. He wanted to try aluminum.

LAST: Or, maybe he was just working his way alphabetically down the periodic table. [laughter]

MOORE: Argon probably wouldn't work.

LAST: Argon certainly wouldn't work. [laughter]

MOORE: But that was one of those suggestions—I had tried everything that I could think of, so why not?

LAST: It was easy to evaporate then?

MOORE: Yeah it was. It was easy to do. For the NPN worked perfectly. With the PNP it didn't work worth a damn. That was one of the main reasons that the NPN was a lot easier to make. Because with the NPN you had this very heavily doped emitter. Aluminum made good contact. The PNP, the base layer was not nearly so heavily doped and it didn't make a good contact. It took an extra step. That's the complication of the PNP.

BROCK: I see.

LÉCUYER: Here on page fifty-one you have an interesting schedule of tasks, with deadlines. That's interesting.

LAST: Yeah.

LÉCUYER: With process equipment tests.

BROCK: Oh, and this is to meet the six-month schedule for the core driver?

LÉCUYER: Yeah. [turning pages]

LAST: So this is essentially our first meeting with Baldwin. Everything was going to be coming together about the end of April.

BROCK: Jay, if you look to that initial meeting of 17 February where you're associating names with the boxes, do you recall where you were going to be in R&D?

LAST: I was in Product Development.

BROCK: Okay.

LAST: Gordon and Jean and I were put in there together, I see. We realized we were going to need product manuals. In looking through all these tasks, Gordon, is there anything in here that you thought, "What in the hell do we need that for?"

MOORE: Not that I remember. It just seemed, you know, I was [laughter] getting educated.

LAST: The thing Ed stressed was quality control and "You have to sell a reliable product." That whole quality control came as a little surprise to me that you'd have to really have a whole department that does that.

MOORE: And electronic instrumentation. Bernie [Elbinger], that took a long time for me to swallow. I don't know if it was the function, per se, or the fact that Bernie came in with a very different view of how much money you ought to spend to get those things done. Now, I was a penny pincher and he was used to doing this at Hughes where—you know, I remember one thing, when he bought one of these machines that engrave labels into plastic, and I couldn't imagine paying that much for a machine just to put a label on the damn tiles. [laughter]

LAST: So, in a sense there still was a little bit of "them and us" in there, which evidently was a lot more serious to Ed than it was to us because he left.

MOORE: Yeah. I—what the heck—I want to say Waldorff. That's not right.

LAST: Dave Weindorff?

MOORE: Weindorff.

LAST: Weindorff. Yeah.

MOORE: Yeah, but Weindorff integrated very well. I worked well with him. To me he was far and away the biggest loss of all of them. [laughter]

LAST: Oh yeah. I really hit it off with him.

MOORE: Yeah. He was just a nice guy, competent and made one bad choice. [laughter]

LAST: I remember I really felt bad when he left. Who else did Ed take?

MOORE: Yeah. [laughter] The secretary. The guy who was doing our purchasing and such. I think he was one of a pair of twins.

LAST: Oh, I remember, yeah.

MOORE: I don't remember his name. And then the group that he brought from Hughes.

LAST: Yeah. And his purchasing guy would be very key because he knew—he'd know where to buy all the stuff and what it cost. And at this stage we were talking about life tests on devices.

MOORE: Yeah.

LAST: It's things that wouldn't have—

MOORE: Well, that would have occurred then I think.

LAST: But not at the point where we had not done enough to build it. [laughter] We were looking for birth tests. [laughter]

MOORE: We were trying to make a hundred of these darn things for IBM. Committing several to life tests would have been pretty tough to do. [laughter]

LAST: This whole area of Application Engineering and things. I can see the need for it, but I just never had anything to do with those. On the bottom of page fifty-one there seems to be a solid line that says, "Additional investment needed for this for the most part." Which part of it meant that we weren't thinking of running out of money but we were demonstrating some existence proof that was going to require more money coming in.

MOORE: "Preproduction equipment budget was light by a hundred thousand dollars." Wow.

LAST: That was quite a meeting that day. Bob was talking about, "What devices do we make next?" And on there you see the PNPN.

MOORE: But what happened to the [PNPN].

LÉCUYER: The power transistor?

MOORE: That's one you could do anyhow.

LAST: Yeah.

BROCK: So this is essentially a list of things you could do once you made the IBM transistor? You would have a process technology that would allow this array of—

LAST: I said, "No major geometric changes." So we could fiddle with the diffused layers and change the parameters enough to get other kinds of devices. Bob had probably thought through all that.

LÉCUYER: And then you mention "backside diffusion." It's the fourth line down the top. "Follow this line. Backside diffusion and accurate lapping."

MOORE: Yeah. That would have been of special interest to Jay who had to worry about lapping the wafers.

LAST: Yeah. I got out of the lapping business about that time, I think. And was taken over by Kleiner and Julie and a bunch of the guys were doing it, starting to do that.

LÉCUYER: What kind of materials did he use to polish the wafers?

LAST: Silicon carbide. It was a standard optical process. I was just following the standard optical processes.

MOORE: Actually, we didn't even use polished front surfaces for the early work. We etched them to kind of wavy surfaces. They were better from a point of view of crystal perfection than the polished surfaces. Kind of wavy.

LAST: Yeah, I was working on that. My notebook is just full of pages and pages of etching wafers and when you'd polish them you had to take off the damage that was created by the polishing, of course. So you had to etch away that fractured layer.

MOORE: And to get a good clear surface you had to have one of these etches that kind of ran away thermally. So, it was a delicate process. You know, brown fumes coming off in copious clouds as the nitric acid went down the sink. [laughter] The etch is a mixture of nitric and hydrochloric acid, and it etches the silicon very, very nicely, and very, very rapidly.

LAST: I remember—

MOORE: We had yellow fingers.

LAST: Yellow fingers. And then later on in the mesaing I had black sticky fingers. [laughter] I had all these solvents at home in my medicine chest to clean up. [laughter] But we were thinking here of the power of step and repeat in photoetching. We're talking about inner digitation to get higher power out of devices. Without getting the capacitance up and things like that.

LAST: February—you can see the sort of trips Noyce took.

BROCK: Oh, I see.

MOORE: Ramo was "Down on TI because of reliability." How about that? [laughter]

LAST: What's new there? [laughter] At this time, people had the technology and could have done what we did. Hughes certainly had it and TI had it. I mean if they—

MOORE: They weren't focusing on the diffusion. You know, TI was doing grown junctions. Hughes was making a huge number of diodes.

LAST: But, they had access to Bell Labs, who was doing the diffusion. That was one of Shockley's strong points. It was never even a subject for debate. Diffusion would be the way we do it. And, Bell Labs, at the time, probably was looking at the problems rather than trying to figure out a solution to them. I think so many of these things just didn't happen because people said, "Gee, this is so hard, [laughter] and it's never going to work." We didn't have any choice. [laughter] If it didn't work we wouldn't have a company. [turning pages] At the 24 February meeting, it was "Talking to GE [General Electric]. Want one of the PNPN device."

MOORE: A thyristor. Not just a diode. [The notes from the Hughes meeting read] "Airborne systems people need silicon now." It shows how the military is influencing the early days without direct contracts.

LAST: We were talking high-priced devices then. Nobody else could consider it. I mean, you had the transistor radio people, on one hand and this kind of stuff on the other.

BROCK: In looking at the places that Noyce and Bay were going to in this very early period, it seems that even the computer manufacturers seem like defense system people, with Litton [Litton Industries]. But I guess that was the preponderance of computing systems?

LAST: There was no thought about a commercial use of these things in those first days. Mainly airborne computers that—you couldn't afford the air conditioning to run them if you used germanium.

BROCK: Right.

LAST: And that's why tracing back the history is so hard on these early devices, because all of these went into classified military systems and they just disappeared and nobody ever saw them again. [laughter] There was somebody back in New England that approached me and was trying to get examples of all the transistors we ever made. You've probably ran across him sometime or another. He said the one he could never get were these first Fairchild devices.

LÉCUYER: "Reliability" appears at almost every entry. These are the meetings with the companies in Southern California?

LAST: Yeah.

LÉCUYER: And "reliability" appears as a major requirement of all of them?

LAST: Yeah.

BROCK: This entry here from Noyce's trip to Los Angeles, he's expressing the opinion that you should work on an NPN for reliability reasons? Is that right? I'm looking at page seven in the synopsis. [turning pages]

LÉCUYER: And the number is?

BROCK: 24 February 1958. It's on page fifty-five of the notebook itself. It says, "First device should be NPN—reliability—then get the PNP."

LÉCUYER: "Get the beta up."

BROCK: Oh, "Get the beta up then work through the PNP with backside diffusion."

LAST: On page fifty-six of the notebook there's another—

BROCK: Oh, wow.

LAST: Another one of those schedules. Here we're talking "IBM devices downgraded specs," so they cut something down to cooperate with what we thought we could make. Most of the customers weren't quite as agreeable. [laughter] But this is something that Ed had said.

LAST: "EB conclusions."

BROCK: So what is this a count of? Devices that you would be making?

MOORE: It doesn't sound like it.

LAST: No, it was probably dollars. Huh. It seems low for dollars and high for devices. [laughter] Because we're talking about spending more money than we thought. Because I said—who the hell was there? Yeah, that'd be dollars. "New equipment, seventy-six thousand dollars."

BROCK: Welder and an evaporator.

LAST: About the only number we knew was dollars with our salary, which was about fifteen thousand dollars. So, these are all [laughter] big abstract numbers.

[END OF AUDIO, FILE 1.2]

LÉCUYER: So, Jay, on the bottom of page fifty-six. There is an estimate—these are the goals. "Start production. Be able to get twenty thousand devices a week." Right?

LAST: Yeah.

LÉCUYER: And with two hundred thousand dollars to thirty thousand dollars of revenues per month, also?

BROCK: "To get production line going by the end of year." That's the cost.

LÉCUYER: Okay.

LAST: Let's see, and inflation in that period is probably, what, ten times?

BROCK: From that period to today's dollars? Probably.

LÉCUYER: So that was real money then right?

BROCK: Yeah.

LAST: Probably a couple million dollars. But still, I mean, you're looking at a scale of anything now you don't even see [laughter] a couple of million dollars.

BROCK: Then on the next page—

LÉCUYER: Then come the estimates.

LAST: Well, if somebody was inclined he could write an interesting article or a little book about the forty-week saga.

BROCK: Oh sure.

LÉCUYER: Actually, I was thinking that it would be really wonderful to do a facsimile edition of this—we've talked about this in the past—of this notebook.

BROCK: Precisely that, if you did that facsimile edition of the notebook, with annotations and sort of contextual pieces.

LÉCUYER: And comments from you and from Gordon. Maybe if one were to do it, to have a page of the notebook and then your comments and Gordon's comments on the side.

BROCK: Or other contextual pieces.

LAST: And, when you got the thing roughed out you could talk to other people who were involved. But I wanted to keep this to myself for a while. But the time has come now to do with it what you like.

BROCK: We can have an ongoing conversation about it, because I think it would be one possibility for a publication about this forty-week period. There are other possibilities too of doing a more traditional short volume about it. We would use it basically as the central background resource and then just write your own narrative of it.

LAST: This is sort of a like an oral history. It gives a feel. And if you look at it, this was a really remarkable thing. We're talking and talking here and we're up to February. And we're talking about all kinds of issues, but we still had not built a transistor.

BROCK: [laughter] Right.

LAST: And I look at these other companies and their huge resources and they just didn't do it.

BROCK: Right. Comparatively someone like Hughes or Texas Instruments as we were talking about.

LAST: Or, there was a company called Pacific Semiconductors. They were the ones that scared me. They seemed to have an awful lot of good technology.

BROCK: On page fifty-seven of the notebook there are these interesting production and income estimates, were these Baldwin's ideas as well, do you remember?

LAST: I would imagine so. Tom Bay was involved. Or we maybe were looking at it from the standpoint of what we could do too. "Half for life tests." That really always bugged me. We were going to have a hundred saleable devices a week that we'd sell for fifty bucks. And that said in July we'd be making five thousand dollars a week. So we were thinking pretty optimistically there, if we were going to be making a thousand devices a week at the end of the year.

BROCK: With the 25 percent yield. And then at the end of the year reach ten thousand devices per week at a linear rate.

MOORE: "Price down by 2x, yield up by 2x."

BROCK: [laughter] In six months.

LAST: Yeah, saying then, "We can be selling two or three million dollars a year the next year, if they are reliable."

BROCK: And it appears that's the key military requirement for these, more so than perhaps specifics on particular electrical characteristics?

LAST: Yeah. I saw that in spades later in my career, where I had some devices in the Minuteman silos and it didn't work. They had to take all the Minutemen out of their silos and replace that part, and rubbed my nose in it every time they took one out. [laughter] On page fifty-eight there's another technical meeting.

LÉCUYER: I see there's a—

BROCK: "Photoresist in ill repute."

LAST: Photoresist was a steady terrible problem.

BROCK: Just lifting?

LAST: Lifting or contaminating the devices. The devices at that time—they were hard for us to make, but they weren't terribly sophisticated. The dimensions were ones you could see. [laughter] You'd look at them under a microscope. With the photoresists, you'd get all sorts of contamination, or it would lift, or stick too tight. You tried burning it off and it'd leave some ash in the next layer. So I can see why nobody else used it for a good while.

BROCK: I'm surprised that Kodak was so receptive and responsive because the actual quantity at the time must have been extremely small—actual volume of photoresist consumed. I suppose they were looking at it as sort of a market development?

LAST: Yeah, I think they were talking to the research people who said, "We've got a pretty good thing here, but what do we do with it?" Because their printed circuit market was developing big in that way and they were probably thinking, "What do we need to do?" They were probably looking at it from a printed circuit board perspective, how to make much more tightly controlled etching. So there would be a market for it.

BROCK: That makes sense.

LAST: We would get bottles of special stuff from Kodak.

LAST: You have a lot of what-ifs, and what if Kodak hadn't cooperated with it? [laughter]

BROCK: Yeah.

LAST: You do that the whole way across the thing and say, "If any one of these things hadn't happened," and "if the crystals weren't any good, or if the diffusion was completely irreproducible."

LÉCUYER: But at the same time you've only got so much experience, even some technical knowledge and previous experience so that was a—

LAST: Yeah.

LÉCUYER: And beta appears also all the time, right? I mean reliability in the beta?

LAST: Yeah.

BROCK: What is that beta standing for there?

LAST: It stands for circuit gain.

LÉCUYER: And the answer is "clean up the wafer."

BROCK: And to clean up the process?

LAST: Any dirt or anything were big killers of devices. The electrons get sucked up to something.

BROCK: "Deathnium."

MOORE: What page are we on now?

BROCK: Oh, we're on—

LÉCUYER: Page fifty-eight.

LAST: Fifty-eight.

MOORE: Okay, I'm caught up.

LAST: On fifty-nine we were talking about membership in committees. And on fifty-nine it said, "IBM order here. A hundred devices at a hundred and fifty bucks."

MOORE: That was the key order.

LAST: Yeah and I was—

BROCK: Order had arrived at—

LAST: And that was March.

MOORE: 2 March.

LAST: 2 March. And they gave us the specs.

BROCK: And also a definition of yield, "The final seal yield will be the number used."

LAST: LaRoque? Was that Rocky LaRoque?

MOORE: Yeah, this was the guy from the Signal Corps.

LAST: I don't know what he was doing in that.

MOORE: Well, he was evidently—I mean, that's what he needed, or wanted to give us a contract on.

LAST: Yeah. He was around a lot. I remember.

MOORE: Yeah. "Here tomorrow," it says.

LAST: So that's out of context with the rest of the page. "Ten a.m. Wednesday. Contract meeting." Whatever that was. Page sixty you had to split up R&D and Pre-production budgets.

BROCK: For what reason, do you remember?

LAST: I think we said, "We're going to have a company now."

BROCK: Okay. [laughter]

LÉCUYER: There's nickel plating.

LAST: Page sixty-one, we were referring to nickel plating.

BROCK: And who was working on the nickel plating?

MOORE: Well, the nickel plating of the wafers was what we had to do to get good electrical characteristics, which again was quite a surprise to me.

LAST: You were doing that?

MOORE: Yeah, but again it was one of Noyce's suggestions. Bell Labs had done nickel gettering to get rid of gold. We didn't understand the soft junctions, and putting nickel plating on took care of that problem. The situation is—the things that gave the so-called soft junctions, these good electrical characteristics in the back direction, turned out to be some kind of precipitated metal in small quantities. And if you put something that acted as a sink for the metal, to kind of suck it out if you're going to look at it that way, the junctions hardened up right away. We didn't understand what made soft junctions. And it turns out nickel plating the things worked that way. Looking back I should have recognized that at Shockley, because there I made the devices, and Noyce and Sah did the space charge paradigm. I made those on the ugliest looking wafers that I had. They were the ones where my furnace went bad, and had little puddles of gallium all over the wafer. That was sucking the stuff out. That gave good hard diodes quite by accident. I didn't understand why. Finally we started putting stuff on on purpose to make hard junctions.

BROCK: Would you plate one side of that?

MOORE: You'd plate the backside.

BROCK: Oh, the backside? And then you would leave it there?

MOORE: Yeah. Well, he'd grind it off afterwards, typically. But these were very fast diffusing impurities. They were copper and gold, or something like that. That came out and went into the metal and the metal was a sink.

LAST: Jean later went ahead and used gold.

MOORE: Yeah, it turns out gold does the same thing. But since the idea of nickel plating was to get the gold out, we never quite were able to correlate all those things. But gold was known to be "deathlium," because it cuts down the lifetime. But we didn't need much lifetime in these base layer devices. Jean put them in on purpose and made a much faster switching transistor.

LAST: His way of working was really something. He was really motivated by being pissed off. [laughter] I shared an office with him. He was storming around and ranting and raving, and he wasn't going to put up with us anymore and then he would go down to the lab and make something remarkable. [laughter] That happened a number of times.

MOORE: I probably told you about the diodes. We were going to go into the diode business after we were in the transistor business. The diodes were relatively simple to make but we still had to go through development and the like. We took one of our junior engineers and assigned him the job of doing this diode stuff. Jean came in at four o'clock in the morning, did all the critical experiments before the guy got there, [laughter] completely cut any fun out of the project for him. He was competitive.

LAST: Oh lord, yeah. [laughter] He really was. We're looking ahead a couple of years on page sixty-three. This was in March. We'd been in business twenty weeks and we say we're going to announce our first product in August.

MOORE: At the Wescon.

LAST: At Wescon. So we met these schedules.

MOORE: [reading] "Selling as many as we can make."

LAST: Ten bucks apiece.

BROCK: That's interesting, predicting an order of magnitude price drop.

LAST: Right.

MOORE: We knew the IBM was just kind of a developmental contract. We didn't expect to sell many at a hundred and fifty bucks.

LAST: I didn't care to see these low numbers. [laughter]

MOORE: And it goes on. "In 1958, 200K, 1959, 900K. Break even in P & L in the middle of 1959."

LAST: We were looking ahead a little over a year.

BROCK: Do you remember your reactions to these sorts of forecasts, the both of you? Did they seem sensible and realistic? Did you have a sense of these things of your own or were you relying on some of the other people who had broader expertise in marketing?

MOORE: I don't remember having any particular reaction to this first one.

LAST: I don't either. This was something somebody said.

MOORE: You had to do the scale-up necessary to get there.

LAST: We were focused on building the first one.

MOORE: Then you looked at the SRI [SRI International] estimates of silicon transistors, "three million and eight million and nineteen million."

LAST: Because then we thought we were a little conservative to get 2 percent of the business.

MOORE: Now instead of nineteen million it's 10^{19}. That's a year.

LAST: In 1958 we were talking about producing twenty thousand good units for which we had eighteen thousand for sale. Ed, as usual, "We should be able to double the sales figure." "TI expects fifteen million dollars semiconductor sales." They were the big player.

MOORE: Million units.

LAST: Yeah. "Transitron coming up."

BROCK: Meaning coming into the silicon market?

LAST: Well, it must have been just a rumor or something because they never did quite hack it on that stuff. And page sixty-five's the Hill budget. That'd be coming back from Syosset, I guess.

LÉCUYER: So these are basically the monies that were sent to you?

LAST: Yeah.

MOORE: Yeah.

LÉCUYER: Invested in the company?

MOORE: Hill was the financial guy from Syosset.

LAST: And I think he's nominally president of the company. When you look at an organization chart.

MOORE: Was he?

LAST: I think I can remember seeing that someplace.

MOORE: I don't remember him well at all.

LAST: I don't either. By February we'd spent three hundred thousand dollars and we still had a million to go. [laughter] "No room for second product until the middle of 1959 on our original budget."

MOORE: Fifty to a hundred square feet at fifteen dollars a square foot. I guess that's what it was?

LAST: Yeah.

MOORE: Ah! [laughter] Good gravy.

LAST: What did your latest plant cost?

MOORE: Oh, we got it down to something like three thousand dollars now. We were over four thousand for a while. I mean that's a wafer fab. But, heck an office building is six hundred at least.

LAST: And that's not just inflation, that's sophistication. "Firm decision on NPN – PNP 15 April. "

MOORE: Right.

LAST: And this was in March. We're saying we had to make a decision in about a month.

LAST: Then on page sixty-six, there was a memo at one time I had a copy of, and I think I lost it, but it was the memo where Gordon set up the basis for making the NPN and PNP decision.

BROCK: Setting the parameters for making that decision?

LAST: We would run devices on a controlled production basis, make them both, and then let the results speak for themselves. Gordon wrote this two-page thought-out memo that specified all these judging parameters and things like that. "Put in twenty wafers and pick two batches and—"

BROCK: "Run five batches in a week." Oh, "Run seven batches and choose the five good ones."

LAST: That was going to be the decision whether we picked Jean's PNP or Gordon's NPN. The results spoke for themselves to everybody but Jean. [laughter]

LÉCUYER: He was really pissed off after that?

LAST: Oh, well he was always pissed off, so you had to look above the noise level, but do you remember interaction with him on that decision?

MOORE: Oh yeah. He was really mad. But you're right, you know, the NPN was just a better transistor. But Jean didn't like to lose. That didn't make that much difference.

LAST: Page sixty-seven, material situation. What were we talking about there?

MOORE: We were obviously trying different crystal orientations.

LAST: Oh, this would be back in Sheldon's domain.

MOORE: "Shorts and good. Phosphorous-filled crystals in 1-0-0 and 1-1-1 orientation. Arsenic is now available for splicing." So we were looking at different dopings in the basic material.

LAST: On page sixty-eight, "Hodgson's visit. No problem of getting money if we live up to our promises. Justify extra money in detail. Travel plans. Six thousand dollars over our budget now for everything but sales. Ed Baldwin said that we should travel first class whenever possible. [laughter] Open to discussion. We will run out of the 1.38 million dollars in November. Break even point, third quarter of 1959." So, Dick Hodgson, who was a great supporter of course, was easing the situation for us and said, "Just do your job, but don't just do

the best job you can do with this amount of money." I guess that was the needed support he gave us.

BROCK: Did Hodgson come out often in these early weeks? We're at week twenty-two? Had he been out before?

LAST: I don't remember.

MOORE: He was out when we were setting it up. I don't remember him being a frequent visitor. He would have probably spent most of his time with Noyce anyhow, or Baldwin by now.

LAST: Who probably went back east to see him more than he came out.

MOORE: Well, in fact, page sixty-nine is Baldwin's report on being at a board meeting.

BROCK: Oh, okay. What were your impressions of Hodgson at that time?

MOORE: He seemed like a very confident guy, friendly. Pretty easy to work with.

LAST: He was caught between Carter and us, and Carter was something else. But I distinctly remember signing the papers at Rickey's and Hodgson turned to me and said, "I hope you guys know what you're doing because if you don't I'm going to lose my job." [laughter] I still looked so young then I had trouble getting served a drink in a bar. I always thought the world of him.

BROCK: Going to page sixty-nine.

MOORE: "A board meeting in a couple of months about starting a new facility."

LAST: And this was week twenty-two of the existence of the company. We were talking about our new building. We sort of made a decision along here. We were talking to ONR [Office of Naval Research] and all these places, and we made a conscious decision that we weren't going to take their money. We were going to do what we knew we should be doing.

MOORE: Well, as I read this it says that, "Carter was for one product and O'Donnell was for two." Who is O'Donnell, do you know?

LAST: I don't know. He must have been—

MOORE: I don't remember an O'Donnell.

LAST: But, they had a structure for the company back east that was complex. The guys I never heard of were often the secretary of the company or something.

BROCK: So, these notes of Noyce's—it looks like he met with some different government agencies?

LAST: Yeah. ONR, [Department of] Defense, all those things.

BROCK: Right. So was this the point in time when you had to come to a sort of group decision about taking development contracts rather than strict sales contracts?

LAST: I don't think it even ever occurred to us to take a development contract.

MOORE: Yeah, it was kind of conventional to do it, so we looked at it, but we never really got to thinking about doing it.

LAST: And I remember some of these government guys came in. For some reason they were talking to me about it. I was realizing that the company that scared me the most with their technology was Pacific Semiconductors. And they were taking government contracts to build a very high integrated power transistor, that they were going to sell one of in a system. [laughter] We were looking at filling the whole room full of our stuff in that same system that this one transistor was going to drive. It's just obvious from the economics that if you can do it on your own you're a lot better off. The government was going to pay for the stuff that people wouldn't do on their own. I don't remember any discussion where we were seriously talking about taking any development contracts.

MOORE: We ended up taking a few small ones later. But none that made any difference.

BROCK: Well, what's interesting—if we look at the week mark, we're in here at week twenty-four and we see the manufacturing orientation of the entire operation. You could think of a counterfactual contrast, one that would be much more, "Let's make it more of an R&D operation, come up with some sort of new device?" You had yet to make a device but you were going toward something that had existence proofs. It strikes me that it's a production orientation from the very start. Do you think that's fair?

MOORE: I think that's pretty much fair. We're going to make a double-diffused silicon transistor.

LAST: And sell them.

MOORE: [laughter] And sell them. We may make two or three of them. [laughter]

LAST: And we were all focused on it. We had existence proofs, and while we were all trained as—in response to your question—we're all trained to be research scientists. And you had to work out of that phase awful fast. We would have done any task that was needed to make the thing.

MOORE: Diamond Ordinance Fuse Lab in here with Lathrop?

LAST: Yeah.

MOORE: And, we hired Jim Hall?

LAST: Nall. From that group. Jim was very useful to me in the circuit world. Take a look at page seventy. "IBM coming out in two or three weeks." There I'm still figuring out the specs.

BROCK: "Talk over more reasonable specs, acceptance specs." I see.

LAST: "GE three lead PNPN."

MOORE: That's kind of what's listed here as the—I haven't seen a PNPN diode, a three-leaded control on it as far as I recall.

LAST: On seventy-one, 3 April, we're talking specs on the device.

LÉCUYER: If I'm correct you had two types of meeting. One was a technical meeting and then you had policy meetings?

LAST: Yeah.

LÉCUYER: Were the people the same?

LAST: Pretty much, I think. There may have been others, but this was just a record of all the meetings that I went to.

LÉCUYER: Okay.

LAST: I think we tried to schedule a Monday morning meeting, but it didn't always happen.

LÉCUYER: Okay.

LAST: The bottom of page seventy-one. This must have been crystals.

BROCK: "No shorting."

MOORE: Yeah, I don't know.

LÉCUYER: I would imagine.

LAST: That was probably crystals.

BROCK: And some of the initial tests on the NPN. "NPN with good contacts meet pulse specifications."

LAST: Vic Grinich isn't mentioned here that much, but he was doing a lot.

BROCK: A lot of this testing.

LAST: He knew all about transistors. [laughter]

MOORE: "Base contact of PNP non-ohmic."

LAST: Page seventy-three we're starting to turn into a company—talking about raises and merits, etc. We probably had fifty people in the company, maybe a hundred.

MOORE: Some of the basic philosophy I've lived with ever since.

BROCK: In what way?

MOORE: "Don't mention cost of living." [laughter]

LAST: Seventy-four. Unusual alloying problems. "Two o'clock Monday, NPN and PNP decision."

MOORE: Coming down to the wire.

LAST: I don't have any notes on that decision process.

BROCK: Was that the meeting of the group of people indicated before? There was a group of six or so of you who met to evaluate the data?

LAST: The devices.

MOORE: I don't remember much of a meeting. I kind of remember telling people what the decision was. [laughter]

LAST: And it was an obvious decision.

BROCK: But that didn't mean that the development work on the PNP was finished?

MOORE: No. That was our second product.

BROCK: So, it was just which was—

LAST: It was just coming later.

BROCK: What was going to scale up first?

LAST: Uhm-hmm. And it motivated Jean to push at it a little harder. Page seventy-five, now we were going to need product manuals. I think you were supervising that manual process weren't you?

MOORE: Yeah. Very shortly after this I went into the engineering world instead of the R&D world. Evaporating, alloying, dicing, baking, mounting, and welding were mine. [laughter]

LÉCUYER: So, these were the tasks that each of you had to—

BROCK: Write for the manual?

LAST: Detailed manuals, step-by-step. It's interesting. Diffusion was Jean and Dave. And you and Bob Beeson?

MOORE: No, that was Bobby Brown.

LAST: Oh, Bob Brown.

MOORE: This was essentially an assignment of who was going to write the stuff.

BROCK: In a way it's a process manual and product description?

LAST: Yeah.

MOORE: Yeah.

LAST: And these were detailed, like hundreds of steps. Have you seen anything that Lojack wrote, Bo Lojack?

MOORE: No.

LAST: He's written a—I've seen a manuscript of his before, and he's written history of this whole business more or less from the technical side. He'll go through and list all of these steps in all of these things. I don't think he ever threw away a piece of paper. [laughter] He was a very opinionated guy so it's a book that's very erratic, but there's an awful lot of stuff in it. I was at this time working on making mesas, I believe. I don't know if it shows up in here.

LÉCUYER: Which means?

MOORE: The old Apiezon printing technique.

LAST: It worked pretty well.

BROCK: Could you describe a little bit of that? Maybe we could ask you both to describe what you were both working on at this point. Gordon, you were switching over to really take the product then from development to production by shifting over to that engineering job?

MOORE: [And] preproduction. Right about then. I did move with the product, essentially.

BROCK: And Jay, could you talk a little bit more about mesaing?

LAST: Well, we obviously had to make a mesa. Ordinarily, when people were making devices one at a time it wasn't a problem. My challenge was to figure out how you could do this on a batch, on the whole wafer. So, I made etched thin-metal masks with holes in them where the mesa was, and figured a way of controlling the temperature just right and putting in just enough black wax on there so that when you printed it, it would print right through the holes. And you had to be able to print this to within, oh, a few thousandths of an inch. So I figured out the temperatures, and came up with a way to make nice little balls of wax on there.

MOORE: I remember at some place along that stage you used a rubber stopper or a cork to dip into the wax, and then—

LAST: A rubber stopper.

BROCK: Oh, and that would cover the entire wafer?

MOORE: Yeah.

LAST: And then you'd just stamp it. [laughter] You'd stamp through this thin metal mask with the holes in it. If you heated it right, you'd transfer enough wax so that it would ball up and would provide enough material to resist the etch.

MOORE: It was a pretty delicate process.

LAST: When that got into production they were still doing that kind of a thing.

MOORE: Well there's some kind of a photoresist eventually. I don't remember that transition well. I remember your wax printing.

LAST: I sure do. [laughter] There were all sorts of things that were needed at the end of the line. After the device was built, I had this experimental assembly line. I remember the thermocompression bonding coming in, which was a Bell Labs idea, and we were trying to do

that, because we had to put the leads on the device. This required sort of a knife edge kind to push down on it.

MOORE: We did the ball bonding first. I thought I invented that and then I read an article in the *Journal of Applied Physics* that I may have read previously that had exactly what I thought I had invented in it. [laughter] I must have had my brain cells stimulated by that article, because my invention was so directly the same as the one that they had published.

LAST: That's right, we used ball bonding. Then we were getting this thermocompression bonding where you could push this—

MOORE: Well, this was thermocompression, but it was with the gold ball.

LAST: That evidently kept going for a long time, because Art [Lash] went into the business of making those capillaries.

MOORE: Gene Kleiner kind of put him in business on a moonlighting basis. Three terminal PNPN keeps popping up.

LAST: You never—

LÉCUYER: Who was working on PNPN then?

MOORE: I don't know. Do you remember? We fiddled with it, but for one reason or another it never became a product that really got into the product line. But the three-terminal device is a lot different than Shockley's diode. You have some real control over what goes on.

BROCK: In terms of control of the diffusion of the different layers?

MOORE: No. Electrical control.

BROCK: Oh, because of the third terminal?

MOORE: We could control the switching with the third terminal. We could turn the device on. I don't know if we could turn it off or not. It was a much more practical device than the diode. GE [General Electric] made those things for ages.

BROCK: So the question of "What next?" occurs as early as week twenty-seven?

MOORE: Yeah.

LAST: Yeah.

MOORE: And the small logic transistor was the one that won out.

LAST: Which required quite a bit of tightening up of the dimensions.

MOORE: It sure did.

LAST: The way to define that was—how small a device did we think we could make? Then we had to make a teardrop on it so we'd have enough room to put the ball down, which gave some little capacitance problem. Here we're talking capital equipment budgets in the terms of fives or tens of thousands of dollars.

BROCK: "Steady effort on various other devices." So you're talking there about the process to decide which of these options to pursue in terms of what's next?

LAST: And making a match between what the world wanted and what we could do. Bob was real good at that kind of stuff.

BROCK: Bob?

LAST: Noyce.

BROCK: Noyce was. Is that in part because he was playing more of the outside traveling role?

LAST: He just understood both sides of it. He understood both how you make them and what they're used for. Because his interest in transistors went way back to high school, I think, so he had been always a lot more interested. I was never very transistor-oriented. I never saw one until we made the first one. [laughter]

LÉCUYER: So how was the decision made to focus on the logic transistors?

LAST: Well, we realized that without making any major change in the diffusion we could make a much higher frequency device, much smaller, lower current, higher frequency. And this was—the first transistor was the order of thirty-five thousandths of an inch across, and this one was seven thousandths of an inch across.

BROCK: Oh, okay.

LAST: So, it was down.

BROCK: Quite considerably.

LAST: Quite a lot.

LÉCUYER: Then the issue was to really improve the photolithographic process?

LAST: Yeah. Everything had to be tighter. So, there were two things coming along at that time. One was the first product was going to be the NPN core driver, and then the PNP core driver, which was a match to that that Jean was working on. And they were looking the next step down, to make both an NPN and a PNP logic transistor.

BROCK: The logic transistor also apparently had the virtue that you could use the exact same sort of assembly process?

LAST: Yes, by making a little teardrop island on it. It really expanded our product line without doing a lot of changing. Here we say "identical assembly," on page seventy-six. "Logic transistor identical assembly to our core driver."

BROCK: Then the capital—"five thousand dollars a month on expendable equipment."

LAST: Yeah, we were—

BROCK: In terms of "expendable equipment," what does that cover? I'm not quite sure what that would mean.

LAST: Well, I'm not either, but it probably was what you had to pay for—all the etchants, waxes that we were using—

MOORE: Masks, things like that.

BROCK: Materials?

LAST: Whatever wasn't going to show up on an inventory at the end of the year.

MOORE: Who's Max, do you know? There's a Max that's going to work out the forecast of the three-month budget?

LAST: Oh. That was Max—he'll be on that organization chart. He was over in that other building. Personnel requests and setting up a personnel office, a formal one. Page seventy-eight. We were formalizing all of the processes. Boy that PNPN is kind of chugging along there. Page seventy-eight.

BROCK: These were essentially project numbers?

MOORE: Cost accounting. And the 300 series, those were heavy production. [laughter]

BROCK: "Improved growing techniques." Oh, I see. "Basic work on contracts charged to PNP." [laughter]

MOORE: They needed it, yeah.

LAST: Here we jump from that to sick leave. Processing.

BROCK: Those earlier numbers have been used for like a timesheet? If you have one for non-allocated direct labor, which must have been the most used number.

LAST: Page eighty and eighty-one really go into meetings.

MOORE: Atalla, I'll be darned.

LAST: "Surface stabilization by oxidation." That's pretty interesting.

BROCK: In 1958?

LÉCUYER: The ECS [Electrochemical Society] meeting.

LAST: That'd be the planar device sitting there, unrecognized. Gordon, did you ever have any talks with the Bell Labs people about what they were doing in those days, and why they didn't do more than they did?

MOORE: Just bits and pieces.

LAST: Because very little of this technology hadn't been started at Bell.

MOORE: That's right.

BROCK: One person who we spoke to talked about the lead time before, when working with Western Electric, how far out you had to work on a product for sort of, if you think about a new telephone exchange system. And the lead time, and the product development time was just enormous, so there was very little opportunity to capitalize on some finding like surface stabilization.

MOORE: There's a real problem with having a single internal customer.

BROCK: And Western Electric, in turn, frustrated by the amount of time it took to develop products by their internal customers of the long distance unit?

LAST: And being focused really on the telephone systems being the ultimate consumer.

BROCK: Yeah.

LAST: But still, there must be a lot of people at Bell Labs who were kicking themselves because they didn't push a little harder on some of these things.

BROCK: This must have been the first time you had a chance to go to a meeting since October?

LAST: No, I think if there were meetings we probably went to them. We were still enough of the R&D mindset, that we'd go to all the meetings.

MOORE: Oh, yeah.

LAST: I just didn't write them down. Or there weren't formal reports. I remember going to some of them. This book is not a complete documentation.

BROCK: It's not a complete diary.

LAST: It's just bits and pieces.

BROCK: Would you go to annual meetings or would you go to West Coast meetings?

MOORE: We had somebody at all of the technical meetings related to this stuff. We couldn't all go. We checked in at the Electrochemical Society meetings.

LAST: And there was a summer meeting that Bell Labs sort of put together, a device research conference that we always went to. It was very informal. We'd all get together and talk about—

MOORE: It was very informal. Very.

BROCK: This was the one that met on different campuses each summer?

LAST: We were in Colorado and Ohio State. And the Bell Labs people, a lot of them are British. They had an infinite store of rancid limericks. [laughter] They would go on for it seemed like hours, singing these things. But that was a good bunch. I thought a lot of times that's where I was destined to go and I had almost accepted there before working at Shockley. I would have been part of that Bell Labs group, except I thought the transistor days were—the fun was all out of the place by then. [laughter] So on page eighty-one, we're talking to Sheldon about the economics of crystals.

LÉCUYER: Five dollars each per wafer?

MOORE: Sixty-seven wafers made with phosphorus and seventy-one made with arsenic.

LAST: At what point did we get our first wafers from outside the company?

MOORE: I'm not really sure.

LAST: It wasn't long. It must have been not long after this?

MOORE: "A wafer now costs us five dolars each." But they were tiny little wafers.

BROCK: Yeah. That's true.

LAST: The first ones I think were three-quarters of an inch.

MOORE: Three-quarters of an inch was the biggest. One of my contributions was showing that if we got above three-quarters of an inch the junctions all went to heck. I wish I had some of those.

LAST: Those old ones?

MOORE: Old wafers, yes.

LAST: I'll look around.

MOORE: There was no sense of history when we were living through this stuff.

LAST: Jerry Lesard kept a lot of this stuff. When I left he said, "Here why don't you take a batch of these." I have like the first integrated circuit chip and things like that that I kept. But we were looking ahead. We weren't looking back.

BROCK: And then next is a report by Allison on diffusion issues?

LAST: What page are you on?

BROCK: I'm on eighty-one.

LAST: We're talking about antimony and gallium.

BROCK: Continuing problems with shorts with the PNP it seems.

LAST: What was the feeling, Gordon, on diffusion and bad batches all the time, and good ones coming once in a while? Just muddling through? Or—

MOORE: Yeah, sort of. I don't know if we were doing nickel gettering on a regular basis by this time or not. That would have made a big difference.

LAST: "Engineering changes on the NPN. Possible changes PNP." [laughter] We were looking at stuff that wasn't going to change the technology that much where you could get all kinds of new devices.

MOORE: NPNN+, a kind of epitaxial transistor without epitaxy.

LAST: On page eighty-three, we're evidently talking about—

BROCK: The advantages and disadvantages—

LAST: Of these various devices.

BROCK: So this is an account of different advantages and disadvantages according to whose ideas?

LAST: We're already thinking through all this. Page eighty-five. "GEM—transistor yield deteriorating."

LÉCUYER: It's 20 percent, which was quite good then wasn't it?

MOORE: "F.S. yield 20 percent. Loss of surfaces."

BROCK: Rejecting, is that "rejecting on voltage"? On base voltage.

MOORE: None failed in forty-five hundred hours.

LAST: And we also put those on, how many hours?

LÉCUYER: Orville Baker appears here.

MOORE: That's a long time.

LAST: Yeah.

MOORE: I didn't know we had transmitting that long. Forty-five hundred hours is well over half a year. And this is in May. How in the heck did we do that?

LAST: Something's not right there.

MOORE: We may have had device hours, and we may have meant each transistor.

LÉCUYER: Yeah. So, then you added these.

LAST: Forty-five hundred transistors each which lasted an hour. [laughter]

MOORE: Could be. But we didn't have forty-five hundred transistors. [laughter] Twenty transistors and they each lasted two hundred and twenty-five hours.

LAST: It was the two hundred and twenty-sixth hour was that—

LÉCUYER: You had twenty transistors going?

BROCK: Twenty, yeah. It's cumulative?

LAST: Oh, twenty transistors going.

LÉCUYER: That'd be twenty hours, really, per transistor.

LAST: Yeah. So that would be—

LÉCUYER: Two days.

LAST: Two hundred hours, so that'd be a couple weeks.

MOORE: Orville Baker.

BROCK: Who is that?

LÉCUYER: He was a designer at IBM, right?

LAST: Yeah.

LÉCUYER: Before he moved to Fairchild?

LAST: Yeah. And then he went on to Signetics.

LÉCUYER: Yeah.

LAST: He was quite a talented guy.

MOORE: It's amazing how you completely forget about these people, and get reminded and then you think about them.

BROCK: Was he coming to check on this or were you reporting to him?

LAST: Or hiring him.

BROCK: [laughter] Or hiring him, or something.

LAST: We did. It could have been that he had just come from them.

LÉCUYER: I think he was one of the very first users of the Fairchild transistors, and then he moved to Fairchild.

[END OF AUDIO, FILE 1.3]

LÉCUYER: The yield goes from 20 to 70 percent, and that's the goal?

BROCK: Yeah. By the end of the year for the NPN?

LAST: Where are you looking?

LÉCUYER: Page eighty-six.

MOORE: "Yield will go from 20 to 70 percent by the end of the year on the NPN, and from 25 to 65 percent on the PNP."

LAST: And look, at the end of 1959 we're making as many PNPNs as anything else.

MOORE: NPN, thirty thousand; PNP, thirty thousand; PNPN, thirty thousand.

LAST: So then everybody, by that time, was thinking big. And we'd done everything except build one. [laughter]

MOORE: "Three or four months' inventory."

LAST: So we were realistic, on page eighty-seven, on price dropping.

BROCK: I was just looking at that.

MOORE: Three and a half to 4.9 million dollars by the end of 1959.

LAST: So that was eighteen months after this was written.

BROCK: "On the assumption of two hundred transistors per assembler per week."

LAST: Where was that?

BROCK: It's in your notes here.

MOORE: Look at all your calculations about the facilities we needed.

LÉCUYER: Yeah, it must have been afterwards.

BROCK: It's at the top of page eighty-eight.

LAST: "Two hundred transistors per assembler per week." That's forty hours. That's five an hour.

MOORE: That was before Bob thought we could get up all the way up to a hundred a day. [laughter] I did five transistors an hour in assembly?

LÉCUYER: But the assembly was very difficult at that time, right, in the early days?

MOORE: An assembler takes eighty square feet.

LAST: We could figure from that how big of a plant we needed, which was [laughter]—

MOORE: Fifty-five to fifty-seven thousand square feet.

LAST: Assemblers were making two hundred and ninety bucks a month.

MOORE: Yeah.

LAST: At that time, Gordon and I were probably making a little over a thousand bucks a month, something in that range.

MOORE: Well, I think we all started at one thousand and a hundred fifty bucks a month, when we started Fairchild, which was a significant raise for most of us. Everybody except for Sheldon and Bob.

LAST: They got more.

MOORE: They had more at Shockley by quite a bit.

LAST: So we're saying on page eighty-nine that we're going to break even in late 1959.

BROCK: Was that the case?

MOORE: Yeah. I think so.

MOORE: In 1959, Fairchild exercised its option.

LAST: So we're looking here at putting in a lot more money than the original forecast.

BROCK: Including buying the new building?

LAST: But it doesn't include what they were going to make from selling stuff. [laughter]

BROCK: So, "sustaining engineering" was already a term at that point? In your estimates of professional staffing.

LAST: Yeah. Quality control. That's probably Ed pushing for the building and for staffing all of these functions.

MOORE: And we got up to a hundred or a hundred and fifty people. A total of six hundred or six hundred and fifty people by the end of 1959. Whew.

LÉCUYER: Afterwards there's discussion about the location, and Carter seems to have pushed for Arizona as a possible location.

LAST: Well he's looking for cheap land and not having a lot of people there per building, to keep the unions out.

LÉCUYER: Okay.

LAST: Which didn't appeal to us at all. [laughter]

MOORE: "Fairchild likes small towns." "We'll stay away from area of—"

BROCK: Aircraft industry?

LAST: Aircraft industry.

LÉCUYER: The unions were there.

LAST: And this was Julie's report of all the areas that were available.

BROCK: [laughter] I like Mountain View [California]. "Cheap but noisy." "South Mountain View, cheap but noisy." [laughter]

LAST: That was probably the Moffat Field area, the airplanes coming in. We didn't like San Jose. The initial place that was picked was San Jose. We fought that.

BROCK: Was that a group decision about sighting that factory? I mean, with inputs?

LAST: It was going to be pretty much the eastern people's decision after all, and it was up to us to drag our feet to avoid getting something we didn't want. I sure didn't want to move to San Jose, [laughter] move that far south. We needed ten acres, and there were a lot of ten acre sites around at that time. It cost twenty-five thousand dollars an acre.

MOORE: That's good old Stanford property. It was sure a lot cheaper than it is now. [laughter] That's just on a lease, too.

LAST: Across the street, probably, was the land that Philco built on.

MOORE: Yeah. The jack-rabbit land.

BROCK: And then on ninety-three we get to the next policy meeting.

MOORE: On ninety-three we start, "Noyce R&D, GEM engineering, CSR," and somebody else, "Materials."

BROCK: EK, maybe Kleiner?

LÉCUYER: It's Eugene Kleiner.

LAST: Sheldon and Kleiner, from a standpoint of Kleiner being involved with Sheldon making the crystal and Kleiner sawing it up.

LÉCUYER: These would be decisions about what each member of the group would be doing?

LAST: Evidently. And at that time Gordon was formally running the Engineering Department and Bob was running R&D.

MOORE: It sounds like this is just when that was getting done.

LAST: Going through this it sounds like we've been in business forever by then, but we were thirty weeks old. [laughter]

BROCK: And then another personnel projection?

MOORE: We're really starting to grow then in the number of bodies.

LAST: And this was still June, still eight weeks before we ever shipped anything. [laughter]

LÉCUYER: I'm struck with how ambitious the goals were.

LAST: This was Baldwin. The minute he got in there he said, "You've got to plan something real big."

BROCK: Do you think that was matching the general expansion that he and other people forecast for semiconductor devices in general and silicon devices in particular? He must be thinking that the market's going to expand quite rapidly? Or could absorb whatever you could make?

LAST: I think he also thought that we had, with our technology, picked a niche that we were going to fill up and that was going to be, it was obviously related to computer things and that would grow. But it was a niche that we had at that time and we were the only ones doing anything there.

BROCK: I see.

LAST: I never, outside of these meetings, talked to him about his grand thoughts.

MOORE: I don't remember anything specifically.

LAST: I never had too much interaction with him.

BROCK: Did you Gordon?

MOORE: Not a heck of a lot. I had some obviously, but nothing really sticks in my mind.

LAST: He was sort of an amusing guy. I remember one day he had a box of chocolates on his desk which he left there, came back and the box was almost empty. He said, "Who ate all my chocolate covered ants?" [laughter] But he and Tom Bay were there together in their own area and they used to talk all the time.

MOORE: That three to four months' inventory idea keeps coming up. Nothing "just in time" in those days. [laughter]

LAST: But with the vicissitudes of an operation where we could lose the process that was good. That made a lot of sense to be able to be a steady supplier. On page ninety-four we see IBM was—

BROCK: So, that is what they're expecting you to deliver by which time and for which price?

LAST: We're supposed to ship a hundred and fifty or one hundred in August, but they said they were going to need three times that many in August, at that high price. And with the price dropping in half they were going to need five times as many.

BROCK: Wow. Let's see, those figures at the bottom were budgets for R&D?

LAST: Right. Operation at a quarter of a million bucks a year. On page ninety-five we're getting feedback from the board that yes, we can go ahead on this stuff. We still had under a hundred people at that time.

MOORE: Then we were still talking big numbers of people?

LAST: On page ninety-five it said, "A hundred and twenty-eight people by the end of the year." I would have thought it would be more than that.

BROCK: "Committed to sales of fifteen thousand to twenty thousand devices this year." [laughter] "At an average price of forty to fifty dollars."

LAST: [reading] "Will this pressure make us look bad in 1959?" [laughter]

MOORE: "Start carrying inventory on 1 August. This could lead to a net operating profit in December." [laughter] There's O'Donnell again.

LAST: He was some eastern guy.

MOORE: Yeah.

LAST: "Philco 2N496. In trouble." It's evidently some potential competitor to what we were doing.

MOORE: We got architect's plans for five thousand dollars? [laughter] Whew. It wasn't the same architect I'm using. [laughter]

BROCK: "Commitment from Owego for two thousand devices."

LAST: "To be delivered this year."

MOORE: Litton talking fifty thousand.

LAST: Aero Neutronics had designed a PNPN into circuits.

BROCK: Do you recall anything Aero Neutronics?

LAST: No.

BROCK: And then "RCA at the top of the list." I guess that's for—

LAST: A list of our competitors probably. It's amazing how these companies were sailing along and just somehow stumbled, and never carried on. I told you I had this memo that I got that summer from the RCA Tube Division, that was a nice colored brochure pointing out why

transistors were a flash in the pan [laughter] and would never work. That's one I, unfortunately, threw right in the wastebasket. That would have been a nice document to have.

BROCK: It would.

LAST: I'm sure they didn't keep that in their archives too long. [laughter]

MOORE: "Our device at six to eight dollars could wipe out the low frequency germanium market."

LÉCUYER: Yes, which you did, right?

LAST: Right.

MOORE: Yeah.

BROCK: Or was that the high frequency germanium market?

MOORE: Miller. That was the name of the—

LAST: Yeah.

MOORE: And there were two Millers, they were twins. And one of them was a purchasing guy and one was the personnel guy. Is that what you remember?

LAST: Yeah.

LÉCUYER: So they both came from Hughes?

MOORE: They came from Hughes.

MOORE: I think they were part of the group Baldwin brought in.

BROCK: Was that an observation, you think, for the Aero Neutronics people, about your device wiping out the germanium market?

MOORE: It sounds like it, yeah.

BROCK: Was that—

MOORE: That's what the customers were telling us.

LAST: This was now the first of April, and there's no record in any of these discussions about shipping our first device, because I think it was that week. I can remember it was a real hot day. I went to the supermarket and got a box to ship them in. I remember that morning just being real, real hot.

MOORE: It had to be in the summer then sometime.

LAST: Sometime in the summer. It couldn't have been earlier than this. So, I would guess—so that's our forty-week story.

LÉCUYER: But there is more to go?

LAST: Yeah.

BROCK: Do you recall how many you shipped, of that first shipment?

LAST: We shipped them all.

BROCK: The whole hundred?

LAST: A hundred.

BROCK: Were you anticipating hearing back from IBM about them, or once you got them in the mail and knew they were delivered was that sort of the end of the story?

LAST: No. It would have been a steady thing, because they were looking at buying expanding quantities of them. And this was the first evaluation of them, so we were very interested, I'm sure in—

BROCK: Okay. In their feedback on it?

LAST: Feedback. As you can see going through this it was a cooperative program. They would bend a little bit on something that was hard for us to do, and gave us the feedback we needed if the circuit didn't work. So, evidently they were pretty easy to deal with. [laughter] Page ninety-seven, the organization chart comes in about just that time, didn't it? It looks like there are about a hundred people or less.

BROCK: In these notes from the R&D meeting of, what's that, 5 August?

LAST: 5 August.

BROCK: These are your active programs in the Research and Development Department?

LAST: And "resistance growing."

LÉCUYER: How interesting.

LAST: Inner metallic, what would that be?

BROCK: I'm not sure. I'm not even sure what resistance growing is.

LÉCUYER: It is crystal growing using resistive heating, is my guess.

LAST: Yeah, rather than—

LÉCUYER: RF [radio frequency] induction.

LAST: Rather than induction heating.

BROCK: Okay.

LAST: "NPN 50 percent. Dave Allison."

BROCK: Well maybe half of his time was assigned to that?

LAST: The PNP and the PNPN just keep chugging along.

MOORE: Boy, it sure does.

LAST: By this time we didn't have PNP yet.

BROCK: Right. And then you're proposing to start two new projects. One on a microwave diode? Is that it?

LÉCUYER: And [a] small geometry transistor right?

LAST: Yeah. And I finally got involved in that diode after a while. I did that parametric amplifier diodes.

LÉCUYER: Was it related to the tunnel diode project, or was it—

LAST: Sort of. You had to make real tiny little holes in them. And we're setting up an antimony furnace for high doping. Well, the intermetallic I think, it says here that Sheldon worked on indium(III) antimonide and gallium(III) arsenide.

MOORE: I thought we started to look at the 3-5's (III[A] – V[A] [on the periodic table]).

LAST: What was our thinking then on that?

MOORE: Well, we've done silicon, what will we do next? [laughter]

BROCK: Is the thought that some of these might have been better materials for the small high-speed logic transistor?

LAST: Probably. I mean, the lifetime is so much higher, you get these—as long as silicon didn't work we might as well have something that didn't work. [laughter] We would have had our plate full working with those things.

LÉCUYER: Absolutely.

BROCK: "Horizontal growing."

LAST: Where are you?

BROCK: I was just reading the notes under Sheldon Roberts working with these new materials.

MOORE: "Gallium arsenide single crystals by horizontal growing, a graphite boat closed system, control arsenic partial pressure in a separate reservoir." A good way to do it. Better than Bill Happs' way of putting it in a closed tube and blowing it up in the furnace. [laughter] We had to evacuate the building.

LAST: Well, something else that comes in here. We were putting into industrial production a lot of really nasty chemicals at the time, and having to deal with that scaling up operation where most people have a little bottle of something and we were having gallons of it, and teaching people working with hydrofluoric acid what a dangerous thing that was. We didn't appreciate all of the problems with these materials. I remember your story, Gordon, of going up to Berkeley and talking to somebody about trichloroethylene, and they came back and said the

only problem that would cause was if you had a big enough vat of it and you fell in you would drown.

MOORE: That was about right. [laughter]

LAST: There was just no knowledge of these things. And we were pouring stuff down into the city sewer system.

MOORE: Yeah, initially it was little quantities. We got into production and we still didn't do a good job with it.

BROCK: But that presumably—

MOORE: The building that Intel started in at Mountain View was Jean's old thing when he worked for Union Carbide. We got in there and started digging into the plumbing and the cross section of the sewer pipe to the street was like a horseshoe. [laughter] The bottom was completely eaten out the whole way along. [laughter] And that was just about the time we really started recognizing how much you had to take care of this. Oh, here's the big meeting.

LÉCUYER: Which meeting?

MOORE: On page ninety-nine.

LAST: The Wescon Show?

MOORE: Well, no, the policy meeting of the California group and Walt English.

LAST: Ah.

MOORE: I think that's about the time after Baldwin left.

LAST: No. Baldwin was around.

MOORE: Baldwin was still there?

LAST: Baldwin was around until next March.

MOORE: Okay, he was around until 1959. Okay, this was a different—Walt English was the accounting guy from Syosset that came out and visited us occasionally.

LAST: Carter stuck his head in the door once in a while.

LÉCUYER: But they would send English too?

LAST: Yeah. And these guys would come and go and I wouldn't even know that they were there.

MOORE: "Competition. No prospect of anybody getting in our way in the immediate future." One of the notes. "We scooped the industry."

LAST: So that would be a good story to tell of that forty weeks.

LÉCUYER: Absolutely.

LAST: From us starting the business until we had a commercial product that scooped the industry. It's quite remarkable when you look back on it.

LÉCUYER: Absolutely.

BROCK: And it's a Bell transistor that's the closest competitor?

LAST: Yeah.

BROCK: That they were using internally, presumably?

LAST: No, they had 2N numbers on them. They must have been selling them.

MOORE: That was a bit ahead of us. We were the 2N60, something.

LAST: You mean our first transistor?

MOORE: Yeah.

LAST: 696.

MOORE: 696 and 697.

LAST: Yeah. And then we made higher gain versions—698 and 699. And then we made the little version which was some four-digit number.

BROCK: And these naming conventions for the parts were—

MOORE: There was a group that took charge of this and the transistors were 2Ns and then as they were registered with a set of specs they got a serial number.

BROCK: Oh, I see. So it's a time sequence number?

MOORE: "Gene Kleiner's personnel situation." "Hughes at PSI in bad shape, morale wise."

LAST: We were hiring all their people. [laughter]

MOORE: "O'Keefe coming." Bill O'Keefe.

LAST: Yeah.

LÉCUYER: O'Keefe was a diffusion guy wasn't he?

LAST: Yeah, he was. He worked for me. You know, he was sort of a cranky Jean Hoerni. [laughter] He was a wild man.

BROCK: When you have a notation like "instrumentation still a problem," that's finding somebody to staff up that function, presumably, for looking at the Kleiner—

LAST: Well, he's talking about, he's saying personnel.

BROCK: Right. Somebody to work with instrumentation?

MOORE: Well, Baldwin brought in the key guy, Elbinger. I would assume that was the same instrumentation, but it probably needed more people in there.

LAST: We were going from testing the things on a fancy Tectronics curve tracer, which was a general purpose instrument. But here it would be too expensive to crank them out that way.

BROCK: A specialized tool?

LAST: So we had to build all this testing equipment and testing equipment for all these lifetime tests. It took a lot of fancy equipment to do all this stuff.

BROCK: That you had been developing in-house, essentially?

LAST: Yeah. The one key thing that we couldn't make and had trouble buying were stereomicroscopes. I remember contacting Bausch & Lomb and saying, "Look, we need about thirty of these." He said, "We make four of them a year." [laughter]

BROCK: For assembly operation or for inspection?

LAST: Both. But we needed really good microscopes and they weren't that easy to come by. At this time nearly everything in that plant we had built ourselves. But what about the evaporation?

MOORE: We bought a basic bell jar system and then we put the stuff in it we needed.

LÉCUYER: So you bought the vacuum pumps and everything and then assembled the system?

LAST: Uhm-hmm.

LÉCUYER: Okay. And by that time you were scaling up the furnaces a lot.

MOORE: We didn't scale them up.

LAST: No, we couldn't. We didn't have any room.

MOORE: And the wafer sizes didn't require it yet. We learned that we could stack furnaces. We started out these seven tables, two furnaces on a table. We started stacking two and we could even stack three of them before we got done.

LÉCUYER: On each table?

MOORE: Yes, three high.

LAST: I don't recall any real bad explosions?

MOORE: No. Nothing.

LAST: You'd think with all that—

BROCK: [laughter] High temperature?

LAST: All these arsenic diffusions going on.

BROCK: [laughter] So here's Tom Bay giving his first sales report post product?

MOORE: It was gratifying.

LAST: "Four hundred and seven responses to our ad that went out. Letters and telegrams. Ten days."

LÉCUYER: Which is remarkable.

LAST: So we had something the world wanted.

MOORE: "An order for five hundred from IBM Poughkeepsie," which is the commercial folks.

BROCK: Commercial computer systems in Poughkeepsie? Is their mainline commercial computer systems?

MOORE: Yeah.

LAST: Howard Bobb was onboard then?

MOORE: Yeah, I guess so.

BROCK: As a sales person?

LAST: Yes. Gene Kleiner was given the personnel situation. He must have been more involved with that end of things than I thought.

MOORE: We kept shuffling him around. We never quite found a good spot for him to fall into.

LAST: He loved working in a machine shop and building things. He and Julie built an awful lot of stuff themselves. I remember the step and repeat camera they built.

MOORE: "A thousand final sales a week." I'm on the next page. "Ten final sales per wafer."

LAST: "Seventy wafers a day."

BROCK: So this is for production.

LAST: You can see the big bind was with testing, that's why all this instrumentation was such a problem.

BROCK: Oh, in the throughput.

LAST: Yeah. We could make them but then we couldn't test them.

BROCK: Here's the rescue of the yield. [laughter] Up from 20—

LÉCUYER: To 37 percent. And this means big burn?

BROCK: No, big bind. The bottleneck would be in the testing.

LÉCUYER: Okay.

LAST: I thought it said "big bird" and I was trying but couldn't figure out what that possibly meant. Look at that. "A thousand inquiries so far." "IBM will order five hundred."

MOORE: And "shipped two hundred and fifty to two hundred and seventy-five."

LAST: "Expected orders five thousand."

BROCK: Wow.

LAST: "We can sell the fifteen thousand units we expect to make this year without any trouble. The unit price is going to hold out through December."

MOORE: "Forty to fifty bucks."

LAST: That was just when Fairchild was thinking of exercising their option I guess. No, was that the next year?

MOORE: It was just after.

LÉCUYER: That's 1958.

LAST: Yeah. So, this would be a year before?

MOORE: Yeah.

BROCK: So, that's at week forty-three. [laughter]

LAST: Yeah.

BROCK: Do you remember that? Did either of you go to that Wescon show?

LAST: I didn't.

MOORE: I'm not sure.

LAST: They, Bay and Noyce, were reporting on it.

MOORE: Julie Blank was reporting, "Building at fifteen dollars a square foot."

LAST: Air conditioned and power in at that price. [laughter]

MOORE: "Timescale nine months from initiation."

BROCK: Do you have any recollection of the sense of things when this initial burst of orders for the product came in? Did you have a sense of relief or excitement? Do you recall?

MOORE: You know, I don't really recall. I was sure happy to get the competitive information. Nobody was breathing down our neck, and one thing and another. Do you recall anything special?

LAST: No. That's just one of those things.

BROCK: Yeah. Because it seems like it was just fitting, right with the plan.

LAST: Something that would temper our elation was the fact that we had to keep these processes under control. That would be a little nerve-wracking from that standpoint.

BROCK: It was all contingent on keeping the process going, to make them?

LAST: Yeah. And following what Baldwin said, that they were reliable and didn't come back.

BROCK: Right.

LÉCUYER: That's the PNP.

MOORE: "PNP status meeting."

LAST: So this would be September.

MOORE: Yeah. "Starting materials—creeping up the resistivity."

BROCK: That's Vic Grinich.

MOORE: "Base diffusion in poor shape." They're irreproducible.

LAST: Boron was okay. But if we hadn't made the NPN decision in March we would have been in big trouble. We still would have been fooling around with it.

BROCK: So it's this alloying issue that's plaguing it? That seems to be the sense of what I'm reading here.

LAST: What, on one oh two?

BROCK: Yeah, on page one oh two.

LAST: "Arsenic will stay in re-growth better than antimony."

BROCK: Oh, and the emitter diffusion.

LÉCUYER: "Base diffusion in poor shape."

LAST: So Jean, if he was working with boron, he must have had it pretty well under control. It was always a mess. It was making the tubes get soft. On one oh three you're talking about the nickel on the back. By this time we had solved all the problems, to some extent, we solved the problems necessary to build a transistor. Some of them weren't working too well. But they were good enough to get stuff out the door. And the devices—I don't remember people bouncing devices back to us and saying they didn't work.

MOORE: No. Not too much. We got into that horrible tap problem.

LAST: Yeah. That was later.

MOORE: Yeah. Still making mesa devices, I know.

BROCK: These pages—one oh three, one oh four—seem to be suggestions for what to do to try and put the PNP on track?

MOORE: Yeah.

LAST: Gordon, as head of Engineering, you were evidently working on this?

MOORE: Yes. There was a leak at the meeting.

LAST: That was on page one oh three you're mentioned doing something with the base and a gold ball or something.

BROCK: Or maybe it's giving suggestions to the group who was developing the PNP. That could be the case here.

LAST: Yeah.

BROCK: For doing these lapping steps, what sort of equipment did you use to do that? You know, for example, where it says, "To lap off the base layer or lap off the nickel plating?"

LAST: I would imagine that we were using standard stuff that was used in the optics industry for grinding crystals.

BROCK: Okay.

LAST: We may have had something where we did them one at a time. It was a standard problem. There was no—as long as you got them clean afterwards.

MOORE: I had forgotten we had this much trouble with the backside of the PNP.

LAST: Yeah.

MOORE: But it was obvious that that would be a real problem.

LAST: Yeah.

MOORE: You have to put metal gettering on it. When you grind that off you grind off the diffused layer, probably, too. Then you got low dope P-type material that is hard to make contact to. This one was "putting aluminum on the backside and using gold and gallium as a solder." Whew. [laughter]

LAST: Nothing about the PNP was easy. On one oh four, "evaporated a heavy layer of gold on the back," which is going to—

BROCK: On one oh five, "What are the target specs?" For the PNP?

LAST: So we could make the matched devices pretty well. And that turned into, once we got the PNP going, that was a real moneymaker because nobody else could make one, and we could sell the complimentary devices. As I recall the prices on the PNP held up for a long time. On one oh six we're talking about what other products we could be making, and products we should have.

LÉCUYER: The first idea is the single metal contact?

LAST: Single metal.

LÉCUYER: Yes. Aluminum.

LAST: In fact, we were thinking of patenting it, so it must have been pretty unusual.

BROCK: "Bell Labs using, we used this at the putty knife factory?"

LAST: That was my name for Shockley's place. [laughter] A guy named H. Allen Smith, a humorist at that time, had written a book called *Life in the Putty Knife Factory*. [laughter] And I just, for some reason, that's the way I referred to it.

BROCK: Up until that time you didn't have a patent attorney yet because we're only forty-six weeks in. It sounds like part of the discussion was choosing a patent attorney to work with?

MOORE: And Lippincott [John] Ralls was the one we chose.

LAST: Yeah. Ralls. John Ralls.

LÉCUYER: You made a diode with oxide over the lap?

BROCK: Over the lap? Did you see this entry down here, I guess that's "Hoerni idea. Diode with oxide over the lap"?

LAST: Overlap.

BROCK: So "with oxide overlap"?

LÉCUYER: Which means oxide over the junction?

BROCK: "Collector only under emitter."

LAST: Yeah, this would be cutting capacitance way down. It may have been thinking vaguely related to the planar. Well, that's something that surprised me when Jean's widow gave me all his notes—his first notebook entry on the planar was in December 1957. We'd been around for just a couple weeks.

MOORE: Yeah, that's what I remember.

LAST: And he wrote down all this stuff.

MOORE: Well, he wasn't very useful in setting up the apparatus, and he was sitting and writing in his notebook. He came up with the idea, but we had to learn to make a mesa transistor first.

BROCK: So the first time he was recording thoughts about the planar was that early?

LAST: Yes. It was December of 1957. And then he went back to it in January of 1959.

LÉCUYER: In some ways this is an idea he had in between that is somewhat related?

LAST: Yes. It was. I'm sure with something like this diode he was thinking along those lines, probably.

LÉCUYER: Yeah, okay.

LAST: And then there was this sequence of events where—and again, when I got material from Jennifer [Hoerni], he had this notebook. He submitted it in the form of a patent proposal in January that was witnessed by Noyce. Noyce put his notebook entry on the integrated circuit three days after that.

MOORE: Oh, I didn't realize they were that close together.

LAST: Yeah. It was the same week. So, this could have been an idea that was in the back of Bob's mind, and that could have just—

MOORE: Okay. My version of that from Bob was that they went to John Ralls with the planar idea and Ralls said, "You know, this sounds important. Have you looked at all the ramifications?" And I thought there was a meeting between that and the time Bob did it. But then he came up with the idea of the integrated circuit in responding to what Ralls had asked.

LAST: No, I think Noyce wrote this stuff down, which was his only patent notebook entry ever on integrated circuits, and it just sketched the general concept. And I think that sat until the summer when he filed, in the summer we were filing the patent on the PNP. No, no. On the planar. And at that time Ralls said, "What else can we patent?" and Bob said, "Hey, I got this notebook entry that I wrote six months ago about making an integrated circuit."

MOORE: Okay.

BROCK: So those are both compatible aren't they?

LAST: But, I was, if it hadn't been for that piece of paper that Jennifer had, where he kept his, this January patent application that said "Witnessed by Noyce" on it, and then Benton's story would still be very confused. And it just triggered Noyce's thinking and he went and—

BROCK: So, can I just replay that for a second and see if I've got it correct? Which would be Hoerni develops this patent application in January of 1959? He shares it with Noyce?

MOORE: It's a disclosure.

BROCK: Noyce signs this disclosure. Three days after that in the same week in January 1959 Noyce sketches out the general idea for the planar integrated circuit. Then later that summer, when they go to the patent attorney, to patent the planar, he says, "This is big. Do you have all the implications?" And Noyce says, "Oh yeah."

MOORE: Yeah, that's consistent.

LAST: And here we dated things. You have Noyce's patent notebook entry and you can look through this stuff in detail. You have Jean's patent entries the whole way through. And he wrote it down in December of 1957, and then in February or March, after this application, he wrote down the whole thing in the notebook entry with nothing in between.

BROCK: December of 1957 would be fairly close in time to the first sort of presentations and publications by the Bell Labs folks, right, on using the oxide as a diffusion mask? Because isn't that in 1956?

MOORE: Well, we knew about using oxide as a diffusion mask when we started Fairchild. We must have known about it at Shockley.

LAST: Yeah.

MOORE: Oxide masks anyway.

LAST: Well, that was the basis of the whole—

BROCK: Right. The whole photolithography. So, it's—

LAST: Didn't you report that you saw a circulated memo on that?

LÉCUYER: Yeah. In the Shockley papers there's a—

BROCK: Oh, a reprint?

LÉCUYER: There's something like a paper coming from Bell Labs, and then each of you have signed—

MOORE: This paper?

BROCK: Yeah.

LÉCUYER: So, it was moved around the group and then each person put on their initials.

LAST: And that was the oxide mask?

LÉCUYER: Yes.

MOORE: That was important. We picked up on that.

BROCK: Right.

MOORE: Very useful right away.

LAST: That was the key, from the standpoint of what we're using, it was the key Bell patent. We were always hassling with Bell about patents. The one that looked like it was really going to hold up was the thermo compression patent.

BROCK: I'm trying to think of when Bell Labs first announced that the oxide can passivate the surface?

LÉCUYER: That's the Atalla entry?

BROCK: That's what I'm looking for. I'm just trying to remember where that came in time. That would be interesting in terms of the sequence if it's contemporaneous, essentially with Hoerni's.

LÉCUYER: So, if we could get, the ACS meeting was after Hoerni's invention.

BROCK: Okay.

LÉCUYER: He must have reinforced his idea somehow?

LAST: I think Jean just—all of these ideas look at them. They're pretty straightforward, but most of them you shoot down completely because, one it's not going to work, or two it's too hard. There are a number of reasons why you don't follow through in something. I think we just always felt that the area below the silicon oxide was going to trap all sorts of terrible things. That's what Bell felt. You had to really get that oxide off of there. If you needed another oxide, you grew another one. But here we're talking "nickel plating for N-type diffusion. Hardening gallium diodes." That must have been another patent idea we were thinking about.

BROCK: Oh, I see.

LAST: And we're still talking PNPN structures as something we could have.

BROCK: And these would be status reports from the R&D group I suppose, after the patent discussion?

LAST: Yeah. We're still trying to figure how to make an ohmic contact with the back of the device. Vic was—who was making PNPNs? It says Vic was evaluating switching time.

MOORE: Well, we must have made some along the way. All you have to do is leave a layer on the back.

LAST: We're talking a small geometry device there?

MOORE: Yeah. An NPN. What's that say on rate?

LAST: Pardon?

MOORE: I didn't understand what the base resistance—Rb collector capacitance. Sheldon was working on some pullaway technology.

LAST: He was working pretty much independently but he was really working.

BROCK: Yeah, I was just looking at that.

LAST: Jack Clifton working on the—

BROCK: Resistance grower?

LÉCUYER: Yeah. That's interesting.

BROCK: "No reproducibility."

MOORE: Oh, Phil Flint. I forgot all about him.

BROCK: "Good shape"?

LÉCUYER: "Lifetime in good shape."

LAST: He was working with Jean pretty much.

BROCK: It sounds like they must have started, Sheldon Roberts must have started with just a traditional radio frequency induction grower, and then—

LAST: Got into the resistance problem.

BROCK: What would be the advantage of the resistance grower? A cheaper machine?

LAST: Probably being able to control the purity content of the basic material. We had a previous discussion about the problems we were having and all that. And also it may have been less imperfections or something.

BROCK: The last person's Flint?

LAST: Yeah.

MOORE: Yeah. P. Flint. Phil Flint.

BROCK: Do you recall where he had come from?

LAST: No.

MOORE: I don't.

LAST: He was working with Jean.

BROCK: And on page one-oh-eight we get to Dave Allison.

LÉCUYER: So this must be for the fast switching transistor?

LAST: Yes. The little one. And these things all scale. And if something happens, then something else goes up four times.

BROCK: [laughter] Right. So it says, "One hour of oxidation and one hour of diffusion gives—"

LÉCUYER: "Thick enough—"

BROCK: Okay. "Oxide layers." These are part of the process steps.

LAST: We're talking about starting to write [laughter] progress reports. We're turning into a real company. [laughter] It looks like we're scheduling this meeting on a monthly basis after the progress report came out. A change from the informal, whenever-we-got-around-to-it weekly things. On one oh nine they decided to put the building in San Jose, which horrified us all. [laughter] And then we did some behind the scenes lobbying. Twenty-nine September we said, "Building location—Mountain View." [laughter] So that concludes the first year. At the end of the year we had made the commitment to build the new building.

BROCK: Right.

LAST: And we were shipping devices in reasonable quantities to a lot of people. Someplace in here I've got the first year's financial. It's in a back page there someplace.

BROCK: Here's this October 1958 balance sheet, end of first year. It gives some of the details here. On page eighteen of your synopsis. Current assets, fixed assets.

LAST: Oh yeah. There it is.

BROCK: Expenses. "Owe Fairchild." [laughter]

LAST: Net loss for the year, seven hundred thousand bucks.

MOORE: And ninety-one cents. [laughter]

BROCK: Is an overall sales figure at the end of the year? R&D expenses.

LAST: "Cost of sales, two hundred and eighteen thousand." I don't see an income statement in there. Well, this is a balance sheet. Somehow between fixed assets and the net loss is what we owed Fairchild.

So we spent seven hundred thousand dollars, plus the capital equipment to get to where we did. And we were just under a million bucks.

BROCK: Moving on from there, on 6 October—page one eleven—it looks like a meeting to pick apart a competing unit?

LAST: The people involved were Bay, Allison, Hoerni, Moore, Grinich, Noyce, Baldwin, and me. [laughter] As I said, I didn't write down what I was doing.

BROCK: Was that something that you did with some frequency, or was it when something that looked particularly competitive arose that you would pick it apart? A competitive evaluation.

LAST: I don't think it was any formal thing, but if something—

BROCK: Something looked interesting.

LAST: We were obviously looking for competition on the horizon. This evidently looked—we were looking at a five by ten mil mesa probably, so we were talking about a small device like the one we were getting ready to do. "There's no point in trying to beat this unit." There are circuit limitations evidently.

BROCK: There's a report on the Ottawa Electrochemical Society meeting with Roberts and Allison.

MOORE: Oh, the good old thermoelectric world was coming along.

BROCK: "Two million a year on thermoelectric." This is on power generation? Can you talk a little bit about that, about thermoelectric, what Westinghouse was spending this two million dollars a year on?

MOORE: That was a hot new field coming up.

LAST: They'd build miniature refrigerators.

MOORE: And use it for power generation.

BROCK: Oh right.

MOORE: To do both.

LAST: Little thermoelectric refrigerators were available.

BROCK: For the space applications? I know that's where they got used eventually.

LAST: Many of these things were extremely interesting technically and then just for one reason or another couldn't compete economically or they had other problems connected with them. Thermoelectrics, I imagine the devices gave out pretty quick with the changing, expanding, and contracting. And 16 October, are you there?

BROCK: Yeah. Next page.

LAST: You can see the original cast of characters showing up at the R&D meeting. Allison, Grinich, Hoerni, Roberts, Warren, Haas—

MOORE: Warren is listed twice there isn't he?

LÉCUYER: I think what's interesting is it's called an R&D meeting rather than a technical meeting.

BROCK: Yeah. It's a meeting of the R&D group.

LÉCUYER: And Noyce is there still.

LAST: And Gordon was presumably—

MOORE: I was off engineering. [laughter]

BROCK: What is the significance of the new people coming into the R&D meeting?

MOORE: Warren was a chemist. Reddi was a salesman. Or, no.

LAST: Gopal Reddi, no he was—

MOORE: Oh, this is Gopal. Okay, I'm thinking of the wrong guy.

LAST: He was a device evaluator.

MOORE: He was very good electronically.

BROCK: And had Isy Haas just been hired at this time?

LAST: No, Isy had been there for a long time. He was one of the first employees and he worked on device evaluation and a number of things for Vic. When the integrated circuits program started, he got involved in starting that. He got involved with that right away.

BROCK: I see.

LAST: Our biggest concern was that you could prove mathematically you could never build an integrated circuit because each component had 20 percent yield, and went around and around on that. Isy did some of the key experiments by going down to the factory and taking transistors from the reject bins and building good circuits. Then we started developing the idea that the reason devices fail is because they don't meet a whole spectrum of specifications, but if you're designing it in an integrated circuit form it's going to have to meet one specific circuit conditions. More than that, the devices are all made at the same time so they're matching a bit. A lot of problems that you'd think were going to come up and keep you from being able to make one away, when you'd start analyzing it. Isy did a lot of work on that. So we convinced ourselves, "Yes, you can—"

BROCK: It's in a way, now, this having to think differently about the cost of the integrated circuit? Right? And it's kind of, it seems to me, related to that new way of looking at the yield issue?

LAST: Yeah.

MOORE: There were a lot of arguments thrown up in the beginning as to why integrated circuits would not be successful.

LAST: And you were making circuits that were, from the circuit designer's point of view, were far from optimum. We were eating into their turf. We were trying to sell the company a circuit and in that put the circuit designers out of business. So it was a long slow process. When I left and was making integrated circuits at Teledyne we were making specific integrated circuits for specific military systems for the moon shot and things like that. So we were making small quantities of very sophisticated circuits. But nobody was having much success selling big quantities of them. And so when you wrote Moore's Law, that was based on an economic argument?

MOORE: Yeah. It was an argument why it was going to be a cheap way to make electronics.

LAST: That was 1964?

MOORE: 1965.

LAST: I remember at that time, I was spending some time in Sweden and I gave a lecture based on these ideas of how the prices were coming down steadily. I was focusing mainly on analog circuits, and I went to people and said, "If you could get an operational amplifier for a dollar, what would you do with it?" Nobody would take that question seriously. They'd say, "Well, they're not going to be a dollar. They're not a dollar and don't bother me with this kind of a speculation." Everybody was making their own, and it was always a big division making and designing these analog circuits. There was just such resistance to it. What do operational amplifiers cost now? [laughter]

MOORE: Well, you can't buy one anymore. [laughter]

LAST: You can buy a thousand of them stuck together in something.

MOORE: Well Warren at least got his initials written on this page. He must not have done much then.

LAST: Well, yeah. [laughter] I sometimes just stopped taking notes. Just quit. [laughter]

MOORE: That was a name I was trying to dredge up a while back. He was a real chemist who went into business, and he went to UCLA [University of California, Los Angeles] and became a professor down there.

LAST: Warren did?

MOORE: Yeah. He stayed at Fairchild for a while but he never quite got a hold of anything worth doing, and he missed a couple of good opportunities. I think at one of our shrinkings I encouraged him to look someplace else.

LAST: This was late 1958, early 1959, when Jean started on the planar, and Baldwin left, and Noyce took over the management and started running R&D. Is that right?

MOORE: A diode's selling for twenty-five cents in Europe.

LAST: Uhm-hmm.

MOORE: Produced here for thirty-five to forty cents.

LAST: Noyce spent a lot of time running around and looking at all these issues.

MOORE: Yeah.

BROCK: Dealing with the—?

LÉCUYER: Entertainment market.

BROCK: Oh, I see. Yeah.

LAST: Where are you?

BROCK: We're on one twenty-four. From his report from Siemens, where he says, "No pressure to go into silicon."

LAST: You skipped one sixteen and one seventeen. I don't know why I didn't copy that stuff. One sixteen is "small geometry meeting." Christophe, you have all the data on when we introduced these things don't you, the data sheets and things?

LÉCUYER: Yes. I think and these are your papers.

LAST: It would be when we first—I don't remember the date but—

BROCK: You were evaluating the specifications of other devices with small geometries?

LÉCUYER: And these are germanium devices?

BROCK: Turning to page one sixteen, with this small geometry meeting, this is looking at what's out there to try and develop more exact specifications for what you want to make?

LAST: Yes.

BROCK: Is that—

LAST: Could we, with silicon, make a device that competed with the germanium devices that were on the market?

LÉCUYER: That would be this one?

LAST: Showing we can make a much better device. And so, one way or another we could out—

BROCK: Extrapolating from your current, the current silicon transistor?

LAST: Yes, we had this device in some degree of production. It's an X1040C so we were, probably had figured on a device and said, "How's ours going to compare?"

BROCK: Did that turn out to be the third realized product after the PNP? Was it this small geometry device?

LAST: It probably came out just about the same time as the PNP. I don't remember.

MOORE: We were a little behind, in my recollection. And then we got the gold doped things coming in.

LAST: Yeah. The 1613 or something. We had to run 698 and 696 and 697 then by selecting devices we can make the 698 and 699 which are higher performance ones. And then we went on and made the PNP and the small geometry devices in both, small geometry PNPs.

BROCK: In both configurations?

LAST: Yes, we actually did a whole family.

LÉCUYER: And there are the specs for the small geometry.

BROCK: It seems on page one nineteen, is that the same meeting or is that the same day?

LAST: No. By then there were hardly any meetings. There were very few organized meetings after that point.

BROCK: Okay.

LAST: It jumps from October of 1958 and the next dated one is January 1959.

BROCK: This is really setting the specifications for the new product?

LAST: And on one twenty-two it's obviously a different date that's written in a different ink and I don't have the date on it. But that's when Jean was coming up with the gold diffusion. Which is going to give us lifetime control over the devices.

BROCK: This is its emergence as a research project, essentially, an R&D effort?

MOORE: Well, you know, you try it to see if it works and if it doesn't kill the device, you integrate it pretty fast. This was one of these blue sky ideas that I don't think anybody but Jean thought was going to be successful.

LAST: It wasn't making radical process changes, so it could—

MOORE: Just adding the gold dopant to devices we were already building. I guess we had to change the resistivity starting material.

LAST: That went into your engineering work very fast?

MOORE: Uhm-hmm.

BROCK: Did that create any problems for you, Gordon, on the engineering side, in terms of contamination with the gold?

MOORE: We sure kept it away. I'm not sure Jean did. [laughter] I kept it away from the other furnaces. Cross contamination could be a problem with just a few more furnaces going.

LAST: And Jean, with these new things, he did them extremely fast. He'd come in all night and do diffusions and things like that. But it would just be a couple of days. He'd get an idea for one of these things and come in and try it. And he probably didn't document the stuff that didn't work. [laughter] But a lot of them did, and there was some degree of insight here just to try these things. He obviously wasn't going to try something that was destined to fail.

MOORE: But this was still at a time when I think most of us were worried about getting long lifetime in materials. And gold was a way to kill lifetime. It wasn't very compatible with the thinking that was going on. And then we found out it also did the gettering job, [laughter] the junctions hardened up very nicely.

BROCK: Would you say he had a tendency to, if he had an idea of this nature, "Well, let's try some gold diffusion," or "Let's leave the oxide on top." Would he quickly go to an experiment that would show whether or not it was worthwhile?

MOORE: He really could, like this. Absolutely. And he wouldn't say, "Let's do it." He would do it and say, "Here's what I found out." [laughter]

LAST: Sharing an office with him, I had lunch with him a lot and I remember that afternoon he was starting to do this he was just madder than hell. "I'll show these bastards," kind of an attitude. [laughter] And he just went and did it. He was really motivated by anger, or something like that. It just brought out his creative juices a lot. I'm sure a lot of these things are

ideas he'd had in the back of his mind and then he'd just get motivated enough to try one of them. But I know when he got going on the planar he needed another mask on it.

MOORE: Yeah. He couldn't do that all by himself.

LAST: He came to me and we made an outrigger on the step and repeat camera so I could make the extra mask for him.

MOORE: Okay. I hadn't remembered how that happened. We did a couple of halfway experiments with the planar. We were able to do selective dipping and leave the oxide over the emitter base junction, and that greatly stabilized the gain of the transistors. We had an existence proof that oxide left over the junction did the kind of thing he was looking for. That was before we made the mask set. And then we finally could try the full-blown planar idea.

BROCK: And that was sort of a quick check, or quick follow-up?

MOORE: It was a quick thing we could do without the extra mask. We were just taking advantage of the difference in the thicknesses of the oxides to do a quick look. Dissolve off half the oxide, over the junction, and all of it over the emitter itself.

LÉCUYER: Was this experiment done by yourself or by Jean?

MOORE: I don't know. I was certainly aware of it going on. I was very interested in the results. So I would have probably been involved but I don't remember if I did the dipping or not.

LAST: I seem to remember Jean calling us all in and showing us the planar working and spitting on the junction [laughter] and the device was continuing to work.

MOORE: Right. He couldn't have done that on the mesa that we did clean the emitter base junction on, you know. [laughter]

LAST: But it was pretty dramatic. It was just at the time when we were in big trouble with foreign bodies banging around inside the transistor.

BROCK: And you were getting complaints and returns based on that?

LAST: Oh yeah.

MOORE: It started out that way and then we discovered that if you took one of these transistors and tapped on it, the characteristics would fall apart. Initially, in almost all of them. And this is where Robson made a major contribution. He looked at one of these and saw it was glowing in a little spot with the stuff there and he actually flicked that thing off and the junction got good again. Bob showed us that it was particles on the side of the mesa that was causing that trouble. Then we started a witch hunt to find every possible source of particles. We even had our automatic pencil tapping. Brrrrrrrrrr. [laughter] We got tired of banging on them. [laughter] And we made big improvements but still weren't getting to the level we wanted to get. The planar was the solution coming down the pike then.

LAST: After we saw the existence proof on the planar we decided that we have to do this.

MOORE: Yeah. We went as fast as we could.

LAST: Fast as we could. This was the week after Ed Baldwin left that the planar was demonstrated. [laughter] He left with mesa technology and we were at that time switching to the planar as quickly as we could. Do you remember how long it took to get the planar going, actually?

MOORE: I really don't. We had the Minuteman contract, and you know they had heard some of the preliminary stuff on the planar. And I think that was the principle reason we got that contract, because we were still a pretty small company. But they heard the planar idea was coming along and it was going to increase reliability dramatically.

LAST: Then the planar was announced in 1959?

MOORE: In 1959.

LAST: In 1959, at the IEEE [Institute of Electrical and Electronics Engineers] March show in New York. And that was the one where I was there as sort of a spokesman and they put my picture on the front of the weekly, of the show journal. It was just a terrible, terrible picture of

me. I took it home and showed my father and he said, "Well Jay, that's a picture only a mother could love." [laughter]

MOORE: It probably didn't make Jean happy either.

LAST: No. [laughter] I was standing there. There was Tom Bay waving this circuit and showing a big mock up of the planar device. We established a track record that we could do stuff fast. But it wasn't yet at the time where we were transferring stuff into a foreign group, which was always a problem later on. That was probably one of your frustrations?

MOORE: It got to be at the end, yeah.

LAST: Where you transfer a product and they'd take the basic idea and redesign it. It took forever. It was turning into what happens in any organized company. But this time Gordon was running engineering so it was just this smooth system, just picking it up and running with it.

MOORE: No, by that time I was running R&D, because Baldwin left and Noyce took over. I went back to R&D.

LAST: That's right.

BROCK: Who took over engineering at that point?

MOORE: I kept Preproduction Engineering. I did have both for a while. Because, Weindorff, who had been head of Preproduction Engineering, he bailed out with Baldwin. It would have been kind of headless otherwise. That did make the transition easy.

BROCK: Right. You're transferring it to yourself. [laughter] Change of hats.

LAST: Easier transition than some.

BROCK: Was it in December or January then that Jean—I guess January of 1959 that he told you of the planar idea? How did his idea circulate?

MOORE: Oh, we knew all about it a long time before that. Probably not too far from the time he first put in his notebook.

BROCK: Oh, I see.

LAST: That would be in December of 1957.

MOORE: It just wasn't on our agenda. We had an agenda to go through to get the mesa transistor, and we couldn't easily try the planar process because of this poor mask problem. So it had to wait until we had time and we had the ability to go back and make the mask.

LAST: We could also say that our problems were probably related to surface states under the oxide anyhow and the planar was probably going to compound them rather than cure them. It was just one of these things where you think, "Well, it's probably not going to work anyhow so why bother?" And it took until January of 1959 that Jean decided to make one. Then he wrote a notebook entry. He didn't write a notebook entry, he wrote this patent disclosure. Mary Lou Weiss typed it up. It's just a one-page thing. That was the one Noyce witnessed. And then he set out to build it, and got the mask. He had it built by March, the week after Baldwin left. That would be March of 1959 that he built one.

BROCK: When was it that this proof of concept experiment happened by just etching off half the oxide layer?

MOORE: Well, it would have been before he could make a mask set. Either early 1959 or late 1958. Before he could really pursue making the final deal. And it may not have even been quite that early. It was someplace along there that just gave some of the rest of us some confidence it was going to do some good.

LÉCUYER: The planar idea was floating around when Baldwin was still there?

MOORE: Yeah.

BROCK: It was just on the back burner?

LAST: Just another idea that hadn't worked but I don't think any of us expected the really dramatic changes in these devices, leakage currents and stuff. It's just unbelievable how much better the device was.

BROCK: In essence two things led everybody to sort of reactivate some work on it which was the reliability problems, the tap test issue, was growing? I suppose the NPN and a lot of the PNP had been developed at this time? You kind of had had the opportunity?

MOORE: Producing in reasonable quantity, you got to do that.

LAST: It was just going on to the next thing.

BROCK: Now that you have the time and the opportunity to?

LAST: After Jean did this quite a bit of work he did on the PNP, he did a number of these other experiments. We recorded the ones that worked. He was fiddling around with lots of stuff. But I shared an office with him so I witnessed a lot of these ideas. As I said, he'd sit around grumbling and not do very much for a while and then all of a sudden he'd get this nervous burst of energy and go try these things.

MOORE: He was a very nervous guy.

LAST: Yeah.

MOORE: And to talk to him. [laughter] He's like jittery.

LAST: I did loads of mountain climbing with him, and when you're in the mountains and it's late in the day and you're hungry you get cranky. [laughter] And Jesus did Jean get cranky. [laughter] I thought to myself, "Gee, I'm alone on the mountain with this maniac son of a bitch." [laughter] It was just so strange. Everybody just got so mad at him and then he was so charming. I went through that steadily. I'd get so pissed off at him and then he'd be charming again and I'd really like him again. [laughter] That relationship stayed with us the rest of his life, with him and I.

LÉCUYER: But to me he was a very Gallic character.

LAST: Yeah.

LÉCUYER: I met many people like this in France.

LAST: Yeah. Sputtering a lot. And angry.

LÉCUYER: It's interesting on page one twenty-two that the Bureau of Ships and Armor appears and they seem to be interested in having devices that have these characteristics? They had these specs and the gold diffusion was going to help meet these specs, as I understand it?

LAST: Well, they were always—

BROCK: Putting out specs?

LAST: There was an awful interest in what we were doing, and there was a steady flow of these people coming in and they'd tell us the device they wanted and we said, "Buy what we've got, we're not going to change our thinking all that much to cater to your device needs." We developed devices that the sales department could sell very effectively. We certainly proved that. So there's always feedback. What was the role of IBM after this? Were they big customers?

MOORE: No, they were never very big customers. Their military wasn't that big, and they never got it into the commercial stuff.

LAST: Was that first airborne computer that they had a contract for. And if I want to drive myself nuts, I start thinking of what-ifs. [laughter] What if IBM hadn't had the contract for that computer? [laughter]

MOORE: In a parallel universe. [laughter]

LÉCUYER: Yes.

MOORE: What is this A-R-M-A? Do you know?

LAST: ARMA? That was Armed Forces—

MOORE: Oh, okay.

LAST: It was one of these—you remember Ed Keonjian?

MOORE: Oh sure. I remember him.

LAST: Well, he was running that. And these guys were, at that time, talking about molecular electronics where you'd deposit atom by atom to make this stuff.

MOORE: That was how they were thinking of doing it.

LAST: Making very miniature devices by watch-making techniques. It was just the wrong direction for everything. But he'd come out and he talked a lot about that.

MOORE: My first trip to Europe was on a speaking tour with Ed Keonjian as our tour leader, and we went through the various NATO [North Atlantic Treaty Organization] sites, such as Rome [Italy], Stuttgart [Germany], Great Malvern [England], and Paris [France].

LAST: That would have been in?

MOORE: 1963. I was talking about complimentary MOS [metal oxide semiconductor] as a way to make low power circuits. [laughter]

LAST: And how long before it was usable?

MOORE: CMOS [complementary metal oxide semiconductor] was announced in February at the Solid State Circuits Conference, and this was June. In the meantime I actually had made circuits and measured them at liquid helium temperatures. [laughter] One thing or another. But

the thing is I used that data in my talk, but I got the data after I'd written the manuscript, and completely lost all my data. I didn't keep a good notebook. [laughter]

LAST: But in 1963, you really didn't get going on that stuff until Intel?

MOORE: No. And, well, that's true. We didn't really need it until then.

LAST: I remember at Teledyne we saw the need for MOS and I came to talk to you once and you said, "The time isn't right for doing anything this way." And people were doing this with Colonel Lowell and that bunch.

MOORE: That was one of my big frustrations. I never could get MOS moving at Fairchild. The production people there wouldn't perform the witchcraft that had to be done.

LAST: What sort of witchcraft?

MOORE: By getting rid of the sodium. They wouldn't get rid of the sodium. Sodium ions were a terrible reliability problem.

LAST: Did you know how to do it and they wouldn't do it?

MOORE: We had ways of making it work, and we couldn't do it in a standard facility and had to do some special things.

LÉCUYER: I see.

LAST: Did you just keep the contamination level down?

MOORE: Yeah.

LAST: And who were the key people working on this?

MOORE: At Fairchild?

LAST: Yeah.

MOORE: In the laboratory Frank Wanlass was the guy who was very inventive in all the circuit ideas, CMOS and one thing and another. He was one of the guys that spun off with Colonel Lowell and Howard Bobb to set that thing up. And then they had a spin-off and we were still trying to get things out of Fairchild. Let's see, who else was it? Warren Wheeler. That whole group went away with enough knowledge to make stable MOS.

LAST: I was facing a decision and I just could think that the thing that was plaguing us was surface states, essentially trying to build a device based on surface states, [laughter] and I said, you know, "If they start putting these things in commercial aircraft I'm taking the bus from now on." [laughter]

MOORE: We had a big program on that. That was the research program I hired Andy Grove into. I remember telling him when he got there that the surface potential was going all over the map. We wanted to learn how to put it where we wanted it and how to keep it there. [laughter] And he really became the leader of that group.

LAST: He had just come from Berkeley?

MOORE: Fresh out of Berkeley. Tom Sah was nominally in charge, but Tom was off at the University of Illinois then, and he used to come out and talk to the group, extract everything they knew, and go away and write papers on it, [laughter] which got pretty frustrating. But Andy clearly became the leader and he did some absolutely first-rate science tracking down what all of the problems were.

LAST: What was your first impression of Andy when he came in?

MOORE: Very good—intense, focused, and competent. When I was hiring him, he gave a good interview. Interviewing Ph.D.s is the easiest thing there is to do. They've all just done something and they want to talk about it. I wrote to his thesis professor asking for a recommendation and I got back my own letter with this written on the bottom, "This is a truly outstanding individual. Whoever hires him will be very lucky."

LAST: He was thinking ahead. So you worked for several years on MOS devices at Fairchild?

MOORE: Particularly on the science of what the heck all these surface state problems were, and the like. We didn't appreciate exactly how much integration you could get with them.

LAST: MOS changed the world, but the growing pains were very long. I can't remember the name of Colonel Lowell's company right now, but it wasn't always a success. I was sincere. I really thought that that device had to be a flash in the pan because nobody could control it. I mean even with our regular processing there were fluctuations that would put us out of business every once in awhile, from contamination problems. Trying to use a device that depended on these surface states for its operation, I just couldn't see that. There was this terrible problem we were always having with impurities, in surface states, and yield would go away, trying to track these things down. At Fairchild you just worked for a long time on basic understanding.

MOORE: We did that and we were developing circuits and the like, too.

LAST: But you felt a frustration that you couldn't get anybody else to make it.

MOORE: Couldn't get the attention of the manufacturing people and couldn't get them to do the incantations that were necessary. In fact, before we left we negotiated that we would set up a significant production line in the R&D laboratory to make MOS devices. It was something we weren't very well-equipped to do either.

LAST: What happened after you left? Did Fairchild continue that?

MOORE: They continued it, yes.

LAST: That was—

MOORE: But they never got quite on the right track.

LAST: There was a guy named Jim Early who worked there?

MOORE: Jim came in after I left. Again, if you hadn't grown up in the development of the technology it was hard to see where it was going to go.

LAST: When you started Intel you felt that this was going to be a reliable product?

MOORE: Yeah. Well, the thing that was new at that time was silicon gate, which gave a lot of potential advantage. It turned out it had a few problems. So we set off actually with three different technologies to do memory—a multi-chip assembly, a new bipolar approach using Schottky-clamped bipolars, and the silicon gate MOS. And it was my Goldilocks strategy. The multi-chip was too hard. The bipolar was too easy. And the silicon gate MOS was just right. [laughter] We've been using that or evolutionary versions of it ever since.

LAST: How long after you started Intel did you have the first commercial sale of it?

MOORE: Well, we launched the product in August, so just over a year. We were incorporated on 18 July, started work the first of August, and August of the next year we announced our first product.

LAST: So the time changed from eight, nine months to a year? [laughter]

MOORE: The process had gotten quite a bit more complex along the way, too. [laughter]

BROCK: What about for you Jay? The timescale from starting Amelco to having the first product?

LAST: We were making devices—there were a lot of devices going into the systems company, so we could send in devices that weren't meeting commercial specs. Probably the first things we were selling were field effect transistors. Jean was making them, probably a year or so afterwards. But I spent a lot of time building fancy optical equipment to be able to work with tolerances that were way down from what we had. We had a twenty-foot long camera bed that I had put on granite, and hired a great optical engineer. This was a mechanical problem and I hired, as a consultant, somebody to build this camera and I asked him if he had the technical skill to be able to do this. And he said, "I built a machine that figured out how to put asparagus in a can. If you can do that you can do anything." [laughter] It had a lens that was three feet in diameter. We had just all kinds of stuff. We were able to make, in small quantities, a lot of specialized stuff to go to the moon. Again, it was all classified stuff and it's all disappeared.

BROCK: Here's an example, page one twenty-five, that's talking about micro-miniature circuits.

MOORE: There was a lot of interest during this period in molecular electronics. Some way to make things a lot smaller to get the electronic function. A lot of contracts came out.

LAST: But the planar was the key. Someplace way back in the notes is one line about who's doing what, it said "Jay Last, microminiaturization." I never followed up on it, I don't think, but it was some idea we must have had then. We didn't really start on it until August of 1959. All these meetings ended and that was that.

MOORE: On 18 March, on page one thirty-nine, we were working on a PNPN, the 5500.

LAST: Isn't that amazing?

MOORE: It was always the three-terminal device, though.

LAST: What do you think finally shot it down?

MOORE: Never got around to it, I guess. [laughter] New programs, 18 March 1959, surfaces outmode the mesa. Oxidized masking.

LÉCUYER: What page?

BROCK: One forty. These are new programs in the R&D group?

LÉCUYER: In March of 1959?

BROCK: Right.

LÉCUYER: That's after the making of the first planar transistor?

LAST: On one forty-one, in March of 1959, I was evidently working on a power device and a micro-miniaturization program. And I was working on a parametric amplifier diode that needed real tiny little dimensions. But I don't know what we were thinking of in micro-miniaturization.

BROCK: This time Sheldon Roberts is in the R&D group and he's basically working on materials-based advancements?

LAST: He was starting to get interested in solar cells. He continued that when we left. On one forty-three you were laying out R&D meetings and programs, Gordon.

BROCK: How many people would typically go to the R&D meeting at that time, if everybody has a half hour? Oh, "one to two speakers, each have a half hour." I guess you would cycle through the different areas?

LAST: "Progress reports." You were putting in some ideas that we had to document all this stuff.

BROCK: [laughter] I like the entry, "Find the reports written up to now and then set up a numbering system."

LAST: Vic Grinich had come out with all kinds of application notes and things in this period.

BROCK: The second half of one forty-three, and then one forty-four must be the report from the ECS meeting?

LAST: Yes, a lot of people went to a lot of meetings, I just never wrote them down in this notebook on any formal basis. That summer electron devices meeting, there were never any published agendas or formal notes, so it was a very informal way that huge amounts of information were exchanged. That's something that seems to have continued, just this informal interchange among people who should have been competitors. [laughter]

BROCK: Here's the balance sheet. This notebook ends several months before the integrated circuit program begins at Fairchild?

LAST: From the looks of it. But I started that in August of 1959, and by late fall was publishing formal monthly progress reports.

MOORE: I remember it was 1959, Wescon, integrated circuit with Ticonderoga resistors. [laughter] Jay kludged together a little circuit and used a pencil on the ceramic to draw the resistors. In a little can he actually demonstrated a complete circuit. It was a Kilby-style integrated circuit, [laughter] instead of a planar one. But it showed Fairchild putting a whole circuit on.

LAST: Put it in a little can. Got a lot of publicity on it, but that was the best integrated circuit you could build in three days. [laughter] That's when Bob could see that we had to be moving in that area. And I remember talking to him about demonstrating this and then starting to work on it.

BROCK: When did Texas Instruments announce Kilby's work?

LÉCUYER: Was it in 1958?

LÉCUYER: Yes

BROCK: Does that sound right?

LÉCUYER: Or in the fall of 1958, that's my guess.

LAST: When Bob saw it, that would have given him impetus to start thinking more in planar lines.

MOORE: And my recollection of the timing of the things is not complete. Did Bob know of Kilby's circuit before he did his? I'm not sure. Getting the timing of when Kilby's work was announced publicly and tying it to Bob's conception would be an interesting thing for me to see anyhow.

LAST: I would be surprised if he did, or thought much of it. I mean, the Kilby thing was pretty obvious and by putting leads on you weren't solving much of a problem.

MOORE: Yeah. [laughter] What Kilby showed, in my forty-year perspective, is that you could use semiconductors to make resistors, capacitors, and so forth so you could build a whole circuit. And he kludged them together. And I don't think anybody in the field really doubted at the time that you could use them for these purposes, but nobody had done it previously. Now, I know Les Hogan, when he was running Fairchild, took a very strong view that Kilby didn't contribute anything. I never felt that way about it. I think he did do a useful demonstration.

LAST: The interesting thing was there were three key things. One is multiple devices.

LÉCUYER: Which Kilby did.

LAST: Which TI got a patent for. There was also the interconnection of the devices, which Fairchild got the patent on. Finally, there was electrical isolation, which Kurt Lehovec at Sperry got the patent for.

MOORE: Noyce reinvented it, but Lehovec was first. He did a diode array.

LAST: Yes, but in Noyce's patent notebook, he didn't discuss how you would do any of these things, it was just a concept. But he was ahead of his time to be able to do any of that.

BROCK: In terms of the isolation, you mean?

LAST: Yes. And it was just beyond our capability. That's why we did all that crazy stuff of etching.

BROCK: Epoxy.

LAST: Etching, epoxies, and then boron.

MOORE: Diffusing clear through to wafer. Oh, that was a miserable process.

LAST: Oh, that was eighteen hours.

MOORE: Epitaxy came along just in time to bail us out. [laughter] Overnight diffusions at the highest temperatures that the furnaces would take.

LAST: And boron would turn everything to mush. [laughter]

LÉCUYER: So it meant the yield was awful right?

MOORE: It wasn't great. The wafers didn't come out very flat after that kind of baking.

LAST: But the thing that made this all possible was some idea that had come from the production group, or preproduction, to use a different boron process, which wasn't quite as destructive to the tube. So we just pulled that back. And Isy and Lionel Kattner gave it a whack and it worked.

BROCK: What would have been different from one boron diffusion process to another? Just temperature, concentration?

MOORE: The original one was boron oxide in a boat, which mixes with the silicon dioxide pretty well. And it went through a different boron compound, and I don't remember which one.

LAST: No. It was—

MOORE: Boron tricholoride?

LAST: I seem to recall. You've seen that someplace? I have it written down someplace. But, it made a remarkable improvement. We said, "Let's give it a whack." And it worked. But in November of 1960, we were just switching over from the etching, backside etching, to using the boron for isolation. I have a memo that you wrote that we have to put this thing into production, and if we have to go with what we know now we'll do it by the etching, etching through the wafer. I later discussed this with Charlie Sporck and he made an appropriate Sporckian, Sporck-like comment about what that thing would do in production. [laughter] I don't know why we were thinking it should be a production device that early. Or that we would—

MOORE: We didn't have a better way at that time.

LAST: Yes, but why we would introduce it as a product with such a screwy process. But we did.

BROCK: I think in February of 1960 at the Solid State Circuit Conference there was a session where I think it was a paper with you, and Norman, and Haas, on the micrologic—it was at a session on microelectronics and it was essentially a paper about micrologic.

LAST: That was the Wescon Conference in the summer of 1960, I believe.

BROCK: Well, there was this solid state, International Solid States Circuits Conference in Philadelphia, and I think it was in February of 1960.

MOORE: Yeah. That's where Norman would have—

LAST: Norman was a crazy man and was going around and saying we can build these 24-stage shift registers. And I kept trying to calm him down, [laughter] and he kept doing the stuff. The first paper we gave where we really started to talk about it was at the August Wescon meeting.

MOORE: In 1960?

LAST: Lionel Kattner and I wrote a paper. We didn't discuss any of the process details.

MOORE: Is it possible that was 1961 at the ISSC?

BROCK: No. It may have been that maybe it was Norman delivering a paper?

LAST: Oh, it was. And I have a big stack of papers that Norman gave at every conceivable place on the future of integrated circuits and how we could build them.

MOORE: I turned down his patent application for a semiconductor memory. [laughter] I said, "That'll never be practical."

BROCK: Well, I think it just detailed some of the devices you made. The question that I actually had was about discussing the making of an integrated circuit product line. This must have occurred in this late, at the end of 1959 or early 1960.

MOORE: Well, there had to be a circuit. Jay started out with a flip flop. And the flip flop was not the most useful member of the family. The gate was.

LAST: Gate and then finally a half-shift register. By the time I left we'd built just the first couple members, and then Lionel Kattner, over the next six months, gradually—

MOORE: He filled out the family.

LAST: Filled out the family in production, and was fighting the frustration of putting the device into production facilities. And then by the end of 1961 you had a big thing going there.

MOORE: By the end of 1961, probably making them up epitaxially.

LAST: Well, maybe not. I don't think so.

MOORE: But the epitaxial transistors were talked about first at the Device Research Conference in 1961, so it would have taken us a while to get the integrated circuits up. But, boy that was a welcome relief. Were you in that expedition that went back to Monsanto and tried to get them to deliver us N on N+ epitaxial material?

LAST: No.

MOORE: Jean would have beaten them, would have beaten Bell Labs to the epitaxial transistor if we could have gotten them to do that. His conception was earlier.

LAST: I think after I left.

MOORE: Well, Jean was still there. It would have been in early 1960. They came around wanting to sell us all the junctions they could produce on the sides of these hexagonal crystals.

Jean thought if he could get an N on N+, he could make a transistor and get rid of the collector resistance, essentially. So we went back and pleaded with them to give it to us, and they were only interested in selling a whole bunch of junctions.

LAST: Oh, I remember.

MOORE: Never got them to make the material. We didn't have the ability to do the epitaxy ourselves. Then when Bell gave the paper we said, "Oh well we had everything for a year before they announced it. So, there's no use of us filing a patent." We were earlier.

[END OF AUDIO, FILE 1.4]

[END OF INTERVIEW]

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