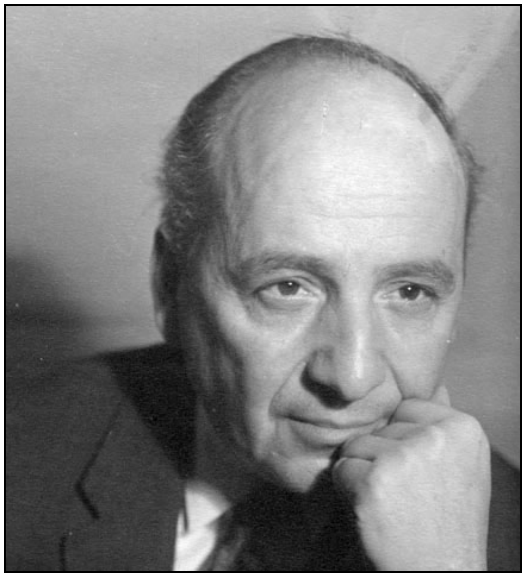

Photo Blackstone-Shelburne, New York

VICTOR WOUK
(1919–2005)

INTERVIEWED BY
JUDITH R. GOODSTEIN

May 24, 2004

ARCHIVES
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

Subject area

Electrical engineering

Abstract

This wide-ranging interview in May 2004 with the engineer and hybrid-automobile pioneer Victor Wouk begins with his recollections of his graduate work in electrical engineering at Caltech (1939-1942), after receiving his bachelor's degree from Columbia. Includes recollections of Robert A. Millikan, Royal Sorensen, William H. Pickering, William R. Smythe, Frederick C. Lindvall, and others. He recalls his wartime work at the Westinghouse Research Laboratories in Pittsburgh on the ignitron and the separation of uranium isotopes. Also recalls his early interest in television and work for North American Philips in Tarrytown, NY. Forms the Electronic Energy Conversion Corp. in 1959 to manufacture DC power units. Recalls work for Motorola founder Russell Feldman, who in the early 1960s asked him to design a practical electrically powered car; eventually, in consultation with Lee A. DuBridge and others at Caltech, Wouk determined that a hybrid vehicle, using both electric power and traditional combustion, was a better alternative. Studies were revealing the detrimental effects of smog in the nation's cities, and in 1970 the Clean Air Act passed. Wouk had meanwhile sold the Electronic Energy Conversion Corp. to

Gulton Industries and gone to work for them; he left, along with Gulton's Charles Rosen, to form a new company, Petro-Electric Motors, to develop a hybrid vehicle for the Federal Clean Car Incentive Program in the early 1970s. He recalls in detail their travails and eventual success, and comments on the opposition of Eric Stork at the Environmental Protection Agency to the hybrid idea, which finally resulted in rejection of his model. He concludes the interview by commenting on the recent history, current popularity, and future of hybrid cars, and on his ideas about regenerative braking.

Administrative information

Access

The interview is unrestricted.

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CALIFORNIA INSTITUTE OF TECHNOLOGY

ORAL HISTORY PROJECT

INTERVIEW WITH VICTOR WOUK

BY JUDITH R. GOODSTEIN

NEW YORK, NEW YORK

Caltech Archives, 2004
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CALIFORNIA INSTITUTE OF TECHNOLOGY

ORAL HISTORY PROJECT

Interview with Victor Wouk **By Judith R. Goodstein**

New York, New York

May 24, 2004

Begin Tape 1, Side 1

GOODSTEIN: Good morning, Victor.

WOUK: Good morning, Judy.

GOODSTEIN: Victor, I would like to jump right away into your story—when you were nearing graduation [in 1939] from Columbia University. What made you decide to choose Caltech, on the other side of the continent?

WOUK: First, I should really tell you something that apparently I have not told anyone before. And that is, in my junior year at Columbia I had applied to Caltech as a transfer student. I wanted to do my senior year at Caltech. I'd forgotten that, and I don't think it's in any of my letters or correspondence. I took a leave, and I received a nice acceptance letter, but for various reasons I did not go. It made more sense for me to plan the last year at Columbia and then go to Caltech. However, making that application for a transfer made it very easy to be admitted to graduate school at Caltech.

Now, why Caltech? My first reason would have to do with Carl Anderson and his getting the Nobel Prize [in 1936] for discovering the positron. I had seen that in a newsreel some place. Also, in the summer of 1937 I had driven across the country with some relatives who lived in Los Angeles, and one of the things I wanted to do was visit Caltech. I stayed in LA and went to UCLA for the summer to fulfill a requirement in mechanical drafting so I could finish my engineering at Columbia; I was very frustrated that I could never get the opportunity to go to Caltech from UCLA.

When I was sending my papers to the Caltech Archives, there was a big fat scrapbook of the articles I used to write for the Columbia *Spectator*, the daily undergraduate newspaper, There were several articles in there about Robert A. Millikan. He gave a lecture at Columbia. I covered the announcement with a nice article in the *Spectator*, and I covered the actual lecture.

I could have stayed in New York City and gone into my father's business. He had a very large laundry with several partners. At the time it was built, in 1925, it was the largest laundry in New York City.

GOODSTEIN: A commercial laundry?

WOUK: Commercial laundry, yes—home laundry and commercial. Remember, this was before World War II, and washer/dryers for laundry were not available. I did not want to go into the laundry business, so I decided I'd better get far away, to Caltech. Everyone was very pleased—the California Institute of Technology was very good! My original thought was that I would go to Caltech for one year to get a master's degree in electrical engineering and then find employment in the aircraft industry, which was then centered in Los Angeles.

GOODSTEIN: We're talking the fall of 1939?

WOUK: Yes. So I drove across the country a second time—this time it was in a Model A Ford given to me by the family. I drove with my friend Walter Shenson, who was a Stanford undergrad. His dream was to become a movie producer, and he did become a movie producer. He produced the two Beatles pictures—*A Hard Day's Night* and *Help*—and that cult movie with Peter Sellars, *The Mouse That Roared*.

GOODSTEIN: Did you actually get to interview Millikan when you covered his lecture at Columbia?

WOUK: I don't think so. I may have introduced myself, saying I was planning to go to Caltech. He must have said, "How nice," and patted me on the head.

GOODSTEIN: Do you remember anything about the lecture? Was he a good lecturer?

WOUK: Yes, yes. He was speaking about cosmic rays—that was the big thing in those days. And he was beginning to be willing to admit that maybe, as well as cosmic rays, there were cosmic particles. He and someone up at MIT had a difference on that.

GOODSTEIN: [Arthur] Compton, I think.

WOUK: Compton, correct.

So here I was at Caltech now, in electrical engineering, and I thought I'd be getting my master's and get a job in the aircraft industry. I started in the fall of 1939.

GOODSTEIN: Did you rent an apartment?

WOUK: No, I stayed at a private home off campus, where they were letting rooms to students. I believe the number was 1036 California Street. So if I was lazy, I would drive [to the campus], and if I wasn't, I would walk. In those days, I could park right next to the High Voltage Research Laboratory, or anyplace I wanted to on campus. It was unusual for anyone, graduate or undergraduate student, to have a car.

GOODSTEIN: I wanted to ask you the circumstances of your graduate career. Did you have a teaching assistantship or did you pay tuition? How did you finance your graduate education?

WOUK: My first year was completely financed by my family. I had no fellowship or anything like that.

GOODSTEIN: Had you thought of applying for one?

WOUK: No, not really, because it just never occurred to me. In Christmas of '39, an associate of mine among the graduate students in the electrical engineering department and I were sitting on the roof of the High Voltage Lab sunning ourselves, talking, when my professor—Professor [S.

Stuart] Mackeown—came up and said, "I'd like to speak to Wouk for a few minutes." And he said, "I have received a grant from the American Petroleum Institute to do some research on static electricity and gasoline"—because there had been either some fires or potential fires at gasoline stations, and it was thought that maybe static-electricity sparks had started the ignition. And I said, "Gee, I hadn't been thinking about it, but what's involved?" And Mackeown said, "Well, it will pay this, that, and the other thing. Certainly tuition, possibly not board." I would have tuition and [live in] the Old Dorm, and have lunches at the Athenaeum.

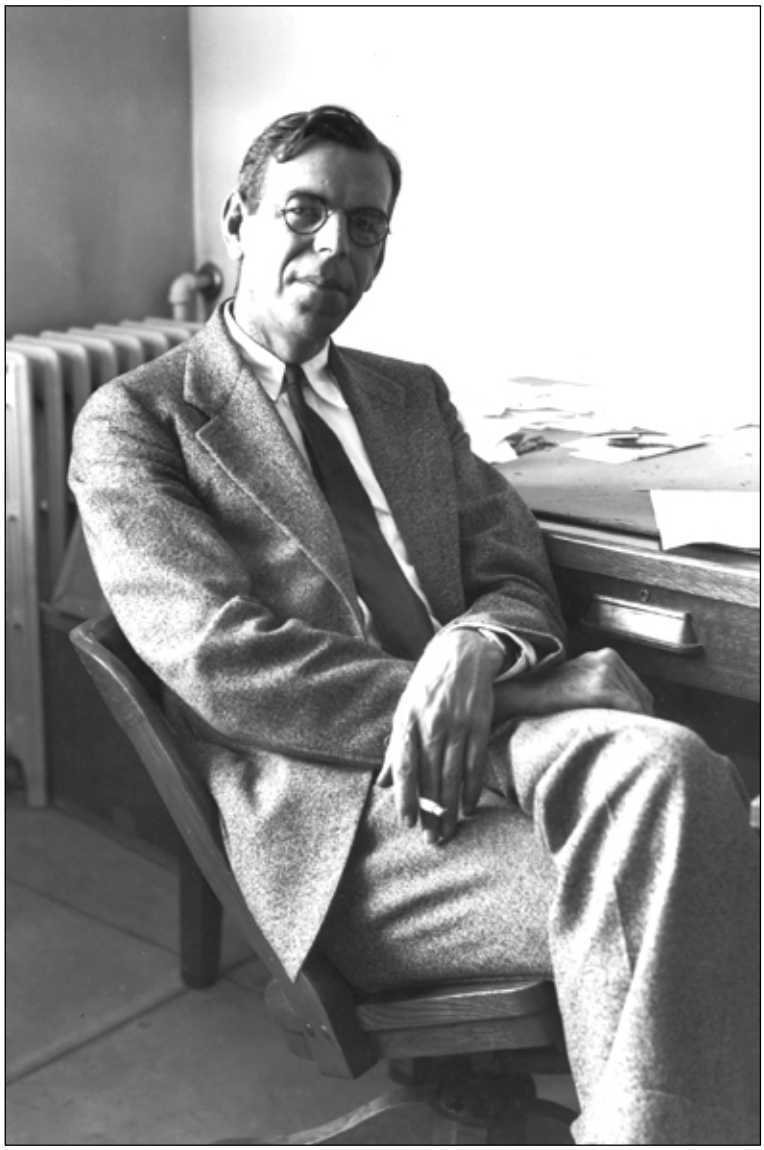


Fig. 1. Samuel Stuart Mackeown, professor of electrical engineering at Caltech during Robert Millikan's era. Caltech Archives.

GOODSTEIN: So the Old Dorm is where you slept. And you took your lunch—?

WOUK: At the Athenaeum. And he said, "In addition, this might lead to a PhD."

"But Professor Mackeown, I wasn't thinking of going for a PhD."

"Well, what are you doing?"

I told him [about wanting to get into the aircraft industry], and he said, "It's much better to have a PhD when you make that kind of application."

So, much to my surprise, and my family's surprise, here I was at Caltech for two more years. Instead of just 1939, it was'39, '40, '41.

Mackeown and I discussed the details later, and he said, "You should go up to San Francisco to the Union Gasoline Company"—or whatever the name was. "They have the most extensive library on anything that has to do with gasoline and the petroleum industry." So in March of 1940 I went up there. I looked through all the publications that had to do with electricity, static electricity, and gasoline, and I realized that there was no quantitative information about static electricity due to flowing gasoline—whether it was filling a car or filling a big tank truck. I had an idea of what I should do, and I discussed it with Professor Mackeown, and he said, "Sounds good to me!"

GOODSTEIN: So Mackeown got the grant from the API, but he gave you the research to do.

WOUK: Correct. I think it was $1,000 a year for two years.

GOODSTEIN: He was not actually involved in the research?

WOUK: No. I was very flattered. I told him I thought this static electricity generation was not a voltage phenomenon, which was currently the idea. But there must be a charge separation phenomenon, when the rubber comes off the concrete as the car moves. I thought I might be able to establish that point with a very simple experiment, involving putting the car on a dynamometer. You put the wheels of the car on the dynamometer, then you turn on the engine, and you can do all sorts of tests.

GOODSTEIN: And the car is standing still?

WOUK: Right. There was a garage that did repairs and studies, so I went there and told them what I wanted to do, and they said, "Oh, we'll help Caltech. Of course!" We put the car on the dynamometer—front wheels on the concrete floor, rear wheels on the metal dynamometer. And I said, "If static electricity is generated that way, then when I start moving I should be able to measure the electricity from the car chassis back to ground.

GOODSTEIN: Whose car did you use?

WOUK: My own car. So I did that. And lo and behold, there was current flowing. It was a rather small amount, and I had to use one of the more sensitive microammeters available in the electrical engineering department. But it was a linear relationship—went twice as fast, got twice as much current; went three times as fast, got three times as much current. I took the data and went back to Professor Mackeown. He was happy as a lark.

Have I told you about the first fee I ever earned because of my knowledge of static-electricity phenomena? Back then, a company near Palos Verdes was having a problem filling shipping bags of diatomaceous earth. Static electricity would cause the bags to completely expand when only three-quarters of the rated bag capacity was reached—sort of like in cereal cartons: "Contents may settle during shipment." I was amazed at the amount of static electricity generated, and glad the material being bagged was not gunpowder!

Anyway, we are now at June of 1940, the end of my first year. During the summer, I did something that turned out to be unique. We would have to measure some very low currents under particular conditions, and I didn't want to take any more chances on damaging the very sensitive microammeter. Microammeters in those days were all mechanical, so I told Professor Mackeown that I would like to build an electronic microammeter, which would measure currents even less than one microampere and not be subject to damage if there was a big overload. The majority of my time in the summer of 1940 was devoted to designing and building this electronic microammeter. I made a lot of tests. Again, everything seemed to work very nicely.

GOODSTEIN: What was involved, in 1940, in building an electronic microammeter?

WOUK: It involved a complete rethinking of what a very low current means and what could be used. Now, there was a particular vacuum tube—I forget its name—but instead of being built with all the connections coming into a bunch of pins which went into a socket on the chassis of the radio or amplifier, this had one of the electrodes up on top, so that the insulation was so great that you could not attribute any current-measuring data to the flow between the input and this collector. However, those tubes were impossibly expensive, and there was a phenomenon—which still exists, but which is so easy to compensate for nowadays—known as drift. As the

elements warm up in the electronic circuit, the characteristics of the circuit change. So I couldn't use one of those expensive tubes.

Now, there was also in those days something called a bridge circuit, so that if something changed there would be compensating changes in another circuit and therefore you didn't have to worry about drift. At first, I had a breadboard where it took about ten minutes for a drifting current to settle down when everything warmed up. I played around with it, and it came down to about one minute—still a little bit too long. I finally had it settle down in about fifteen seconds. So I could turn it on and be comfortable that the current I was measuring was the actual current flowing and not some imbalance. I continued to do tests of that nature on the dynamometer, and I was able to make arrangements to do it on automobiles that were being charged when gasoline was flowing. Now we knew that if static electricity went into the car for whatever reason, I'd be able to measure it.

So I went to one of the major filling stations in Pasadena. Instructions had been given to the people there that this guy was coming from Caltech and he was going to do something crazy, but let him do it. So now we had the first big test. They began to pump in the gas, and lo and behold, the meter went up.

GOODSTEIN: Where was your meter with respect to the gasoline tank and where you're filling up the car?

WOUK: The meter was between the chassis of the car and ground. And lo and behold, there was a current in the microammeter. I would ask them to go very slowly and the microammeter would go lower down. Then I would say, "Come on full." And the meter would kick off scale. But then I would change the range. I collected a reasonable amount of data.

GOODSTEIN: How many days did you spend collecting data?

WOUK: All told, about thirty days. So I was now ready to do more testing, to see what happened when the car was actually moving. There had been—and there still are—stories about people driving a car on a warm day and sliding across the front seat in order to get out on the other side. And then when the driver goes over to take the nozzle out of the self-service pump, there's a

spark. This doesn't happen very often, but there have been reports. So now I was going to have to make tests with the car moving. This is now the end of '40, beginning of '41.

I have to digress. At the end of 1940, I went back to New York City. I took the train—*El Capitan*. That was a very exciting trip, two-and-a-half days to Chicago, all coach, you would sleep in your seat. In those days, the *El Capitan* went only to Chicago; you could not take a train [straight] from the West Coast to the East Coast. You had to change in Chicago. I forget who it was who took out big ads in newspapers saying, "Pigs and cows can be driven by rail from the West Coast to the East Coast, but not human beings." And Herman [VW's brother], who was doing pretty well as Fred Allen's scriptwriter, offered to underwrite a plane flight from Chicago to New York, which I took.

GOODSTEIN: What kind of plane? Do you remember?

WOUK: Oh, yes. It was a DC-3—the only ones available then—with the incredible passenger capacity of twenty-three people. A very nice flight.

GOODSTEIN: Was that your first airplane flight?

WOUK: No. It was my second commercial flight, but I would say about my fiftieth airplane flight, because I had become a pilot while I was at Caltech, in the Civilian Pilot Training Program and I got my license.

So I flew from Chicago to New York, was met at the airport by family, and everyone was very happy, and so forth. I had been corresponding with a longtime girlfriend named Joy, who was a year behind me in college. So I got engaged to Joy, and I went back to Caltech—again, flying to Chicago and then taking the *El Capitan*. And the winter/spring of '41, I continued making more measurements at more places where gasoline was being pumped. I established all sorts of things, which aren't very important. I would say to Professor Mackeown, "Let's see if there's a difference between leaded and unleaded gasoline." Well, if there was a difference, it was not important. And a few other things like that.

Now, actually, the main purpose of the API [American Petroleum Institute] spending all this was that they could then possibly satisfy a requirement for understanding whether drag

chains are necessary. If you are old enough, you will remember that in the 1930s, 1940s, and even early in the 1950s, gasoline trucks would trail behind them a chain that of course would go bouncing up and down as the gasoline truck drove. Because it was thought that the static electricity that was generated—and they knew it was generated—would be dissipated by this chain going back to ground. And I established the fact that when it was so dry that a lot of static electricity was being generated, then the resistance between the chain and the ground would be so high that it wouldn't dissipate any of the electricity. And on damp days, when you weren't generating very much, you didn't even [need the] chain. So that instead of changing these things, possibly as often as once a week in some places, you really didn't have to use them at all. They did no good whatsoever. So this justified the expense. There was an actual savings for the members of the API.

This wasn't adopted immediately. Some people said, "Some thinker at Caltech, one of these theoretical people, wasn't big on these drag chains." But we calculated these chains to be about—in those days—about $1.3 million a year for the industry. So it was something very practical.

GOODSTEIN: And it cost them nothing to find this out.

WOUK: Nothing! Exactly. So everyone was very happy.

But I still wanted to measure the static electricity while we were driving along. It's now June of 1941, and Mrs. Wouk—Joy and I—were married.

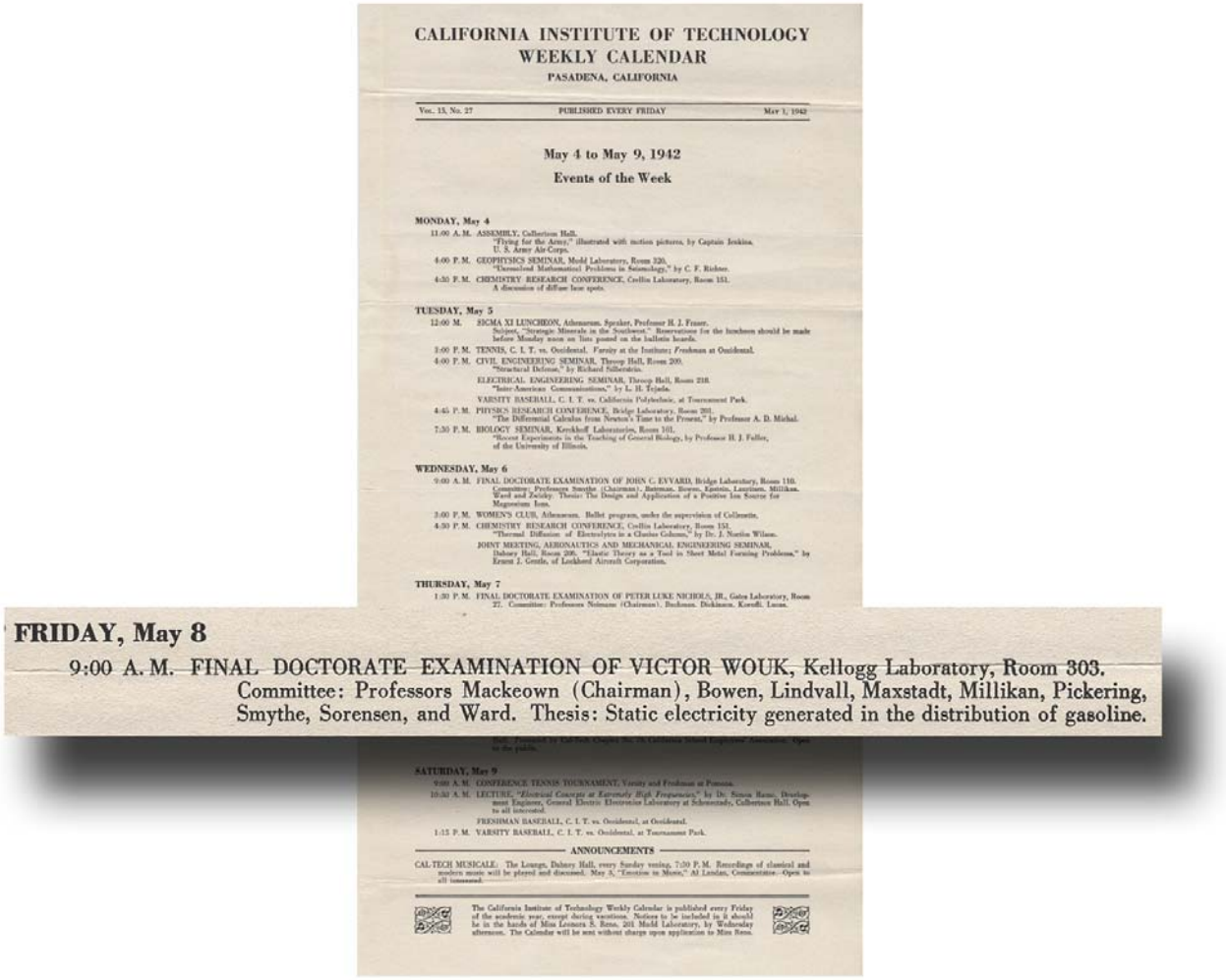
GOODSTEIN: You were married when you went back?

WOUK: We were married in New York, yes. I went back to be married, in December 1940. And this time my father and mother gave us a brand new Chevrolet. The war had begun in Europe and the production of cars had slowed down substantially. So we got a 1937 Chevrolet coupe that we drove across the country in and had a great wild time on the honeymoon.

Then I had the idea that if Joy drove the car and I had a drag chain and a grounded something-or-other, I could measure the current. Now, where would I find a well-grounded something-or-other? There was an abandoned Red Car track in Pasadena—I forget on which of

the big avenues it was on, but it was on one of the big north-south avenues. And I set everything up, with the drag chain on a rail. And Joy was a pretty good driver. And lo and behold, I got the same linear relationship.

So now it was getting toward the end of ’41 and the beginning of ’42. No more experimentation was necessary; I had to write up the thesis. So I wrote the thesis [“Static electricity generated during the distribution of gasoline” (1942)]. It was distributed to the necessary challenging committee. Professor Millikan was one of the members. And I was called in to see him after a couple of weeks of the thesis going around. This was my first direct man-to-man talk with him. He said, “I read your thesis. How come it’s so simple? You have only two equations, and the whole thing is immediately applicable for an important product and yet represents original thinking.”



CALIFORNIA INSTITUTE OF TECHNOLOGY
WEEKLY CALENDAR
PASADENA, CALIFORNIA

Vol. 15, No. 27 — PUBLISHED EVERY FRIDAY — May 1, 1942

May 4 to May 9, 1942
Events of the Week

MONDAY, May 4
11:00 A. M. ASSEMBLY, Culbertson Hall.
"Flying for the Army," illustrated with motion pictures, by Captain Jenkins, U. S. Army Air Corps.
4:00 P. M. GEOPHYSICS SEMINAR, Model Laboratory, Room 320.
"Unresolved Mathematical Problems in Seismology," by C. F. Richter.
4:30 P. M. CHEMISTRY RESEARCH CONFERENCE, Crellin Laboratory, Room 151.
A discussion of diffuse laue spots.

TUESDAY, May 5
12:00 M. SIGMA XI LUNCHEON, Athenaeum. Speaker, Professor H. J. Fraser.
Subject, "Strategic Minerals in the Southwest." Reservations for the luncheon should be made before Monday noon on lists posted on the bulletin boards.
3:00 P. M. TENNIS, C. I. T. vs. Occidental. Varsity at the Institute; *Freshman* at Occidental.
4:00 P. M. CIVIL ENGINEERING SEMINAR, Throop Hall, Room 200.
"Structural Defense," by Richard Silberstein.
ELECTRICAL ENGINEERING SEMINAR, Throop Hall, Room 218.
"Inter-American Communications," by L. H. Tejada.
VARSITY BASEBALL, C. I. T. vs. California Polytechnic, at Tournament Park.
4:45 P. M. PHYSICS RESEARCH CONFERENCE, Bridge Laboratory, Room 201.
"The Differential Calculus from Newton's Time to the Present," by Professor A. D. Michal.
7:30 P. M. BIOLOGY SEMINAR, Kerckhoff Laboratories, Room 101.
"Recent Experiments in the Teaching of General Biology, by Professor H. J. Fuller, of the University of Illinois.

WEDNESDAY, May 6
9:00 A. M. FINAL DOCTORATE EXAMINATION OF JOHN C. EVVARD, Bridge Laboratory, Room 110. Committee: Professors Smythe (Chairman), Bateman, Bowen, Epstein, Lauritsen, Millikan, Ward and Zwicky. Thesis: The Design and Application of a Positive Ion Source for Magnesium Ions.
3:00 P. M. WOMEN'S CLUB, Athenaeum. Ballet program, under the supervision of Collenette.
4:30 P. M. CHEMISTRY RESEARCH CONFERENCE, Crellin Laboratory, Room 151.
"Thermal Diffusion of Electrolytes in a Chalice Column," by Dr. J. Norton Wilson.
JOINT MEETING, AERONAUTICS AND MECHANICAL ENGINEERING SEMINAR, Dabney Hall, Room 206. "Elastic Theory as a Tool in Sheet Metal Forming Problems," by Ernest J. Gentle, of Lockheed Aircraft Corporation.

THURSDAY, May 7
1:30 P. M. FINAL DOCTORATE EXAMINATION OF PETER LUKE NICHOLS, JR., Gates Laboratory, Room 27. Committee: Professors Noyes (Chairman), Buchman, Dickinson, Kornfeld, Lucas.

FRIDAY, May 8
9:00 A. M. FINAL DOCTORATE EXAMINATION OF VICTOR WOUK, Kellogg Laboratory, Room 303. Committee: Professors Mackeown (Chairman), Bowen, Lindvall, Maxstadt, Millikan, Pickering, Smythe, Sorensen, and Ward. Thesis: Static electricity generated in the distribution of gasoline.

SATURDAY, May 9
9:00 A. M. CONFERENCE TENNIS TOURNAMENT, Varsity and Freshman at Pomona.
10:30 A. M. LECTURE, "*Electrical Concepts at Extremely High Frequencies*," by Dr. Simon Ramo, Development Engineer, General Electric Electronics Laboratory at Schenectady, Culbertson Hall. Open to all interested.
FRESHMAN BASEBALL, C. I. T. vs. Occidental, at Occidental.
1:15 P. M. VARSITY BASEBALL, C. I. T. vs. Occidental, at Tournament Park.

ANNOUNCEMENTS

CAL-TECH MUSICALE. The Lounge, Dabney Hall, every Sunday evening, 7:30 P. M. Recordings of classical and modern music will be played and discussed. May 3, "Emotion in Music," Al Landau, Commentator. Open to all interested.

The California Institute of Technology Weekly Calendar is published every Friday of the academic year, except during vacations. Notices to be included in it should be in the hands of Miss Leonora S. Rena, 201 Mudd Laboratory, by Wednesday afternoon. The Calendar will be sent without charge upon application to Miss Rena.

Fig. 2. The 1942 Caltech Weekly Calendar announces Wouk’s thesis defense. Caltech Archives.

I said, “Well, sir, I got this idea about the separation of charges.” And he said, “Well, others have had this problem for ages. We’ve had it—Bill Pickering and I and the group—with our balloons, sending them up. When they’re being charged with”—whatever it was, hydrogen or helium—“the balloons would have static electricity, and if there was a spark it would interfere with Professor Pickering’s telemetry. Have you ever made any measurements on our balloons?”

I said, “Yes, sir.” Pickering had heard about my work, and he was also an instructor in the EE department, and he asked me, “How about making some tests? We’ll blow up a balloon here. What should we do?” I told him we had to get a Faraday cage or its equivalent. A Faraday cage is just a big conducting cage that can be grounded. And the wonderful thing is that if something inside, not touching any of the metal, is blown up, and if any charge comes with it, the charge will not dissipate but will drag a current in the other direction, and that will indicate how much charge you have.

I made these tests, and they were so sensitive that if someone walked by, four or five feet away, a very small amount of electricity separated and would show up on the meter. And Pickering said, in his New Zealand accent, “Hey, Wouk, pretty sensitive device you’ve got there!” We made some measurements, did some calculations, and there was not enough energy to start a gasoline fire or anything like that, but there was enough energy to disturb radio signals.

Now I had to establish how much energy is required, if it’s a static spark, to ignite an inflammable amount of gasoline in air. It turned out to be a rather difficult thing to do—not the test, but the explosion. So I concluded that the fires that occurred while cars were being filled at gasoline stations were probably caused by static matches—where someone had lit a cigarette and tossed the match. I could find absolutely no evidence of sufficient energy to start a spark. And this was one of the points that Professor Millikan was very happy about. He said, “I used to think there was voltage involved in the spark, and I think your tests and explanations of energy are very important.” Off the record, I was told later by Professor Mackeown, after my challenging session, that the reason I got my doctorate *magna cum laude* was that Millikan was so impressed by this practical PhD thesis.

So the API got a lot of wonderful information and at low cost. I was happy. Caltech was happy. Everyone was happy.

GOODSTEIN: That's a wonderful story. I want to know something about Professor Mackeown, because no one has ever talked about him.

WOUK: He was a great fellow. S. S. Mackeown—S. Stuart Mackeown. S. S. Mackeown, so of course we nicknamed him Steamship Mackeown. His voice [imitating a deeper voice] was all the way down here. His specialty was radio equipment. He was a good instructor, very painstaking, but he preferred to lay out the basics and let the students figure out the rest of it. When I came to Caltech in September of '39, I had classes with Professor Mackeown.

GOODSTEIN: What did he teach?

WOUK: I was taking basic radio—vacuum tubes, oscillations, amplification—and after about two months, he had to go back to New York. One of the other graduate students, who was ahead of us—it might have been John [J.] Lentz, or it may even have been Wolfgang Kurt Hermann Panofsky, chief of SLAC [Stanford Linear Accelerator]. We would be taught by them. And I said to Professor Mackeown, "You know, that's going far. You'll be away for two or three weeks, I understand. I'm very curious. It's none of my business, but…." And he said he was going to New York City to be an expert witness for RCA and David Sarnoff in a suit being brought by [Edwin Howard] Armstrong against RCA for FM violation of patent. It sounded very interesting

"What is the basis of your position?" I asked. And he said, "Well, FM had been developed before basic frequency modulation, and in one of the books on radio engineering, Professor [Frederick] Terman, who wrote the book, said that frequency modulation is interesting but [has] no practical applications." So there it was, and what Armstrong did was improve FM to make it reasonably priced, and with more very important advantages. And Mackeown and Sarnoff won the case. Oh, and Mackeown also said, "Wouk, as an expert witness for $100 a day, *I am going*."

GOODSTEIN: That was a lot of money in those days.

WOUK: Yes. The apartment Joy and I moved into on El Molino Avenue was $36 a month, fully furnished. Recently we drove by—at Dr. [David] Baltimore's inauguration [as Caltech's president, 1997]—and there was a sign out, "Apartment for rent." I went in to ask. What had been $36 a month was now $600 a month.

There are so many little details about life in Pasadena in the early 1940s. For example, there was a marvelous restaurant named Pierre's, in San Marino. It was expensive—dinner ran about $1.25, *prix fixe*. If you ordered Crepes Suzette for dessert, the price was $1.50. When the crepes were brought in, flaming, the lights would be dimmed and a recording would play "Ave Maria."

Where are we at this point?

GOODSTEIN: Well, let's see. You told me something about Mackeown. Did you ever end up teaching any courses at Caltech yourself?

WOUK: Yes. My second and third year, in addition to this $1,000 stipend, I had a teaching fellowship. I taught undergraduates who were not EE [electrical engineering] majors, and I did that for two years. Also, in my second year, as part of the fellowship I taught the graduate student course in rotating machinery. We had a lab in the bottom of Throop Hall where we had rotating machinery. And also the high voltage, in the High Voltage Lab.

GOODSTEIN: And you were the instructor there too. How many students?

WOUK: I don't think there were more than six graduate students. And in the undergraduate classes, there could be twenty-five to thirty.

GOODSTEIN: Did you enjoy teaching the undergraduates?

WOUK: Very much. I felt it was a challenge to inculcate the non-electrical engineers with some sort of low level of interest in electrical engineering. I was most proud of the final exam, which was given to all three sections. There were three sections—chemical engineering, mechanical engineering, and electrical engineering.

GOODSTEIN: You taught all of them?

WOUK: No, I taught only one of the three, and my class always won the prize.

GOODSTEIN: So this was basically electrical engineering for poets.

WOUK: Exactly. I had some very bright people in my class. Some of them were going to be a hell of a lot smarter than I was, but I was a little bit ahead of them.

GOODSTEIN: Did you use a textbook?

WOUK: I don't believe I had a text; I may have had a syllabus. It was a lot of fun. I never had anyone complain to me that the course was dull, or say, "Gee, why do I have to take this?" So I taught for two years. I would give high-voltage demonstrations. Do they still have that at Caltech—once a year, all of the labs were open to the general public for an arranged . . .

GOODSTEIN: Tell us about that. Because I think that's now history.

WOUK: The public was invited, and by far the most popular of all exhibits was at our High Voltage Lab.

GOODSTEIN: Was this done on a weekend?

WOUK: Yes. On a weekend, they could visit the GALCIT [Guggenheim Aeronautical Laboratory, California Institute of Technology] wind tunnel, the High Voltage Lab—and I'm trying to think of what else. But there would be a line around the corner, and we would be able to take about a hundred people at a time on the control level, one balcony, and final balcony, which led to a roof, which led downstairs—if we had tried to bring the people down the same way they went up, the lines would still be there today. So you went up one way, down the other way. We would demonstrate, first, the high-voltage transformer itself, a million-volt

transformer, demonstrated by some brave fellow in the electrical engineering department with a well-insulated rope, letting down a chain that was connected to a metal girder up above. A fellow at the controls, another graduate student, would turn on the voltage. There would be a spark. And then, as the rope was pulled up, the spark would go up, and there would be this magnificent spark going all the way up to the roof, and the voltage would be turned off. Very interesting.

The other interesting experiment with the high-voltage transformer was what is called a Jacob's ladder, where two electrodes, like two horns, are coming up, and an arc would be struck between the two of them at the bottom. The spark would blow itself out as it heated up the air and the air would push it up and it would go out. That picture would almost always be in the *Pasadena Star-News* the next day. Those were the two transformer experiments. The other was a lightning generator, and that was something.

The lightning generator was a device that would create a lightning stroke—imitation lightning, of course—of about 3 million volts, and that would cause a great big spark and a few other things. Our curtain demonstration—then everyone would go home after that—was a disintegrating wire. We would have a long wire strung from one end to the other, and we would put on the wire a bunch of little pieces of paper. The lightning stroke would go to that wire and blow it up, disintegrate it by the heat, and then all the little sheets of paper would come floating down and we'd get a lot of applause and everyone would go home.

What we did to keep the people happy while they were waiting was to have them inhale some helium gas. And [imitating a high-pitched voice] *they'd talk like that.* We had a lot of fun.

These are a few of the many reasons why Caltech is such a great experience. [Tape ends]

Begin Tape 2, Side 1

GOODSTEIN: I was also going to ask you about other instructors and members of the faculty. Besides Professor Mackeown, did you have much interaction with Royal Sorensen?

WOUK: Yes. He gave the first graduate student course on transformers.

GOODSTEIN: Did you take that course?

WOUK: I took the course and I enjoyed it immensely. And I found out during that particular course an unusual characteristic of our High Voltage Lab.

This was the first million-volt transformer that was ever built, and in those days the technology was not advanced enough to generate a million volts in one transformer; the best you could hope for in those days was a quarter of a million volts. So Professor Sorensen designed the system with four cascaded, and the top of the output of the first one would go into the input of the second one, and part of the output of the second one would go on, [and so forth]. Westinghouse either won or was given the contract; I don't know that detail, but Professor Sorensen said that when the transformers were installed, there were no nameplates on the transformers. You could not tell where they had been built.

Why? Well, Westinghouse did not believe it was going to work, for some fairly good technical reasons, but not factual reasons: They were afraid that instead of a million volts coming out, only 750,000 would come out. So that's [why there were no] nameplates on the transformers.

It gave me an exciting feeling to go to the high-voltage transformers and the lab, so I volunteered for any work that ever had to be done in the High Voltage Lab. I have a picture, taken from the roof of the catwalk, of a big accelerating tube into the little well-insulated hut where someone was doing experimentation on accelerated electrons.

GOODSTEIN: That might have been Professor [Charles C.] Lauritsen?

WOUK: No, I'll go back to Lauritsen. This was Dr. [Arno] Brasch from Germany, and his assistant was from the UK. Brasch had to get out of there because of Hitler, and he wanted to continue his tests, which were rather interesting. All sorts of unusual, unexpected items came up when high-speed electrons hit certain targets. At one time I gave a talk on that. This was another good thing about Caltech: You'd go as a first-year graduate student and you'd be doing quite advanced work.

Now we get to Professor Lauritsen. When I first came to Caltech, Lauritsen had finished his really seminal experimentation on high-voltage X rays. Now, where could he get a million volts for high-voltage X rays? It would be in the High Voltage Lab. So he had set up a very interesting experiment with a million-volt X-ray tube, but in order to be sure that everything was

cooled properly, he had to feed water through the target to keep it cool. So that meant there was going to be a long rubber tube going up from the ground to the X-ray tube and another one coming down. The experiments were finished. I forget what Dr. Lauritsen and his associate accomplished, but it was seminal. But he was finished and the system had to be dismantled.

I was then enrolled in a program known as the NYA—the National Youth Act—where young people in college could earn fifty cents an hour. Caltech had its own allocation for that, and that's what I was being paid. I was swung up on a bo'sun's chair. I can't imagine that I was willing to do things like that then, but I did. Byron Havens was doing the pulling. He, incidentally, worked with John Lentz at the IBM labs in New York City, at Columbia, during and after the war, on radar. But anyway Byron was pulling, and I guess I was hanging on for dear life, but I enjoyed it. I had to take screws apart and big bolts apart, make sure they didn't fall down on Professor Lauritsen, and all that sort of thing. It was a lot of fun.

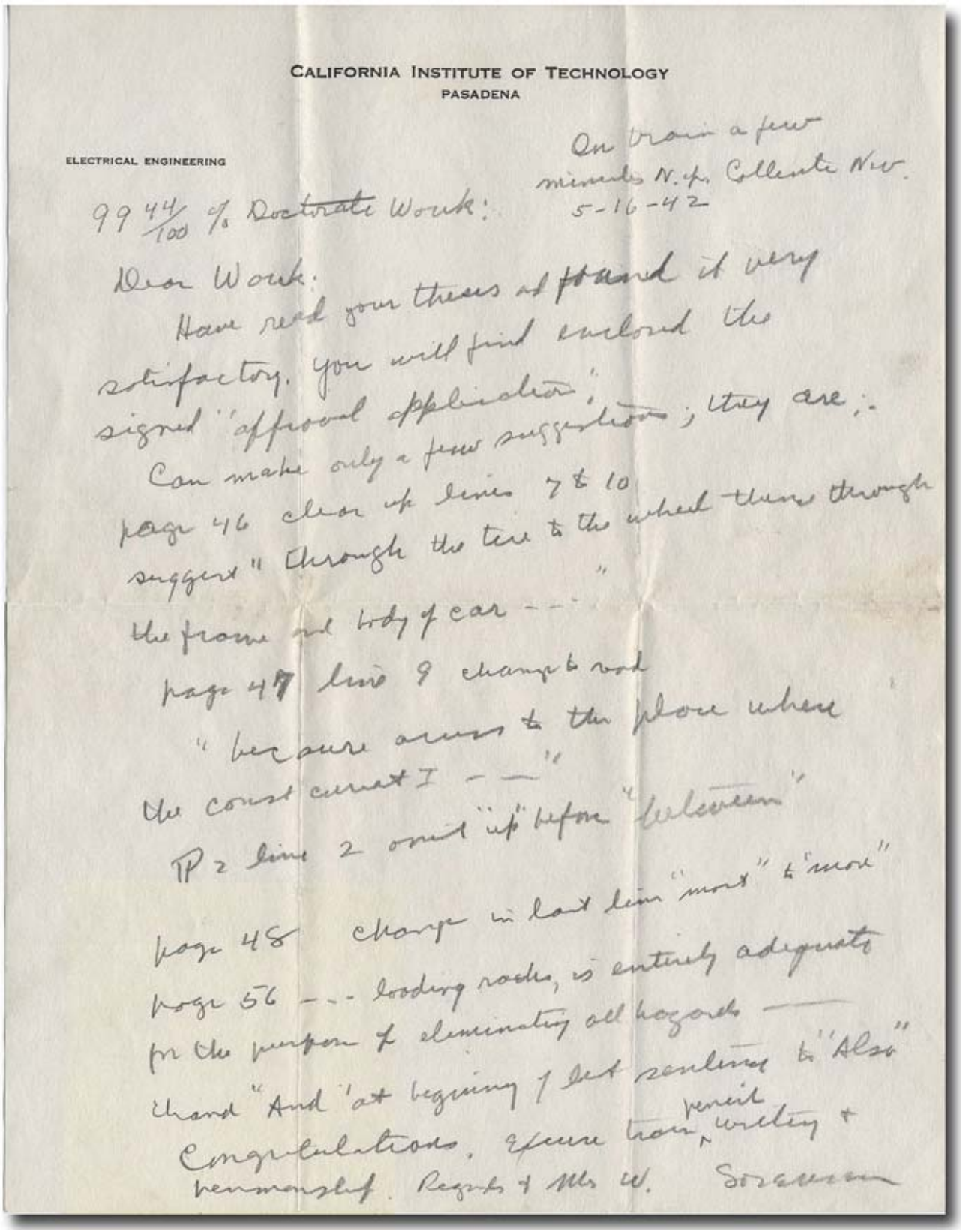
When that was over, I worked in the photography lab that developed all the pictures at GALCIT—with the planes going up and down and the streamlined smoke patterns.

GOODSTEIN: These were photographs taken in the wind tunnel on test airplanes?

WOUK: In the wind tunnel, yes, and the film had to be developed, printed, enlarged. So I was helping someone there, and after about two months of this, Professor Sorensen called me into his office and said, "Victor, I know that in New York City the salary of $8,000 a year isn't all that great. But for the NYA, it's a very high salary, and you have to be poor to be entitled to this." That was the end of my NYA, but not the end of some of my activities, because I liked them.

So now I've gone back to the very beginning. And the very end was getting the PhD. I went through, had my thesis challenged. All of the professors came out. Millikan was first: "Congratulations!" About three weeks later—this was in the spring of '42—it had to be before April 27th because I had not reached my twenty-third birthday; I was still twenty-two. Anyway, Professor [Richard Chace] Tolman's secretary called me in one day and said, "Wouk, you have a problem. You don't have enough points for a doctorate."

GOODSTEIN: Tolman was dean of the graduate school.



CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA

ELECTRICAL ENGINEERING

On train a few minutes N. of Collinsville Nev. 5-16-42

99 44/100 % Doctorate Work:

Dear Wouk:

Have read your thesis at hand it very satisfactory. You will find enclosed the signed "approval application"; they are:-

Can make only a few suggestions; they are:-

page 46 clean up lines 7 & 10

suggest " through the tire to the wheel thence through the frame and body of car - - - "

page 47 line 9 change to read

" because arcs & the glow where the const current I - - - "

TP 2 line 2 omit "of" before "between"

page 48 change in last line "most" & "more"

page 56 - - - loading racks, is entirely adequate for the purpose of eliminating all hazards - - -

Change "And" at beginning of last sentence to "Also"

Congratulations. Excuse pencil writing & penmanship. Regards of Mrs W. Sorensen

Fig. 3. Letter to Victor Wouk from Royal W. Sorensen, Wouk's thesis advisor. Caltech Archives.

WOUK: Yes. He may have been in Washington already, working on coordinating everything. So she was alone, and she said, "You don't have enough points."

I said, "What do you mean, I don't have enough points?"

She said, "Well, the points we gave you for your optics"—and Professor Ira [Sprague] Bowen was the optics man on my examination committee—"the points we gave you for that course was a graduate course at Columbia. Very fine! But you can't [get credit] twice [for one course]. So you're ten points, or whatever it is, short for the doctorate. What are we going to do?"

So I said, "Well, let's take a look at all the subjects for which I had not received any credits because I didn't need them." And lo and behold, there was a course given by Professor [Frederick C.] Lindvall called Mathematical Engineering Physics—a damn good course. I had taken that in my second year.

GOODSTEIN: Was that a yearlong course?

WOUK: I can't remember; I think it was a half year. In my second year, I was Professor Lindvall's grader, or whatever you call them. So they said, "Well, it's not math, it's not physics, but it's engineering. Hurray!" That's how I got through.

GOODSTEIN: Tell us something about Fred Lindvall.

WOUK: He had the stories, too, that he could always bring into his classroom. He was a very nice fellow. I enjoyed his personality immensely, and vice versa. There were two things I remember specifically, one of which was rather important to my future development, particularly in electric and hybrid cars. And that was the story of regenerative braking. I forget how he dragged this into the classroom, but he told us a story about when he was young and living in Colorado—I think Denver. His family lived at the end of a trolley line, up a rather steep and long hill. It was so far away from the generating station and so much current was being drawn going up a hill that the voltage would drop to an unacceptable amount and the trolley car would stop there. But if there was a trolley coming down, instead of using mechanical brakes to slow

your trolley down, the motor would be turned into a generator by switching some leads, and the generator voltage would go into the overhead wires and that current would go into a trolley down at the bottom and help get it up. This impressed me enormously, with regard to the possibility of regenerative braking. It wasn't important to me then, but it was very important to me when I went into electric cars.

The other thing with Lindvall, which had to do with Caltech, was this particular course—Mathematical Engineering Physics. I would usually have problems solved in a way that wasn't particularly familiar to him, and he would ask where I got the background, and I'd tell him, and we used to chat about those things. A tall fellow, quite good-looking, who always wore bowties.

GOODSTEIN: In those days did all the professors wear ties, or bowties, and jackets when they lectured?

WOUK: Yes, and most of the students also wore shirts and ties and jackets. When I first came there, I saw many students walking around without shirts, ties, and jackets. And then Professor Mackeown took us on a field trip to one of the outskirts of Los Angeles, when the power from Hoover Dam was coming into LA. We went to see the cables coming in and the transformers that were going to be connected. We got a very good view of what a high-voltage substation looks like, where the 275 KV would step down to 36 KV, then step down again. I have a picture of the group there, and lo and behold, everyone is wearing a jacket, shirt, and tie—except me. I was wearing a sweatshirt; we were going to a hot area. Thereafter I was careful to wear at least a shirt and jacket. I may also have worn a tie—that was not a major aspect of my life there, so I don't quite remember.

GOODSTEIN: When you used to eat lunch in the Athenaeum as part of your—what they offered you under the API grant—did you sit at the table with the professors?

WOUK: No. The grad students would usually sit with other graduate students. I can't remember sitting with faculty, unless…I might have been invited.

GOODSTEIN: In other words, there were two worlds.

WOUK: Yes.

GOODSTEIN: Were you required to take any courses in the humanities as part of your graduate program?

WOUK: No. But I did have to show a minimum capability in two foreign languages in those days. I had taken German and French in high school, because at my particular high school two languages were required. At Columbia, I would have had to take two languages, but I achieved German, which meant I could take an exam and if I did well enough I wouldn't have to take German. I decided to go that route, because it would give me more time for math and physics. When I got to Caltech, I was informed that I would have to take two courses. There was a man who looked very much like [Wolfgang Panofsky]—same height, same size, same accent, perfectly understandable, slightly German. And I was administered a test in German and a test in French and, duck soup, very easy. Particularly since they allowed open book, though not a dictionary. But I didn't need the open book. It was good scientific French, the equivalent of the IEEE [Institute of Electrical and Electronics Engineers] *Spectrum*, or one of the *Proceedings*. It was about some radio waves. So I didn't have to do any foreign language.

GOODSTEIN: You did the same in German? You tested out?

WOUK: Yes. Again, I have a story about the instructor or professor who gave the tests.

GOODSTEIN: Tell us.

WOUK: About three-quarters into my first year, this instructor—I'm sorry, I've forgotten his name—but the instructor met me on the Olive Walk and said, "Wouk, I remember you took the test and you did very well. You may be able to help me. I've been hearing strange…what sounds like early German on the radio every now and then. And you might be able to understand it better than I."

I said, "Well, when did you hear it?"

"Sunday morning at ten o'clock," on something-or-other. So Sunday morning at ten o'clock on something-or-other, I tuned in. And what is it? It's Yiddish, which is an ancient German language—a strange combination of having the Hebrew alphabet but with the words pronounced in the Yiddish manner. So that was my experience with that particular professor.

I'm trying to remember more about Professor Sorensen. When I was admitted to Caltech for graduate work, I got a letter from Professor Sorensen saying that he was going to be in New York for the then AIEE—now part of the IEEE.

GOODSTEIN: What did AIEE stand for?

WOUK: American Institute of Electrical Engineers, later combined with the Institute of Radio Engineers to become the Institute of Electrical and Electronics Engineers.

He said he was coming in and he'd like to meet with me at the engineering institute. I said fine, so at the arranged time, I went to the [institute's] building on 40th Street, went into the dining room, where Professor Sorensen was waiting for me. And he said, "Before we start, I'd like to find out how your name is pronounced. We were having difficulties at Caltech—is it 'Wook', is it 'Wowk'?" And I told him it's 'Wouk'—like "I woke up." He said, "Oh, that's easy. Woke, woke, woke. Goodbye, hope to see you in Pasadena in September."

Now I was in Pasadena in September, and I walk by his office. In those days, it was literally open door for every professor, unless he's talking to someone in there or [saying] something personal on the phone. I came and stood at the door, and he said, "Hello, Wowk." Well, I didn't say anything thing; I let that go. As I mentioned before, all students in EE had to take this course in transformers. And after I'd been in the course three or four weeks, answering questions and volunteering to do problems, he took me aside after a class and said, "I think I've been pronouncing your name wrong. Didn't you tell me it's not 'Wowk,' back in New York?"

I said, "Yes, sir. It's 'Woke,' but it really isn't important."

"Woke, woke, woke. I won't forget that."

The next morning in class he said, "Wowk, do you know thus-and-so?" So I let it go. I think by the time I was graduated, he may have pronounced it as we like to have it pronounced.

GOODSTEIN: There's one more instructor listed in the catalog in those years. His name was [Francis W.] Maxstadt. Can you tell us something about him?

WOUK: Yes. He, again, was a very nice fellow and very knowledgeable in machine design—rotating machinery. He was in charge of the rotating machinery lab. The small transformers were there, too, for testing. And he was perfectly happy with the field, which was not particularly sexy in those days. Rotating machines—who cares? As an aside, I can say that nowadays there's only one major engineering institution in the country that teaches rotating machinery, and that's MIT. Now, this was true ten years ago—I don't know whether they've dropped it, too. Because the thing turns around—anyone can design it. That's not quite so: Rotating machinery is still a very technically complicated field, where small size, light weight, and high efficiency are important. And they're usually electronically controlled, which of course was not possible in those days.

So I liked him. He was friendly, understanding. But some people felt, "Why is he in rotating machinery?"

Then there was [William H.] Pickering. When I came there in September, Professor Pickering and Professor Millikan were out in India someplace, up very high in the Himalayas. And Pickering informally would tell us about his experiences there. He said to me once, "If you've been to the Grand Canyon—forget about the colors, but with regard to sheer cliff just dropping down, it doesn't compare to the Himalayas, where you get drops of 10,000 feet." Whereas the Grand Canyon is only 5,000 feet.

GOODSTEIN: Was Pickering a good storyteller?

WOUK: Yes. A good storyteller and a great sense of humor. He was quick to give someone positive feedback on whatever the person said. And he gave, as far as I know, the first course in radar at Caltech. But what he did do to me was ask me to read a new paper on something called binary mathematics, where you had switches that were open or closed, and therefore you just had ones or zeros, and you could develop complicated circuits that way. Nowadays of course this Boolean algebra is used mainly in electronic circuits—for on-off, 0 or 1. And we did a little bit of that on-off, 0-1. But the application was for simplifying switching circuits at power

distribution systems. There's a lot of logic involved, and by using this Boolean algebra and digital electronics—or its equivalent—you could simplify the previous switching systems enormously.

GOODSTEIN: Did he give this paper to you to read in a course?

WOUK: No. It was part of the weekly—or bi-weekly—seminar. So I made a presentation.

GOODSTEIN: You read it with the idea that you would then present it?

WOUK: Yes, I would then present it to everyone, which was very flattering. From the very beginning—I've mentioned this—at Caltech, the professors assumed you were good enough to do something. And lo and behold, they were usually correct.

GOODSTEIN: The presentation was to other graduate students in EE—or open to all graduate students? Do you remember that?

WOUK: This was just for EE—because it was nothing but electricity in those days. Switching circuits were what was important. Switching circuits are still important, but instead of having fifteen, you have 15,000 or 15 million on something this big [showing size with hands]—a centimeter squared, rather than an acre.

GOODSTEIN: Did you take any courses from Pickering?

WOUK: Yes. In the last half-year, he gave this course on radar, microwave transmission, and such things. And by the way, I now have to bring in another name—Hsu Chang-pen, who was a doctoral student at Caltech for the first year I was there. Hsu was having his last year. He did an analysis of microwave transmission. He had a thesis, which was maybe 200 pages thick, with equations going across both pages ["Propagation of electromagnetic waves inside a cylindrical metal tube and along other types of guides." (1940)]. A real honest PhD student—not like me. He and I were very friendly. I've got pictures of him playing tennis on what used to be a court

next to the Athenaeum. I was very sad when that court was filled with a building. Hsu went to the MIT Rad Lab, and I understand he did some wonderful work there.

In 1946, when I had just founded my company, Beta Electric, for making high voltage—one day I got a call from Hsu Chang-pen, saying he would like to talk to me about something. "Fine, come on up." My lab building, my office and production facility, was on Third Avenue, between 97th and 98th. I lived four blocks away and I used to walk to work. He came to see me and he said, "I'm having trouble getting a job." His uncle, or grandfather, or something, was a red-hot liberal in China, and China was just beginning to be a little bit of an outcast in the United States, so he couldn't get a job on radar or at Los Alamos or anything like that. And he said, "Well, I'll have to go back to China." This was *absurd*! I said, "I can't recommend you. You're better than I am!" And he said, "Try. Please!"

I called up a few places where I knew he'd already been. Not a chance. He could not be hired. So he went back to China. Fade out, fade in. A few years later, China explodes its first nuclear bomb. And I said to someone, "I would not be surprised if Hsu Chang-pen was head of that project." And then other things were done.

In 1998, you may remember that I ran a meeting celebrating the 30th anniversary of the cross-country run of electric vehicles—Caltech versus MIT. And one of the invitees was [a professor] from Hangchow—well known and respected all over the place. At dinner one evening, when we sat next to each other, I asked him, "Do you by any chance know the name 'Hsu Chang-pen'?" He said, "He's the man in charge of the atomic energy and atomic weaponry in China. How do you know him?"

I also heard that Hsu died recently—I don't know. And there's no point asking. You don't want to get into any trouble. That's one of the sad stories, because at the time when Hsu was working on the atomic weaponry, another Caltech grad who made the newspapers was in charge of the rocket.

GOODSTEIN: [Hsue-shen] Tsien.

We're going to go back. I was curious—when you were in your last year at Columbia, it was the first year that Enrico Fermi came to Columbia. Did you ever meet him?

WOUK: No, I never met him but I was at a seminar where either he or Professor [J. R.] Dunning gave a presentation on this report from Germany by Lise Meitner and Otto Hahn on nuclear fission, and we were given a demonstration. Dunning, as soon as he read the paper, had run down to the cyclotron lab, made a test with the uranium, and lo and behold, out came neutrons. So that was very exciting. But I had nothing to do with Fermi.

I did have a minor relationship with Major [Edwin Howard] Armstrong. What was the relationship? I had hoped to go into the field of television; that was why I went to Caltech. They had a good radio-television—

GOODSTEIN: What did Caltech have in the way of television?

WOUK: Not much, but they did have a good radio course with Mackeown.

So, since I was interested in television, I had heard that Major Armstrong was using a lab at Columbia, in Philosophy Hall, in the basement, to do some further work on television. He had already done all his work on FM. So I went there, to the lab, several times. It was all very interesting. And on one particular day, the first broadcast ever of a sports event anywhere in the world was going to be made at Columbia's athletic field—Baker Field, up at the very northern tip of Manhattan—and RCA was going to televise it.

Well, in those days, there was just one transmitting tower, which was on the Empire State Building, and in order to get a good reception, all they had was a simple dipole, none of the fancy things you have now or are capable of, of course. Just a simple dipole, and it had to be oriented straight at the transmission tower. There was no way of connecting the TV tubes at Baker Field, where the transmission was taking place, to the Empire State Building. So it was just going to be broadcast omnidirectional, from Baker Field. The antenna on top of Philosophy Hall was oriented toward the Empire State Building. And they would not get very good reception that way; it would have to be reoriented to Baker Field. So that meant that someone had to climb up on the roof—which was a sloping roof—and get to the chimney where the antenna was and reorient it.

Well, who was elected—or who volunteered? I volunteered for that. And one of the faculty was up there with me, but he was down at the bottom of the slant, to relay to me how the picture was coming along. I stood there and rotated it until he said, "Hey, that's it! Leave it

there!" Maybe that's what gave me the nerve to do what I told you about [the bo'sun's chair and] Professor Lauritsen.

GOODSTEIN: Did you have a safety rope on?

WOUK: Nothing! Nothing. When I was working on Lauritsen's equipment, the pictures I took were from the catwalk, and it was just a plain I-beam—no handrails. I'd just walk across. You'll see pictures of that type in the newspaper advertising, the pictures the *New York Times* has of when the Empire State Building was built, and you see thirty people sitting down on the beam, having lunch. Or you see someone like Margaret Bourke White, out at the end of the gargoyle, on the Chrysler Building. Anyway, that was my first experience with Professor Armstrong.

The second one was after World War II. I was working at North American Philips in Irvington-on-Hudson, on television high-voltage equipment. There was going to be a big demonstration at Philips Labs to the community—politicians and big businessmen, and so on, pretty limited. We weren't going to have much more than about forty people. We wanted to demonstrate this projection television system that I was working on that Philips had developed. And during some of the tests, all of a sudden the picture would become cross-hatched and almost invisible, nothing intelligible on it. When I brought in these people who knew about the transmission aspects of TV, they said, "A signal, a very strong signal—which is either in the carrier frequency range or generates harmonics that are in that range—is just wiping your picture out. Someone nearby must be transmitting a very strong signal." And they came to the conclusion that it must be Armstrong, with his big tower in Alpine, New Jersey, where he was sending FM to Boston. Plus, the fact that this occurred between five o'clock and eight o'clock in the evening. And I was elected to communicate with him: "Please don't do this on such-and-such a date, when we will be showing the first prizefight ever televised between Joe Louis and [Billy] Conn."

So I wrote a letter to Armstrong, explaining the situation. I got a very nice letter back, saying, "Naturally I don't want to rain on your parade. I won't transmit. But in return, I would like you to use your influence to get the FCC [Federal Communications Commission] to rearrange some of the basic transmission frequencies for FM and television," because there was a

lot of interference. Now, whether my letter to the FCC was important or not, I don't know. But that was my second and last encounter with Armstrong.

GOODSTEIN: OK, so now we've really reached the end of the Caltech. Now you have to tell me how you got into World War II work. You've done your PhD; you've defended it. You've gotten enough points.

WOUK: Then I have to go back to what I was doing at Caltech.

GOODSTEIN: No problem, let's go back and make the transition.

WOUK: I don't know why I was given this by Professor Sorensen, except for the fact that he knew I loved to do these things. Before I came to Caltech, Professor Sorensen had been given a new type of mercury arc rectifier, changing AC [alternating current] to DC [direct current]. This was going to be very important in big electrochemical plants for doing such things as getting aluminum from ores. An aluminum plant needs an awful lot of current, a large amount of power, voltage is high, and so on. So the ignitron was developed at Westinghouse by the man I worked for at Westinghouse—Dr. [Joseph] Slepian. This was a device that made it surprisingly simple to control the output voltage of a mercury arc rectifier. For various good and sundry reasons, it was rather difficult to control the amount of voltage in the types of mercury arc rectifier that existed at that time. This ignitron would send a pulse into the mercury when you wanted to ignite all the mercury that was in the vacuum tube, and this was a marvelous way of getting large amounts of DC. One of Sorensen's earlier students had built this equipment—had used six rectifiers, in something known as a three-phase bridge—and it worked halfway. It wasn't as good as it should be. So Professor Sorensen said—this was in my second year—"Would you like to fix this thing up and see what's wrong with it?" I said, "Yes, sir," and the thing was turned over to me. And I did find out something that was minor with regard to the basic concept but turned out to be major with respect to implementing it. And I had a lot of fun making the six- to three-phase bridge work from zero voltage to maximum voltage. Professor Sorensen was pleased, everyone was pleased, I was pleased.

I was then taking a course in aeronautical engineering.

GOODSTEIN: Who was teaching that?

WOUK: Clark B. Millikan. I loved it; I was doing very well. And one day, in my last year, I came to see him in his office, and… [tape ends]

Begin Tape 2, Side 2

WOUK: I asked him, "Could you get me an introduction to people [in the aeronautics industry]?" And he said, "Wouk, a PhD in electrical engineering in the aeronautics industry? What do we need that for? We've got radios and other simple things. No, it would be a waste of time. Professor [Theodore] von Kármán has a PhD, I have a PhD, in aeronautical engineering. And you're doing very well in my course."

So I gave up electrical engineering for aeronautics. And there were three places in those days—1941 and '42—where I could apply for work: GE Research, Bell Labs Research, Westinghouse Research. Bell Labs offered me $40 a week, GE $50 a week, Westinghouse $55 a week. So guess where I went—Westinghouse.

Now, Westinghouse may have offered $55 because of the work that I had been doing on the ignitrons, because the ignitron was a Westinghouse invention. So I got the job offer from Westinghouse.

GOODSTEIN: Did these interviewers come to the campus?

WOUK: Yes. They interviewed on the campus. They were all very nice people. I enjoyed the interviews. And I was told that when I went to Westinghouse I would be working on these ignitron rectifiers to improve them. And indeed, I went to Westinghouse, in Pittsburgh.

GOODSTEIN: How did you get there? Did you drive?

WOUK: We drove. I had the car my parents had given me that Joy and I drove west in. Westinghouse had found several places in East Pittsburgh where Joy and I might lease an

apartment. There was one—1306 Wood Street—that the trolley ran right by, so I took the trolley to Westinghouse.

So I continued my work as described previously, got the doctorate *magna cum laude*, and I have a minor anecdote to tell about that, because I now drop another name. You heard me drop Walter Shenson's name before. I now drop I. A. L. Diamond, of Billy Wilder and I. A. L. Diamond. Wilder was a great director and the basic story man was Diamond, a friend from Columbia, who was the detail writer and the joke writer, making things funny. He had a great sense of humor. The anecdote about him is about Commencement day, when I went up and got my diploma and hood from Professor Millikan. The dais in those days was in front of the Athenaeum.

GOODSTEIN: Where did you robe up and march?

WOUK: We robed up someplace—maybe in the Athenaeum, for all I know. It wasn't much of an academic procession, because the dais was on the lawn of the Athenaeum. Those getting degrees would be seated up to the Olive Walk, and then beyond that there would be guests and so on. After we got our diplomas and everyone said goodbye and so on, a wealthy man who lived on Orange Grove [Boulevard]—Mr. Ledeen, a mechanical engineer who had his own business—wanted to throw a big party for Joy and Victor Wouk. So we called Walter Shenson to let him know that this party is being thrown and he should come out. And I asked, "Is Diamond coming?" They were working together at Paramount. I could hear Walter saying to him, "Come on, I'm going out. Party for Vic Wouk. Oh, come on. I've known Vic all along, and he's very, very smart, you know. He got a PhD. I'm not surprised." I relayed this to Joy, and Joy said, "Tell Walter to tell him you got *magna cum laude*." That's exactly what happened. I could hear, "*Magna cum laude*? I'm coming." And we had pictures with everyone shaking my hands or whatever.

I don't know whether you heard me say this: Dr. Baltimore was bowled over at the lunch on April 14th when I said I was keeping all this information for a possible unauthorized autobiography. It took him about a half a second to laugh, and it took Herman three seconds to have it sink in. By the way, after that lunch, Herman told me, "Vic, when I saw Dr. Baltimore there, what with my impression that originally he had to be someplace else, I realized for the first

time that your contributions must have had much more impact in your fields than for what I had been giving you credit."

But anyway, I. A. L. Diamond came to my commencement. How did I get into dropping that name?

GOODSTEIN: Because you were going to tell me the transition, I think, from your PhD to the first job. You went to Westinghouse.

WOUK: OK. Dr. Slepian was not there. I said to the director of research, "I'm suppose to work with Dr. Slepian on ignitrons." He said, "Oh, Dr. Slepian is out on the West Coast doing some tests. So you work with Louis Casanova. He's more of a hands-on man for designing the system. He would not claim to be able to do anything resembling basic research, so he'll tell you what the problems are that we're trying to fix. You work on it, or maybe you'll have your own ideas." When I met Casanova, he told me there was a serious problem in all mercury arc rectifiers, the ignitron and the standard design, and that was something known as arc-back. The current is supposed to go only from the cathode to the anode and then add to the load, but every now and then, for reasons unknown, the current starts flowing from the anode—the positive back to the negative, which it shouldn't do. And when it does that, the amount of current generated is enormous. Now, all the circuit breakers open very fast and all sorts of other protective devices work. But who wants to open all the current to an aluminum plant? We've got to find out why there is arc-back.

There were some theories. And again, I went to the library there at Westinghouse. I read everything I could find on the subject of arc-back. And there was a—might have been a Caltech man, I'm not sure—who had a theory that sounded pretty reasonable. I thought I could follow the theory by a particular type of experimentation. I set up the experiment. I was making a lot of tests and taking a lot of data. And Dr. Slepian came back from California for a short visit. He asked, "What are you doing?" I showed him what I was doing, and he said, "Well, I agree with you on the basic concept of what you're trying to do, but you may have this and this trouble." Which indeed did develop eventually.

And then, at the beginning of 1943, possibly a little bit earlier, Dr. Slepian came back with the whole story as to why he was on the West Coast and who was there with him. It turns

out he was at Berkeley. Why? Because [Ernest O.] Lawrence had built this great big cyclotron with a magnet six feet in diameter that had a very nice strong uniform magnetic field. There was no point in doing more of the Lawrence cyclotron work; he had already become a Nobel laureate because of that, and most of the immediate benefits had been achieved.

But there were other projects that needed a strong, big magnetic field, and this was one of them: an ionic centrifuge for separating U^{235} isotopes. Anyone who was alert and read newspapers would have heard about the mechanical centrifuge for separating U^{235} isotopes; all the bad guys—Iraq, North Korea—they have these mechanical centrifuges, and this was supposed to work just like that. There would be a swirling mass of U^{238} ions in a vacuum, and with them U^{235}. U^{238} should go this way, U^{235} should stay near the center; and when we collected the material after a run, there should be a lot of U^{235} at the bottom and top near the center, and a lot of U^{238} around the back. My basic assignment was twofold: to instrument the system to measure the currents that were flowing and to develop the necessary high-voltage controls for controlling the voltages on the electrodes. And this was what I did for two years.

Occasionally there would be a very positive result. A positive result was that instead of enriching 0.01 percent per stage—which was what was happening at Oak Ridge—it would be 0.03.3. Now, if that could be consistently maintained, it would cut the number of stages by a factor of three. Plus a lot of other things it would reduce.

It never worked. The small low-current microampere tests at Berkeley would not scale up, because certain other bionic conduction problems would overcome everything else at these high currents, just like the problems that exist nowadays in trying to get fusion reactors. Speak to any physicist who's working on it. At these high-ionization states of a gas, it's very difficult to avoid instabilities. And the instabilities in our case would just mix up the U^{235} and U^{238} so that there was no great advantage. In fusion it's the problem of keeping the ring of fusing hydrogen or helium—whatever it is—keeping that stable, and they still haven't made too much progress.

GOODSTEIN: Was the work you were doing on this at Westinghouse considered secret work?

WOUK: Yes. As far as I know, it was the only project relating to the Manhattan District that was handled by a commercial organization with their own funds. The only benefit that Westinghouse

had from the government on this project was not financing but the ability to obtain scarce materials and the ability to retain any personnel who were being summoned by Selective Service.

GOODSTEIN: Was that a problem for you? Could you have been drafted at that point?

WOUK: Yes, I could have—for two reasons: number one, I was young and reasonably healthy; and number two, when I joined the Civilian Pilot Training Program I mentioned previously, one of the things I had to agree to was that if I were ever invited to join the air force I would accept the invitation. Because after all, all I had paid was $25 for some workbooks and so on and got the equivalent of a damn good pilot training. So on two occasions I was invited down to the Selective Service office at Westinghouse. The first time, Westinghouse received a letter from someone saying, "We need this guy for such-and-such a project. Please defer him until it's absolutely mandatory." The second time—early in '42—Westinghouse received another letter, this time signed by President Roosevelt, saying "Victor Wouk is on a project which may result in a shortening of the war, and I would appreciate it if you defer him." So that's what happened.

GOODSTEIN: You had two deferments.

WOUK: Two deferments. And although the project I was on—the Manhattan Project—did indeed shorten the war, my particular project just didn't.

GOODSTEIN: Did you know when you were working on your smaller project what the larger project was?

WOUK: I knew only indirectly. I knew something was going on in New Mexico, in a little town called Los Alamos, and it was believed that nuclear fission could result in quite a powerful explosion. I had followed the original work I mentioned previously at Columbia, and I didn't get very excited about it, because I thought it would blow itself apart before anything happened. Of course, I didn't know anything about core-section interactions. I didn't know anything about Fermi's work or anyone else's work. And I certainly didn't know that that small an amount of U^{235} would work. And I knew nothing about plutonium.

GOODSTEIN: So it was really a closely guarded secret.

WOUK: It certainly was. And when we get to the hybrid car, one of my jokes, which wasn't so funny, is that the government program—the Federal Clean Car Incentive Program—I was on to develop hybrids was more secret than Los Alamos and the atom bomb. Because nobody in Washington knew about that particular project.

GOODSTEIN: In the seventies.

WOUK: Yes, in the early seventies. When I wrote a book report for the magazine of the New York Academy of Sciences, it was about hybrid cars. I was reviewing two books, and I made some pretty strong statements. I said, "Nobody ever says anything about the FCCIP." I got a phone call from the editor saying, "Hey Victor, you know, we can't find anyone who knows anything about the FCCIP, and we always check background. Can you give me some hints?" I said, "Oh, if any one of these people is still alive, they will confirm that the FCCIP was actually a program." Of course there was a program, but nobody knows anything about it now.

GOODSTEIN: Yes, we're going to talk about the FCCIP program.

I know you've mentioned it, but I think for the record, you should tell us about the explosion. There was an explosion in a Caltech laboratory.

WOUK: It was in the Kellogg Lab, where the EE department was.

GOODSTEIN: Oh, the EE department was in Kellogg? And your classes—

WOUK: Were in Throop.

GOODSTEIN: Oh, in Throop. You took your classroom instruction in Throop.

WOUK: In Throop, and the EE lab was in the basement [of Throop].

GOODSTEIN: But the offices for the professors…?

WOUK: They were all in Kellogg.

GOODSTEIN: And you shared a space with Lauritsen and Willy Fowler?

WOUK: Right. I was very pleased; I had my own office. And I was there one day, minding my own business, when I heard this horrible *whoosh*—not a bang, but a *whoosh*, which took quite some time *whoosh*ing. So I ran out of my office. There was a balcony overlooking [the lab]. So I ran out to the balcony, and there was some poor fellow writhing in agony. It looked as though he had no clothes on. And some people were running in to put salve on him or whatever. And that was enough for me. Pretty terrible. Oh, I helped connect a hose to a faucet that was available right there near the entrance to Kellogg. And someone down below began taking the water and spraying it all over the man and the inside of Kellogg with it.

There were headlines in the *LA Times* and other papers: "Mystery Explosion at Caltech; One Dead." Nothing thereafter—never mentioned. Because this was a lab for the jet propulsion group—Lauritsen, Pickering, von Kármán. They were taking the powder there to machine into a proper form to do experiments on the most efficient use of the powder for the propulsion of jet-assisted take-off [JATO] rockets.

GOODSTEIN: These would be rockets you'd put under—

WOUK: Under the wings and fire them up and add that to the engines and propellers to cut down the size of the engine you needed for just taking off. It's almost like my hybrids.

GOODSTEIN: It's only for the take-off. When you're in the air, you don't use them anymore.

WOUK: That's right. Like the hybrids—once they're started by electricity, you don't need that anymore, because the engine will operate rather efficiently between 30 mph and 60 mph, or whatever it is. So, in this case, just the take-off. And they were successful, from what I

understood. They did have this one mishap. And either then or later—I think it may have been Willy Fowler who told me what was going on, somehow or other a spark must have fallen on the pile of powder, and it was just damn lucky that the powder was loose and not tight. Otherwise, half of Caltech would have been blown up.

GOODSTEIN: I believe they did not continue to do the experiment.

WOUK: That's right. It was moved someplace. I think that's when it was moved to the Arroyo, so that that became the basis for JPL [Jet Propulsion Laboratory].

GOODSTEIN: What was the climate on the campus in the war period? I've heard stories that there were some people who were pacifists.

WOUK: I can tell you this. My experience that had anything to do directly with the war was the Monday after Pearl Harbor, when President Roosevelt was going to speak to the nation and to the Congress. It was going to be broadcast at, let us say one o'clock Washington time, ten o'clock our time. I was in a class with Professor [Morgan] Ward, who was teaching a course in mathematics on complex variable theory.

GOODSTEIN: Oh, you took some math courses.

WOUK: Yes. I think that's the only one I took, and it might have been mandated, because complex variables are absolutely mandatory in electrical engineering. I asked him if I could go and listen and come back and report. He said go ahead, and I listened. It was pretty short, as you may recall. And I reported that President Roosevelt said there's war going on as of yesterday, and we're declaring war.

Two days later, I had my course with Professor Clark Millikan; it was not an everyday course. And he started off by saying, "I've heard some of you fellows saying you want to join up or you want to go and work in the aircraft industry. You want to quit and do something to the Japs. You will be much more valuable staying here, finishing your degree, and then going into the aircraft industry or whatever you want."

Now, of course, by then, radar had come in. The electronics on an airplane, and in the aircraft industry and in aerospace, was almost as important as the plane itself. But by that time, I think I had already agreed to go to Westinghouse and I wasn't going to change.

GOODSTEIN: You said there were some stories about Clark Millikan, but you'd rather not tell them on the tape. But if they illuminate his personality, we can always strike them afterward.

WOUK: OK. One of the things was that he was the first person I ever saw who was as interested in an automobile as some automobile nuts are today. He would park next to the aeronautics building and he would take out this canvas and cover the car. I had *never* seen that before. And I realized that this was someone who thought that the appearance of the car was the most important thing.

GOODSTEIN: You had never done that to your car?

WOUK: No, and I'd never seen that done in the East. I saw it done more often in the West, when I would come to the West Coast frequently after the war. So he obviously had some sort of interest in good-looking cars.

And he also had an interest in good-looking women. How do I know? Once when I was at Ciro's, which was *the* place to be in the 1940s—where I can tell you that an elaborate dinner was $3.50. And on more than one occasion, when I was there sitting at the bar with a girl I was trying to impress—and we could drink for fifty cents—there at a table would be Clark B. Millikan with a different female each time. I don't think he was married then. But he had a good time.

GOODSTEIN: And good taste?

WOUK: Had good taste, yes. And you'd never know that he was a professor of engineering at Caltech. He was the one who told me that nothing important was going on in the aeronautics industry in electronics. At that time, he was right, but soon after he wasn't. But I couldn't

switch back, because then I would be eligible for the draft. I couldn't change because they wouldn't accept me for one project from another project that had a deferral.

GOODSTEIN: Did you ever have any encounters with [William R.] Smythe?

WOUK: I had a course with him. [Recites]:

There once was a professor named Smythe
Gave a problem in balls made of pithe.
And with plain [word unclear] normal
and transformations conformal
The class solved the problem forthwithe.
[Laughter]
There was a professor at Tech
Whose course it was tougher than heck.
Though assigned nine hours,
nine raised to nine powers
Was more than he came to expect."

Now, you didn't have to know [much to know] that that was Smythe. I dropped the course in my first year.

GOODSTEIN: What was the course called?

WOUK: Static and Dynamic Electricity—one hell of a good course. I dropped it because it was just taking too much of my time to do a good job. I picked it up again in my second year, and got along all right with Smythe. I got along particularly well with him when we were doing the chapter on alternating currents, because I had already taken most of this stuff in electrical engineering, and I would present the answers to very complicated problems with simple EE approaches—absolutely correct. And he would say, "Hey, where did you get that idea?"

A story about Smythe: I later consulted for the Ransburg corporation, which was the first to use electrostatic painting, which is now a pandemic technology. At one point the Ransburgs

wanted to know more than I could explain, so I wrote to Professor Smythe to ask if we could come to see him for consultation. When I asked him about a fee, he answered to the effect that he should pay me; he had never had a request to consult on a practical, commercial application such as the electrostatic painting device. He welcomed the opportunity. At one point in the exposition, I asked, "Why is the image charge of the paint droplet so powerful in attracting the paint with the original charge?" When he said, "The droplet is attracted by the image charges of all the other droplets," I figuratively smacked my head to say, "How marvelous!" The chief engineer of Ransburg, who was with us, turned to me and I turned to him, and we said simultaneously, "This pays for the entire trip!" Professor Smythe, with a cat-that-ate-the-canary smile, said, "What's so important about that? It's obvious." The Ransburg brothers, who were not technically trained, wanted to know what all the excitement was about.

A few years after that meeting—after my Beta Electric days—I was hired by Ransburg as a consultant in a lawsuit. Ransburg was suing a fat slob World War II surplus-equipment dealer who was building and selling electrostatic painting equipment. The equipment was an obvious infringement on the Ransburg patents. The defendant said his equipment was not an infringement, because Ransburg used a rotating cone at high voltage to charge the paint and generate paint droplets. The defendant said he distributed the paint from a rotating flat disk and the droplets were formed by centrifugal force, not electrostatic force. I vaguely remembered a "problem for the student" at the end of some chapter in Smythe's *Static and Dynamic Electricity*, referring to static effects at the edges of a rotating disk. El slobbo was all wet. I discussed this with the Ransburg team, and we decided to hold it in abeyance, as it was sort of advanced static electricity theory, equations galore. It was not necessary to use it. The judge directed the defendant to pay up. Of course, if I had used this ace in the hole, this would have been another feather in Caltech's cap.

My further contribution to the electrostatic painting industry was building several air-insulated 200-kilovolt units for Ford. The first-place one was used at the Ford assembly plant in New Jersey for the Edsel. It was not *my* power supplies that made the front grille look like a horse collar, a toilet seat, or a female unmentionable. There are great stories about the man in charge of the Edsel program, which cost Ford $250 million. He was fired—or allowed to resign—and went to Raytheon. There he managed to lose almost $1 billion. I stopped following his career after that.

GOODSTEIN: OK. Back to Caltech. Any memories of Ira Sprague Bowen?

WOUK: Ira Bowen! Now, what did I have to do with Ira Bowen? Since I had this optics credit on my escutcheon, and it hadn't been spoiled yet by someone realizing that I couldn't count it twice—I never thought of it at all, except at the challenge of my thesis. So he's there and he said, "I don't know what to ask you about optics. So I'll give you a question in electron optics." He asked, "How would you measure the mass of an electron?" I said, "I would accelerate up to some reasonable speed—a few hundred thousand, preferably more, volts in a magnetic field. And I would get a deflection that is a function of *E* over *M*"—*M* is the mass; *E* is the charge—"and the greater the mass, the less the deflection." And I went on, "Now there was a very ingenious experiment performed to measure the charge of the electron, but the problems might be pretty daunting. If you want to accelerate, you must know its energy. You have to know the strength of the magnetic field. But once you've measured all of those, *pow!*" He said, "You are right." Next question, from somebody else. I assure you that Professor Millikan did not object to this answer. [Laughter]

Now there's one other thing about Professor Millikan. When I went to see him—his office overlooked the Olive Walk. He was in Throop Hall, when you climbed up the steps of the first level. And he said, "Are you married?"

"Yes, sir."

"Do you walk with your wife on the Olive Walk?"

And the answer was yes, because we had quite a lot of privileges. We ate lunch at the Athenaeum—at least, mine was paid for; I don't remember whether hers was paid. And he said, "Then you're the husband of that very beautiful young woman."

Next question…and we went on from there.

Now, do you folks know about the two lithographs he had in his two offices? He had a secretary to the secretary.

GOODSTEIN: He had two secretaries?

WOUK: Yes, almost like in the movie industry, where if you want to see a boss, you've got to go from secretary to secretary.

GOODSTEIN: I knew that he had one secretary, named Inga Howard.

WOUK: Well, the first one, when you entered, may not have been the secretary. But anyway, here there was an old lithograph entitled "Early Experiments with the Physics of Air." And there was a picture of someone having air blown into his mouth and coming out of his buttocks.

GOODSTEIN: Oh, this is a very famous lithograph! And Millikan had it?

WOUK: He had it in his office.

GOODSTEIN: Did he? I believe that was a demonstration at the Royal Institution. And all the people watching the demonstration are very well known.

WOUK: Coming out from the rear, and the poor fellow trying to get his trousers up. I didn't know that it was supposed to be at the Royal Institution.

GOODSTEIN: And I can tell you who bought that lithograph. Earnest Watson was a collector of prints in the history of science, so he had obviously—I'm guessing, but he may have offered it to Millikan. But Millikan obviously had a sense of humor, then.

WOUK: Oh, yes. And we forgot to talk about the Watson lectures. There were lectures of this nature in my time. Were they also called Watson lectures? Or he gave them?

GOODSTEIN: They're named after him today. They started in 201 East Bridge. He pioneered them—that concept—and they were then called, I think, the Friday Night Lecture Demonstrations. Open to the public. Did you go to any of them?

WOUK: Yes, I went to several of them. I went to hear Watson himself, because his big demonstration was the effect of liquid nitrogen on things. I also went to one by Lindvall. If you hadn't asked me, I wouldn't have been able to think of this. He would talk about electricity and some of the cute things you can do with electricity. His biggest eyebrow raiser was to demonstrate the effects of eddy currents and how they can dampen oscillations. He would have a pendulum with an aluminum square at the bottom, and it would go swinging through an electromagnet. At first, the magnet was not energized, and then he would energize the magnet. And instead of going like this, when the pendulum, swinging from the top, would come near the magnet and enter the magnetic field, it would suddenly stop, because currents were being generated. The currents flowing through the metal would heat up the metal and all that energy would be absorbed in heat. It would not stop a hundred percent, but it would slow down quite a bit and it might or might not get past the electromagnet. But it was a pretty darn good demonstration. I'm trying to remember if he then demonstrated with a different pendulum—instead of being solid aluminum, it would have been made of barred aluminum.

GOODSTEIN: That would make a difference?

WOUK: That would make a substantial difference, because the currents couldn't flow around in the direction they had to flow in order to stop the pendulum swinging. There would still be some decelerating effect but not as big as the first one. I have to admit I don't remember many of the other experiments.

GOODSTEIN: Fred Lindvall was a good demonstrator?

WOUK: Excellent. His personality was wonderful. He had this very pleasant voice. He never talked down, under any circumstances. As a matter of fact, I never heard anyone at Caltech in an academic position talk down to any student. This was not the case at Columbia.

GOODSTEIN: I was going to ask you about the differences—how you would contrast those two institutions of higher learning.

WOUK: I would say that at Caltech the faculty wanted the students to learn and possibly be better than their professors eventually. At Columbia, there may have been some professors who wanted you to learn, but there were very few who wanted you to be smarter than they were. I can mention specifics, such as, in the final exam of one course—optics, the one for which I got all that nice credit—the professor, Professor Farwell, gave what was to me the first final exam ever in true-or- false. And when I left, I thought I had all the questions correctly. One or two I was uncertain about. And by the way, this was something that was a god-given ability—I have several god-given abilities; none of them are very important. Number one is my sense of direction. Number two was the ability to know how I had done on any exam. Back to the exam for Professor Farwell. Instead of having an A-, which would have been the worst, I had a B+. So I went to see Professor Farwell. I said, "Gosh, the only ones that I knew that were possibly wrong were these two." And he looks at it, and says… [Tape ends]

Begin Tape 3, Side 1

GOODSTEIN: So, we're now talking about your getting a B+ on the true-or-false test, and you've gone to see the professor.

WOUK: Correct. So he showed me the question where he thought I was wrong. And the question was of the following type: True/false: "All roads do not lead to Rome." Well, that's not true; what they really meant to say was, "Not all roads lead to Rome." This particular question had to do with birefringents. So I pointed this Rome analogy out to him. I said the answer was "false." So he said, "What do you mean, false? You know very well that there are some roads that go over here and some go over there." I said, "Yes, sir, I know that. But that's not what the question said." Then I said, "This is not a course in English, sir. It's supposed to be optics." So he looked at me and said, "Oh, you're right. I'm changing the grade to A-."

That was not the end of it. A few weeks later, very much towards the end of the year and at the end of my time at Columbia, one of my very good friends comes up to me and says, "Vic, why is Professor Farwell so mad at you?"

I said, "What do you mean, he's mad at me? How do you know?"

"He's chairman of the Phi Beta Kappa committee. And all of us junior Phi Betes, when your name came up, we all said, 'Absolutely,' and even the instructors said 'Absolutely.' And

Farwell says, 'Absolutely not.' Why not? 'Well, look. He got a C in Freshman hygiene.'" So, he got even.

Many years later—it might have been twenty years later, I don't remember where I was; I don't remember the circumstances under which this happened—some professor at a respected university asked me a similar question: "Hey, how come you weren't Phi Bete?" And I said, "Well, Professor Farwell was head of it." He said, "Farwell? You had that Fartwell guy?" [Laughter] So, there's the story. You'll have to clean that up!

GOODSTEIN: [Laughter] So, at Caltech, did you have the feeling that the instructors, the professors, treated the students as colleagues?

WOUK: Absolutely as equals—just inexperienced equals, not having lived long enough to know this, that, or the other thing. But there was great respect for the students, and usually the students reciprocated.

I may have been too harsh on the Columbia faculty: There indeed *were* some nice men in the math and physics departments. In the humanities courses I took, I was teacher's pet in Music Appreciation and The Symphony. I met the professor for those courses, Douglas Moore, at the Pasadena Playhouse in the 1940-41 year. He remembered me as the student who introduced *him* to the Organ Symphony of Saint-Saens. I also got along with well with the professor in my French courses, which included plays by Moliere, Corneille, and Racine. Greek Drama and Its Influences was a breeze for me—I was the first engineering student to take the course. I got along very well with the professor.

GOODSTEIN: OK! So I think we've come to the end of the Caltech era. Are there any questions? Is there some subject I should have brought up that you wanted to talk about?

WOUK: Well, I don't know whether this belongs at Caltech, but it has to do with Caltech. Have I ever told you the story about Professor [Frederick] Terman at Stanford?

GOODSTEIN: No.

WOUK: My friend Walter Shenson, with whom I drove across the country in 1939, lived in San Francisco and he was a student at Stanford. So after our trip out, I stayed with him in San Francisco for a while. And he said one day, "Let's go down to Palo Alto; I'd like to show you the campus." And I said, "While we're there, I'd like to see Professor Terman"—who had written *the* text on radio engineering. So we called and got through to Professor Terman. He was going to be there the day I was going down, and he'd certainly be very glad to see me. Walter shows me around the campus—very beautiful. We're going through the engineering building and we go to Professor Terman's office. I went in and sat down. Walter stood in the doorway there. And I thought it was going to be a fast "Hello, sir. I admire the book very much. This is going to help me," and that would be the end of it. He said, "You're going to Caltech?"

"Yes, sir."

"Graduate work?"

"Yes, sir."

"Radio engineering?"

"Yes, sir."

"Why do you want to go there? We have a much better radio engineering department here." Which was true. "Professor MacKeown is a great man, but that's not the department. Caltech is high-voltage, you know, and we here are high-power radio."

So I said, "Well, I applied to Caltech."

He said, "You don't *have* to go there, do you?"

"I like Caltech."

"But if you're interested in radio engineering, you should really come here."

"Well, I don't know what to say, sir."

"What kind of grades did you get?"

I said, "Well, in engineering and physics and math, all A's; others B's mainly."

"So, mathematics? What was your last course?"

I said, "Mathematics, that was theory of functions."

"And you got an A in that?"

"Yes."

"Who was your professor?"

"Professor [name unclear]."

"That tough old SOB? You got an A from him?"

"Yes, sir, an A."

"Well, I'll tell you what," Terman says. "We need a graduate student here in our department. You can have the graduate student's fellowship. It'll be tuition and some board, and a few things like that. Won't cost you a cent. We'd like to have you here."

Well, I'm stuttering; I don't know what to say. And poor Walter, he's standing in the doorway with his mouth open, wondering, What the hell's going on here? I finally thought of an argument that Terman couldn't overcome, and that was that I had shipped all of my things from New York to Long Beach, American Express. Five dollars for the truck from New York, through the [Panama] Canal. So that was my answer. I said, "Sir, everything is down there. While I'm there, I might as well stay."

GOODSTEIN: Did you ever have any regrets?

WOUK: Oh, absolutely not! Not that Stanford would not have been an excellent experience. But again, the great attraction for me about Caltech—the school is small. I'm not the only one who has said that. So there's my story of me and Stanford.

GOODSTEIN: When you went to Caltech as a graduate student, even that part of Caltech was small.

WOUK: Yes, there were maybe five other graduate students in electrical engineering.

GOODSTEIN: Everyone knew you right away.

WOUK: Yes. That was marvelous.

GOODSTEIN: Did all the electrical engineering professors do research in the way that we understand research?

WOUK: No, none of them was doing that kind of work. There were no facilities. The only research possibility was in the field of high voltage. So there, there was activity. I wouldn't say they were doing research. It was testing existing equipment, to see if it met specifications.

GOODSTEIN: You were fortunate to have a good idea—and that Mackeown got the grant. And you actually went out and did your field work.

WOUK: Yes, in and around Pasadena.

GOODSTEIN: OK. So I think we should now move on. I'm going to make an abrupt jump—even in decades—and let's move on to hybrid electrical vehicles and your interest in them and how it all got started.

WOUK: I recommended that you read a paper or two of mine. Did you have a chance?

GOODSTEIN: I read that one [pointing to a paper].

WOUK: You didn't read "Electric and Hybrid Vehicle Technology, 1995"?

GOODSTEIN: I did not, I confess. But what I did read are some documents from 1975 and '76. Actually, there is a document here—a proposal to the EPA [Environmental Protection Agency] dated January '71 signed by you and Charlie Rosen [VW's partner in Petro-Electric Motors]. And then there is your company's—Petro-Electric Motors'—hybrid vehicle under the Federal Clean Car Incentive Program. I was most intrigued by a letter you wrote to Eric Stork [then deputy assistant administrator of the EPA's Mobile Source Air Pollution Control] but never sent, and at some point I'd like to know why you decided not to send it. That's in '75. But now we're getting ahead of the game. So, where do you think the story begins?

WOUK: It begins in 1962 or '63. That was when I formed Electronic Energy Conversion Corporation. This also goes back to California and a company in San Diego that was anxious to take advantage of a big boom in the stock market for anything that had the word "electronics" in

it. I had sold my first company, Beta Electric, to Sorenson & Company [in 1956], and a few years later, I was approached by people from a company called Electronics Capital Corporation in San Diego. One of the men from Electronics Capital, who had had his electronics business and sold it and wanted to grow with the electronics industry, came to me and said, "Hey Vic, I'm sure you have some good ideas about improving some of the equipment you make." At that time, most of the equipment was at Sorenson—I had become chief engineer there. Sorenson's business was mainly high-power, low-voltage electronic equipment. Frequency changes—AC to AC, and rectifiers, AC to DC.

So there I was, chief engineer. I wasn't very happy at Sorenson. I told this Electronics Capital man what I would like to do—this idea about so-called off-the-shelf DC power supplies. One night when I was up in Pittsfield, Massachusetts, where I had gone with Joy and some other friends for a weekend, I thought, "Lo and behold, let's take the AC from the line and rectify it right away, get DC!" Therefore you could transform it up and down at a much higher frequency if you so wished. You put in systems that generate AC, but at high frequency, so that the transformer will be smaller and the filtering circuits will be smaller.

I made this proposal to the Electronics Capital Corporation and they thought it was great. The qualified people looked over the idea, and there was absolutely nothing to vitiate my technical reasoning. The only question would be whether it would be low-cost enough, because I would be using a lot of semiconductors.

Well, I got the funds. By then, I was in a position to start building breadboards to see if the concept worked. Even before I started building breadboards, I wanted to be sure that the idea of turning the DC on and then off, then on, then off—at high frequency—would work. What I was looking for was a good calibrated oscilloscope, a good pulse generator, waveform generator, and a good electronic voltmeter. So I either called or wrote a letter to Dave Packard [at Hewlett-Packard] and told him what I wanted. He said, "Vic, no problem. You know the people now handling us in New York City. Tell Bob what you've asked of me, and he should get it." And I did.

I got the test equipment. And lo and behold, everything I predicted came to pass—constant peak voltage, if you change the pulse width, the [words unclear] would go up. OK, so now I needed more room to work. Joy had found a place for me on Madison Avenue—342 Madison Avenue—where I had my office and the first little experimental lab, and then some

more space became available on that floor, and that's where I did all the experimental work. This was all for lower weight, smaller size, higher efficiency AC-DC equipment. I had one very, very smart fellow working for me as a circuit designer.

Now we get to about 1963. This DC power supply had been technically demonstrated. We had been in one of the electronics exhibits on the West Coast. We demonstrated it; it all looked very, very good, and we sold a reasonable number of these to IBM and other people for experimentation.

And then in 1962, a man named Russell Feldman called me and said, "I'd like to talk to you about electric cars." Very interesting! Well, Russell Feldman was one of the founders of Motorola, so he was pretty well-heeled. And he came to see me and said, "Electric cars are going to be necessary. The air pollution is terrible. I bought thirty Renault Dauphines, took out the engines and everything else. I put in batteries and an electric motor and a speed control, which consists of a bunch of relays, and it would go *clickety-clack-clack* as you went up to speed."

Well, it couldn't go very far and it couldn't go very fast with the design he had, and some of his Wall Street colleagues had said, "Hey, there's a company being financed by Electronics Capital Corporation and they have invented a new device that can be used for speed control, lots more efficient than what you've got. You ought to see them." So he came up to see me, told me the situation. And I said, "Oh, sounds exciting. I'd like to drive some of your vehicles and see what the problem is."

So I went up to his estate in Connecticut—a big fancy estate. And there were these cars, which I drove around on the private estate. My son Jordan could drive them around—I think he was twelve years old then. And he said, "Pop, this is so easy!" I made a couple of very simple measurements and I wrote a report for Mr. Feldman saying I could build a speed control for his car, but it would not save that much energy. It wasn't the energy wasted in the speed control, it was just that the batteries didn't have enough energy to take the car far or fast. I said I would be very glad to build him an experimental vehicle and it might cost $75,000.

So he came back and said, "What you tell me about batteries not having enough energy—is that inherent in all batteries? In which case, I shouldn't waste my time. Or can there be better batteries?" So that's when I dragged in Linus Pauling. I said, "I don't know the answer, but maybe Linus Pauling can give you the answer." I wrote to [Caltech president Lee A.] DuBridge,

and told him the story and said, “How about asking Pauling?” About two months later—maybe less—I get a very nice letter from Lee [DuBridge]. “Dear Victor, your letter intrigued me. No end to the possibilities.” Instead of speaking to Linus, he had called a sort of informal seminar on the subject—chemical engineers, electrical engineers, physicists—and come to the conclusion that there are electrochemical couples that have as much or more energy density as [the lead battery]. Usually, though, they are very sophisticated systems—high temperature, very corrosive materials, and so on and so forth.

So two things would have to happen: There would have to be a demand for the performance, and the performance would have to be made available on a commercial scale. That left out electric cars. So I told that to Russell Feldman, and [he said], “Thank you very much. I’ll forget about it.” Which he did—except he then sold the vehicles. There may be some around with probably the same lead batteries but modified to give a higher speed and undoubtedly an electronic control, because Curtis Instruments, a company for which I did consulting for about four years, built the speed controllers on basically my principle—but no one was interested.

Then along comes air pollution, a very serious problem. And our good friend at Caltech, Arie Haagen-Smit, had proved that the smog in Los Angeles was a function of gasoline exhaust and not chemical plants or refineries, which was originally thought. So we had to cut down the air pollution and therefore electric cars should be a big thing.

Just a little before that, I had sold the Electronic Energy Conversion Corporation to Gulton Industries, a company that was making nickel-cadmium batteries and had a subsidiary in California making power supplies based on the principle of what I call the convertron—putting in AC, changing it to DC, and then chopping it up at high frequency. So Gulton bought my company—I was very happy with that. The Electronic Energy Conversion Corporation was now a subsidiary of Gulton, operating out of 342 Madison.

Then one day Dr. Gulton calls everybody in—the section managers, and I was head of electronic research—and he said, “I want more applications for nickel-cadmium batteries that we are now building for the air force.” They use those in each jet plane, because the instantaneous power that can be drawn from them—much higher than lead batteries—would get the engine started again.

So at the meeting I said, “Oh, Dr. Gulton, maybe electric cars would be a good application.”

“Why?”

“Well, you can get much more current, so the cars need not be sluggish.” This had been the *big* objection. People would say, “Well, I don’t care about the range, but they’re sluggish.” And Gulton said, “Fine idea—start working on it.”

I thought about it and realized that if we’re going to get some performance and the vehicle is going to be quasi-experimental, I want a big car—a station wagon. And Gulton wanted a tie-in with some automobile company in Detroit. Well, we couldn’t do it with GM—GM had their own program. Couldn’t do it with Ford—Ford had their own program. Same problem with Chrysler. But American Motors was getting into a lot of trouble in those days. And after some negotiation, a contract was drawn between Gulton and American Motors. Gulton Industries would develop a new battery based on lithium and using my speed controller: a wonderful car.

Fig. 4. Wouk explains to Congressman Edward Patten the function of the nickel-cadmium batteries in the power system of the Gulton-American Motors electric car in November 1969. Caltech Archives.

GOODSTEIN: What brand of car?

WOUK: This was an American Motors station wagon. So I put a lot of batteries in the back, put other things in the back, and you could still have at least two people up front and three people behind. I began to build this machine, because I liked the idea and there was this great potential.

Then along came the Clean Air Act of 1970.

GOODSTEIN: How long had you been building this car?

WOUK: I started building the car in about 1967. That is, I set up breadboards of a speed controller and this and that and the other thing. I had to go through a lot of stages, testing things that were absolutely new.

But then in 1968, Washington began to legislate—and California already had legislated—emission limits on vehicles. So everyone already immediately thought of electric cars. And I had to go to various people to disabuse them: "It isn't the smart controls, it isn't this, that, and the other thing, it's the battery. Until we multiply the battery capacity by at least a factor of three, and preferably eight, we'll be no competition [for conventional cars]." And I would be told, "Oh, you don't have any faith. It's got to be all electric."

I was actually being accused of being anti-electric-car! I'd say, "It's not that I don't want electric cars, I want cars that will work." [And they would say,] "If it's a hybrid, you've still got an internal combustion engine. You're going to have some emissions. We don't like the idea."

So along came the Clean Air Act, which was passed in 1970, requiring that by 1976 emissions be reduced by a factor of ninety-five percent. And I can interject here that at one time, while Dr. DuBridge was still the science advisor to President [Richard M.] Nixon, he was following my program, because I let him know what was going on. Oh, and of course the business with the battery. I told Dr. DuBridge about this, and he thought that was a great idea, that the hybrid is wonderful. And he said, "Victor, do you know why the pollution regulations require ninety-five percent reduction and not eighty percent or ninety-nine percent?"

I said I had no idea.

"Were you ever in California in the 1930s?"

And I said, “Yes, I went to summer school in 1937.”

“Where were you?”

“UCLA.”

“Oh, then you will remember that on a clear day, you could see Catalina.”

“Yes, sir.”

“And you could see it rather often.”

“Yes, sir.”

He said, “Well, we made the specifications on the basis of some computations as to how much would we have to reduce current pollution to get down to where we could see Catalina. So, the number of cars has increased, the mileage they’ve gone has increased, [and] when you put the two together, it turns out that there are maybe twenty times as many sources of pollution than in 1937 from cars. So we want to reduce emissions ninety-five percent.” That’s the interpolation.

So I spoke to several organizations about hybrids, and nobody was interested. By this time, Dr. Gulton was no longer involved with Gulton Industries. He’d retired; some other fellow was involved, who wanted nothing to do with hybrids because there was no government program for hybrids.

GOODSTEIN: No source of funding.

WOUK: Exactly. So then all of a sudden we hear about the Federal Clean Car Incentive Program, which was initiated in 1970. I forget how I heard of it; maybe Charlie Rosen heard of it first, because he and I worked on the electric car also. He was a chemical engineer and a chemical researcher at Gulton.

GOODSTEIN: Oh, is that how you met Charlie Rosen?

WOUK: That’s where we met. Now, for some reason I had been out in Ann Arbor several times and I knew the EPA people who were going to run this program. And they said, “Hey, Vic, let’s talk about your hybrid car, how about proposing.

GOODSTEIN: Were you the first to propose the name "hybrid vehicle"?

WOUK: No. Some of the early cars in the early 1900s would be referred to as "dual powered," and I think "hybrid" was in one of the early patents, the word "hybrid."

GOODSTEIN: And those early cars, when you speak of dual power, what were the two sources of power?

WOUK: Same thing—batteries and internal combustion engine. There had been some studies, underwritten by some program or federal agency or other, by Aerospace Corporation, in the LA area. They had a contract to study all types of hybrid. And I knew the president of Aerospace Corporation, Ivan Getting. So he and I communicated. I said "I'd like to get more information," and arrangements were made. I went to see him and got the information. And lo and behold, they more or less agreed with what I had been thinking—that the hybrid *could* do this, cut down emissions, cut down fuel usage. So I went to the president of Gulton and said I'd like to bid on this. And again, for various reasons much too complicated to discuss here—but basically it was the fact that we did not get the contract for the 42nd Street Electric Bus Program, and the new president had wanted that very badly. We were not even allowed to think about the Federal Clean Car Incentive Program, number one, and even if we did, it would not be hybrid.

So, Charlie and I decided, well, we're not going to work on the DC sources [anymore]. We want to work on a car, which Charlie and I were confident would at least meet the specifications. So Gulton said, "OK, goodbye, thank you very much," and I had to start a new company. I didn't know quite what to call it. Herman [VW's brother] came up with the idea. He said, "You use petroleum, you use electric—so, Petro-Electric Motors. And 'Ltd'—Limited, which makes it sound very fancy." So Charlie and I worked on the proposal [for the FCCIP]. It took us about almost a year. And we prepared this and bid. And there's a story about the bid.

It was due in Washington at 10:00 a.m. the next morning, or whatever it was. I did not have a Xerox machine, but I did have a Thermofax machine. We had to make eight copies, nine copies, and the bid was pretty thick—I think it was about thirty pages. So I got a pile of Thermofaxes this high. And we needed extra people. I called up the 92nd Street Y, where I was still on the board of governors, and spoke to the man in charge and said, "Look, please get two

bright residents, male, female—I don't care what. Tell them we'll pay them so much an hour, to begin at 6:00 p.m., and it may go as late as 12:00 p.m." So we did exactly that. But after about an hour, I get a buzz from my secretary: "Dr. Wouk, we can't make any more prints."

"What do you mean you can't make any more prints?"

"They all come out black!"

I go in and put my hand on the machine and it was very hot—the Thermofax was never designed to be a continuous operating system. But it was wintertime, and it was very cold out, and the Thermofax machine was near a window. So I opened the window and said, "Let's wait five minutes." We ran something through—perfect! So, a little piece of ingenuity. And Charlie was able to fly down the next morning and deliver it in person—on time and the correct number. What we were asking for was the privilege of building this vehicle at our own expense and having it tested at our own expense, to prove that it would beat the 1976 requirements on emissions.

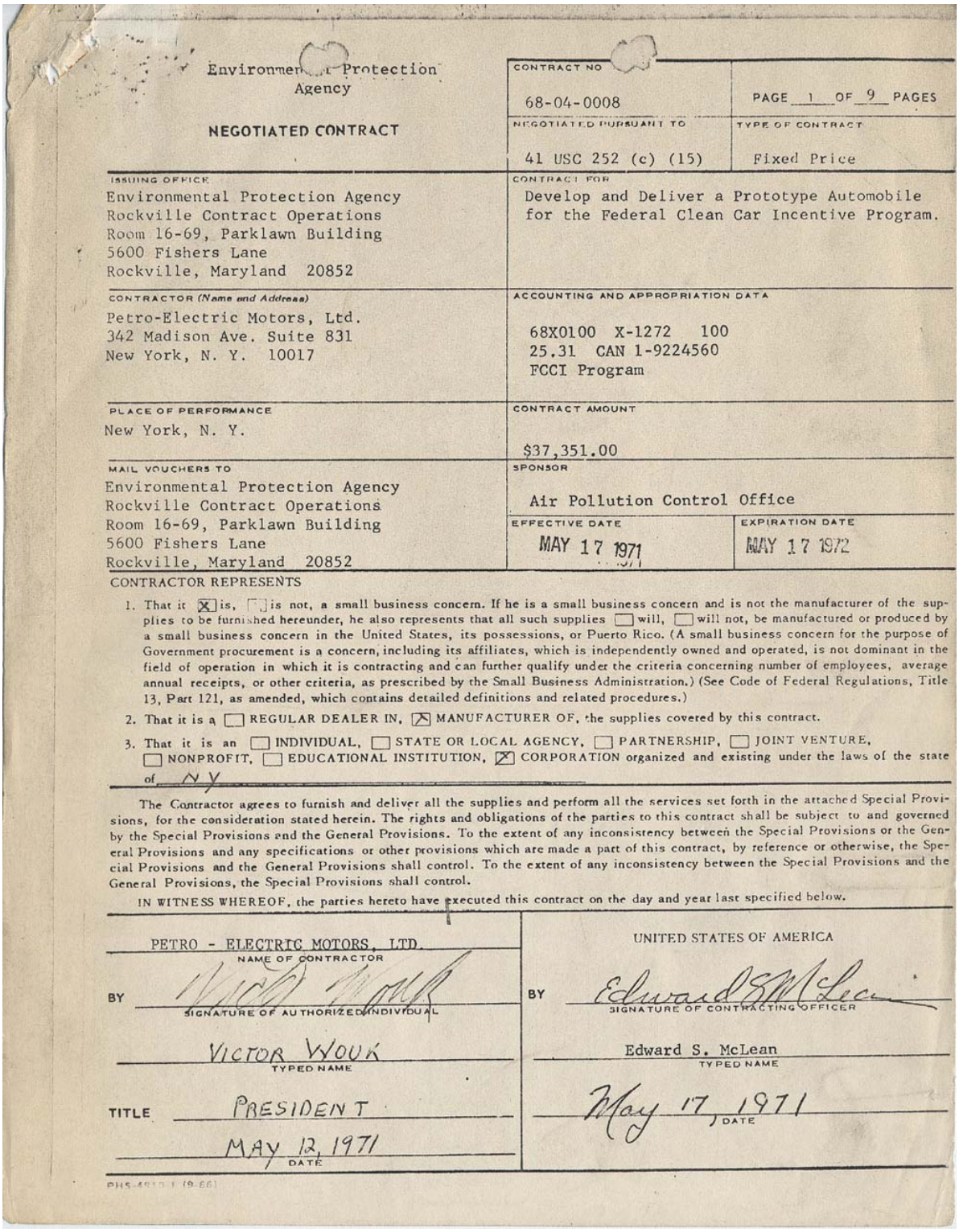
What [the EPA] would do is, after we had called them in and said, "Hey, this meets the specs as indicated by a test at such-and-such a lab," which was certified, they would give us one dollar for having made the preparation and bid. And when they're finished with the tests, they'll give us $30,000.

GOODSTEIN: But all of the R&D is on your nickel?

WOUK: Correct. Now, where's our incentive? The incentive is that if the vehicle really works, they'll then order ten of them at a price, which might write off most of your R&D. No guarantee, but it might: "And we'll test them, and if after a year they are still low emissions, low fuel users, we will order 350 for testing throughout the country. And as a *real* incentive, you will be allowed to be paid twice the mandated price that the government could pay for an automobile." My real incentive was mainly to prove the damn thing worked. After that, we wanted to be able to move ahead, let someone buy us out, and I'd get out of it.

So we sent the proposal in, and I forget how long it was—two months, three months—before we get a phone call and a letter, saying, "We like your proposal. Very interesting. Technically feasible. You are hereby given the contract. Get started."

There were six other vehicles in the program. There was our hybrid, one electric car, one diesel, one with a simple exhaust filter.



Environmental Protection Agency

NEGOTIATED CONTRACT

CONTRACT NO: 68-04-0008 | PAGE 1 OF 9 PAGES

NEGOTIATED PURSUANT TO: 41 USC 252 (c) (15) | TYPE OF CONTRACT: Fixed Price

ISSUING OFFICE:
Environmental Protection Agency
Rockville Contract Operations
Room 16-69, Parklawn Building
5600 Fishers Lane
Rockville, Maryland 20852

CONTRACT FOR:
Develop and Deliver a Prototype Automobile for the Federal Clean Car Incentive Program.

CONTRACTOR (Name and Address):
Petro-Electric Motors, Ltd.
342 Madison Ave. Suite 831
New York, N. Y. 10017

ACCOUNTING AND APPROPRIATION DATA:
68X0100 X-1272 100
25.31 CAN 1-9224560
FCCI Program

PLACE OF PERFORMANCE: New York, N. Y.

CONTRACT AMOUNT: $37,351.00

MAIL VOUCHERS TO:
Environmental Protection Agency
Rockville Contract Operations
Room 16-69, Parklawn Building
5600 Fishers Lane
Rockville, Maryland 20852

SPONSOR: Air Pollution Control Office

EFFECTIVE DATE: MAY 17 1971 | EXPIRATION DATE: MAY 17 1972

CONTRACTOR REPRESENTS

1. That it [X] is, [ ] is not, a small business concern. If he is a small business concern and is not the manufacturer of the supplies to be furnished hereunder, he also represents that all such supplies [ ] will, [ ] will not, be manufactured or produced by a small business concern in the United States, its possessions, or Puerto Rico. (A small business concern for the purpose of Government procurement is a concern, including its affiliates, which is independently owned and operated, is not dominant in the field of operation in which it is contracting and can further qualify under the criteria concerning number of employees, average annual receipts, or other criteria, as prescribed by the Small Business Administration.) (See Code of Federal Regulations, Title 13, Part 121, as amended, which contains detailed definitions and related procedures.)
2. That it is a [ ] REGULAR DEALER IN, [X] MANUFACTURER OF, the supplies covered by this contract.
3. That it is an [ ] INDIVIDUAL, [ ] STATE OR LOCAL AGENCY, [ ] PARTNERSHIP, [ ] JOINT VENTURE, [ ] NONPROFIT, [ ] EDUCATIONAL INSTITUTION, [X] CORPORATION organized and existing under the laws of the state of NY

The Contractor agrees to furnish and deliver all the supplies and perform all the services set forth in the attached Special Provisions, for the consideration stated herein. The rights and obligations of the parties to this contract shall be subject to and governed by the Special Provisions and the General Provisions. To the extent of any inconsistency between the Special Provisions or the General Provisions and any specifications or other provisions which are made a part of this contract, by reference or otherwise, the Special Provisions and the General Provisions shall control. To the extent of any inconsistency between the Special Provisions and the General Provisions, the Special Provisions shall control.

IN WITNESS WHEREOF, the parties hereto have executed this contract on the day and year last specified below.

PETRO - ELECTRIC MOTORS, LTD.
NAME OF CONTRACTOR

BY Victor Wouk
SIGNATURE OF AUTHORIZED INDIVIDUAL

VICTOR WOUK
TYPED NAME

TITLE PRESIDENT

MAY 12, 1971
DATE

UNITED STATES OF AMERICA

BY Edward S. McLean
SIGNATURE OF CONTRACTING OFFICER

Edward S. McLean
TYPED NAME

May 17, 1971
DATE

PHS-4010-1 (9-66)

Fig. 5. Petro-Electric Motors, a Victor Wouk company, received its first EPA contract to build a hybrid vehicle in May 1971. Caltech Archives.

GOODSTEIN: You're the only hybrid?

WOUK: We're the only hybrid. And we start building it. It was a long, uphill struggle because I'm not an automotive engineer nor is Dr. Rosen. Charlie Rosen is a thermodynamicist, got his PhD in thermodynamics engineering at what was then Brooklyn Poly, now just Polytechnical Institute. We divided the work—I would be doing all the electronics; he would be doing the emissions reduction. When we had a vehicle pasted together—again due to stuff that I'll discuss later—there was a Professor Smith at the University of Michigan, in Ann Arbor, whom I knew very well, who was familiar with my background on electric cars and who liked the idea of hybrids. So he spoke to the chairman of the automotive engineering department, Professor David Cole. And by the way, at present Cole is head of the Center for Automotive Research, which studies the automotive industry throughout the world—a very highly respected man. Smith got permission for us to bring a car out to Ann Arbor to do the final tuning up of the engine and the electronics and everything, so that we would have a working vehicle, with low emissions, and it would be up to the two of us back in New York to tweak everything so that we really get the best out of it. We did that, and … [tape ends]

Begin Tape 4, Side 1

GOODSTEIN: We're in the middle of the development and the tweaking of the hybrid car.

WOUK: Correct. Now, again, I will interpolate. I did say that we took the car from New York to Ann Arbor by truck. And then we tweaked the car, back in New York. How did we get the car *back* to New York? This is now 1973, and there was going to be a hearing in Washington about some new legislation about emissions and fuel economy. I was planning to drive the car, with Charlie, from Ann Arbor to Washington. We had driven it quite a bit before, and it worked. People ask, "What was the top speed?" I say, "I never went over eighty-five miles an hour," because there was some rattling. The car was not assembled the way they would do it at GM.

GOODSTEIN: And what kind of a car was this, now?

WOUK: This was a 1972 Buick Skylark.

GOODSTEIN: Who provided the car? Did you buy it?

WOUK: The car was provided by General Motors—a Buick Skylark. Once we got our contract, I went looking around for the car I wanted. I went to various showrooms in New York. I looked under the hoods. The Buick Skylark seemed to have the most volume under the hood. And not knowing exactly how much [space] we were going to need, I wanted a car with the largest volume under the hood, and it was a Buick Skylark.

So I went to a dealer and said I wanted a Buick Skylark. And he said, "Very sorry, but the one here is already sold."

"So how about a new one?"

He said, "I don't know. The line is closed." So I had to send a letter to the head of the GM Technical Center, in Warren, Michigan, a magnificent R&D park. Now, how do I know him? I knew him because I was on a panel with him at the American Bar Association building in Manhattan, discussing low-pollution cars. Eric Stork was on the panel. And when it was all over, the GM executive came to me and said, "I certainly appreciate what you said about electric cars being extremely limited and that's why you're talking about the hybrid. Most people involved will not admit the serious hurdles that have to be overcome." So that's how I knew him.

So when I explained this situation to him—that I wanted a Buick Skylark and there were none to be had in the country, they'd all been sold out—I got a telephone call or letter saying, "Let me investigate this." And about two weeks later, I get a telephone call from a Buick manager in New York saying, "I don't know what's going on here, but I've been told that I'm going to be getting a Buick Skylark, and it's for you. But you have to buy it; it's not being given to you for nothing." It was $2,700, in those days. Obviously the reason for their not giving it to us is because it would mean they were neutral, they're just helping out some young fellows with some cute ideas.

So we're now driving from Ann Arbor to Washington. And it snowed. The meeting in Washington was, I think, to be on a Monday, and there was the biggest snowstorm in the history of Ann Arbor. It was three feet deep outside of our Holiday Inn, and all that sort of jazz. *Uff!* The roads had not been cleared yet. So, soon it's two days before the congressional hearing at

which I was going to testify, and the roads are still impassable. So I look in the phonebook for aviation freight. I call them up and tell them what I want to do. And they say, "Yes, we'll do it. You'll have to bring the car to us. It's not very fancy. You'll be sort of cold where you're sitting."

Charlie Rosen told this to Professor Cole. Charlie told me that when he reported that we were going to take the car back on a plane, Cole said, "Holy smoke! Wouk must be independently wealthy." And Charlie said, "He was until we started this program." [Laughter] Professor Cole was very impressed with the concept of the hybrid. And what with that, then we were able to tune it up, it worked very well. There were a few problems we had, and they helped us out.

GOODSTEIN: And you put the car on the plane?

WOUK: On the plane. They winched it up, of course. And we flew to National [Airport] in Washington and took the car off and drove it to the hotel where we were staying. I gave my testimony, and we showed the car to a lot of people, who were very impressed, and we drove it back to New York. No problem at all. And there we were given the run of the labs in Brooklyn—the Clean Air Department of New York City had this very good car-testing laboratory in Brooklyn. You could get on a dynamometer, you could do all sorts of things; they measured the emissions and the fuel economy. And tweaking the car for optimum emissions was a pretty tough thing, because we were using the Wankel engine.

I have to backtrack here. The reason I wanted a Wankel engine is that it was squat for the same amount of horsepower as a conventional piston engine. And as I mentioned, I didn't know how much electronics I would have to put under the hood or how big an electric motor, so I wanted something that was squat, and the Mazda fitted this requirement absolutely beautifully, the Wankel engine. The Mazda had proved to be a sensation on the West Coast, where it was being sold. Because here was this little, small car—a pipsqueak—and if it was up against a Caddy, and they were both stopped at a red light, the Caddy would slam the accelerator all the way down and by the time he took his foot off the accelerator, this pipsqueak would be a half a mile ahead of him. Why? Because it was a small car, lightweight, and had this Wankel engine, which developed twice as much power per unit volume than a conventional car.

So we got the Wankel engine. But you couldn't go to the corner store and buy a Wankel. GM had paid $50 million for some contract with Mazda to do something with the Wankel, and Mazda had some sort of arrangement with Curtiss-Wright to do something with the engine on the East Coast—maybe apply it to propeller-driven planes. So there was a Mazda representative on the East Coast. Now someone who knew Curtiss-Wright very well introduced me and said, "This gentleman would like a Wankel engine." In fact, I made a presentation to the top brass at Curtiss-Wright and they said, "It sounds good. We'll see what Mazda has to say back in Hiroshima."

Three or four weeks later, I got a phone call saying Mazda liked the idea and they were going to send me *two* engines, so if something didn't work well on the first engine…. Well, I'm absolutely flabbergasted, they're sending us two engines! Which they did—complete engines with all the auxiliaries. So here I had this nice squat engine and we were able to put that in the vehicle. Now the only car on the East Coast that was using the Wankel was our Petro-Electric Motors hybrid. When people say the automobile and gasoline companies won't give you the time of day, the answer is, "On the contrary!" They were very interested in what was being developed, because the thing worked. The Wankel engine is still used today, I think, by Mazda on their RX.

So, anyway, we needed to get the operation perfect, and we had use of this enormous lab in New York City, where there were four dynamometers for testing cars and two for testing trucks. So one or the other of the truck [dynamometers] was always available, but the car ones were usually tied up. We had been given the run of the place because the man in charge of the Clean Air Act in New York City—one Brian Ketcham—I had met, because at that time I was one of the founders and active in the Citizens for Clean Air in New York. He liked the idea of a hybrid and he said, "OK, you can have it whenever you want." So, over a period of about two or three months, we were in and out of the labs in Brooklyn. And soon the car was ready to be tested.

We called the EPA in Detroit and said, "We're going to be testing the car. What do you want in the way of certification, so that one of your people from Ann Arbor can come down to see the vehicle and run the tests for us?" And the lab that they would accept, which was in the New York area—it couldn't be the New York City department, because we were New Yorkers; it couldn't be the facilities at, let's say, Mobil Research, because that's a gasoline company. It

had to be an independent lab. The closest independent lab was opposite a big town in New Jersey, on the other side of the Delaware River, in Pennsylvania. We went down there two or three times to have tests made.

GOODSTEIN: Did you drive the car there?

WOUK: That's where I had the eighty-five-miles-per-hour maximum. We would drive the car occasionally, just Charlie and I, and sometimes other people. We went for the tests; all the specs were met. And we called and said we're ready [for someone] to come. He said, "OK, we'll send"—I forget his name, some other Charlie. At that time, the car was garaged in Charlie Rosen's garage, in Teaneck, where he lived, and his sons began pestering this EPA man. "Come on, are you going to say 'OK we'll test'? Or 'Not OK, we won't.'" He couldn't tell them to go jump in a lake, so he said, "Yes." He looked at the data. We took him for a ride. And he said, "Well, when I get back to Ann Arbor, I will report to John Brogan, who's the head of everything."

[It turned out that the] EPA, through Eric Stork, wanted to drop the program.

GOODSTEIN: This was before your car had been tested?

WOUK: Yes, before the car had been tested, before we had even built the final. Meanwhile we were the only ones left who could possibly even be tested.

GOODSTEIN: You were the only people left?

WOUK: Others had dropped out for one reason or another.

GOODSTEIN: And just on principle, he wasn't willing to have it tested?

WOUK: That's right. He thought—and he expressed the opinion—that the function of a government agency is to set standards and regulate, it is not to help a company pass tests and everyone become millionaires. Now, I forget whoever it was, someone on my behalf—well,

more on Herman's behalf—said, "Don't drop it so fast. The vehicle should be tested." And this was more or less the determination at a meeting of the NSF [National Science Foundation] people. Eric Stork, who was in charge of mobile systems emissions for the EPA, and John Brogan, who worked under him, were there, and Herman was there. This was not a secret meeting; it was an open meeting.

GOODSTEIN: Had the NSF formed this committee?

WOUK: There was a committee that had visited us in New York City and I had made a presentation, and they all agreed, "Hey, you know this sounds like a good idea. At least technically, let's start with whether it works, and then we'll determine whether it's economical." And our bid showed how it would be economical under certain circumstances.

Anyway, a meeting was called, and I was asked to give a presentation. And the head of the NSF committee turned to Stork and asked, "Why do you want to drop this? It sounds like a good idea." And Eric Stork said, "Well, I don't know, I guess maybe it's a good idea. We will go through with what we owe. If the thing does what it's supposed to do, we will move ahead. Of course we will conform with the Congress's will."

Anyway, we made arrangements about going out [to Ann Arbor]—this was now something like the middle of January. We might have to do some final tuning up at the University of Michigan, where we were doing the testing. And that's what we did. We brought the car out, drove it on a truck, backed it in, and we began to make some final changes. There were some slipups in the beginning, and it looked as though Wouk's idea was not a very good one. Then I realized what the mistake was. I had the mistake corrected at the university and the car breezed through the tests, except for one thing: Every now and then, there would be a spike of emissions and that would vitiate the entire test. All you needed was a little spike of emissions for one half-second and the average emissions would be above what was allowed. We eventually found out what that problem was, and that was going to require some more tweaking of the emission control. Now, one of the advantages of this Wankel engine is that it had its own catalytic converter—except it wasn't catalytic, it was just thermal. And this is how Mazda got such low emissions with its RX-4. Fuel economy was no problem. Where the car had problems

was with the emissions and so on, and that had to be cured—otherwise we were wasting our time.

I didn't know what to do. Charlie didn't know what to do. But every now and then, Murphy is on your side. About three weeks before we finished testing—and the tests looked good, except for these spikes every now and then—about three weeks before that, people from Ethyl Corporation came with a car. The Ethyl Corporation was about thirty miles away, in Troy, Michigan. They were always coming in with reformulated gas, because "ethyl" means lead—it's tetraethyl lead—and they had to get the lead out or else a hell of a good business was going to be destroyed. So they were working on all sorts of reformulated gasoline and they would come to Ann Arbor every week or so with a newly formulated gas, or whatever it was, and make tests on this particular car. They were having problems. Back at their place, cars worked beautifully—low emissions all along. But here at the EPA lab in Ann Arbor, all of a sudden the emissions were very high.

And they were complaining to someone and said that the spark was terrible, and a few other things were terrible. So someone said, "Go see that guy, Dr. Wouk, over there. He knows electronics." The man [from Ethyl] comes over to me, tells me the story. I say, "OK, let's take a look." I take a look, and the spark is indeed very weak: "You say it was strong back in Troy?"

"Yes, it was very strong."

"Well, then something must have happened between then and now."

"But what?"

"The only thing I can say here is that the coil on the ignition coil has opened up due to a bad contact."

"Well, how do you find that out?"

I said, "Very simple. I've got an ohmmeter here that tests resistance. I'll test the resistance and we'll see where it is." And I tested the resistance, and it was something like 100,000 ohms—which is absurd; it should be maybe 1,000 ohms, and that's why the spark was so weak. And what that means is that there is a little gap someplace that closes when the wires are cold and opens when the wires are hot, and what you needed was a new spark coil. Put in a new spark coil and everything worked perfectly. They were very happy. And the man said to me, "Dr. Wouk, if you ever need my help, call me."

So here we have these little spikes, and we needed help to do something about the emission control. I told him what it was all about. And Charlie Rosen said that what we needed was a richer mixture, which should come down when the vehicle starts running, because otherwise with a richer mixture all the time, the fuel consumption would be too high. So we did that. We spent about a month in and out of the Ethyl labs, and finally we got a beautifully operated thing. We were then getting ready for final tests.

We made the final tests at the EPA in Ann Arbor, and most of them were well within the range. And the question now is: "We'll determine whether you go on to Phase II of the program." So we see the report about a month later from the EPA people as to why we did not meet the specifications. I made a response to it, [saying that] seventy-five items were either wrong, irrelevant, or exaggerated, and if those were taken away, the vehicle should have gone into Phase II.

Fig. 6. Before relations with the EPA start to go downhill, Wouk poses proudly with his 1972 hybrid Buick Skylark at the EPA test site. Caltech Archives.

GOODSTEIN: Were you shocked?

WOUK: No, no. And that is something I'm glad you asked. When we were near the end of our tests at the EPA, we had become very friendly with the engineers who were supervising. There was one who was particularly upset that we were sunk from the very beginning. Eric Stork had come in and said, "Under no circumstances is the hybrid to be accepted."

GOODSTEIN: Eric Stork had said that to the engineer?

WOUK: Yes, before we finished. "Under no circumstances…." Why? Again, he thought that the government should regulate, not make people rich—"If you think you're so smart, build the car and build lots of them and we'll buy them. Don't have us test them."

GOODSTEIN: Didn't you have a contract to do just that?

WOUK: Yes. So the question was in the interpretation of the contract—as to whether we met the requirements. There was a lot of Mickey Mousing, and the record is this thick [showing with hands the thickness] of letters back and forth.

GOODSTEIN: This thick, meaning?

WOUK: Oh, maybe a half an inch. Now the Archives has them. What you don't have is, unfortunately, the smoking gun.

GOODSTEIN: OK, tell us about the smoking gun.

WOUK: When I was shipping the papers to you, I had not sent all of the papers from our home in Westchester, where I had sent a lot of stuff. And I still had a lot of stuff left when I'd used Curtis Instruments for a month to do the winnowing and send it out. It was when I was at the Town Club on 86th Street in New York that I ran into this very important series of letters, on top of which was a two-page letter from Eric Stork. This was [dated] 1976, a year after we were passed over and we had been trying to get the contract moved on. It was a two-page letter, saying, "Sorry, Vic. I really respect you as an engineer, and I agree that the hybrid cuts emissions. And

I agree that the hybrid can save a lot on fuel. But that's not what I think the end vehicle should be. It should be a single source of power, and a single driving mode that does the job. I just don't believe in hybrids, despite the fact…." He goes on to say, "If in the future I am proved to be wrong, I will be the first one to admit it."

Now, here comes Murphy's Law again. I'm at the Town Club on 86th Street. It may have been my grandson who had been helping me with the papers, and here was this letter, right on top. So I said, "I have to make some photocopies of this and start getting after Stork." I take it to the woman who's operating the copy machine, and she says, "I'm sorry, Dr. Wouk. The Xerox is not working." So I took the letter and I was going to make—this was over a weekend—was going to make Xeroxes at a place nearby. The letter disappeared! If we need it, we can get it under the Freedom of Information Act.

GOODSTEIN: This is the letter from Stork to you?

WOUK: From Stork to me on federal letterhead saying, "You have a very good thing; it works beautifully. It cuts emissions, cuts fuel economy. But basically I think it's the wrong approach. And if I'm proved to be wrong, I will be the first to admit it." So I may still either (a) find the letter or (b) I don't have to find the letter but send him a letter—registered of course. I had my son Jordan look up—on Google or whatever it was—Eric Stork. And there was a story: Eric Stork left the EPA and he's now in Arlington at Eric Stork & Associates, giving advice. As soon as I find the letter, I'm going to tell him I'd like him to fulfill his statement and have a full-page ad in the *New York Times*, *Wall Street Journal*, *Washington Post*—I won't insist that he have it in the *Los Angeles Times*.

GOODSTEIN: Suppose Eric Stork had been a different sort of person, not as committed to his point of view. Do you think it would have meant a different outcome for this country and the evolution of hybrid cars?

WOUK: That is my firm belief, and that is what I had been espousing for almost thirty years—after the first tests at the EPA and others. As I always said, the hybrid is the way to go if—if, if, if—if we must reduce automobile pollution and reduce automobile fuel consumption a large

amount in a short period of time. The only thing you should do is use existing technologies, base your design on existing technologies, and as these technologies improve, even when you're filling the design and improving your design, you just go ahead. Once you prove the principle—the principle was proved by our tests at the EPA. But nobody did anything about it until, independently, the Japanese—Toyota and Honda, both of whom had good relationships with me. Their American representatives and those representatives who were on international committees with me—the IEC [International Electrotechnical Commission], the ISO, International Standards Organization.

GOODSTEIN: How many decades did you talk about this?

WOUK: Oh, from 1970 through 1980 and from 1990 up until about 1997, when Toyota came out with the Prius.

GOODSTEIN: So, do you consider yourself the godfather of the Prius?

WOUK: I may or may not be. There was a book endowed by the SAE [Society of Automotive Engineers] by Ernest H. Wakefield, a professor at Northwestern University, outside of Chicago. He was commissioned by the SAE to do a fundamental book on electric cars and then one on hybrid cars. He had very little commercial experience with who had tried what when, so I was his pal, helping him out on the electric vehicle book, which got a very good reception—it sold well for an SAE book.

Then, when we started on the hybrid book, we were slightly at odds, because he wanted to call them "multipowered." And I said, "People are going to say, 'What do you mean?' And you're going to say, 'Well, a hybrid.'" Eventually it came out that way. In it he talks about all the early hybrids—the ones I mentioned—and there were quite a number of them. They never took off commercially, because by the time they were perfected, the internal combustion engine was so much better. So his paragraph on current hybrids begins with something like, "If anyone can be given credit for being the father of the modern hybrid program, it's Dr. Victor Wouk." And he gives a lot of my references and quotations and pictures, and so on. He passed away about two years ago. A very nice fellow.

GOODSTEIN: Who are the bad guys in your opinion?

WOUK: *The* bad guy is Eric Stork, who told his men that they had to flunk the Petro-Electric Motors vehicle, before any tests. And Eric Stork was told by some of the engineers at Ann Arbor that it would never work anyway, because this was complicated, that was complicated, so "stop worrying about it, Boss." But it did work. And the orders had been given, somehow or other, "You've got to flunk them." So there was this report by Ann Arbor EPA, back to Washington. We got a copy of it. I had to write a seventy-five-item rebuttal. And it just dragged on and on. And then finally some of the things I objected to were used in the final meeting on the subject. And then I quit.

GOODSTEIN: Then you quit. Did you close down that company?

WOUK: Yes. We go back now to that meeting with the NSF. Herman was there, and Brogan and Stork. Brogan whispered to me in an aside. He said, "Vic, you are getting screwed, and I'm going to see to it that you get some money back." So on the basis of some tests, he told Stork that it would be a good idea to give us another chance. So that in addition to the $30,000 we got for the first series of tests, because some of our tests had looked very, very good, we were able to do another series of tests, for which we got $50,000. The last $50,000 went to Gould, a big manufacturer of batteries. I think their biggest item now are the multichannel oscillographs for electrocardiograms and things like that.

GOODSTEIN: So you basically paid them back for batteries.

WOUK: They ran a lot of good things for me. But by 1976 I was so disgusted, I lost so much energy, that I gave up, and I went into straight consultation.

GOODSTEIN: Do you feel vindicated today?

WOUK: Absolutely. And not only do I feel vindicated, but people high up in automotive technology—to whom I had forgotten that I'd mentioned things, would come to me and say "I'm sorry I didn't agree with you then. It was just a professional opinion. It didn't affect anything." Like people on the IEC committee or the SAE committee, others like that. "You've been right all along and we've been wrong." So I feel vindicated. I won't feel fully vindicated until I get that letter into the *Times*.

GOODSTEIN: I want to ask you—in the article you wrote in 1980, "From Horsepower to Shanks' Mare Power: Is the Automobile Doomed, or Is it Just Us?" [in *Engineering & Science*, May-June 1980], you talk very little about hybrids. Why is that?

WOUK: At the end, I do discuss hybrids.

GOODSTEIN: At the end, that's correct.

WOUK: And that's the way it fit in. Because my paper … [tape ends]

Begin Tape 4, Side 2

GOODSTEIN: If you were to write today the postscript, what would you say today? And twenty-five years out from today?

WOUK: I began to write such an article. Things got in the way. Jane [Jane Dietrich, editor of *Engineering & Science*] was very good-natured about it; she didn't get mad at me. She said, "Whenever you want to." I did a rough draft—this was 1990. So maybe I'll make it five years from now. But even then, we still won't know what's going on. Because if you look at the last paragraph, I say something to the effect that all bets are off if things are getting troubled in the Middle East. Pretty near the end.

GOODSTEIN: So you don't want to make any predictions?

WOUK: No. Because the people in charge in Washington are completely incompetent. During Bush's presidential campaign, …

GOODSTEIN: Which Bush?

WOUK: The current Bush. He made fun of the hybrid. He said, "Oh, if that guy [Al Gore] gets elected, you won't be able to drive anything but hybrids." And now he has been able to give the entire automotive industry twenty years in which to play around—at least in the United States. He said, "Let's forget about everything except the Freedom Car, which runs on hydrogen [fuel cells]. Maybe *we* won't be driving them, but the children who are born today will be driving them twenty years from now."

GOODSTEIN: What would you say to that?

WOUK: That maybe twenty years from now we'll be able to make the statement that children born today will be able to drive them in twenty years—the hydrogen-fuel-cell cars. Now, the hydrogen engine is simply one I cannot make the criticisms or evaluations of quantitatively. Lots of problems have to be solved. The overall energy picture with hydrogen is a very poor one.

GOODSTEIN: But we do have the hydrogen fuel cell.

WOUK: The hydrogen fuel cell presents a lot of harrowing technical problems.

GOODSTEIN: So you're not saying twenty years from now we'll have it, but that twenty years from now we can say that twenty years from then we'll have it, for our children's children?

WOUK: Yes. Because the last three years I was on committees in all three organizations—the IEC, ISO, and SAE—where we began being interested in fuel cells for cars. And the ambient conditions that a fuel cell has to withstand in a car are so very different from the successful applications that exist now, with the stationary generation of electricity. Everything is standing

still, so there's no vibration, there's no problem of something coming apart and releasing unpleasant and potentially dangerous fuels or fumes. Plus all sorts of little details here and there. The economics of the fuel cell will be so great that cars just will not sell, and hence, if the situation really becomes serious, the hybrid is going to be the only answer. And we're going to have to live with it.

The transition of a car manufacturer from one type to another is a long haul. When I first demonstrated regenerative braking in Detroit to the automobile press, there were about fifty guys in the audience with movie cameras and TV cameras, and all that sort of thing. One of the automobile critics got up and said to the president of American Motors—who was up front, where I was demonstrating electronic controls—he said, "When can you have something like this in production?" And the president of American Motors said, "Jack, you know very well that if I gave you a stack of blueprints this high and said, 'Start making it,' there wouldn't be a car available for three years."

So, let's say that the day after tomorrow, Ford says, "Hey, look, you guys. I believe that you've been pussyfooting around with the type of hybrid you want us to build. An SUV has been simplified with regard to emission control and maybe a little increase in fuel economy. I want you guys to design a hybrid that's more like the Toyota Prius but can be charged by plugging it in. So that we can then advertise eighty miles per gallon. This guy, Dr. Wouk, who wrote all these things that proved to be correct—if you just use some batteries for propulsion, and all that sort of thing, the best you can expect is doubling the fuel economy, or maybe 2.3. I want to triple the fuel economy. Quadruple the fuel economy." And the engineers will go away, and their bosses will say, "Hey, you heard what he said? Get to work"—we're talking about six years before a really good hybrid comes out that triples the existing fuel economy.

GOODSTEIN: But say it *is* possible in six years?

WOUK: Well, it's possible in six years. But then we get into a problem that I introduced. I live in New York City. Traffic is lousy. I want a hybrid that I plug in overnight. Where do I plug in? So the initial sales are not going to be where it's needed the most, where the pollution's the worst, but maybe out in the suburbs. So, if you go to plug in, it will be a $16 trillion business, which will take care of all unemployment for the next ten years, as outlets are made all over the

place, very much like parking meters. It's not an impossibility, because many parking meters in several parts of the world have an outlet in which you plug a heater for keeping the engine warm.

GOODSTEIN: So you could use existing—

WOUK: To some degree, but it would still require lots and lots more.

GOODSTEIN: When we needed to build the bomb on a crash basis, we had thousands of engineers and scientists at Los Alamos and elsewhere on a crash program. Are we capable of such a program today?

WOUK: Yes. And one of my letters states in 1979 that if we're really serious about this, we should have a crash program. There are no basically new technologies. Improvements, yes; technologies, no. The major improvement that Toyota made was this continuously variable transmission. So you get absolutely smooth acceleration [with the Prius] and this switching from one power to another—or to both—is almost a hundred percent imperceptible to the driver. You'd have to be pretty sensitive to what's going on to know when the engine comes on or goes off. I would say, yes, if we had a crash program, I think it would be less than two years before the pile of drawings is this big. And it would be still three years or so to get the car into your friendly neighborhood showroom.

About the beginning of the '90s—it's that or it's at the end of 1997, after my article appeared in *Scientific American* ["Hybrid Electric Vehicles," *Scientific American*, October 1997]; I don't know which. I got a call from General Motors. "Dr. Wouk, we understand you come out here for SAE meetings and things like that. We would like to talk to you." Fine. After one of the SAE meetings, I go to meet them at their Technical Center. And there is a Dr. So-and-So and a Mr. So-and-so. Who are they? They're in the procurement end of General Motors. And here they're located in the Tech Center—you know, not downtown in the fourteen-story building. "What are you doing with a PhD and you're in purchasing?" I said, though I may not have phrased it that way. But they explained to me that it takes three years to get some products, start planning for them, talking to manufacturers and so on. "And one of our GM departments, or subsidiaries, or whatever"—I think Delphi at that time was the subsidiary—"is planning to

build a passenger hybrid. And since this has not been vetted outside of General Motors, and we're trying to keep it very secret, we would like some outside analysis. And we were wondering if you would do it."

"Well, I'd be glad to do it. I need this, that, and the other piece of information. And here is my fee." A reasonable fee. I wrote the report, and I said, "I'm still not able to give you a final answer, because you have not sent me a circuit, a basic block diagram for what they plan to do. So I can't finish the report."

I got a telephone call about a week later saying, "Dr. Wouk, we're dropping your project."

"Why?"

"Someone at Delphi got wind of whom we are talking to, and the fellow at Delphi said, 'Dr. Wouk? Absolutely not.' Why not? 'Well, because if it's no good, he's the guy who'll find out and tell you.'" [Laughter] The project was dropped. Which was a good thing—they thought they'd invented something. I had seen that on the road in 1974.

So, all along I had a lot of fun. But there's my experience with the construction of automobiles and what it represents.

GOODSTEIN: You had mentioned to me that the Clinton-Gore administration was not necessarily any better or more receptive to the issue of a hybrid car versus a big gas-guzzling car. What can you point to?

WOUK: I can point to six years of waste, doing studies, doing analyses and tests and programs, and organizations trying to find out what the best vehicle would be. This was the PNGV—Partnership for a New Generation of Vehicles. There would be a three-year study—half funded by the government, half funded by the automotive industry—as to what would be the best approach to a vehicle that would do eighty miles per gallon. Then after that was determined—what it would be, what the basic architecture would be—there would be another three years for companies to do designs as to how to implement this architecture. That was the PNGV.

Now, I first heard about it before it was announced to the public. In 1991 or '92, Dr. John Gibbons, a very bright fellow, scientific advisor to the president, completely competent, was giving a talk to the New York Academy of Sciences at a science breakfast. And he said, "I

can't announce this now, but there's going to be an announcement soon of a new approach to get low-pollution, low-fuel-consumption vehicles. It's going to be some sort of partnership with the automotive industry."

Now half the people who were there turned toward me with big smiles: "What are you doing?" So I wrote a letter to John Gibbons saying, "Dear John, please, I would like to talk to you about this whole program. We've been through it in one form or another, and I can give you information that would save you years." Never got an answer.

About three years later, Mary Good, who had been on President [George H. W.] Bush's Council of Advisors on Science and Technology, was giving a talk at the Academy. Again, the same thing. By then it had been announced, but they had not announced the architecture of the car. She spoke at the Academy, and she may or may not have referred to the PNGV, but I wrote a letter to her. By the way, this was all on New York Academy of Sciences' letterhead, with my name there as vice president in charge of engineering. I never got an answer from her.

Then, about 1996 or '97, the announcement was made as to what had been decided. The hybrid car was the way to go, and contracts were going to be let with these companies to develop the best type of hybrid. It was the only time I ever got up and asked an embarrassing question. Luckily, I was the first one at the mike. This group at the SAE was announcing the Partnership for a New Generation of Vehicles and the conclusion that it was the hybrid, and now we were going to study what type of hybrid. My question was: "Do any of you people know about the Federal Clean Car Incentive Program?" Blank stares. "Have any of you or your associates read any new material that was presented at a conference run by the EPA in 1979, on research required to achieve the type of car we're looking for?" I had an article on the research required to make the hybrid more practical than the one I had built, and the report they finally came out with, was almost point by point by point what I had covered, including the goal of eighty miles per gallon—how it could be achieved. There was one, and only one, subject that was discussed in PNGV that I didn't touch, and this was ultra-capacitors. In 1979, there was no such thing as an ultra-capacitor. Now the ultra-capacitors look very interesting for certain limited applications, particularly in a fuel-cell hybrid, where you can't change the power fast. So I said, "Have any of you read any of this stuff?" Again, they all looked blank. What are you going to do? They were now committed to a three-year program of studying what hybrid should be done—as a result of which, no hybrids are being built in the United States.

GOODSTEIN: So here you have all these well-meaning people in the Clinton-Gore administration, but they want to start from scratch, when you're saying that it's all been done; go implement it.

WOUK: Yes, that's why I was frustrated for quite some time. But I found the following: Not only in the hybrid vehicle business but also in some of the other aspects of electronics, in the United States the NIH factor—"Not Invented Here"—is much, much stronger than it is in Europe and Japan. If you go to someone in Europe with a damn good idea, they'll say, "Hey, that's a good idea." Whereas in America, if you achieved this ten years before they did, well, they get mad at you. So, I've run into that.

GOODSTEIN: When the Japanese developed the hybrid vehicle, they were familiar with your work?

WOUK: The engineers I spoke to over a period of many years knew of my work. The answer is yes. One man I wrote to—a Dr. Soshi Honda, who worked for Daihatsu—he and I were quite friendly. He spoke English surprisingly well. When I wrote to him about something else recently, he came back with, "Congratulations. You were talking about this all along and you've been proved correct." So he and others….

GOODSTEIN: Because they were not afraid to take an idea that was born in another country and another culture—you're saying that. And here, it's a homegrown idea.

WOUK: The economics are not here. The economics actually *are* here, but the people don't know it. The price—the apparent price—of gasoline is very low. They're paying for the gasoline with higher income taxes that are used to send fleets and soldiers overseas and all that sort of thing. So it's not as immediate and obvious a problem. If gasoline were indeed $4 a gallon, I think the story would be different. Because it did happen, after the first gasoline crunch. All of a sudden, the small cars were desired, and Volkswagen was able to get more than the sticker price for immediate delivery. And in one of my testimonies I say that the automobile industry objected to the new regulations because people wouldn't buy small cars and Detroit

would lose 600,000 jobs. In my testimony I had to admit that with the small cars, Detroit lost 600,000 jobs. But that was because they weren't making anything. And people went from ten-percent foreign cars to whatever it is now—thirty percent or more. If you walk down Park Avenue, you will find nothing but foreign cars. And up in Westchester, as a fast indication of whether a restaurant is toney or not, you look in the parking lot. If they're all BMWs and Lexi and so on and so forth—toney restaurant. You go to a diner, they're all Fords. Not that there's anything wrong with a Ford, but they're not foreign cars.

GOODSTEIN: I think we've come to the end of our interview. Is there anything I didn't ask you about electric hybrid vehicles, the politics? Is there anything you'd like to add? We mentioned the regenerative brakes.

WOUK: From the battery, as you slow down. As far as I can tell, I wrote the first paper on regenerative braking since semiconductors became available. So we're talking about 1963, '64. All cars that have electricity always use regenerative braking.

GOODSTEIN: Did you patent that?

WOUK: Well, the only thing you could patent is the specific circuit; you can't patent an idea. Maybe you can nowadays, with computers. I know there's been quite a difference of opinion on this subject. But the idea was rapidly picked up. I wrote a reasonable number of articles on regenerative braking. The main thing that I've always said and which still applies is that regenerative braking is a plus. I would not use it as a technical or a performance point in trying to sell a vehicle—saying that without regenerative braking you go twenty miles per gallon, with regenerative breaking you can go twenty-three miles per gallon. Of course that's not the case. It's only in the given test sequence that you might get it. But it's very handy in cutting down the maintenance of brakes—particularly in buses, and particularly in New York City buses, where the driver slams his foot down, goes like that, and slams his foot down again on the brake. It's an important characteristic but it's not a determining characteristic. But all cars with electric drive of any sort have regenerative braking. They even tried to put it into electrically driven

wheelchairs. I understand they do have it there, in order to be more reliable with respect to braking. It's backed up with a mechanical brake, and people like it; it's smoother.

GOODSTEIN: Thank you.