NASA HEADQUARTERS ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

JUSTIN J. RENNILSON
INTERVIEWED BY SANDRA JOHNSON
HOUSTON, TEXAS – MARCH 10, 2020

Note: Justin J. Rennilson made significant edits to this transcript during his review. The changes are not indicated, and as a result, the text no longer matches the archived audio recording.

JOHNSON: Today is March 10th, 2020. This interview with Jay Rennilson is being conducted in Houston, Texas, for the NASA Headquarters Oral History Project. The interviewer is Sandra Johnson, assisted by Jennifer Ross-Nazzal. Thank you for joining us and for traveling all the way from California to come see us. We really appreciate it. I want to start by asking you about your background, where you're from and your education, and how you first got involved with NASA.

RENNILSON: All right. I was born in Berkeley, California. And on my father's side a long history of California, going back to 1865. They came originally from Scotland. I grew up in the Berkeley system, I went to the University of California, Berkeley, for about three years, and I did my senior year down at UCLA [University of California, Los Angeles]. My major was astronomy, and shortly thereafter, before I even had a job, the Korean War broke out. I was in the Second World War the last year, and they said you're never out of the Navy, so I was recalled. I spent 26 years active and reserve in the Navy.

When I was ready to be released in Japan, I wanted to take graduate study, and I wanted to go to Germany because my interest was in optics. I had a nice German consulate official that wrote all the necessary letters. I was finally accepted at the Technical University in Berlin in the Optical Institute.

When released, I traveled for two and a half months around the other way, so before I was 30, I'd been around the world. I studied there for over two years. I stopped my study for personal reasons having to do with my German wife's family, came back to the United States, and through connections had a wonderful opportunity to make contact to a laboratory in San Diego, which was a part of Scripps Institution of Oceanography at the time. It's before the university at San Diego was established. That was the Visibility Laboratory, Vislab for short.

That laboratory had been a part of MIT [Massachusetts Institute of Technology, Cambridge], and Dr. Seibert Q. Duntley, moved the whole laboratory, his area of expertise was in atmospheric optics, hydrological optics, and the interface between

I became the optical engineer at the laboratory. We had several people who had come and worked at White Sands [Test Facility], New Mexico, together with Wernher von Braun, when they had V-2s [rockets] and they developed the Jupiter [rocket].

One of my friends, Edwin P. Martz, at the Vislab, went up to JPL [Jet Propulsion Laboratory, Pasadena, California] and got a job. Shortly after this, Ed Martz called me and said, "We got a great optics lab—we need to have you come on up." We tried to get Dr. [Seibert Q.] Duntley interested in the space program. It was the early stages of NASA.

Rudy [Rudolph W.] Preisendorfer, a great theoretical physicist, and I were very much concerned because when we watched Sputnik [Russian satellite] go over in '57, and said, "What are we doing now?" We both wanted to get into the program, so we tried to talk to Duntley, and he said, "I know a lot about the atmosphere, the ocean, interface, but I know nothing about planetary surfaces, including the Moon, I'm not going to do it."

Later on, that laboratory got involved in the Gemini [Program] for visual tests. But Rudy went to General Atomics, and I went to JPL. That was the very beginning, and JPL had done a lot of work on rockets. They had developed a rocket assist during the war for heavily loaded bombers that allowed them to take off, and they felt that they were really the expert. Now the government had formed NASA and oh, great, "we'll tell them how to run things." This worked for about a year until they said, "Now, who's the boss? We are."

But JPL was very interesting. When I joined it there were about 500 employees and within one year, we had scaled up to about 4,000. Of course everything was in trailers and some of them are still there. That's the way I got involved.

My desire even when I was a young boy, I was 10 years old, and our fourth-grade teacher took us to the observatory at UC Berkeley. I looked through a beautiful brass telescope on the craters of the Moon, and I was hooked.

JOHNSON: Talk about the position at JPL. How did that relationship with NASA work?

RENNILSON: That's another story. It's interesting. Originally it was a Laboratory, and it still is a part of the California Institute of Technology [Caltech]. It was a university arrangement and they had built the Lab, not on campus, but up in the hills, where they'd done the rocket testing and everything else.

Dr. [William H.] Pickering, who took over the directorship, was from New Zealand, great man. He was approached probably a year or two after we had organized everything and NASA Headquarters came out because they had Ames [Research Center, Mountain View, California], they had Langley [Research Center, Hampton, Virginia], they had Huntsville [Marshall Space

Flight Center, Alabama], they had Houston, and they said, "We're a little concerned that JPL is kind of out in the boonies. You've got a direct thing. All of your checks came via Caltech, not NASA."

They said, "Well, we think we'd like to bring you into the whole group since all the buildings and everything else is owned by NASA." Dr. Pickering listened very carefully at this, and he said, "Oh, okay, well, I want to give you a little comment, that if you decide to do that today, tomorrow 80 percent of the lab will be gone." They said, "Oh, okay." Since that time JPL has been run by Caltech.

But it's been I think a very good relationship. There's been a lot of problems in the various programs for JPL and NASA administrations. Headquarters couple times have said, "I'm a little worried about the direction." Because this is a laboratory and if you take responsibility for an entire project, you're going into a different organizational level. I think the lab learned a lot and we had a lot of wonderful people as leaders.

JOHNSON: Talk about some of those people, and when you first got there who you were working with. I know we talked about Gene Shoemaker before the interview. Also, Gerard Kuiper, were you working with him? Talk about those early days and what you were working on and who you were working with and how that was organized.

RENNILSON: When I first joined JPL it was in '61. It was in April. The head of Space Sciences Division, which is the Division I was in, was Al [Albert R.] Hibbs. Al Hibbs was also the voice of Surveyor [Program]. He had a wonderful voice. Al was a unique individual because he had quite a connection to Hollywood personalities.

Bob Newhart [comedian/actor], Leonard Nimoy [actor best known for his "Spock" character on Star Trek], these people showed up periodically during our missions. The reason why is that he and a group of Caltech students got together and went to Las Vegas [Nevada], and they looked at the roulette table and they figured it all out and they broke the bank. After that, he was a persona non grata. But he made a lot of notoriety especially in Hollywood, and so he kept that.

When I joined JPL, I belonged to a photoscience group. In the photoscience group, there was about six of us. Two people in that group, Don [Donald E.] Willingham and Tom [Thomas C.] Rindfleisch, were responsible for setting up the exposures that the cameras would have to take on Ranger [spacecraft], for good photography and also where to go. They developed a wonderful theoretical parameter called a figure of merit, which was one number that you would choose as to your landing site, your lighting, and everything else.

Now I had been trained in Berlin and done some stuff like that, and I was a little skeptical with it. But a lot of managers loved to have one number. "I want to go there. What's the number, from 1 to 10, oh, that's 9, that's good, I'll take that one."

Optics is not something you can simplify, but they did a marvelous job and Tom Rindfleisch left later on, he got his PhD from Caltech and was responsible for the entire digital medical facility of Stanford [University, California]. I talked with him a couple years back. He's still alive, but we don't know where Don is.

The first task that I had was in the Surveyor program which we'd just let contracts to Hughes Aircraft aerospace division, and lots of experiments aboard that spacecraft, of which there were many (10), almost as many as Curiosity [Mars exploration rover] has today. "We're going to appoint you as the cognizant scientist on the television experiment and your job is to act as liaison to the principal investigator [PI] and his team to the lab and also to the contractor, Hughes Aircraft." That was my first job. Associated with that was a cognizant engineer. The cognizant engineer's responsibility was basically instrumentation, what it would take, in this case cameras. He was very knowledgeable, that was [L.] Harold Allen. He passed away couple years ago. Harold was very good, and I think when you go through some of that effort, he was very instrumental in our entire Surveyor Program, which I can go into a little later.

That's the way I started. It was an interesting effort because the first thing that Al Hibbs told me, he said, "This is the beginning," early stages of the Ranger Program, which was divided into three phases. The first phase was really just to see if we can get something up, do something. That wasn't too good. The second one had a little bit more. They were going to put a seismometer capsule on the Moon, and it would measure moonquakes. Then they said, "Maybe we should have, because we know that the Soviets are doing it, they're pushing," they had the Sputnik, they had Yuri Gagarin [first human in space], all the way around the Earth, and so on. "We haven't done anything. We need something for the U.S. to get excited about."

The first suggestion was "Well, there is a contract at Ford Aeronutronics [Division, Ford Aerospace, Ford Motor Company]. They were doing the capsule, we need maybe a facsimile camera which would rise up from this capsule and take the first pictures of the lunar surface. But it's quiet, we don't want the Soviets to know, we don't want anything leaked. You are a military person." By that time, I was a commissioned officer in Naval Security Group, which was naval intelligence. "We're going to classify that as Secret. You go down and monitor the effort and then come back and tell us how they're progressing, what can we do." Hughes was also interested but they wanted to put a bigger camera on that.

The story is of course that that second phase didn't work. Our entire efforts to beat the Soviets failed. Of course they were there four months before Surveyor landed.

Now what I intended to do was to monitor them, and I was involved in the Ranger Program, because by that time I had met the two other people that were involved in Ranger. As the cognizant scientist for Surveyor, my first job was to make contact with the principal investigator. During Ranger Dr. Gerard Kuiper, who was a Dutchman, and nobody ever called him Gerard, they always called him Dr. Kuiper, this is Dutch, so he basically said, "I should meet you."

I talked with, for the first time, Eugene Shoemaker. He was at Menlo Park, that's the headquarters in the West for the United States Geological Survey. He said, "All right, we need to get together and meet." I suggested a date, and he said, "Oh, I'm not going to be in Menlo, I'm going to be in Arizona at the meteor crater. Why don't we meet there?"

I said, "All right," and I flew out to Flagstaff. You drive to Winslow, and from there you can walk over to the rim of the crater.

Now Gene did his PhD thesis on that crater. He was way down in the bottom of the crater, and he climbed up, and we sat for about two-and-a-half hours just talking about what he wanted to do on the Moon. I suggested a couple things like colorimetry and polarimetry.

Then about a day later we all went down to Tucson to meet with Dr. Kuiper. We had one other fellow from JPL, Herb [G.] Trostle, from the project office, . He was in the instrument section. He joined us.

JOHNSON: You can add that later.

RENNILSON: We had a meeting with both Gene and Kuiper. The discussion was what kind of instrument do we have for a television system. Kuiper said, "I want to have something that'll take in a lot of wide area so we can capture all of that."

Gene said, "Well, I have just a little bit of a disagreement with that, because what a geologist does when he's in the field, he looks at the whole area he likes to reach down, pick up something, and look with a magnifier in detail. So, I've got to have something that will actually increase the resolution that I can examine closely." That basically was only enabled by using what we called a zoom lens, a vari-focal length lens. Now you have a 25-millimeter focal length, which gives you your wide angle, and then you have a 100 mm focal length, which gives you the high resolution.

In one optical system, we've got both of these and the investigators were satisfied. At the time Gerard Kuiper was in charge of the Ranger, so he was the PI, and Gene was the Co-I [Co-investigator]. Along came Surveyor, and they just flipped roles. Unfortunately Dr. Kuiper didn't live to see a lot of our successes. But he did establish a wonderful facility at the University of Arizona, the digital building with six stories with a lunar and planetary lab, still doing marvelous work in planetary science.

JOHNSON: The cameras and the lens and everything that they were discussing, talk about that for a minute. Was it the same for Ranger and Surveyor?

RENNILSON: No.

JOHNSON: Talk about the two then and how they were developed for Ranger.

RENNILSON: The final phase 3 of Ranger and purpose was to aid Apollo who wanted to know how detailed, how many rocks, how many craters are we going to have when you get up close. We had only terrestrial information. Some of it was pretty good, but it really missed the mark, because we're talking about several hundred meters of resolution, and what we needed was something up close. Phase three, because they'd had problems with phase two, there is a wonderful article written by [R.] Cargill [Hall], who wrote all of the history of the Ranger Program. It's really on the whole program because it delves into everything. It also delves most importantly with the organizational problems.

At one point, because we'd had failures in phase two, they said, "Well, okay, we need to redesign what we're doing." Instead of one camera coming down, they said they'd put six cameras. RCA was responsible for that. They had six cameras.

The purpose of the six cameras, some of them were overlapped, so there was wide angle a narrow angle. At the very last second, they would take a section of one frame—these were television pictures—just before they crashed, which would give them a resolution probably on the order of a fraction of a meter. That would be just a snippet of that one area but to give an idea of how dangerous things were.

Phase three started with Ranger 6. Everybody was alerted. The press had come in to Dr. Pickering because he thought it would be nice; local, national maybe. Then they told him, he said, "Oh, no, Dr. Pickering, we're worldwide." Everything was fine, it was all going great, no problem, till they were ready to turn the cameras on and everything disappeared. Pickering, I got to know him pretty well. He said, "I don't want to ever go through that again."

There was a lot of pause in between to find out what had happened before they came up with 7. In 7 obviously we did it. My involvement came about because Gene Shoemaker established the Astrogeology Branch at Flagstaff. He loved Flagstaff. Of course, it was close to the crater where he did his doctorate. But it was a great place to live, and it had Lowell Observatory, and a lot of the interest for Mars, etc.

He started the Astrogeology Branch and really is one of the founders of that particular science today. We give him honor. He set that up. He got together with Ames Research Center and Don [Donald E.] Gault, and they had developed up at Ames a special series of two guns which would fire a projectile into an object at roughly the velocity that you would have for an asteroid coming onto the Earth.

You'd watch the effect, they would use special cameras from EG&G [Edgerton, Germeshausen, and Grier, Inc.] back in Boston that would capture in a microsecond the image. What they would see was a flash, it saw debris thrown up, and so on. Gene said, "We've got a mass that's Surveyor, and it's going to crash into the Moon, and hopefully we'll see something, and maybe that display, what we're seeing, might give us a clue as to what the material is."

At the time I joined JPL, it was interesting, there was only three other people that had a degree in astronomy. One was Ray [L.] Newburn, and he and I worked and established the Table Mountain Observatory which the Lab still has up in the mountains. Another one was Ed [Edwin F.] Dobies, my boss of the photoscience group with some astronomy, and Roland [L.] Carpenter, who was a guide with me at the Griffith Observatory LA when I was at UCLA. That was it.

Gene said to me, "Well, since you're an astronomer, and we don't know exactly when this impact is going to go, Jay, we want you to organize observatories around the world to look at the impact to see if we see something." We had several people. They were at Berkeley [Leuschner Observatory], they were at Mount Hamilton [Lick Observatory, California], Kitt Peak [National Observatory, Arizona], all around the world. I had telephone calls with people in Australia and a bunch of other places. It was really interesting because all these people that I had heard about when I was studying suddenly were on the other end of the line, so I had a great collection.

The result is we didn't see anything, it was a lot of false artifacts—they sent pictures back, we had teams going. In retrospect our purpose of course was to get good lighting so we could see the imagery, and to see something that small come out against that background would be almost impossible.

Years later, LCROSS [Lunar Crater Observation and Sensing Satellite], nice mission, came in and they separated the payload to the upper stage for that rocket. So, they had the opportunity to see the impact of the upper stage in a dark crater and still take a picture of it, and there they found debris, and they saw a flash. That is years later. But that was my involvement, organizing all of that.

Of course we were all members of the photoscience group, so we had a lot of interaction with everybody.

JOHNSON: Talk about Surveyor. From what I read, they were both conceived—Ranger and Surveyor—at the same time. Were you actually working with both of them when they were being developed, both programs?

RENNILSON: When I first joined the photoscience group our major effort at that particular time was for Ranger because we needed to have that success. I worked closely with Don Willingham and Tom Rindfleisch and everybody else in that particular group as a help, because we were all looking at the optical characteristics. The Ranger spacecraft was built at JPL.

There was some effort that required research, going back and finding out who did this and who did that. The photometry on a lot of the observation of the Moon, believe it or not, has been done by Russian astronomers. They decided they didn't have the big instruments, so they didn't go further out, but they concentrated a lot on the solar system. Their remarkable research we used quite heavily in designing what we needed to have for the camera's exposures.

I started with that. But my major task of course was to respect what Gene and his team were developing in terms of instrumentation. The contract for building the Surveyor was let about six months before I arrived. That would be in the '60s. Hughes Aircraft, one reason for this, was because NASA felt that Ranger had so many problems, and delayed, that they felt it would be better for JPL rather than build it themselves to have a contractor outside.

I think there were three contractors involved, but they did determine that Hughes would be best. Hughes had a proposal to build a spacecraft, and on that spacecraft would be various instruments. They would take the responsibility for the camera, but it would be subcontracted for the optics.

When I first joined and they gave me that task, I talked with Shoemaker about what he wanted to do, what we had to be capable of, and we went back to Hughes with my cognizant engineer Harold Allen. The first thing we discovered is that in their contract all they had was that the camera would be situated here so that they could look at all the other instruments. The instruments we had initially in Surveyor was absolutely amazing because it had a transport picking up a sample, would dump that, would do all kinds of analysis on that sample, like what Curiosity is doing. I think there were a total of about—don't quote me on this but—about ten instruments all associated. We had geologists, we had mineralogists, we had a lot of people that were forming the committees that would engineer it.

At the same time we were dependent upon a new rocket, which was called Centaur, and that rocket was supposed to sit on top of the Atlas and give us the necessary push to take 2,500 pounds, which was the flight weight of Surveyor initially, to the Moon.

They had a lot of problems, and there was one delay after the other, because they were using a fuel which they had never used before, liquid hydrogen and liquid oxygen. When I was a young man in Berkeley at the university, we used to have a rocket club, and we'd sit down and calculate what kind of ingredients you need to get off the Earth. We said, "Well, the best is hydrogen and oxygen. Got to liquefy them." Of course we all joked, "Boy, what an explosion that would be!"

It took a while for them to really engineer it, and we used to have a little joke that Hughes, I think, had coined. We said that, "Oh, that's easy, the time to launch is a constant." Now if you understand mathematics you know you never get to the end. But we were able to develop a lot of the things that we needed for successful landing during that interval of time. We weren't sitting around idle. We had a lot of little tools that we could use.

Eventually we obviously were successful, but 400 pounds of that was off-loaded. We had originally four cameras aboard that spacecraft. The Surveyor has three legs, so there was a camera at every one of the 60-degree sectors, which is three, and they had one looking down.

Surveyor 1 and 2 had that camera looking down but we never turned it on. The rationale for that is because of Ranger 6. Ranger 6 went down, and we turned on the cameras and bang, all communication was lost. They said, "Now if there's something that might when we trigger the downward-looking camera, who knows? It could be a spark that would start the retro-rocket ahead of time or something else would happen. We're not going to turn it on." We never got our pictures which gave us location when we landed on Surveyor 1. But we had a great coinvestigator called Ewen [A.] Whitaker that did it all for us.

I could go into the details on the camera, but we ended up having only one camera, and that was a limitation. But we did something with that camera which enabled us to have several firsts, which more than 50 years later we haven't duplicated.

JOHNSON: Talk about that, and talk about that landing, Surveyor 1. I read that you were at Goldstone when it landed, so talk about why you were at Goldstone and that experience of the landing. It was broadcast, wasn't it? Wasn't that one that was broadcast and caused a few nerves?

RENNILSON: Yes, it was broadcasted. Now understand, we had done a lot of engineering, failure modes, a whole bunch of things like that, and when we got done, the people that were directly involved like Harold, myself, and a few others, we said, "Well, the probability is maybe 10 to 15 percent success." There were several people in Hughes, and Gene, on the 25th anniversary, gave a nice talk at JPL, and he pointed out a couple people from Hughes that were pretty secure that we would be successful. There was not very many. I think Gene [W.E.] Giberson was initially involved in that. [Howard H.] Haglund and a couple of others at Hughes. But there was a lot of doubt.

One of the major problems I think we had initially was that people were afraid to even talk about that. We had established about two years earlier—because our launch success was supposed to be—I think it was planned for early ’65. We obviously would have been there before the Soviet capsule and everything else. But since it got delayed, the television camera had a unique opportunity. It was a camera that was vertical. The zoom lens had a filter wheel and a mirror as a separate unit that sat on top of that. The television detector was a vidicon tube that was used in all the standard broadcast cameras at that time, was below the zoom lens, and below the shutter.

This module, that is the mirror and the filter wheel assembly, was built by Hughes. The camera would look up into the mirror and the mirror would now tilt and turn around almost 360 degrees, go in one direction about 225 degrees and the other direction about 135 degrees. This would give you an entire panorama at two different focal lengths, so that would be either a wide angle (24 degrees) or narrow angle (6.4 degrees). You’d have to put all these images together on a template array. As you rotated the mirror so did the image, so you had to put that down in a particular orientation.

We created a Television Science and Analysis Command, a TSAC group, which basically attempted to automatically take pictures. In those days there were a couple ways to do this. You could have a Polaroid and you’d take Polaroid pictures, you’d cut them up into small images, or you could use paper print rolls. The image you got was about 2 by 2 inches. Then you’d take that, and you’d put that down on a template array, which told you what angle and where it was supposed to be laid.

We would try that out with a couple of groups. We would have a timer and we'd find out how fast they could take the images and put them down to have an entire panorama of that particular section.

One of the things we did in the very early stages with the principal investigator, Gene Shoemaker, we said, "We need to demonstrate one of these instruments in the field." Harold Allen and I got together, and we said, "What we need to do is build up some sort of a mock-up."

We had gone to Hughes and they said, "We can't loan you any cameras that are being built now, sorry. But we can tell you what it takes, and you could get a commercial zoom lens and you could take a television camera and put that together and you could put a mirror on top and you could move the mirror by manual means."

We built a model, a structure like the spacecraft, and we went out to the desert, and we spent about three weeks in the desert camped out there at a location. We collected all this information, and we did this at JPL without any of the experimenter team involved. We said, "One of the things we need to do, nobody's ever done this before, we got to take a whole bunch of panoramas. Now we're going to toss that to the investigator team, all geologists, most of them, and tell us what you see." This is the first time.

We did that, and by doing that we said, "Well, we created now an actual model of what's going to happen when we actually land." We would create two teams. We'd have a stopwatch. We'd say, "Okay." There would be a whole bunch of little stacks of images. They would be passed out to the team and the team would automatically put them down. We got really efficient, that within about five minutes after any kind of landing we had a panorama for the scientists to take a look at. We had a second field test near Flagstaff, where later the astronauts went, and we used one of the early Hughes cameras. We operated again for over three weeks and put together pans and observed stars.

When Surveyor 1 was about ready to go, they said, "Well, okay, there's only a 10 or 15 percent success. But in case it lands we're prepared." We had a problem. The control for the flight was at the Space Flight Operations Facility, SFOF, at JPL. Everything went through them. All of the commands, however, came from the Goldstone antenna site [California], which is out in the [Mojave] Desert. That was the beginning of our Deep Space Network all around the world. At that time we had Australia and we had Johannesburg, South Africa, which later was pulled back to Spain for obvious reasons.

Now we had tried communication from Goldstone to the SFOF and it was done by microwave, and during the testing sometimes there would be a complete dropout. There was no communication. Gene said, "Jay, we need to have somebody at Goldstone in case we have a dropout, in which case when we land and there's something we have to do, we can by telephone say, 'All right, send this command, send that command,' and take care of it."

Another engineer that had been involved with us was Don [Donald R.] Montgomery. He's still alive, lives in Ashland, Oregon, great guy. He and I were out there for that emergency if it happened. We were sitting there watching an oscilloscope which had the signal coming back and we watched it and they counted it off, 100 meters, 50, 10, so on like that. All of a sudden, we're landed, and there was the signal still coming in. "Hooray," everybody shouted.

Fortunately our link was okay. Gene gave us a call. He says, "Oh, you get on an airplane and get right back."

To give you an idea of the time that was spent, we had one level in the SFOF, and above that were a series of rooms with beds so you could go to sleep, because these are long missions.

Gene was required, in that euphoria, to come out with a report right away. Gene was not one that would sit at a typewriter and type that. He would dictate everything. He'd walk back and forth, and he'd dictate the geology, what we were looking at from the pans, and so on.

That was the beginning of that. I think we had been awake for maybe 38 hours, something like that, a little bit snooze back and forth, but we did create the very first preliminary science report for Surveyor 1. That was a success, and we were prepared.

JOHNSON: It was a success. But unfortunately, I think Surveyor 2 had some issues, right?

RENNILSON: Yes, 2, we had three thrusters on each one of the three legs. In midcourse correction we could use those thrusters to alter a little bit of our orbital direction, and so we would give a command, and these three thrusters would not only stabilize things, but they could be oriented so they actually would increase or decrease the velocity at that particular time, depending upon where we're going.

It turned out when they gave the command, two of the thrusters came on and the third one didn't, which automatically meant a roll over and again and we lost lock. That was the end of 2.

Surveyor 4 had something we still don't understand, because in 4 everything was perfect, we didn't need a midcourse correction, we were going just great, everything was working, we were right on the nose to go right there. We gave the command. I think that was the command just before the retrofire, and something happened. We don't know, it could have been a malfunction, the retro-rocket could have exploded, a whole bunch of stuff. I think we're still trying to look to see whether we could find—I can't remember whether Lunar Reconnaissance

Orbiter has been able to locate it. That wonderful orbiter that's going around that picks up tremendous detail of where we were and what we did, it's really fantastic.

JOHNSON: One thing I just wanted to ask about Surveyor 1, I had read that one of the first pictures, you could see the foot, and that was important for a lot of reasons. But mainly because it proved that they could land for Apollo later on, that it wouldn't sink.

RENNILSON: That's right. The biggest concern we had, the Soviets beat us by four months. But it was a small capsule. It went down, it had balloons to cushion the landing, a couple of covers that unfolded, and it bounced a couple of times, but it was fairly light, maybe 100 pounds, little bit more.

Surveyor was going to be 2,100, a lot of weight. It actually wasn't that much when it landed (650). Then Apollo of course, the LM [Lunar Module] was much heavier. There was still sufficient doubt as to how much support the surface was going to be. It supported the capsule, and so if it supported Surveyor, we were okay, that okayed the LM. But if it didn't and we sunk down a little bit, then it could be that you could get the situation where the LM, when it was coming down, would not be able to get oriented to lift off or something else, and it would be stranded. We were concerned about that.

Other issues: The camera had unique properties because it was looking up into a mirror. Now the mirror was closed in general, and we did a lot of tests. Don Montgomery—I mentioned him before—was down at Hughes a lot watching these tests. In one of the tests they had for that, the mirror refused to open. It stayed closed.

What we didn't know at the time, and I mentioned this a little bit to the engineers, all the engineers including Hughes and JPL, we want the mirror closed because we don't want any dust or anything else on the mirror. That's really important. But what we didn't know is that the very first picture that was coming from the Moon would have given about $100,000 to Hughes as an incentive. So we leave the mirror open.

It came down, and that was pretty good, because what happens, the thrusters are here, and we turn those thrusters off about 13 feet above the surface. Then it drops to the surface. Now with one-sixth gravity, that's like jumping from this table down to the floor. Pretty soft. It was a little harder for the Soviets, because they had to bounce a couple times. Matter of fact, I think I talked once with one of the Soviet scientists. He said, "Well, we have to really say that yours was a soft lander because if you had somebody aboard that spacecraft they could have stepped off onto the lunar surface. If we had somebody on the capsule they would have been done."

But it was nice. In deference to the Soviets a lot of time when I'm talking, I say the first controlled landing, because the capsule was sort of boom, we land. But we had total control. We could have cut things off or done anything else like that directly from Goldstone.

Once we had done this, we had a little bit of dust that was kicked up, but not much. Matter of fact, it was almost undetectable. We had aboard two special targets which we called photometric targets. These consisted of about five different gray steps around the circumference together with three unsaturated colors and then a couple little arrows to give you an idea of the resolution you were taking. One was located on leg two of the spacecraft when you looked directly at it, and another one was on one of the omni-antennas [omnidirectional]. There were two omni-antennas. When you first landed, you had very low signal because you had to orient planar antenna [high gain antenna] and the solar panel at the same time.

What you ended up doing with that small amount of signal required that you had to use a real coarse resolution from your camera. That was about 200 lines through the whole image. You could do that with the omni-antennas. If you needed high resolution you had to orient the planar array in the direction of the Earth. You also had to have on that same gimbal the solar panel, which the sun illuminated, to bring up the power. You're going the entire flight from here to the Moon on battery. The very first thing you need to do is to orient that solar panel to recharge the batteries.

That was the very first effort. The first thing that happened is that—I don't have a description but there's a picture someplace of one of these photometric targets. Now Hughes built those, designed it. We had input. One of the engineers there, his name was Roy Blanchard, great optics guy, there was only a small number in the Hughes organization at that time. I'll go into later on. He said, "Well, we're going to put a pin that's perpendicular to that target. On that pin there'll be a series of little rings so to speak, and when the Sun illuminates that pin it'll throw a shadow and the length of that shadow will tell you what the altitude of the sun is with respect to the target and also the direction." You could see that pin shadow with our poor resolution of 200 lines.

When we first landed, we had a picture first of another leg, which is leg three, didn't have a target on it, that was the first picture. That captured it, that got them the bonus. Then they swung over and looked at that target on leg two with 200 lines. Now if you look at it very closely, you have to enlarge it, you can see the shadow. In the science team that we have—we have a science team, it was run by a space chief inside the SFOF for all the science activity. All the commands were sent by him. Like in the Apollo Program you have a CapCom. No one else talks to the astronauts except through him. We had a space chief, Jack Lindsley, who did exactly the same thing.

When we had something we needed we would say, "Jack, send the command, take a picture, one one zero zero." Click. That would be the end of it. We had that idea, and we sat down and we figured, "I think the Sun is about there," and systems engineering, who has the responsibility for orienting the planar arrays and the solar panel, they were hunting around, because we had no firm knowledge when we landed what orientation we were in. We had a gyro in a general session, but we're not really sure what direction to look. So, we gave them a couple of suggestions, and the systems engineering said, "All right, we'll try it." In a couple of hours, it took about I think 2 or 3 hours, and they finally acquired the Sun, which at the same time then acquired the planar array. We started getting 600-line images.

It was a little bit of a joke back and forth—the geeks told us where to look. Anyway, it was nice. There's cooperation that you have in a group like that. It's a wonderful wonderful group.

JOHNSON: Talk about that for a minute, because you mentioned being with JPL you were in that side of it, but then NASA was involved. Did you have a lot of interaction with NASA people too? Or were you just working in your groups and that was at a higher level?

RENNILSON: Yes and no, we had a lot of interaction. The program director was Ben [Benjamin] Milwitzky. The science director was Steve [Stephen E.] Dwornik. I had a lot of interaction between those two, especially with Steve, because later on he moved to another area. When I moved down to the campus, I had grants. I had to live on my senior research fellowship with grants coming in. Steve was sort of monitoring those. We set up a good rapport. Ben was very much involved as well.

When there were differences, they would come when we'd have something to iron out. We had some good project directors. We had Bob [Robert J.] Parks who really handled Surveyor initially and also, we had [Eugene] Giberson. A lot of others that were involved in Ranger continued. A lot of these guys were all Caltech grads, so they'd all known each other.

I added more later on about that. Bud [Harris] Schurmeier was involved. They did changes when there was a failure or something like that, they would flip, but they would be down in the same office, so they were always together on that. It was good. It was a little hard maybe for NASA to understand the relationship that we had, because this is a university environment. You have laboratories, so people are talking to each other and helping each other and so on. But we had a lot of directions from NASA on making sure we have everything okay, which required committee meetings. We'd have LOTS of committee meetings. They'd go back and forth. When we had this impasse where we had a delay because of the Centaur they kept saying, "Well, don't worry about it. All we have to do is lay down all the paperwork of all the committees and we can walk to the Moon." But in some cases, they were very effective.

There was one little note, and that's probably on one of the talks that I gave on Surveyor, Al Hibbs like I said had this great connection. He had a wonderful voice when he was talking about Surveyor. He had a wonderful rapport with Gene Shoemaker. They would get together and talk. Gene had that capability of taking very complicated geological information and putting it down so everybody could understand it. He would do it in such an enthusiastic manner that when you get done listening to Gene talk, you'd like to rush up and say, "Where do I sign up?"

That was his capability. We used to kid him that if Gene had an ego it was buried geologically many thousands of kilometers below the surface.

There were a few other people that didn't have that character. Anyway, I won't bring that up. But Al had a good friend, that's Bob Newhart, you remember now, this goes way way back. You probably don't. Bob Newhart had a gig that he used to do on the radio and then went on TV where he would talk to somebody on the phone, and you never heard that person coming back. One night when we had passed all the control for the spacecraft to Australia, Canberra, and they had cut down the lights in the SFOF to save energy or something even then, he got on the intercom throughout the entire SFOF. He said, "You know, we're going to see something tomorrow which man has never seen before. We're going to see where the Earth blocks the Sun, it'll be a first solar eclipse as seen from the Moon. I'm going to give Ben Milwitzky, the Program Director, a call."

We hear ding ling ding, and he calls him. He says, "Ben, hiya. Oh, the spacecraft is doing fine, everything is just great, and we're just anxiously waiting for an event that man has never seen before. A solar eclipse from the Moon." Then explained a little bit to Ben what it was. The Earth blocks, the Earth is much larger so the Sun will be way behind it. But it'll still be important because we have an atmosphere.

On the other end, "Well, when is that going to occur?"

Al says, "Oh, let's see, it'll be about 8:00 to 8:30 your time in Washington, DC." Then [pretending to listen] on the other end, and he said "What? You have an important meeting that you have to be at that time? Oh, geez, I'm really sorry, Ben, that's too bad. What do you want me to do? Delay the eclipse?" So everybody of course, they just broke out in laughter. Unfortunately Al, this was all taped a lot of times when you're on the intercom, and he didn't have it on. He told me later, "I really should have had it on there." That was fantastic. Of course Ben was the center of the joke, but he took it, he was a very good guy.

JOHNSON: Talk about some of the hours. You mentioned that there was some place for people to rest, because the hours were long. Talk about what you were doing and what your hours were like—you had a family I'm assuming at that time—and how much time you spent when these things were flying, when they had landed, and when they were bringing those images back.

RENNILSON: About a year before Gene approached me and he said, "Now you've been a cognizant scientist and you direct this TSAC group, but Jay, we would like to make you a NASA coinvestigator on the experiment."

I said, "Accepted," and then you had to pass the TSAC group to a couple of other people that would take charge of that, and they did. So, I was there as a member of the investigative team, and our responsibility was to do all this. I had Ewen Whitaker. Ewen was an Englishman. They gave him an honorary doctorate at the University of Arizona. He joined Kuiper's group when Kuiper was at Yerkes [Observatory, University of Chicago]. He moved with that whole group to Tucson. Kuiper had the university behind him, and they built that whole facility up.

One of the reasons of course that happens, in those days of astronomy, if you dealt with the solar system or planetary stuff you were sort of shunted aside from the rest of the astronomy groups. Because you want to look out at the galaxies and the stars and everything else like that, who's going to worry about the solar system? Of course later on they discovered hey, that's where the money is.

But Gene basically felt that astronomy was an important aspect. I think we had Leonard Nimoy visit us once during spaceflight operations, but when you're there and you're active and you're a part of that, your adrenaline is up. "Oh, you should go take a nap. Go upstairs," he would say. Gene would be constantly working back and forth. What he said on one of his reports, about at least 30 hours without sleep or something.

My wife was at home. We had three children, and she called and said, "Justin." She always called me Justin. "Aren't you coming home for dinner?"

I said, "Honey, I'm sitting here at an historic moment in the entire history of mankind, and I've got to come home for dinner? No thank you." That was the way that worked. It was a heady time.

JOHNSON: We talked about Surveyor and how there was worldwide attention when it landed. What was that like? Working at JPL and working in that environment, you were very concentrated on what you were doing. This was in that buildup to Apollo because the president [John F. Kennedy] had made that announcement that we were going. Then President [Lyndon B.] Johnson was continuing that. But there was a lot of media attention. Talk about that for a minute and how much attention was on what you were doing in your group and JPL and that work on Surveyor.

RENNILSON: I remember matter of fact I was in a car riding to American Optical in Massachusetts at the time, because we were interested in a new optics, fiber optics, different ways for a new kind of technology. The driver turned on the radio, and there was Kennedy giving the announcement. When I first heard that, I was hmm. Because JPL has always been and still is the robotic interest. All of your missions that are out there are robotic. Wasn't any man involved.

We felt that was a little premature. Matter of fact, Kuiper used to say, "The problem with NASA, they want instant science, and you don't have instant science." If you're going to explore something, as you do on the surface if you're a geologist, you set up a camp." Jack [Harrison H. Schmitt] said that. How many hours did we spend on the Moon? You just touched it. If you were a geologist, you would have put up a tent and you would have stayed there for two or three weeks to map that whole thing. We didn't have that opportunity. So, we always felt that we were premature, we should do all our homework first, send a lot of robotics, examine what we need to do. We need to do that on Mars, the same thing. We are doing it on Mars.

There are certain circumstances where the human being is going to be very important. Jack, thank goodness, proved that by finding orange soil on the Moon. You have a gray Moon. The very first front cover that *Life* magazine had when Surveyor I landed, "the true color of the Moon". Because everybody said, "Well, it's a gray Moon, do we have color?" We had our photometric target. We had a gold tip on one of the thrusters and you took that picture and you had to create a color picture from it, which we did. Because you have a filter system. You have three filters with different sections of the spectrum, the wavelength, you take those three, you put them together, and you have a color picture. Today that's automatically done in a device with a little tiny sensor. But in those days, you had to do that, all three black-and-white pictures and put them together. We built an apparatus to do that as well. I was in the first national press conference to talk about that color.

That is the direction that we had to do. I would say we had already established at JPL techniques for examining and extracting real important information from any image whatsoever.

We developed a whole slew of individual apps or programs that would go back and attack every one of the digital images that you had.

Often when I'm talking, I give a little commercial, because the Chinese have a saying that "when you take a drink of water, think of the source". Think of the source, the Photoshop, Lightroom etc. Everything else, all of that technology came from JPL. They did it in an Image Processing Lab [IPL], and that was headed by Fred Billingsley who wrote a book on that subject. Houston and the NASA program were well aware of what JPL was doing.

At the very early beginning we had a relationship with IPL, JPL and Houston here in the Manned Spacecraft Center [MSC, later renamed Johnson Space Center]. People like Richard [W.] Underwood that was responsible for all of photography here in the MSC was a good friend, and we worked together. They would send requests up to the IPL and it would be worked on, on the pictures. We did that throughout the entire Apollo missions.

We were not isolated from that standpoint. We were integrated because we had this digital capability. Then later on of course after Surveyor ended, Gene came to me and he said, "I'm going to move down to the campus because I'm taking over the Division of Planetary/ Geological Sciences, and I want you to come with me. I want you to be a part of that Lunar Geology Exploration Team [LGET]."

Together with Henry [H.] Holt who was a member, a geologist, of the astrogeology group, we were responsible for the photometry, all of the settings that the astronauts had to do for the data camera on the Moon, all of that kind of thing basically stemmed from our work in Surveyor. We just continued it on the Apollo Program.

Henry and I provided the albedo maps that the astronauts used in their traverses. We did that on some of the equipment which today would be considered pretty primitive. We had a special Joyce-Loebl & Co. [Limited] microdensitometer and you put a film in there and you turn that on and take a very, very small part of that film and move that all the way around. You would load it, and it would be computer-controlled. That image would be done overnight, all night long. You'd get that image. Today you go click click and there it is. But in those days, we used the tools that we had.

JOHNSON: Were you already working in that once Apollo started with the geology? Were you already moved over into that?

RENNILSON: Yes.

JOHNSON: Talk about Apollo and what you were doing during that time and what you remember of the landing of Apollo 11 of course and then Apollo 12 when they brought part of the Surveyor back.

RENNILSON: Yes. Probably should mention, and you probably know that from all your information, the lunar geology exploration team consisted obviously of a chairman, the astronauts, and a group of geologists and those like myself, which were astronomers, optical physicists, there were not too many of those. Henry Holt actually learned a lot of optical physics. We would have working groups occasionally with some of the astronauts. The astronauts, the ones that were on the surface, were a part of that team. Actually I think the one as well in orbit, all three would be involved in writing the initial preliminary crew observations, and so on. They were in the meetings that we would have.

There was a selection of where we were going to go, which EVA [extravehicular activity], what craters they would look at, the names, and so on. That was all done by that team. They would then have to be implemented by a whole bunch of things. One of the things we had as involvement—because I had done a lot on the camera with Surveyor and everything else, and I had also learned a lot in Berlin—we needed to calibrate these cameras, the data cameras the ones that they had on the Moon. Just a couple of days ago I was working with the lunar planetary lab at University of Arizona, and at the time I came in, John Anderson has been instrumental for four years now digitizing all the 70-millimeter film that we have from the Surveyor, and he said, "Well, there's an interesting fellow giving a talk tonight, and it's about a book that he's published called *Hasselblad Compendium: A Complete Listing and Description of All the Cameras, Lenses and Accessories Made by Hasselblad AB.*" [Written by Dr. Richard N, Nordin, Associate Professor, LPL, University of Arizona, 2003.] It's about that thick. Very good. He gave a talk on that. [One of my fellow students in Berlin went to Zeiss in Oberkochen, Germany, and headed the photography section responsible for the Hasselblad cameras the astronauts used. Sweden built the camera and Zeiss the lenses, and the complete cameras were shipped from Zeiss to MSC. A few years ago I met the President of Hasselblad. Small World! The story in more detail is in one of my talks at JPL.]

My work for Henry and I to come up with, first of all, what kind of film should we use. If you're doing photometry, everybody said, "Well, why didn't you choose color film for the whole thing?" First of all, the Moon is pretty gray, and except for a couple of people finding a little bit of green, that was on [Apollo] 15, and of course Jack's orange soil, we figured that if you're going to extract photometry you want to use black-and-white. You always have a black-and-white cassette you could load.

That required a documentation of the samples. That is sort of unique because you want to take a picture of what you're going to collect first at maybe a couple of orientations with the Sun behind you, and then you want to take a picture after it's collected. The reason why you do that when you're getting involved—and I hope I'm not digressing—in Apollo was when you have the sample coming back and you could measure these, and we actually ended up generating equipment at Caltech as well as other places and measuring it. When you do that you have a small sample, but you have a huge picture of everything else that's there. If you can measure some of the properties of that sample, then you can make an assumption that's similar to what else you see, that we didn't collect, and use that. You're expanding your knowledge with something that you have not retrieved.

That kind of thing is very important. But it required looking at your film, finding the characteristics of that film, giving directions what kind of f number [aperture of lens] you need, distances, all that kind of thing. That came up on their cuff. You could look it over. There's a little decal on the top of the Hasselblad cameras. I don't know if I'm answering everything that you asked.

JOHNSON: We were just talking about your memories of what you were working on for Apollo and then Apollo 12.

RENNILSON: Yes, 11, we had an involvement. Gene was the only one that I remember—oh no, I think Jack was there too—when 11 first landed. Henry and I were in the auditorium because most everybody not directly involved in that location viewed and listened on a big screen.

Now the time limit was very short they were on the surface. They were anxious to get them back alive. Consequently there wasn't a lot of interaction with respect to the geology. I do remember one little comment after it landed and we were all enthused that Neil [A. Armstrong] did a great job, he was the most perfect guy that they selected for that job. Couldn't be any better. We also said, "But we need a geologist on the Moon." I remember everybody sort of laughed about that. But it took us a long time before we got one. Matter of fact, I think people probably understand that Jack was originally assigned for 18. We mounted a huge scientific effort to tell NASA, "Hey, keep your promises. You promised that you'd have a scientist on the Moon." So they flipped. I think Cernan was not too happy about that. But afterward Jack proved that he was really" the person."

During the interval of time between missions, we had an interaction with the astronauts on things like the photometry, taking the pictures, a bunch of other things, and especially on the color aspects. The way that interacted is that you would meet with Jack or someone else and you would talk to them. You would not call up a group of astronauts and talk to them. That was no-no. You worked with one person. They in turn would go to the astronaut group and explain what they learned and maybe bring them up to date.

There was a lot of field geology work with all the astronauts out in the field. Henry was out with those for quite a bit. I was not. But we had given presentations to these people of what to do.

There is one story, which people have forgotten but I think it's worth bringing it up. In the early stages where you had these teams, Gene initiated, and when Gordon [A.] Swann took over, together with Ray [Raymond M.] Batson, who was a cartographer at astrogeology, said that we need a new camera, we need one camera that we can take to the Moon that's going to give us everything in terms of optical properties. It was called the Lunar Geological Exploration Camera, LGEC. This consisted of a camera and we let a contract to [C.P.] Goerz Optical Company in Pittsburgh, a Swiss company in the United States. They were going to build a 35-millimeter camera which consisted of two lenses and a telephoto in the middle. Behind each one of those two lenses, which give you a stereo view, you had 3D, you had a series of three color filters and three polarizing filters, and then you had a telephoto in the middle.

When you get done taking a picture you would advance the film, and you had nine exposures that you could use, and you're capturing everything you need to look at in that particular sample, both the color, the polarimetry, the photometry, and high-resolution imagery. I was a monitor on that camera's project. We had several others who went back, and we worked with them consistently. I think that whole project was well over $1 million, I'm not sure, you'd have to look at that. That was fine. But in the end result you present something like that to the astronaut crew, and it's like talking to the prima donna in front of the stage in the opera house. "I don't like the way the chorus is going on. Fine, we'll rework that part of the opera." They said, "No way are we going to take something that complicated to the Moon."

It was probably just as well because on Apollo 12 unfortunately poor Alan [L.] Bean had his problems. It's really kind of sad because Alan went on to have beautiful paintings of Apollo and in everything he did. But his spot on the Moon was just sort of sad. It started with losing his camera and they had only one camera left. When you look at some of the mounting stuff on there, it was a handle with a knurled screw that you use when you're putting your regular camera on a tripod. I don't understand to this day how anybody with a design like that could have let it go through with all of the testing. I would not have done that - put a setscrew into a knurled head? You know how big a setscrew is? You know how big around it is? The tool to turn a setscrew is about that long and it's bent. Try to do that in your hand, you can't. Those things, if they get loose and fall, the whole handle falls, and the camera can't be attached to the suit. Throw it away. They redesigned that after 12. Thank goodness Pete's [Charles "Pete" Conrad] camera was okay and so Al did most of that photography.

Then he had the problem with the 16-millimeter camera, which had color when they came down from the LM. There should have been either a lens cap on that camera, or there should have been a sign in bigger letters, "Don't point it at the Sun!" It's really sort of sad and he probably felt very bad about that.

But these are things that in such occasions you have a human being and they can do something about it. They can react in a quick fashion. If [on Apollo 17] Jack had not stopped to take a pan at shorty crater, stirred up the regolith through his tracks, and raised his gold visor to exclaim "there is orange soil," and Cernan replied, " Well don't move it until I see it," that probably would have been missed. You had to be there!

We landed Surveyor 1 with a 10, 15 percent success rate. Maybe there's something out there that's looking out for us. I don't know if I've covered enough on that Apollo.

JOHNSON: Like you mentioned before we started, you worked with Gene Shoemaker and Swann and then [William R.] Muehlberger. Maybe just talk about the three of them and your interactions. Were they looking for different things? Or were they running things differently? Because Apollo 11 and 12 was for Shoemaker, Swann was 14 and 15, and Muehlberger was 16 and 17. Talk about them and working with them and what they were doing the same or doing different as the astronauts spent more time on the Moon and were able to do more geology and were trained to do that, and then that final mission when Jack Schmitt got to go.

RENNILSON: We were most of the time left on our own. I think Gordon, who was very involved, and of course Henry and Gordon were right in the same facility, astrogeology, so they were much closer than I was. I was out in Pasadena. The initial few years, so was Gene. But Gene didn't want to continue after 12. I think he'd had enough of bureaucracy, he went off and did something else.

But they all said, "Okay, now what we need would be an albedo map." We had to hunt for information that we had. When Surveyor 1 landed, the one thing that we really needed was location, where were we on the Moon. Ewen Whitaker because he had been involved in so much terrestrial measurements, and they had created the entire lunar atlas that we used initially to pick out the various sites, was done extremely well, and used the best photography that we had taken from the planet Earth on the Moon for that task.

But now that had to be put in an albedo map. Albedo is basically the range of low reflectance (darkness) and high reflectance (lightness). The albedo map is an indication, not exclusive, as to the kind of different materials that you have in the area. From the studies we'd done together with terrestrial work, the geologists basically said, "Well, I think that this kind of albedo range is prominent by igneous rock, in some other types." And we would zero in on that.

We would create the maps, dependent upon where the geologists said we'd like to go. Once we had enough information then we were relying on the orbiter photographs that brought us new information. When you look and you're landed in Surveyor 1, there was a bright area out of there which is over the horizon. There was a couple of other rocks over there, and Ewen would look at those panoramas and he'd look at the terrestrial maps that we had, and he said, "You know, I think this is where we are."

When he first did that on Surveyor 1, the people that were tracking and a few others didn't agree. He was convinced. What you do is you locate something that you really recognize, and you recognize this one and recognize that one. Now you take a line to those things and you resect, and you come back to one point. That's where you are. He was very good at that. He could pick that out because he'd done it for years. After Surveyor 1, boom, we knew within a few hundred meters, where we were.

Then they started flying lunar orbiters. The first at that time was Surveyor 2, Surveyor 3, and the rest. We got lots of information from that. But Ewen in addition had to do this on Surveyor 3. He pinpointed exactly where we were.

When the initial goal of Apollo 12 was announced, they said, "Well, we want to go there." The prime reason was not necessarily to go to the Surveyor and pick out the parts and bring it back. That was an afterthought, I guess. They said, "What we needed to do, we needed to go on the Moon where we exactly wanted to go, because the rest of the missions in Apollo we're going to pick out a location based upon the albedo maps, based upon what we think is there, and you're going to go there, and we want it to land within a kilometer. One thousand meters, that's pretty far, but we want something even closer."

The whole idea of going to Surveyor 3 was driven largely about this point, going there. Now they said, "Now if you're going to go there, why not look at the Surveyor, see what they have, and then bring something back?"

There was another little aspect of Alan's task. One of his tasks on the second EVA was to take pictures of the entire Surveyor before they took parts off. We had a unique landing on 3 which was not programmed. Remember before I said on 1 they're coming down on these vernier thrusters, and they cut them off at 13 feet and drop to the surface. We had radar and attitude sensors, four beams. Three beams gave the spacecraft stability, and the fourth was locked to Goldstone and gave us our velocity. It would be the control beam that would turn off the thrusters at 13 feet and drop to the ground. For some reason we don't know, we lost lock with Goldstone. The verniers, the thrusters, kept working at 13 feet all the way down. The amount of thrust that the thrusters had was about equal to the weight of the spacecraft, so it lifted off again, went over, then landed, and then it landed again. So we had three footprints from Surveyor 3. Coincidence??

Alan went over to take pictures, and here was a nice footprint from pad 2 right beside the pad. The footprint was made by the bottom of one of the leg's pads, made out of honeycomb aluminum. Back in the old days when they used to build airplanes, they would take aluminum foil and they would be glued, together in a hexagonal pattern.

This way with a hexagonal pattern vertically, it was very strong horizontally of course it wasn't. They built a lot of aircraft wings out of these things. The footpad that we had on three of the legs were built the same way. We covered those with a thin sheet of aluminum on the bottom. When they hit the lunar surface, they made imprints and that pattern, this waffle-like pattern, was there to see. Two of those imprints from pad 2 came from two of the three landings.

The interesting thing about those imprints is that we found some particles of dust in those imprints. Dr. Leonard Jaffe, who was our chief scientist on the Surveyor program, did a lot of analyses, and said, "Now there's a bunch of dust clumps which we can't see from the pictures we took during the mission, Surveyor 3." They obviously came from the regolith that Apollo 12 had disturbed. When Pete Conrad came back, I remember meeting him up on the third floor of MSC, and he came back with a happy face—they were all Navy people, which is of course was another bond with me. They were jovial naval aviators. He said smiling, "Hey, do you like the rocks we brought back? How do you like them?" He was very good.

Of course he took a lot of chances. He rode motorcycles and that killed him. He said, "Well, I came very close." We had a little limit that said don't come closer than 500 meters away from Surveyor. He came in from the west and he curved around. I have a little diagram and you can take a look at that. When they did that, he came within 190 meters. He was very close, even though it was fairly high. We determined that a lot of our stuff, the dust and so on like that, was contributed by Apollo 12 coming in. You couldn't help, because you're going in on different material. The dust is a real different type of an environment than we've ever encountered. You have no atmosphere, so anything that you have seen here in what you do on the Earth is very colored by our atmosphere, and now you come in an environment, you are a total stranger, and stuff happens. Just think of individual electronic tubes and where the beam goes. That's all in vacuum.

We're still learning how to handle, lunar dust. We used to take pictures of it. The irony is if you're visiting a site that something else has laid down, like visiting the pyramids or so like that, you'd be very careful in taking pictures. Al wasn't. He walked over and all this beautiful imprint that we had on 3, it's all gone. But it has his footprints.

We did a lot of analysis on all those parts that came back that were very, very instructive. A large part of that investigation was handled by JPL. There's a book about so big on all the analyses we did. We had about I think, 40 teams looking at all kinds of things you could imagine on all these parts.

It's something we have suggested now that people are going out on other spacecraft throughout our exploration put something on the spacecraft which is unique material that will act as what they call a 'coupon'. It's not something you get from Trader Joe's, but this is something where if you ever go back and visit that spot and you take that unique material and perform analysis on it, you've got traceability, and a history of their environmental life. That is sort of a test philosophy that you have, and we recommended that.

Another thing that we recommended on this whole recovery thing, is these photometric targets. They've got those on almost every spacecraft now, because you have to have calibration before launch and then after launch when you're there, wherever you are, to see whether your imaging system is okay, following the same calibration you did.

The LGET was also responsible for the photometric and polarimetric investigations of the lunar regolith which required extraction from the data camera photography. Thus the team was worried about all the camera parameters, which required complete calibration of the data cameras that the astronauts used on all missions. We started that on 11, Henry and I. Some of the calibrations were done here at the Johnson Space Center or Manned Spacecraft Center in those days, or at the Cape [Canaveral, Florida]. We had special equipment. We had all of the photography people from MSC working with us.

We'd calibrate every parameter you can imagine on a camera, you have a regular camera, that you can use for pulling out all the important aspects of optical properties from your image. Those were really documentation, and we did that, and I think we set up a procedure that every mission that we're going on now has that. We were the groundbreakers.

JOHNSON: In talking about the cameras, I don't know during that time period how much changed. But now technology changes daily, and you began working with this in the optics area, late '50s, early '60s. Then starting with Ranger all the way through the end of Apollo. Was the technology, like the camera technology, was that changing during that time? Or were you working with what was available at the beginning of the program and then that was carried out through the end? Like they did with the computers for Shuttle, the computers pretty much stayed pretty basic on the Shuttle. Did the cameras stay the same because you knew the technology? Or was that changing rapidly?

RENNILSON: The rule that existed in those days, you'd have a technology level. At some spot in that development you stopped. Everything was frozen. Depending upon everything following, it could have been frozen for six months, could be frozen for a year, it might have been frozen for several years.

The problem was with Surveyor there were a lot of new tools that were being used. The vidicon sensor that you had was a unique piece. It was used for most of the television cameras that were used commercially, NBC, CBS, all those people used that kind of tube. Ours was just a little different because we could not send images back at 30 frames a second because we didn't have the bandwidth for that. We had what we called a slow scan. You have one picture in 3.6 seconds. That includes—so you have a transmit, then you have to refresh, erase old imagery that's there, so you have something new. All of that required a slow scan.

When we had color filters, we attempted to fit the spectral response, that is the response as a function if you go from blue to red it has a certain shape. We followed an international system of color, from an international standards organization known as the CIE, which is the abbreviation in French of the International Commission on Illumination. This is an organization that sets up standards for colorimetry. Your derivation of your RGB [red, green, blue stimuli] if you pulled out your camera and your color image that is directly transferable to this CIE system.

The advantage of using the CIE system, if you take a measurement of a sample and you have now identified the color of that sample in that system, you can transfer that information worldwide and people could come and say, "Oh, this is what the color looks like". You don't have to have a copy of that sample."

That system was used and is used all the time. We had a color consultant by the name of Dr. Günter Wyszecki who was the head of the colorimetry section in the National Research Council in Ottawa, Canada. He was a German. When I studied over there, he had just finished his Dr.-Ing [Doktor der Ingenieurwissenschaften, German engineering doctorate degree]. He was also a good friend, and so I asked him to act as consultant to JPL, and he did. That was the system that we used for color.

During the time we were using this tube (vidicon) it was still sort of what you call magic, I guess you'd have to call this, like *The Sorcerer's Apprentice*. They would take a certain cathode which had a certain spectral response that we desired. This was a company in Texas just outside of Dallas about maybe 20, 30 miles called the General Electrodynamics Corporation. They were tasked to manufacture these devices, and we would come up with an idea of what kind of response we'd like to have, and they would mix it up, they'd put it on the cathode. Then they'd measure it.

We'd say from one, "Oh, that's really good, that's fine." They make the next one. What happened? It was really hit-and-miss. Almost every individual tube that we had had to be initially reconfigured for what we were using for that mission.

At the same time—somebody asked me this question in one of the talks—there was all new development. Get rid of that, use silicon, you don't have to worry about these tubes. But this was state-of-the-art. We were going to fly with that state-of-the-art, because that was it. The cameras on Ranger were state-of-the-art. You had a lot of new things coming up, but they were unproven. If they're unproven and you make a mistake what are people going to do? They're going to point at you. "Yes, you made a mistake, see? I told you not to do that."

There is a delay and it is a significant delay. I think right now we're at a position in our technology that detectors we have now will probably last for maybe another decade. Then we'll have something new. All of archival digitization that we're now doing we're doing in a new format called the Planetary Data System, which is what we're doing at Arizona. But it's configured so that in another decade or two there'll be a totally different format, but it will be transferable, so you're not going to lose the valuable resource you have.

I think we have not done—I hope now we're redoing it—thinking enough about the archival storage that we need to do on all these historical things. MSC and all of the Lunar Receiving Laboratory have done that. They said, "Just a little bit of these samples we're going to give out. We're going to keep the rest all hidden and all preserved. In another decade we'll bring out something new." It'll come out in spurts, which is an advantage, because you're going to have a new generation. You have a lot of new people coming up with new ideas, and they're going to use it.

We always hope that when our kids grow up, they'll be smarter than we are. Doesn't necessarily hold true.

JOHNSON: We were going to talk to you about that, the work you're doing now, and how it relates to Surveyor and what was being done then. You talk about the archiving. When Surveyor, when those images were coming down, you mentioned the 70-millimeter. But the original TV, as you said that slow scan.

RENNILSON: Slow scan, yes.

JOHNSON: Okay. Then it was preserved on the 70-millimeter film? Is that how it was done?

RENNILSON: I'll talk to you about the ground data handling system. What they had, everything ran as an analog aspect. You had signal transferred on a radio wave. It came out from the sender, from the spacecraft. It would be recorded on magnetic tape. The tape would be about 1 inch wide. It required a huge apparatus built by Ampex and it would move at 60 inches per second in order to capture the entire bandwidth on that tape.

From those tapes they would be replayed into what we called a flying-spot scanner. Now this is an electron beam that illuminates a phosphor, very very smart phosphor. It would write what they were reading from that mag tape onto film. That film was 70 millimeters in width. That's two and a three-quarter inches. Each image would be 4 inches in length with a 48x48mm image. The remainder of the image area would have the metadata. That's the kind of format. You could do processing on those mag tapes and also make copies of what you're doing, processing on 35-millimeter film.

The 70-millimeter film that Ewen Whitaker had stored on reels are about 7 inches in diameter. These were duplicate film copies made from the magnetic tape. Today we have no capability of retrieving those magnetic tapes. They've all gone. The equipment that used to read them is all gone. There was one little small exception which I should mention. Lunar Orbiter used a unique piece of collection film. They actually took pictures in the orbiter with a camera and with film. It was done by Eastman Kodak. When the film was exposed there was an immediate processing that they used, and it would have a chemical, film that would come in contact with the exposed film, and it would be developed. Kodak called this a bi-mat process.

When it developed you had both a positive and a negative. Then the orbiter used a flying spot scanner and the signal was read by a detector and that was then sent like we were doing Surveyor back to the Earth. It was recorded also on mag tape. A lot of this was done through JPL/IPL because of their knowledge of image processing.

When lunar orbiter tapes were stored, they had piles of magnetic tape, and one of the employees at JPL had an inkling that they were going to destroy them. We have people who in their wisdom, if you want to call it that, go through and they say, "Oh, this is a whole bunch of junk on this. That's taking up space. Let's get rid of it. Throw it away." They'd walk through and they said, "Oh, but you got a whole bunch of piles here with film and reels. Oh, we get rid of that."

One time they were going to take all the archival film that we had on Surveyor and get rid of it because they needed space. I asked somebody, "Well, how big is this space?"

"It's 3 feet by 3 feet by 3 feet." We had somebody walk through areas of JPL, and they'd look up. We had built a prototype optical system for one of the Mariner cameras, I think it was the Mariner 9. I don't know how many dollars were spent on developing a prototype. It was sitting above one of the cabinets.

A manager came through and he says, "What's that doing up there?"

I said, "Oh, that's a prototype for Mariner."

"Ah, get rid of it."

You go round the corner to one of these salvage people and you say, "Here's this optical system."

"Well, I'll give you 15 bucks for it." A lot of stuff was just lost because of that and it's a shame.

Someone found these tapes, she took them home to her garage, she kept them. About a year later somebody said, "Somebody saved it all." They got a group together, got some NASA funding, and they found some Ampex FR-1400s that they used for reading all these tapes. They had to get about four or five so they could borrow parts and get one operating. When they finally did, they could replay all these tapes back with now new processing equipment that they had, opposed to then, and they had really excellent results that they could compare with some of the images that the Lunar Reconnaissance Orbiter is doing right now. So they retrieved it. But except for the good graces of somebody that realizes what was going to happen, it would have gotten lost.

These are unfortunate stories. If you talk to somebody here that explored the Egyptian tombs, they would have been panicked. Archival information is essential. Of course I came from a discipline, the very first science was astronomy. Astronomy without archival storage is lost. You see something for the first time. Gee. "Have you ever seen this before?" You got to go back to the records. You got to go search this, and you've got that. So, archival information is essential.

Fortunately I think we've now got to the point we don't destroy those things. We look at some way to save it. I have a 4-terabyte hard drive, contains all 93,000+ images that Surveyor took. I can sit there, call them up any time I want.

JOHNSON: Those are the panoramic images?

RENNILSON: No. They are parts of a panorama. We started this from a website I found about almost 10 years ago. I was hunting in NASA about what Surveyor had done. They missed this, and they missed that, and so on. I said, "I wonder." Because there's still a lot of data you can keep on film for a long long time, especially if it's black-and-white film. I encouraged them to find where these caches were. It turned out that Ewen Whitaker realized that—obviously, as another astronomer—and had saved all these reels in a huge cabinet down below next to the mineral exhibit that they have. They have one of the largest mineral exhibits in the United States at the University of Arizona, if you ever get a chance to see that. It's a special room that was protected, relatively climate-stable, which it had to be in Tucson. He saved all of it. So, we started.

Some of the films were missing. We also collected at Flagstaff the same thing. Ray Batson, there were four us who were then alive, and we basically said, "We need to find out how we can digitize all this information." JPL had done a good job on saving that. Each image that you have consists of the image itself, and then beside that on that same image is a whole series of parameters related to that image, all details that was sent.

JOHNSON: The metadata you're talking about.

RENNILSON: Yes. The date and time, the azimuth and elevation of the mirror, the focal length, iris, shutter, etc., everything else was detailed. Including some of the temperatures that were there. That's all in a parameter base all associated with the image called metadata.

I said JPL had saved these reels, but they had cut these reels up into each image about 4 inches in length and put them in nice manila folders and labeled them by the date/time group.

Now to digitize each one of those, taking them out of a folder, scanning them, putting them back in again, I figured would take about one and a half man-years. That was out.

Then I hunted around and suddenly I found someone in Texas that lives just outside of Austin about 30 miles away. He has on his ranch, besides cows and so on, a wonderful high-tech facility that he'd built that will take all these 70 mm films, 35-millimeter, 16, on reels, feed them through with a light source, a high-resolution camera, a platen, and capture these things with a computer program at about seven frames per minute.

I said, "Gee, on the graces of that, with all the pictures we've taken, we could probably do that in three months." I contacted him, this is about I think it was like 2011, and he said, "We can rent it for you." All right. How much is it going to cost? It was less than 50K. I said, "Great, that's wonderful. Now all we got to do is find the money."

I ended up by writing a letter that we found this outfit and we could do that, now we need funding. I crashed a regional planetary imaging facility at ASU, which is an organization all around the entire world devoted for the imagery from space. You can go back and find anything you want. Supposed to be organized. They had a meeting in Tempe which I crashed. Because I had developed this letter, and there were four of us who were still alive, and I sent it around to all four, Ray Batson, Henry Holt, Ewen Whitaker, and they all signed it. Somebody said, "Why don't you come up to the executive meeting when we get all done with this meeting, and present that letter?" I did. I sent it around, they all read it.

I said, "Well, these are four experimenters. We were all part of that team. Now we need financial support and we can digitize everything, so it's not lost." There was a Mike [Michael S.] Kelley I think from NASA Headquarters involved in planetary studies, and he suggested, "Well, you need somebody to make a proposal to get a grant from NASA. It has to be a full-time faculty member." One other fellow, and I can't remember his name right now, he said, "Now Google does research and they offer funds. Try that." We did, and they weren't interested.

As I was leaving a great big tall fellow with red hair came out and he says, "I'm a professor at the University of Arizona and my name is Shane Byrne, I'm an Irishman, and I got my doctorate at Caltech." He said, "I'll be glad to write that proposal." So he did, it was granted, and a little comment, "This is one of the best proposals we've ever seen at NASA, absolutely marvelous," they said.

We said, "Hooray with champagne, now where's the money?" It came finally!

We started about a little more than four years ago. We hired one great guy that was a cameraman, photographer, a ham radio tech, etc., John W. Anderson, that had worked with Apollo. He was the one in charge of the digitizing effort. They have a clean room. We digitized all these images. Took us a little longer than three months because several people had gone through the rolls, which were available with a reader. They said, "Oh boy, look at this image, that's really good." Snip snip snip.

JOHNSON: Oh no.

RENNILSON: Oh boy. If Gene were alive, they would have had it. But they did that. You have problems. A lot of it was stuck together with tape, and when you see something like that, you're out of sequence, so you've got to stop and rework and bring it back. It took us about five months, but we still did everything, and how we have it.

Now we can extract, from the technique we have, a whole slew of aspects. One particular area, now we've almost got to the point where John is generating every parameter that has to be associated with it. The time at which it was taken, all of the parameters, including the selenographic (lunar) location. When the camera is looking this way, where on the lunar surface is it? Selenographic location, and that's all there, because we did stellar observations during Surveyor. As an astronomer, we always look up. We look up so not to worry about all the problems that the Earth has.

When you do, just as the old days of the seafarers, you look at the stars and you find out where you are. You can do that and then you generate what you call mathematical rotational transformation, which automatically takes the camera azimuth and elevation, puts it in selenographic (lunar coordinate system). There's a lot of other things you can pull out from that collection that we're still doing. Shane, a planetary geologist and he's our PI, guides us, have meetings periodically.

The kind of information we're extracting We're putting it in a format, it goes to the Planetary Data System which is based up in Flagstaff, and then it'll be available for everybody on the Internet. You can go in and pull up a high resolution of where you've landed. We have some wonderful pictures of Surveyor 7. Surveyor 7 was unique because for all of the other Surveyor missions we were really instructed to look at Apollo landing sites. Initially they were looking for Surveyor sites when they had the Lunar Orbiter, and then it went to the Apollo sites.

The Surveyor Program was actually divided—I should start back at the beginning—into two sections. They had four missions which were devoted to engineering, to get all the information you needed if it had input into the construction and the development for the Apollo spacecraft. The LM and so on. When that was done, then you had the opportunity to use it for science. So we had a little bit of time on each one of the engineering missions, when they were all done looking at parts of the spacecraft and everything else, to use that for science, do our pans, and so forth.

Then for 6 we wanted to do the science thing, and NASA said, “No, we need one more Apollo site.” They had four individual sites which were devoted to the Apollo landing. The fifth one, we could go anywhere we wanted, so Gene said, “Let’s go to the crater Tycho.” If you look with a pair of binoculars at the full Moon, you’ll see a crater that has a bunch of rays sticking out of it, you remember that if you look at the Moon. That is the crater Tycho, it was named after Tycho Brahe who was a Middle Ages astronomer, great guy. Gene said, “I like that, that’s really good, but we’re not going to go inside the crater because I think that’s dangerous, so we’re going to go outside.” We went on one of the rims of that particular crater, and that was Surveyor 7. Beautiful area.

I have now a panorama that my son has done which takes all these individual images which have variations in brightness on one side or the other, because of the vidicon you had had a lot of problems. It was not uniform in the individual pictures. You had to take out that non-uniformity by adjustment in Photoshop, and then you had to put them all together in the right orientation, and you had a little bit of overlap, and you use that, you mix them all together. Then you had a little bit of artistry because he also does painting—from his mother. He ended up doing all that, and he makes a beautiful panorama, which I have. Covers about 130 degrees, it goes 93 inches in length and about 30 inches high, that big. I can stand and look at the Moon right in my hallway.

Anyway, this is the kind of thing that you could do with that. In 6 we landed, and we lifted off, that was another first for Surveyor, this is before Apollo did when they came back.

We went up so high, we landed, and we had a little of stereo on that basis. When we did that, we threw a lot of lunar dust up on some parts of our spacecraft.

Some went onto one of the photometric targets on our omni antenna, just covered it with a bunch of lunar dust. I was thinking the other day, I said, "Now we measured that. We have exactly the reflectance of each one of the targets without any material on it. Now we have dust material. You can measure that, and you have now a transparency and thickness of that layer that you've got on that surface." We didn't do that during the mission reports. These are things you can still do.

Took a lot of effort, and we still have the people involved.

JOHNSON: That's pretty amazing.

RENNILSON: It's interesting. During the space program I was often in Houston.

JOHNSON: It's changed, hasn't it?

RENNILSON: More times than I would like, and [Apollo] 11 was the prime example. When Henry and I were in that auditorium and when 11 landed, and we walked out, it must have been about 1:30 in the morning, maybe 2:00, and it was like a big gorilla had jumped on our shoulders. It was unbelievable. Richard Underwood, I was talking to him and a couple of other people. I said, "Now are you Navy?"

"Yes, I'm Navy, going way way back."

I said, "What did you do for air-conditioning?"

He said, "You get up in the morning at 7:00, or maybe 6:00, and you have breakfast and you start to work at 7:00 and you work till 11:00. Then you go home and try to relax for three hours. Then you go back to work, work till 7:00 at night. That's the only way you can exist." You stop to think, like this.

JOHNSON: Yes, it's a different environment. Usually if you come there's a few times a year where the weather is really nice and it's nice to be here. But the majority of the time it's either hot and humid or cold and humid. We have those nice days every once in a while, but it doesn't last unfortunately.

RENNILSON: It's overcast now too.

JOHNSON: Yes. Yesterday was lovely and then today is all overcast.

RENNILSON: Yes, it was nice. We have overcast skies where we are in San Diego because in the summertime you got the marine layer comes in. People are living close to the ocean, they may not see the Sun for a whole week. A lot of times. My wife and I live inland by 15 miles or so. But we have direct view of the ocean. Every now and then we get a call from people in Point Loma that we know. "Hey, what's for dinner tonight? We haven't seen the Sun for a week!" But you take it into account. Of course San Francisco, I grew up there next to the city. What did Mark Twain say? "That was the coldest summer he ever spent".

JOHNSON: Right. In Texas they always say, "If you don't like Texas weather just wait a minute." Because it'll change for sure.

I just had a couple more questions and then Jennifer said she's thought of some things. We could probably talk a lot longer on Surveyor and those images, but I know a lot of it is documented. We're always interested in the human side of it, your experiences, and that sort of thing. I know you worked through the Apollo Program, and then you left and went on to something else. You started your own business.

RENNILSON: Yes.

JOHNSON: What made you decide to leave working with NASA or through JPL?

RENNILSON: It's called this green stuff. When you go as a senior research fellow at a campus, you do have initial support. It's not like a professorship. When you have a professorship, they guarantee your salary, at least at a minimum. I already took a pay cut when I left JPL, that was another reason why the JPL'ers with Pickering were going to be 80 percent gone, because they were getting a really good salary.

But my wife understood this was important. We had known Gene from the very beginning. Carolyn [his wife] lives up in Flagstaff. Every year I see her. She's now in a special senior home. Gene had built an absolutely fabulous home. He was awarded the [National] Medal of Science by [President George H.W.] Bush. You look out of his two-story house on the San Francisco Peaks with all the forest. You don't see a house, you don't see a road, it's like standing out for the first time. He built that in stages. Gorgeous home. It was always hard to say no to Gene.

One of his daughters lives very close by.

Carolyn left her home, and Carolyn has an honorary doctorate. She taught astronomy. But she is a remarkable woman, not only because she obviously survived the crash where Gene was killed, but she helped on all the observations right side by side with Gene.

When you're in astronomy and you're looking for detecting asteroids or other—comets and so on—you had what you called a blink microscope. You took a picture at this time, and maybe several days or months or years thereafter you get another picture.

You put them up this way, and it has lights, and you're looking at both of these pictures (glass plates). You can flip it back and forth. You watch when you register things that jump back and forth. The problem is that things that are artifacts on the plates also jump back and forth. So which is it I'm looking for and which is an artifact?

If you do topographic mapping, which geologists do, they live with it, you create stereo views, and when you do that you have it in 3D space, the object that moves steps out of the entire plane. The other artifacts missed in the noise. Immediately you pick out what's coming.

Carolyn was good at that. She could look at that and pick up something. We often stayed in Flagstaff picnicking with the whole family, knew all the kids when they were growing up, our bad and good problems. Gene and Carolyn were doing all this on an 18-inch Schmidt-Cassegrain telescope at Mt Palomar observatory.

On March 25, 1993, Thursday, I called up Gene and I said, "We haven't seen each other in a couple years, we're going to come up to Palomar."

He says, "Oh, great. Wonderful." We drove up there. Gene greeted, he says to my wife, "Oh Renate, you're a sight for sore eyes." She was a good-looking woman. Anyway, we sat there, and he says, "Well, it's kind of cloudy. We picked up something last night which is really interesting."

I said, "What was that?"

"Well, first of all we had a couple plates. We had these plates that had been sort of opened a little bit in that, exposures, so maybe we could just forget about it, throw it away."

Carolyn said, "No, let's take some pictures." They took pictures. They are developed and Carolyn is looking at these. All of a sudden, boom, all these little things that show up like a string of pearls. "Look at this, Gene."

"Oh, that's probably an artifact. Forget about it." He looks at it. "My God, that's right." That was the very first—this is the next day after they discovered the comet. David Levy, a writer and amateur astronomer and a French astronomer visiting at Palomar, P. Bendjoya, were also there. Then they had to call Kitt Peak, because any time you observe anything astronomically, you have to go to the main headquarters which is back in Cambridge and get some other observatory to confirm it.

Kitt Peak in Arizona went to the same coordinates. "Yes, we got it." Two days later.

We didn't know at the time, but all of those particular comet parts were going to impact Jupiter. In '94 it impacted Jupiter. Gene for the first time was able to watch an impact. Of course it came by way of the Hubble [Space] Telescope, but it was fantastic.

All of his effort, they sometimes call him the impact man. David wrote a book entitled "The Man Who Made an Impact" He was the one that started the impact studies. All the stuff that he did, so he was rewarded with that. Unfortunately he didn't live and it's a shame.

Those were moments that you treasure when you go through life. I lost my wife 15 years ago. There's a reason why you continue to live. I had a good friend from the Visibility Laboratory, worked for years, great guy. I went to luncheon on Wednesday with a couple of other people from the Vis Lab. We always get Mexican once a month. I got on a train Wednesday night. Yesterday I saw something on email that we're going to have a celebration of life at the home of this friend. You get on the train, there's no communication. You'd think they would have some Wi-Fi, but no.

I didn't know it, and then I got an email. It confirmed that he passed on with a massive heart attack the next day on Thursday. They're happening; I'm the only one alive. I don't know how many people are alive in the lunar geologic exploration team, that's another question to ask. Only four of the twelve that walked on the moon. Is Muehlberger still alive?

JOHNSON: No, he passed away a few years ago.

RENNILSON: You got all of that. Gene is gone. Every leader of that team is gone. Henry Holt passed away. The only one.

JOHNSON: That's why we're trying to capture some of this information, I think it's important.

RENNILSON: I know, I know, that's important. I think as Jack said once, he said to honor everybody, he says, "Remember you're a part of that 400,000 that did it all."

JOHNSON: Exactly right. I was going to ask you another question about Surveyor 1 just thought of. Were there any surprises with that, or any disappointments that you want to talk about, about the Surveyor Program?

RENNILSON: There were a lot of surprises, yes. I think the beauty is—as [Edmund] Hillary said when they climbed [Mount] Everest—that for mankind we relish challenges. We can't exist without them, regardless of what it is.

To the Surveyor Program, we were surprised from seeing all the dust and rocks. When we landed 7, we said, "Now we're going to go there. We don't want to go in the crater because there's a lot of rocks there. We'll see if it's all right." We landed, great big rocks about this big not that far away, and we landed pretty much level. My God. Now that was a surprise. And it was a good surprise.

But the other thing we did, we happened to have a camera on the spacecraft, which was tilted. There's the big mast and you have the two, solar panel, planar arrays. Then the camera was tilted about 16 degrees at one particular azimuth orientation. Now why was that?

It started in '61 and I mentioned before there was oodles of experiments that were going to go on. We had four cameras, so one in each 60-degree sector. Our stereo coverage would have been there. Complete coverage would have a down-looking camera. We really would have had fantastic coverage. Then all of it got thrown off because of the Centaur, and the weight was 2,500 pounds beginning, we ended up with 2,100. All of those other experiments were gone.

Now you had to be able to see all those instruments and operate them, it, so that required the camera titled at 16 degrees. Now the problem you have with 16 degrees is that you have now an orientation which involves the camera to the spacecraft as well as the spacecraft to the surface. You're going through two rotational matrices which you have to measure and determine.

All of that was really a task. We recommended many times to Hughes, "Please put the camera straight up because it's easier. Then we have only one rotational matrix. It's a lot easier to do all kinds of things." If you look at a tilted camera and you're looking at the horizon you have a curve that looks like that, a sine curve. When you're putting the images together as Ray Batson did, you've got this mosaic curve structure.

Now you can flatten it up, Photoshop and everything else like that. But it's disturbing. Hughes kept putting us off. I can say why, because they would have to go back, cut off the struts as mounted, and remount it. Now turns out that those struts were easy because that's what Alan Bean did. I think his task was to cut it. He has this big huge cutter. They wondered what kind of a cutter they had. Oh, just the kind you use in your garden. They would snip, and each one of the supports that supported it were cut cleanly. You pick the camera up and put it away.

They tried to cut one of the tapes that we had on the scoop that measured the surface mechanics and picked up soil and deposited it in several areas. That was hard to do. It didn't click, they couldn't cut it. All of a sudden it broke, and what happened is we had a band, that went around and was welded, or soldered I guess, to that part, and that came loose. Whether that was the environment? They were able to pick the scoop up and bring that back, and a couple of other struts. All of that was very valuable.

When we landed in 3, we landed in a crater. It was a big crater. We didn't know that ahead of time. About 200 meters in diameter. We landed at an angle, an angle was about something like 12 degrees. We're tilted. It turned out we were tilted in the same direction as the camera was, 16. You add 12 plus 16, now you can see the Earth. We couldn't see it at a narrow angle but in wide angle. One section. We saw a solar eclipse.

Now one edge of the mirror stopped what you can still see, but it was a small image, it's like 40 by 40 pixels. Interestingly that's another point. JPL invented the word pixel. Anyway, we had all that. Then later on, a couple days later, we took the very first color pictures of the Earth from the Moon, the very first, that was two firsts for Surveyor.

We also in 6 lifted off before Apollo did when they left. We landed a distance away. We photographed the Earth because we were in the southern hemisphere for 7 for a whole 24 hours watching it turn around. We looked at a whole bunch of things.

Matter of fact, there was an interesting picture. I like to show that one. Look at that. There are beautiful cloud patterns when we analyzed the solar eclipse. Now you've got an atmosphere which is about 65 kilometers above and the light is refracted by the Sun through there. Like a sunset most of the blue is gone but the red and pink and yellow is there. That was our picture.

There're little blobs or beads we called them that you can see, because what was that? There was no cloud cover, there was no blockage, so those things Ewen Whitaker went in and evaluated. We had several years before 3 a satellite moving around the Earth from ESSA [Environmental Science Services Administration]. That monitored cloud covers of the entire planet. One in northern hemisphere projected and one in southern hemisphere. Gene knew all this, so the first thing we did when we got those pictures, he calls up the Director of that Program, he says, "I want you to send me pictures that you took at exactly this date because that's when we saw the solar eclipse."

We got all those pictures. Ewen Whitaker gets in, and he draws a line on one of those projections which is the line between day and night, that's the terminator, and all of a sudden it cuts through. No clouds, and there's clouds. Now you look at that in terms of its latitude orientation, and you look and find out exactly where these beads are in our eclipse image. Aha, see, that's a bright area, no clouds. Oh, dark area, clouds.

We did all of that. If you look at the picture that either Alan or Pete took, on the way back they were about 35,000 miles away from landing, it was pretty close, and they capture a solar eclipse. They had a little bit of luck, so there's a bright spot on one side. You can go back and take a look at those images.

Right at the very top of that image is a little bright spot there, a gap, a spot and another gap, which is what we saw on the Surveyor 3 images. Now the problem you had in Surveyor is that our resolution wasn't very good. If you look at a star, it was always spread. If you were standing on the Moon and looking at a solar eclipse, it would be just a thin rim, that's all. You see that in the 16-millimeter pictures that they took before coming back.

JOHNSON: I was reading that I don't know when you first saw it, or it was seen. Something about there was dust on the horizon on the Moon and now you've been able to see more of it since.

RENNILSON: Now you're talking about my PR sell. David [R.] Criswell who lived right here in Houston, approached me when I was at Caltech, because we had seen this phenomena on four of our five missions. When the Sun went down, we saw a bright line along the horizon, and we called this "horizon glow." This bright line, especially on Surveyor 7, where the horizon was very close, it was like 150 meters away, followed the exact contour of rocks right along the horizon. Because we were in the southern latitude, the path of the Sun goes down at an angle. We were about minus 40 degrees southern latitude. When it does that, you can see this entire event moving sideways.

People like Tom [Thomas] Gold and Bruce [W.] Hapke from Cornell [University, Ithaca, New York] proposed that there is an electrostatic field that gets generated as the Sun goes down, and that the dust is levitated in this field at a certain height. Now the Sun is below the horizon, and it shines through this cloud, like the Sun behind a cloud. The cloud follows the inclination of the sun's path. So we wrote a paper and it was published in a journal called *The Moon*. The editor of that journal was Professor Zdeněk Kopal, a great man, he worked a lot with not only Ranger but Surveyor as an astronomer and headed the Astronomy department at Manchester University.

David and I worked together for two years with the magnetic tapes at JPL and he came up with the theory. The astronauts were clued. Gene Cernan had a couple of sketches that they had. But you're sitting in orbit, and now you're seeing something that might be that high (3 feet), something like that that occurred. Pretty hard to see that from orbit and pick that out, but it's there. We saw very definitely examples from the other missions, just a little spot. In Surveyor 6, we were prepared for it took many images. But we didn't start looking till many hours after sunset.

Last year they had the 50th anniversary for lunar science just north of Houston. Ron [Ronald A.] Wells who works a lot with Jack because Jack does all his memories online, he has a 12th man on the Moon now series.

After Jack's talk, I went to say hello as. I hadn't seen him for a couple years. We greeted each other and then I brought the subject of our horizon glow up. I said, "Well, I'm still waiting for somebody to take a picture, 50 years ago of that horizon glow. The Chinese landed." The first thing I said when they landed, "My God, the Chinese ought to be doing this." Connections of others to the Chinese mission were told they turn the cameras off about 18 hours before sunset.

I come back and I said, "You know when Surveyor 1 landed, they were still taking pictures the fourth lunar day." Each lunar day has 14 Earth days. Know how long that is? We stayed on our instrument 50 years ago and survived. You tell me you can't survive today? I can take out my cell phone and put it in a little cavity that controls all the temperature and I can take a resolution which is 1,000 times better.

That hypothesis is on the table. I asked Jack and he says, "Well, Jay, I know, but I can't buy it."

"Why can't you buy it?"

He said, "Well, I looked at all the rocks out there and they all looked nice and clean, and yet there's piles you can see right around the rock." Because one of the things you do, if we observe this phenomenon, is watch it one and a half hours after sunset.

Matter of fact, my son has taken all our images and made an animation. So you see that start out this way and there's a lot of a big cloud, and then it gets smaller and smaller and drifts this way, because the Sun is going down the opposite way.

Now you have something like that. I said, "Okay, Jack, you're a geologist, explain it."

Shakes his head. "I have no idea." So there is still something that somebody should see, because we observed it. If you're an astronomer and you see something for the first time, you're not going to go away. I want somebody to see that again. Why the Chinese haven't done it I don't know. Maybe they have. They're on the far side, maybe they have something like that.

But the interesting thing you have is that if it is true, and you have something that goes up in an event that lasts for an hour and a half, the Moon rotates. These particles may not come back in the same place. If they don't, it's an erosion process. Another possibility of what's happening on the lunar surface. We call that the regolith, the upper layer.

I built a special instrument at Caltech, which I called a goniospectropolarimeter, GSP. Now what this does is it sets a sample up and you illuminate that sample and you look at it from different angles, and you can change the angle of illumination completely. Then you can pass that view through fiber optics to look at its spectral characteristics, that is UV to IR, and the polarization characteristics at the same time. You're examining all the optical properties of that particular sample.

We used the GSP on a couple of lunar samples that came back with Lee [Leon T.] Silver at the campus. But if you look through all of the history of the crew coming back on all of the Apollo missions, the one thing that stands out more than anything else is glass. Glass stuff. Glass is a significant part, up to 30 percent, of the soil samples you get. You stop for a minute and you think okay, you're out on the road at night looking at the road markings, and that's my next job after Caltech and JPL, I went to work for Gamma Scientific in San Diego. That was the last time I was employed full time for an academic institution. They hired me to run the R&D department.

One of the company things they did, they built a lot of instruments for photometric measurements, which the space industry used. I developed a couple of instruments that would be used for measuring the (retro) reflective properties of traffic control devices, not only traffic signs, but markings that go on the road. Now when you do a marking on the road, you're putting glass spheres in together with that paint. That's the reason why the light comes back from a bright stripe. Very important for driving. The percentage of the glass to the rest of the material is about 30, 35 percent, the same thing you get from the glass in lunar soil.

A large part of the first discovery I'd say was when Surveyor 1 landed. The difficulty that astronauts have in visiting the unusual environment were two things, distances and contrast wipeout of all the contrast when they're looking down Sun. That is a retroreflective phenomenon. If you have pavement markings—you can see this yourself—that might have little markings or dips or something like that, and when the Sun is shining directly behind you, all you see is a bright line, you don't see any of the structure that's there.

You're on the Moon, it's a bright area, a halo right around your camera, your Surveyor. Everything is wiped out. To not fall or anything, the astronauts had to look right and left constantly, so they didn't hit anything or run into a crater. Have you skied, both of you skied?

JOHNSON: No.

RENNILSON: When you ski, you can have a situation called a whiteout and there isn't any horizon, it's completely gone, and you have no contrast. That's a dangerous situation when you're skiing. It's dangerous on the Moon, because you don't want to fall.

So they learned this way. We had a pretty good idea because our photometric function had found the brightest part is full Moon. This is a nice curve. We'd known that for years, the astronomers had measured that. We said "This is what you're going to see when you land, but until you had that picture and you see it from Surveyor 1, oh, it's bright, there it is. So you have lost your contrast.

The second thing, you have no atmosphere, everything is black, all shadows are black, unless you have something else that's bright that throws some light in the shadow. So you have a black-and-white life. Now when you have something like that, your problem is estimating distances. The one thing that I always remember from the Apollo Program was 14 when they had Alan [B.] Shepard. Alan Shepard really wanted to be the first to orbit, the first on the Moon, etc., etc. Unfortunately Alan didn't have quite the personality I might say, to be the first to land.

Now the team had picked out a couple of beautiful craters, and there was one that they were really interested in having them visit. In those days before the rover, he got a little cart, golf cart, so he'd pull that with him. We were communicating through the CapCom.

CapCom: "Alan, okay, now, do you see the crater?"

"No, I don't see the crater."

Five minutes later. "Al, do you see the crater?"

"No, I don't see the crater." He keeps going.

"Hey, Al, do you happen to see the crater?"

"No, I don't see it."

"Okay, well, cut that out, it's too much time you're taking." Everything in the timeline EVA was all written down and you just skip that and go to the next event. Then we got a Lunar Orbiter picture and he's like 15 meters away from the crater. It wasn't his fault. You can't judge the distance. That was a problem. That was something, a prime example.

They found samples that had a lot of black glass in it. Now glass is there, because, stop for a minute and think. You have an asteroid or a meteorite, coming in at this extreme velocity.

It hits the regolith with that kinetic energy, and it's turned into heat. It throws things up. There's no atmosphere. They fall down. If they're glassy and molten, they assume a glass sphere shape as they fall. They can also be clumps, which would still be glassy. Anything that's glassy, when you're shining a light on it, you're going to get light returned, even if it's a little bit. That kind of thing, we call retroreflection.

There was a program that Apollo brought in both 11 and 14 that was a series of retroreflectors. These were silica glass cube-corner materials. If you have glass that is made up such that each one of the three sides is 90 degrees exactly to the other light entering, it will reflect three times and go right back where it came from.

There will be a little bit of spread because you can't make it perfect. There is spread when it gets back to the Earth. People asked us especially on Surveyor 7, "Is this experiment that we've got planned for Apollo 11 going to work? It's a lot of weight. Is that really going to be advantageous?"

We said, "Well, not only can we help, we can look and send a couple of laser beams toward the Moon and we'll see if we can see those." We captured an image with our camera with two dots. One came from a laser at Table Mountain close to JPL. The other was from Kitt Peak in Tucson. There was pride.

Now the Russians on Luna 9 with their rovers also had retroreflectors built. The French built those. We have five points right now on the Moon where we have measured the distance from the Earth to the Moon accurately to a matter of millimeters. When you think of that, it is really fantastic. That was another thing that we did on Surveyor to confirm that.

The other thing that is interesting, there was a talk given by one of the researchers, Dr. Tom Murphy from University of California San Diego, and I asked him, "Now you've been monitoring this for how many years?"

"More than 50."

"Have you noticed over the years if there's a change in signal?"

"Oh yes, yes."

I said, "Oh, what do you attribute that to?"

"Dust." So there's dust and it's on there. A little bit of an extrapolation. If you create an electrostatic field you've got something like dust that goes up and comes down.

We went through all of the other possibilities. I have Harold Allen, who was a great engineer. He doesn't buy that. He wrote a whole section that said he doesn't believe our hypothesis. Said it was diffraction, a bunch of other things. David Criswell went through it, he said, "No, that's not diffraction." How about micrometeoroids? No, you don't have a flux large enough to create something like that. One of the Russian astronomers aboard one of the Lunokhod [Soviet robotic lunar rover] had a photometer that looked straight up to the zenith. When he took measurements, he didn't get zero response, which you might expect of a complete vacuum. It's possible that not only the lunar dust that we see coming up, but it must have finer particles as it goes up.

Somebody said, "Well, if they see something that could be maybe a kilometer in height." Maybe there was something. We still have things to get answered. If that's true, somebody ought to go back to that poor Soviet scientist and give him credit.

In 1982, I formed my own company and started building instruments like that to measure retroreflective devices. They're internationally standardized all around the world, they use them to monitor traffic control devices. There's a whole organization that handles the subject in the United States called the Society for Materials and Testing, ASTM.

It was interesting because matter of fact, I wrote a chapter in AIP Press "Handbook of Applied Photometry" where I use pictures from the Moon and say, "Basically here's glass. This is retroreflective." Bruce Hapke was a theoretical physicist at Cornell, and when we're trying to match the photometric function, he did all kinds of mathematical structures to explain the function.

Then years later, I don't know why it didn't occur to him, after the astronauts landed, he did consider the geological aspects. You couldn't see it with the Surveyor. Until the astronauts were actually there and picked this up and looked at the soil. Now you put that together. And that's a big component of that photometric function.

JOHNSON: Do you have anything that you want to talk about that we haven't talked about? Or do you think we've covered enough?

RENNILSON: About the only thing I did mention, you were interested in the organizational aspect.

JOHNSON: Oh, yes, yes, that's one of the questions I had earlier.

RENNILSON: JPL's history was as a rocket lab and worked with the army and the Huntsville facility under Werner von Braun. The Explorer Program (first US satellite) was jointly done with his organization and JPL. When NASA took over in 1959-60, the lab had to learn a great deal on directing outside contractors and there wasn't training in systems admirations at the lab. To go from a laboratory used to in-house operations to directing other companies was an on-going process.

The relationship with the Hughes aerospace group was very difficult for the first four years. I was the cognizant scientist on one of the experiments on board with no influence on the contract. Harold Allen, as the cognizant engineer, and Don Montgomery, from the systems side, were more directly involved with the hardware and later where JPL took over more control of the project. One important problem was coordinating between the two organizations.

We eventually found a way to set up communication by helicopter flight between Pasadena and Culver City, where the Hughes Aerospace group was located. We had three choppers at the lab, and they were in daily operations. At my, Harold, and Don's level, we interacted with at first a poorly equipped group at Hughes and we tried to urge them to hire optics people for the television camera, which they finally did in about 1964. We began to take over more direct responsibility for the hardware, such as the filters in the camera and the calibration of the TV system as well as the spacecraft. NASA stepped in on the higher level by changing some of our directors, but in actuality, because more of the upper JPL management were all Caltech grads, there was almost no friction between them, and even though offices moved the close communication continued.

As more knowable people were hired by Hughes, we began to work more closely together with ideas shared and problems solved quickly. The best example was the use of the integration mode of the shutter and electronics of the camera. At first the Hughes engineers resisted the suggestion in turning off the electron beam in the vidicon and opening the shutter to store the photons over a long time period, up to 30 minutes, and Harold showed them how to do that and they quickly agreed. That was a major step in allowing us to capture events which would have been lost except for that integration function.

Acting as the liaison with the PI and the lab was at times difficult because science and the engineering associated with an experiment don't often understand what changes in the hardware are required to fulfill the desires of the scientist. We had, however, no such problem with Gene as field geologist are used to equipment problems.

My final words are on the learning curve for working together as a team. This is sometimes difficult between experiments where there is "turf mentality" and a desire to control one's research separate from others. We overcame that on 7 where we had a malfunction of the ASI [Alpha Scattering Instrument] release mechanism and required the SMSS [Soil Mechanics and Surface Sampler] and the TV to all work together and solve the problem and retrieve great science. The time in mission operations was for me the greatest reward of the project because of the teamwork and camaraderie it instilled.

We had a great group. Matter of fact, there was a book, "NASA Exploring Space with a Camera. Edgar M. Cortright [NASA SP 168]. He wrote a book and a foreword by James E. Webb, the NASA Administrator at the time.

I miss a lot of the guys. One person that I really want to acknowledge, however, is Parks Squyres. When I first started at the lab, we had a lot of optics to do. We measured the optical system that went into the Surveyor camera, detailed. He built special apparatus, light sources for test targets, a spectroradiometer for calibrations.

For the color we had to take three black-and-whites positives, we put them together in a special apparatus to combine them and you look at that visually and photograph the result. That's probably the first time we would call the television camera a colorimeter where we actually measured the color all carefully controlled. The color image that we reconstituted in 35-millimeter film, we would give that slide to the press and we'd say, "Okay. Now when you make copies of that in your press, take a look and make sure that it's a good copy.

It's been an interesting life.

JOHNSON: Yes. Sounds like it. I want to thank you for coming today. We appreciate you coming and talking to us.

RENNILSON: You can use whatever you want in this interview.

[End of interview]