# Nevada Test Site Oral History Project

## University of Nevada, Las Vegas

# Interview with
# Byron Ristvet

## April 17, 2006
## Albuquerque, New Mexico

Interview Conducted By
Mary Palevsky

Oral history is a method of collecting historical information through recorded interviews conducted by an interviewer/researcher with an interviewee/narrator who possesses firsthand knowledge of historically significant events. The goal is to create an archive which adds relevant material to the existing historical record. Oral history recordings and transcripts are primary source material and do not represent the final, verified, or complete narrative of the events under discussion. Rather, oral history is a spoken remembrance or dialogue, reflecting the interviewee's memories, points of view and personal opinions about events in response to the interviewer's specific questions. Oral history interviews document each interviewee's personal engagement with the history in question. They are unique records, reflecting the particular meaning the interviewee draws from her/his individual life experience.

Produced by:

***The Nevada Test Site Oral History Project***

Departments of History and Sociology
University of Nevada, Las Vegas, 89154-5020

Director and Editor
Mary Palevsky

Principal Investigators
Robert Futrell, Dept. of Sociology
Andrew Kirk, Dept. of History

The material in the *Nevada Test Site Oral History Project* archive is based upon work supported by the U.S. Dept. of Energy under award number DEFG52-03NV99203 and the U.S. Dept. of Education under award number P116Z040093.

# Interview with Byron Ristvet

April 17, 2006
Conducted by Mary Palevsky

**Table of Contents**

# Interview with Byron Ristvet

April 17, 2006 in Albuquerque, NM
Conducted by Mary Palevsky

**[00:00:00]** Begin Track 2, Disc 1.

**Mary Palevsky:** *Thanks so much for meeting with me this morning, and if you could just begin by saying your name, place of birth, date of birth.*

**Byron Ristvet:** OK. Well, my name is Byron Leo Ristvet, and I was born in Tacoma, Washington in 1947, and went to school there. [My] family had a long history of living in the Tacoma area; it goes back to when it was a territory, 1842. I just always had a knack for math and science. My dad was an architect, the first one in his family to go to college. Most of the rest of my relatives were either loggers or farmers. I do know how to milk cows and cut down trees and blow stumps.

I was very interested in science and was good at it, and I thought I was going to go into chemistry. Then I had a[n] opportunity to participate as a high school student in an NSF [National Science Foundation]-sponsored summer science program at the University of Puget Sound in Tacoma, and so I did that; I guess it was between my sophomore and junior year. And I found I really liked geology, and I was kind of an outdoors person anyway, and so I went into geology as an undergraduate. I went to the University of Puget Sound for my undergraduate degree. Lovely school. I don’t think any undergraduate should go to a school that has more than 3,000 students, just because of the personal touches you get, and you really don’t need all that other stuff as an undergraduate.

But anyway, when I went to undergraduate school was right at the start of Vietnam, ’65. I went through ROTC [Reserve Officers Training Corps] just because otherwise I was going to get drafted and I figured it was better to go in as an Air Force officer than to go in as an enlisted

Army type. And my senior year of college, I had the opportunity to get what's called an educational delay from active duty. I had applied for several graduate schools and I got accepted by all of them. I wanted to actually go to the University of Calgary [Canada] but the Air Force didn't think that was a good place to be. They didn't know at the time, I had a permanent Canadian work visa because I had worked up there in the summers as a geologist. But I instead went to Northwestern [University]. It probably turned out OK. I specialized in geochemistry, chemistry of coral reefs and also recent marine sediments.

When I came on active duty in 1973, I got assigned to the Air Force Weapons lab and let me tell you, that wasn't random. I fought to get an assignment there simply because I had a Ph.D. in geology and they wanted to make me an intelligence officer, and that's very common. You'll find a lot of geologists in the intel field because we know how to read air photos; that's the mentality behind the assignment. And in general that's good, but not if you've got a Ph.D.

So I was supposed to come do environmental chemistry in a brand-new group assigned to the Air Force Weapons lab that was starting to worry about waste water and sewage and all the unique problems related to the military. In fact I was supposed to come down and work on chrome and wash water from washing airplanes. A lot of chrome comes off. It takes very little chrome to kill a sewage lagoon. I solved that problem. But because I knew a lot about coral reefs, they sent me out to Enewetak and Bikini to understand the large-yield nuclear craters. At the same time, as a basic geologist, there was a thing called the MX [missile experimental] missile at the time and it was going to be a land mobile shell game kind of thing. They didn't know **[00:05:00]** anything about these great big valleys of the western United States where the concept was we were going to locate them, and this was for nuclear weapons effects: depth of water, all these phenomena that affect the ground shock and those things. So I and about four others, when I wasn’t doing Enewetak, I was running around mapping the geology of these big alluvial valleys. In fact there’s probably not too many square miles of Nevada I haven’t stepped foot in, doing that mapping, and also Arizona.

*And that would be to place the MX there?*

Yes.

*That’s where they would be—*

Yes, it was to see which valleys were the most suitable from geologic characteristics with respect to nuclear weapons effects, primarily the ground motion, because you wanted it in valleys with a deep water table so you didn’t get a reflection of the ground shock and things like that.

I also worked on the geology related to the current Minuteman system at the time; we had a thousand Minutemen out there. And talk about foresight, one of the things we did in that study was to decide, if we ever did a reduction in force, which Minutemen we would get rid of first, and that was based on which were the most vulnerable to nuclear weapons effects. And that’s really controlled by the geology. So that affected the upgrade of the systems, some stayed Minuteman Two, some became Minuteman Three. And today with the drawdown, that was the purpose behind it.

Then also, my first trip to the Nevada Test Site [NTS] was in early 1974 to assist in getting ready for a nuclear weapons effects test out at Yucca Lake called pre-Mine Throw Four. And pre-Mine Throw 4 was 105 tons of nitromethane in a sphere and it was tangent to the surface of Yucca (dry) Lake. At the time, the Air Force had a program where they were looking at using the big playas, the big dry lakes as alternate basing sites for the B-52s and the KC-135s because if we were involved in a nuclear exchange, they probably would not have a base to come back to and so this was a place for them to land; this was just to gather basic ground shock, cratering, and ejective phenomena on a playa. And so we did that test.

And of course while I was out there, we had another program going on. Of course in the early sixties through the beginning of the seventies, DNA, the Defense Nuclear Agency, tended to use technical directors from the Air Force Weapons lab, now the Air Force Research lab. That's where I was assigned. And so we had a technical director assigned on a shot called Mighty Epic, which was an underground nuclear weapons effects test; a big structures program, an underground structures program. The first really big one since the days of Hard Hat and Pile Driver which were done in the sixties at the Nevada Test Site. This was to look at the feasibility of underground command and control facilities both from a defensive and an offensive nature, and also to look at the possibility of putting the MX in what they called the safe, secure facility, i.e. something that you couldn't ever get at. I always found it funny, you know, it should've been called "deep underground missile basing," but then somebody would've looked at the acronym and realized what it was all about. DUMB. And it was.

*It was dumb?*

Yes.

*Why?*

Well, it's just you couldn't dig your way back out without somebody figuring out you're digging back out and then they're going to nail you. In terms of mitigation of the ground shock phenomena and all that kind of stuff and being safe and secure, fine. But where you get—you're very exposed: all of your umbilicals to the surface, your antennas, all those kinds of **[00:10:00]** things, even for a command and control facility—unless you communicate through the earth or some way like that. But it was interesting and that's how I started in the tunnels and that was in like July of ’74. And so, you know, I knew a lot about ground shock from what I was working on at Enewetak and the Minuteman stuff and the MX stuff. And so we had a follow-on to Mighty Epic called Diablo Hawk. Mighty Epic was executed in ’76 and then Diablo Hawk [1978].

In the meantime, I had decided not to make a career of the Air Force and so I was going to separate in September of ’77. And I had worked a little on Mighty Epic, which was my experience in the tunnels initially. And you have to remember, the tunnels were no problem to me because I had worked in northern Canada as a geologist and did a fair amount of underground work, so I had been in a lot of mines, and so it just seemed kind of natural.

I was originally going to go to an oil company, and I was actually going to go to the Chevron Oil Field Research Company in La Brea, California, at La Habra, California, Brea, California. And my wife was pregnant with our first child. Her mother lives here in Albuquerque [New Mexico]. She sort of wanted to stay close. In ’77 inflation was going through the roof, especially the cost of houses, and Chevron and I were having a little discussion about either cost of living or a one-time housing allowance, which incidentally they from then on offered to people.

*You made them do it.*

But I went ahead and took a job at DNA which was open, and it was a containment geophysicist job—just as sort of a temporary thing and I figured, we’ll have our daughter and then I’ll run off to an oil company later. Well, I never did, but that’s beside the point. So for six years I did mostly the geology and the geophysics related to the containment of underground tests, but also these structures experiments that we were doing as add-ons. And I was involved in a fair number of other DNA programs, including still trying to understand the craters in the Pacific.

And then in ’83 I went out and worked in private industry for five years. It was called S-Cubed , Systems, Science, and Software, which became part of Maxwell Labs and today the remnants are part of SAIC [Science Applications International Corporation]. And all I did there was just a continuation of what I was doing as a government guy, except only on the Pacific, because we were planning this big program called PEACE (Pacific Enewetak Atoll Crater Exploration). We actually went out with a drill ship and drilled the craters and all sorts of things and resolved how those craters really formed. At the time that was the biggest uncertainty in nuclear weapons effects, and if you took the conservative view about crater formation, it was driving the cost of MX, which was still in the planning stages. It hadn’t been cancelled yet.

*Explain that to me, why the uncertainty was driving the cost.*

Well, the craters in the Pacific were the only multi-megaton-yield craters anywhere in the world from essentially a surface burst. The craters were very broad and shallow craters, they were dish-shaped, whereas the craters that were formed from near-surface bursts and buried bursts out at the Nevada Test Site, not the collapsed craters, were bowl-shaped. And everybody thought, well, it’s because the low-yield-kiloton-type shots at Nevada **[00:15:00]** were caused by cold sources, i.e. the X-rays that come out of them are very cold; whereas out of a megaton-yield weapon they’re very hot in energy, and so the coupling was different, and so the calculations kept saying, no, they should be a bowl shape like in the Pacific. Well, some of us quickly realized, after we went back—and this is how I kind of got into this history stuff—I went back and started digging out all the old records at Los Alamos and [Lawrence] Livermore and photographs—I mean literally down in dusty basements and everything else looking for this stuff—and realized very quickly that liquefaction was a big factor in this. And then I started digging back in some of our old HE [high explosive] shots. We used to do air blast simulations up at a place called the DRES site in Canada, Defense Research Experimental Station, and it was near Medicine Hat, Alberta, and very shallow, ground water out on basically glacial till, alluvial. And all those craters liquefied. And then we did some shots down at White Sands Missile Range [New Mexico] and they liquefied. And I said, gee, you start off with a bowl-shaped crater and guess what? The ground around it is all liquefied and it just slumps in almost immediately and you end up with this big, shallow, broad crater. Not only that, but compaction takes place for weeks to years. And you know the people who really know about liquefaction are the Japanese and the people in Scandinavia where that's a real serious building problem. In fact, the Dutch commonly fire high explosives over areas to pre-liquefy it and settle it before they build on it. In fact, they came over to observe some of our stuff because of that.

So anyway, we resolved that question and the crater problem was resolved finally once and for all. But it's funny, while I was a contractor, I was still a technical director for the Agency, even though I was paid on the outside. And the only reason I left and became a contractor was I wanted to try it, i.e. a little more money, in fact quite a bit more money; number two, I could dedicate my time because our underground test program was ramping up again at the same time, I had to do this Pacific thing. It was sort of like a quest I had to resolve, so I made that choice.

I came back to the Agency in '88 and I was requested to think about coming back because we had had a major containment setback in the tunnels in '86 on a shot called Mighty Oak—

*And I want to understand that better. That's one of my questions about what happened with Mighty Oak?*

Well, we'll talk about that as best we can. And at the same time there was a real question about the Agency's credibility to conduct these tests. And so I was pretty much wrapping up the Pacific work and so I agreed to come back. And even though I came back at sort of the top of the GS [General Service] salary level, I did take about a 15 percent cut in pay.

*Let me understand one other thing about the importance of understanding—I want to make sure I'm getting this right. You need to understand what's happening with the craters on these megaton tests because you need to protect our missile systems against a possible big Soviet attack?*

Right, and you also wanted to know how effective your offensive warheads were against the very hard targets that existed in the Warsaw Pact, mostly in the Soviet Union itself. And so the difference is, let's say you throw a multi-megaton warhead with a surface burst, the Pacific data said it would have a radius maybe of 3,000 feet, so you're inside the crater, whereas if you took the bowl-shaped stuff, that same let's **[00:20:00]** say 5 megaton warhead would have a radius of about 1,200 feet. So the difference between 1,200 and 3,000-feet radius is huge when you look at CEPs, the circular error probable of a missile miss, that's well within the CEP distances. So in one case you would say 100 percent damage probability; in another case you might say 50 percent. So resolving that made a big difference to both the targeteers and how we were going to design the MX missile system; if we put it in silos or in shelters as far as the effects against it. So you were talking billions of dollars in terms of spacing things and all this and that, which is why in '84 finally the Office of the Secretary of Defense agreed to fund going out to the craters and drilling them. That was not cheap to take a ship out there, a commercial ship, and a fairly good-sized team of people, including a large number of excellent geologists and geophysicists from the U.S. Geological Survey [USGS], in addition to ourselves, and do this really comprehensive stuff. Those reports on the PEACE program are coming out finally. There's a bunch of open file reports and a couple of classified reports and things like that; but as a USGS professional paper—very few projects from the survey get nominated to be professional papers but those are—and so they're finally being published as professional papers.

*Interesting. And so by analyzing the crater, you can verify this liquefaction theory—*

Yes. Basically we verified that the craters were initially small, bowl-shaped. They didn't stay that way for more than a few seconds because they're highly unstable in this liquefied manner. That means the pre water supports the load, not the skeleton of the soil, and these are coral sands and gravels primarily, and they just flowed back into this bowl. But they actually continued to settle for up to a year.

Now there were actually accounts of people, too. I went out and interviewed a couple of gentlemen who were on the edges of a couple of these craters right after they were shot, and of course one of them was Bob Taft who still lives in Las Vegas. Another was John Malik who had passed away about five years ago at Los Alamos. And they would go back to recover neutron experiments. And Taft had a hilarious story to tell, and he was a great storyteller, about on [Operation] Ivy, Mike [1952], which was the first thermonuclear test and was expected to go somewhere around 10 MT and went at 10.4, and when I say “around 10” I think five to twenty was the planning. And that was for safety reasons. And public safety was always of premier importance in all of these nuclear tests—I think people think we were bunch of, you know, cavalier cowboys out there. We weren't.

But anyway, Glenn Seaborg, the discoverer of plutonium—passed away now about three years ago, '99 I believe—well, Glenn knew that there would be this tremendous flux of 14 MEV [$10^6$ electron volts] neutrons, the fast neutrons (we can talk about that today; we couldn't a few years ago) from the fusion reactions, and he was very interested in transuranic elements, those greater than atomic number 92. And so he put out on a radial along a causeway where the line-of-sight [LOS] pipe (it was actually a box filled with helium) from Ivy Mike back to the island, a string of uranium balls, spheres, on a stainless steel rope. And I think they expected the crater to be about 2,000 feet in radius or so. There's an old paper by Francis B. Porzell—another gentlemen who just passed away this year, and unfortunately I hadn't seen **[00:25:00]** Fran in about fifteen years. He retired from the Navy [Naval] Research Lab. But anyway, so they put these things out, and so Taft went back with Malik, and Taft was the radiation safety officer. Of course they left their badges on the boat because they knew they would max out, and they went back into a 5-to-10-R [Roentgen]-per-hour environment (of course they didn't spend more than about an hour on the island) recovering what are called foils which tell what the neutron fluence was or the neutron flux, whichever you want. And they're usually foils of gold or arsenic or uranium, plutonium, things that are activated by the neutron flux where they tell you the energy plus the total number of neutrons. And you want to recover them typically as soon as you can because these are usually rapidly decaying daughter products, the activation products, and/or fission products, so you want to look at them fairly quickly.

Anyway, so they get back on the island, and Taft's job, with a couple of Holmes and Narver guys was to recover this cable and get them back to [University of California] Berkeley [Radiation Laboratory] so that Seaborg could dissolve them and start analyzing. And so he did. And of course that's how Californium and one of the other transuranics was discovered; and as Taft says, `There I was out there recovering Seaborg's balls. I just got a lot of radiation and he got a Nobel Prize.` True story, and unfortunately Bob could tell it much better than I can, but it's well-documented. Even in the report, Bob did get credit from Seaborg for doing that.

But anyway, that's sort of a background leading up to that. But while they were on the island recovering the foils and stuff, there was quicksand everywhere. That's because the island was still liquefying. In fact, where they recovered a lot of the stuff, six, seven days later was under water because it had settled, you know, five or six or seven feet. And it took days to months to even a couple of years before all this comes back into some sort of an equilibrium or steady state. But of course they didn't measure the craters until several days afterwards. The earliest surveys were typically day-plus-three, day-plus-seven because (a), you were busy doing other things—you were popping these things off about every four or five days during the test period—as a result, you had crews that were not available, even for the surveyors because they'd have to go reestablish some ground stations, you wanted the radiation environment to be down at a fairly low level, and so that's what they did.

But it was going back and digging out all the original stuff, including surveyor's notebooks and stuff like that, and there were all these little innuendos about that these craters really did liquefy and so they were there.

*And the documents were at the labs basically, these things that you're looking at?*

The photos were mostly with Los Alamos. There were some Livermore ones. There were some at DTRIAC [Defense Threat Reduction Information Analysis Center], in those days called DASIAC [DoD Nuclear Information Analysis Center], not well-cataloged at the time, not captioned very well, not identified very well. Still a problem we have. Los Alamos currently up in its archives probably has about a million-and-a-half negatives of just the atmospheric test period. We have about half-a-million at DTRIAC and about 20,000 films. Livermore doesn't really have a good handle on what they have, nor does Sandia. And you know nobody ever has any money to spend on archiving.

*Right. I got the chance to interview Bob Campbell before he died and he talked to me about how important those photographs from the atmospheric days were and how difficult it was to come upon particular ones.*

Father Campbell was really good at helping me when I went up there as a lieutenant-captain first **[00:30:00]** few times to Los Alamos, and you know Bob had a nickname at the test site as Sweet Old Bob because he could be that way. And I think all of the test group directors or test directors for the labs and even DNA, the guy I worked for was sort of that way. They had to be tough as nails in part, but at the same time most of them had hearts of gold underneath. Bob was certainly that way.

I went up to Los Alamos, I wrote some letters, because I figured these photos had to exist. And so on my first trip up there, I go in and I meet this, you know, gentleman, Bob Campbell. Actually the first one I met was Bill Ogle, and Dr. Ogle was just one of these outstanding, outgoing, unbelievably brilliant guys. In the forward to a classified book called *A Return to Testing*, Johnny Foster wrote the preface, and Johnny put in it that Bill Ogle was equally at ease describing some complex scientific phenomenon to a craft worker out in the flats or in the tunnels as he was to the president of the United States. And Bill did both. And a very patient, very brilliant guy, and I wished I'd have known him better. He died a few years after I first met him. And he said, `Well, the one you want to talk to is Bob Campbell, and you want to talk to John Malik, and you want to talk to Stirling Colgate. You want to talk to all these`–and that's how I got to know all these guys back in about '75-'76 time frame. So I felt very much at ease when I started working at the test site, because I knew the Los Alamos people. I knew the guys out at Livermore, not so much the testers but the remnants of the old explosive excavation working group, which was the Plowshare guys: that was Milo Nordyke and Louis Circeo, and then I got to know Billy Hudson and Cliff Olsen who were containment guys. We exchange a lot back and forth and we have a really good working relationship. And I do with Sandia and we do with Livermore. It's just they're not as well-organized as we are, as Los Alamos is.

So you want to talk about tunnels?

*Yeah. Just a general question about the military, to help me understand these effects tests, and then I want to talk about both containment and the kinds of things.*

We did two types of testing, starting way back, and the [U.S.] Department of Energy [DOE] under the Atomic Energy Act, the [U.S.] Atomic Energy Commission [AEC], the McMahon Act of 1946, November of '46 which created the Atomic Energy Commission—I guess it was October—starting 1 January 1947, was concerned with the production and development of nuclear weapons. General [Leslie R.] Groves realized that the military needed a central point to turn to for this, and he really didn't want to turn nuclear weapons at the time, atomic weapons at the time, over to the control of the Navy or the Army. He felt that they were not ready to control them.

*Just because they didn't have the knowledge yet?*

Yes. They were still thinking in World War II mentalities of conventional forces and this and that. Just like when we started World War II, we were using World War I tactics, and it cost us a lot of lives.

**[00:35:00]** So Groves convinced Senator [Brien] McMahon and others to create the Armed Forces Special Weapons Project [AFSWP]. There was actually a lot of support from Vannevar Bush and James Conant and others that the military needed a sort of parallel group, and so it was originally, here at Kirtland Air Force Base [New Mexico], at that time Sandia Base. Kirtland was a base, but AFSWP was to the east of Kirtland, which was Sandia Base, and in addition another facility which became known as Manzano Base. But Groves was a man of great vision, there's no doubt about it, and it was the idea of having the two groups was looked on.

Anyway, effects testing really started in '46 with Operation Crossroads. And it's kind of interesting because at the time that the idea of, you know, the infamous Einstein letter to [President Franklin D.] Roosevelt that was carried by [Edward] Teller in part—

*And Szilard. Right.*

In fact Edward drove the car with Leo [Szilard] and they went and delivered it to the president. They had an early meeting, and that early meeting consisted of Bush, Conant, the president of the United States, I believe Harold Ickes was present and was one of Roosevelt's most trusted advisors, and then General [George C.] Marshall and Admiral [Ernest J.] King. And basically Admiral King, who was an ordnance officer, didn't want anything to do with it because he didn't want the Navy to look bad when it failed, because there was no way you could put that kind of energy into that small a package. And George Marshall basically spoke up and said, `The Army will take it on and I know just the man to direct the program.` And of course who was he thinking of? This was in '43. He was thinking of Leslie Groves who—at that time the Pentagon was about 90 percent complete. Groves was not only a year ahead of schedule, but he was about two million dollars under cost, 1.7, something like that, which in 1943 was a huge amount of money. And you know it's funny. Groves was never the dashing, classic military officer. He was a great civil engineer from the Midwest, son of a minister and all this good stuff, and I still talk to his son once in a while.

*Really!*

Oh, yeah. But General Groves was very no-nonsense. He did have a good sense of humor. A lot of people failed to realize he did. But he was very no-nonsense and very organized and methodical, and yet very innovative. Methodical when it came to building something, innovative when it came to thinking about how to build it and how to do it. And so he was given the task and of course the rest is all history. To think what was done in that two years is just mind-boggling, up there on Pajarito Plateau [Los Alamos]. And incidentally, Groves and [J. Robert] Oppenheimer really did get along quite well. They had deep respect for each other, and quite often in certain meetings Groves would just roll his eyes and just let Oppenheimer and the scientists go do what they needed to do, with a lot of support. Groves may have been a little overly concerned about security at the time. It turned out he was probably right, given Klaus Fuchs and David Greenglass and probably three or four others that will remain nameless forever. At least two, there's some people that say three, some people say four [spies at WW II Los Alamos laboratory]. But of course, during the thirties there was a lot of sympathy towards the Communist movement and all this and that. If you ever get a chance, read this book, *Brotherhood of the Bomb* [Henry Holt, 2002] by Gregg Herken. It's just fantastic, and he did an excellent job of doing his research. And I also have **[00:40:00]** a new book in there that just came out called *Spying on the Bomb* [Jeffrey Richelson, Norton, 2006].

*Oh, I don't know about that one.*

Yeah, it's fairly new and I haven't even started to read it yet. It's just sitting on my desk in the other room. But Herken gave it high marks. So did Richard Rhodes, so it's obviously pretty good.

*Because I don't know that much about the military, is there a tradition—? There must be some kind of tradition of testing effects pre-nuclear.*

Right. There was always sort of an understanding and given the missions. DOE, AEC, ERDA [U.S. Energy Research and Development Administration] had this mission of the production of nuclear weapons and the control of special nuclear material. The Department of Energy was always only concerned with what was called the physics package. Now Sandia was established out of the Z-Division of Los Alamos back in ’51 to be responsible for all of the non-nuclear components of a nuclear weapon, the arming and fusing, all the safety features, et cetera, et cetera, plus the responsibility for the surveillance of the stockpile and things like that. So the Department of Defense of course was responsible for the operational use of a nuclear weapon. Incidentally, I might just mention, AFSWP was actually founded before the Department of Defense existed. So you had a joint-service organization started on 1 January 1947. (It was actually 27 January but they backdated the orders.) Really didn’t stand up till July when the operational orders came out that were signed by Dwight David Eisenhower, Chief of Staff of the Army, and [Admiral] Chester Nimitz, Chief of Naval Operations [CNO], assigning people from the Army and Navy to this joint thing. Because the Department of Defense didn’t stand up till November of ’47, and that was primarily the efforts of [James V.] Forrestal and others to do that. [Harry S.] Truman was so angry with the lack of cooperation between the Army and the Navy—you know his thing was he wanted a joint armed forces, and that even goes back to his days when he was a captain in World War I. But he did try to do that.

So historically, we had the operational delivery, which from a targeting standpoint meant you needed to know what kind of damages you were going to cause. Secondly, you had to worry about the defense of your own things. The civilian defense fell upon the new Federal Civil Defense Administration [FCDA] which started in 1951 after the Russians exploded their first bomb in August of ’49. So it was from a military standpoint. And like I say, starting in ’46, the

Navy suddenly realized, this thing works and we need to go out and test it against our kinds of things and Crossroads was that first effort: forty thousand people, five hundred ships all total. Humongous operation, but we still had troop strengths that were half of World War II levels but still huge compared to what they were being brought down to. When we did [Operation] Sandstone in '48, it still was ten thousand people.

*Now was Sandstone the same purpose? There was another purpose to Sandstone.*

Sandstone was weapons development. But two of the shots had fairly significant weapons effects studies on them, especially the first one, X-Ray, which was up on the northern tip of Site Janet or Engebi. They named all the islands out there with military phonetic-type names because nobody could pronounce all the Enewetak names. You have to remember, there was no written **[00:45:00]** Marshallese language until the thirties when people from the Bishop Museum in Hawaii went out and tried to phoneticize the spoken language; and of course which only has, if I remember correctly, twenty letters in it because there are some of the consonants that are just missing. It's very vowel-laden like so many of the Melanesian and Polynesian languages.

So that was a shot that was very historic in the development of nuclear weapons because they did a basic design in which they were able to essentially double the yield with the same amount of special nuclear material. And that led to the way most primaries are designed today. And so the last shot [Zebra] they did in that series was just the standard Fat Man-type bomb and just again as a calibration point. That one didn't have much in the way of effects experiments. They still measured the air blast because they were still trying to develop the air blast curve for predictions. It wasn't until '51 that the technical manual came out that was actually the predecessor to *The Effects of Nuclear Weapons* [see Glasstone, Dolan DSWA 1977], but of course it was secret. Originally it came out as top secret, you know, because everything was so close hold.

So of the 215 atmospheric tests that the U.S. conducted, there were effects experiments on about 185 or 188 of them, and it depends what you'd call an effects experiment or not. The vast majority of those were development shots either to test new designs or build better ones. There were only a very few that were dedicated effects experiments where we used a device of a very known yield and the primary effort was to either demonstrate its operational use. A good example is the shot Cherokee out at Bikini which was an air drop of a 3.8 megaton weapon out of the B-52 that sits there on Wyoming Street on Kirtland Air Force Base, which was the AFSWC, the Air Force Special Weapons Center drop aircraft. But there was also basic effects experiments. The only problem with Cherokee is they made a slight bombing error of about 19,500 feet and so it didn't go off where it was supposed to and as a result it sort of negated the experiments, just totally obliterated some of the structures, whereas some of the other structures received very light damage. And the structures that were tested on Cherokee in '56 were very similar to the structures that are out on Frenchman Flat [NTS] today that were tested on the MET [Military Effects Test] event, 25 kilotons on a 500-foot tower in 1955 [4/15/1955], and this was to look at the difference for the same peak overpressures of the effect of the positive phase duration of the air blast wave. See, from a 25 kiloton shot, the positive phase duration is about 800 milliseconds, eight-tenths of a second. When you get up at 4 megatons, it's about five or six seconds. So the impulse or the total time you're pressing against something is much higher.

*OK. So that positive—you mean as it moves out—*

That's how long the pressure is pushing against something. It's called the positive phase duration of the air blast. And if you're a drag-sensitive target, i.e. you stand above the ground, the longer you push on it, the more you're going to break something. Pressure times time [pressure x time] is basically impulse. So they wanted to validate the calculations and their calculational or empirical calculational capability. And unfortunately, it got kind of negated because of this bombing error.

So it had two purposes: to show that you could drop a thermonuclear device from **[00:50:00]** a B-52 and have enough safe separation between the aircraft and the detonation, and then these structures experiments. So that was a very known device. It was a device modified but basically right out of the stockpile.

We did a few others where we did that, too, but not very many. Most of them always had physics package development things, but the designers typically knew the yields well enough—yeah, there were a few that, you know, fizzled, but in general knew the yield well enough that we got very valuable effects measurements.

Now, in '63 when the Limited Test Ban Treaty [LTBT] went into effect, we were now—well, actually '58 was when the thinking came about. A lot of things happened in '58. First off, missiles were coming into being, Sputnik was '57. We had decided—actually in '52, Dr. [Willard F.] Libby had decided that we couldn't test in the atmosphere forever because of the fallout. He was a physician, very concerned about the cesium [Cs] uptake by children and getting it into their bones and how it was going to affect their bone marrow and potentially leukemias. There's actually a couple of scientific papers he wrote back in the '52-'53 time frame. And when he became chairman of the Atomic Energy Commission, that was later on, but even when he was a member, he strongly encouraged the labs to think about it. Well, Los Alamos said, `No way. We can't go out and do this because we got to make these measurements`, da-da, da-da, da-da, whereas Livermore said, We'll take a look at it, Livermore being a brand-new upstart lab, Edward Teller trying to make a name for the lab as an innovative, thinking lab.

And so anyway they did, and by the time ’57 came around, they did their first underground test. Of course Livermore did it in a methodical method, Rainer, which was designed to be contained. Los Alamos figured, well, if Livermore is going to do it, we’d better do it, too, so they did three safety shots in ’57 called Pascal-A, B, and C.

But in the meantime, ’58 time period, we did three high-altitude tests. One was called Yucca, which was a balloon off of Enewetak, launched from an aircraft carrier. And unfortunately, Yucca yielded almost no data. It was 80,000 feet and I want to say 12 kt [actually 1.7 kt] but you’d have to look at NVOO [Nevada Operations Office] 209 [DOE/NV—209-REV 15, December 2000]. And because the tether cable to the balloon to the device was also the instrumentation cable, and while the tether cable holding the balloon didn’t break, the instrumentation cables to it did, just from the weight of the cables. So they didn’t get much in the way of the data they wanted.

Then they did Teak and Orange which were originally to be launched at Enewetak. But the concern—primarily of a physician who still works up at Los Alamos, still alive today, still very active, Payne Harris—about chloral retinal burns convinced them that they ought to do it at a much more remote location. So they did them at JA [Johnston Atoll], and they were very successful and they were again 3.8-Mt shots, and of course Teak had an effect on the telecommunications all over the Pacific, in fact all over the world. It just basically took out the ionosphere for about twenty-four hours, plus it knocked out street lamps in Honolulu and things like that because of the thing called high-altitude electromagnetic pulse. Orange was at a lower altitude, so it didn’t have as far-reaching effects.

Anyway, suddenly we realized there was a thing called the Brode Effect, and that is **[00:55:00]** most of a nuclear weapon's energy comes out as X-rays, in the neighborhood of 70 to 80 percent, and in air the mean free path of an X-ray is a few meters, typically less than ten meters. And so all of that energy gets absorbed primarily by the nitrogen in the air, some by the oxygen, and it heats and excites those atoms up big time, and in turn they create the shock wave and the fireball and everything that you see in an atmospheric phenomenon. Out in space there are no molecules, so the X-rays go forever. So the effects on military equipment in space suddenly become significant. Suddenly you're looking at radiative energy that can travel long distances and then deposit its energy like in the nosecone of a reentry vehicle or in a satellite or whatever.

So in '58 we were still in the infancy of putting things into space. By '62 we were definitely putting things in space. We did some more high-altitude tests at Johnston Atoll, six of them to be exact, and we learned a bunch. And incidentally our Russian friends were doing the same thing over at Kazakhstan and learning about high-altitude phenomena, too. And so we realized we were going to have to test our military equipment to simulate the environment of space to ensure that it would survive. If you look at the old atmospheric tests, primarily at Nevada, a few in the Pacific, almost every shot out there had tanks and Jeeps, people and animals and equipment to look at its resistance to air blast, to the neutrons and gammas which travel fair distances in the atmosphere, and to the ground motion, et cetera, phenomena from an atmospheric nuclear test. We had to do that same simulation underground.

At the same time, we were also trying to build what we call "above-ground simulators," which are typically pulse-power machines. It's very, very hard to simulate the amount of energy that's released from a nuclear weapon in a few microseconds—any way but with the tremendous release of energy in some other form, especially if you want to get the timing to be the same. And so we developed these big machines, and we still have a few of them around. Sandia operates the Hermes III machine, they operate the Z-Pinch machine, you have another pulse-power machine at the Nevada Test Site called Atlas, we operate Python and Double Eagle out on the West Coast, and they simulate the X-rays or the gammas from a nuclear weapon. And to simulate the neutrons, we use what's called a fast-burst reactor. There's only two of them left operating in this country, one at White Sands Missile Range and one here at Sandia National Laboratories.

*So it sounds like coincidental with the move underground because of radioactivity and because of the Limited Test Ban Treaty, you also have this environment now where you can simulate outer space in a way that you couldn't with atmospheric tests, is that what I'm understanding?*

Well, I mean you had to do the tests in space. Those high-altitude tests were in space.

*They were in space, but when you go underground—*

Basically, space starts at eighty to a hundred thousand feet, depending on whose definition you want to use. You're in true space when you get about 300,000 feet above the earth. That's where now you're below a ten-millionth of an atmosphere. You know what I'm saying. There's still a fair amount up there. It's not till you get out about fifty miles or so—actually you get out about 150 miles before you're really in true space where now you have very, very little cosmic dust or oxygen molecules or anything. The earth is incidentally always losing a little bit. **[01:00:00]** The gravity doesn't hold it all in.

You had two things happen sort of simultaneously. One, this new phenomena to test against called the ability for radiation to travel long distances and do damage of a different type that you didn't see in atmospheric phenomena because the X-rays don't go anywhere, but instead made a fireball and that. And now you had two different phenomena to worry about. You had the direct radiation effects on anything that would be transiting space or residing in space, whether it's a satellite or a warhead or a missile, and then you had this phenomena that we saw in atmospheric tests as source region electromagnetic pulse, and it was originally considered just to be bothersome to trying to make measurements.

*Say the word again.*

Source region electromagnetic pulse. That's where the gammas interact with the oxygen molecules in the atmosphere and it creates a small electromagnetic pulse, nothing like the phenomenon of the high-altitude electromagnetic pulse where again the gamma rays interact with the oxygen primarily in the ionosphere, the ozone layer. And they strip off compton free electrons which then spiral down the earth's magnetic field and they make basically a conjugate wave that can have voltages of several thousands of volts per square meter. To vacuum tubes, it didn't make any difference. To transistors, it started to, and integrated circuits, it just wipes them out, unless you shield against them, and basically you shield against them by putting on surge protectors. They're very fast surge protectors and they're very strong surge protectors, but they're basically a surge protector.

And so in order to replicate that space environment and do it underground, we started to test first in vertical holes. OK, actually that's not true. The first one we did was a shot called Marshmallow [1962] which was a radiation effects test. It was in the 16a tunnel and it was less than 20 kt. The yield is still classified. And it involved two small line-of-sight pipe[s]. And it turns out Marshmallow was almost a landmark, besides being the first underground, in understanding the phenomena that led to major changes in the design of the physics package.

*OK, stop right there. I'm going to [create track on recording]*

**[01:03:15]** End Track 2, Disc 1.

**[00:00:00]** Begin Track 2, Disc 2.

*So Marshmallow was important, you were saying.*

Marshmallow was important because we observed a phenomenon related to the design of the physics package itself that led to a major change in the design of the physics package and it was still incorporated in the designs of the weapons of today.

*Now was it intended to do that? Was it intended as an effects test?*

It was intended as an effects test on the physics packages to assess their vulnerability to the radiation itself, the radiation environment of space. So the experiments were placed in a[n] evacuated steel pipe called a line-of-sight pipe because at one end is a small aperture that looks at the nuclear device and at the other end is a test chamber where the things you want to expose to the gammas and the X-rays and the neutrons is located. And protecting the experiments from the explosion is very important, and that's where containment comes in, because containment is—primary purpose, especially for the laboratory development tests, is just to prevent an uncontrolled release to the atmosphere. For us in the weapons effects tunnel tests, it was also experiment protection in addition to preventing an uncontrolled release to the atmosphere. Now, let's go back to this basic difference. The big difference between what DoD [Department of Defense] did and what the labs did, the national labs, the national labs again were primarily at Livermore and Los Alamos as the two design laboratories, weapons development, and why weapons development? Several things. One, the military was constantly changing its targeting needs and the delivery platforms. And there used to be a thing called the Military Liaison Committee. It's now been replaced with what's called the Nuclear Weapons Council . And the military provides to the Department of Energy basically a thing called a Statement of Need, and that says, we need a weapon to do this. The last Statement of Need to go to the Department of Energy in recent years was for the development of an RNEP, a robust nuclear earth penetrator. Prior to that it was a nuclear earth penetrator. And that's so you can get better energy coupling in the ground to get at deeply-buried targets. That goes back into the eighties. That Statement of Need has not gone away. It's still there. The Department of Energy has said they don't intend to build an RNEP, but they're not the customer. I think it'll keep rearing its head.

There's a thing out there called global strike, which is a program initiated first by the Air Force and now part of the STRATCOM [United States Strategic Command] requirement by presidential directive that you will be able to hold any and every target in the world at risk with either conventional or, as a last resort, nuclear weapons. That's the policy of deterrence this country has used since the early fifties. It's hard to say how many wars it's prevented. It certainly hasn't stopped them all by a long shot. And how many it'll prevent in the future. A good example of deterrence is the reason there were no chemicals in the scuds [tactical ballistic missiles] that Saddam [Hussein] launched against Jerusalem and some of the other cities of Israel is Saddam knew if he did use a chemical attack, because the Israelis told him in very open terms that there would be a bright white flash over Baghdad. So that's deterrence.

*When you said DOE isn't the customer, you mean the armed forces is the customer.*

The armed forces is the customer. We set the requirements. The Department of Defense sets the **[00:05:00]** requirements. The Department of Energy is not charged with defending the nation. Only the Department of Defense is. So that's something that has to be thought about sometimes. I know in today's environment it tends to get blurred occasionally.

So anyway, they [AEC/ERDA/DOE laboratories] were doing these development tests. They were also doing tests related to safety. This was a big concern because in the late fifties we suddenly decided—we had had already about twenty-five broken arrow incidences involving accidents with nuclear weapons. They had been safe so far because they were inherently safe in their design because the special nuclear material was not necessarily mated with the device. In the late fifties, they started all becoming one package because that eased the maintenance requirements, et cetera, and they became what's called sealed designs. And so suddenly there were the questions: what happens if this is in an aircraft crash or in a fire or somebody shoots a bullet into it or you know, all sorts of things. About that time, a special group at Sandia was put together that still exists to do reverse engineering and figure out every way they can to defeat all the safety systems. It still exists, a very dynamic guy who runs that group and he gives great talks.

But anyway, there's safety and there's basic physics phenomenology studies, i.e. ways to improve the output of a nuclear weapon, increase in yield to mass ratio and things like that, or to tailor the radiation output, i.e. to give more fast neutrons or more gamma or different kinds of X-rays or whatever.

*And that would be to damage—*

It would be to provide a nuclear weapon for a specific military application. And then let's say you want to make a weapon that will give you more electromagnetic pulse. So you design a weapon with a lot more fusion, so you get a lot more gamma.

*And the military is saying it would be for this kind of purpose or that kind of purpose and that's why we wanted to do this thing?*

Yes. And that all used to go through the Military Liaison Committee and then later on the Nuclear Weapons Council. Since the military isn't developing any new systems per se and relying on old systems, there haven't been too many requirements presented to the Department of Energy, and in turn the Department of Energy, the secretary of energy, now through the administrator of the National Nuclear Security Administration [NNSA] is in turn supposed to instruct the laboratories to resolve those problems and come up with a viable design. And in the later years of weapons systems, as you're probably aware, there was actually competition sort of going on between the two labs as to which one. And Sandia of course is the one that works for both labs because you have Sandia Albuquerque, which is the biggest part of Sandia, but you also have a thousand people out at Livermore called Sandia California, which works on the Livermore systems. And of recent there's even been load leveling between the two labs in which responsibility for certain enduring weapons have been transferred from Los Alamos to Livermore. A good example is the W-80, which is the cruise missile warhead, and that recently was—well, not recently, five years ago, was transferred from Los Alamos to Livermore, so now they have an equal number of warheads to worry about.

*Do you think the two labs are still necessary?*

A lot of consideration about getting rid of the two labs and just combining them into one, including maybe having two separate design divisions. I think competition is good. It's kind of interesting, the Russians paralleled us exactly; they copied us. We started Livermore in '52, I **[00:10:00]** think it was October of '52, Herb [Herbert F.] York and Edward Teller and company, and at the same time, just before his death, [Lavrenti Pavlovich] Beria decided that he needed a second lab and created the Cheliybinsk-70 [laboratory]—which is just a mailbox number, incidentally; it's the town of Snezhinsk—and with all the same kind of guidelines as Livermore was: go out and do innovative things. At the time, Los Alamos was extremely conservative in their design and Edward, who started the A and B Divisions at Livermore, A is the secondary division and B is the primary division, but even in the primary division he said we are not going to do things the old way. We're going to do innovative ideas. We'll let Los Alamos design spherical primary systems. We're going to design non-spherical primary systems. And we're going to look at more innovative ways to do things. We're going to make things more efficient, more, so you know it was good. And you know a lot of talk about converting Livermore to a green lab back in the early days of the Clinton administration, as the Cold War was winding down. And you can still do that. I'm not sure there's big cost savings there. I think having two groups still checking on each other is good.

*Now, because we're sort of limited for time, I wanted to ask you about Mighty Oak, but I had a question before that which was, you put all sorts of things in this test chamber to test the effects of these devices. Am I correct in understanding that sometimes that thing would be a nuclear weapon itself, to see if there was an effect on it?*

We often tested full-up warheads. When I say "full-up," they were always safe in such that you could never have a nuclear yield down there. That usually meant replacing some of the special nuclear material with surrogate material, the same thing that's done on what were, you know, the test drops of warheads up at Tonopah [Test Range, TTR] and you know the test-firings of missiles out to Kwajalein and before that down to an atoll in the South Pacific—Canton (Gilbert Islands).

*Or even the pre-Trinity tests, I guess, too, they did that?*

Yes.

*So then you'd use physics to measure what that effect was if you're not getting a—*

Yes, you know, I mean for example, one of the big things you're concerned about is a thing called thermo-mechanical spall. These X-rays are very energetic, and depending on their energy level, because they range from an eV [Electron-volt] or so on up to about 500 KeV, thousands of electron volts, and an electron volt is 11,000 degrees Kelvin, basically twice the surface temperature of the sun as Lord Kelvin defined it. If they're low energy, they tend to deposit all their energy on the surfaces of things, so if you happen to be a mirror or you happen to be an optics on the window of a satellite or whatever, you can destroy those coatings or whatever with low energy. Warmer ones will penetrate a little deeper before depositing all their energy, so if it's a warhead, it might get into the aeroshell, or if they're a satellite they get inside the internal components. And if they're very hot, they can get through all that stuff and maybe deposit their energy in the most dense material, which might be the special nuclear material itself, and cause it to heat up. Now when things heat up very quickly, they create a stress wave, they create a shock wave, just like heating up the atmosphere, and basically the shock wave will propagate from where it's being heated, and when it hits a free surface, you get a reflection or a rarefaction wave, but the inside surface will spall off, and that's called thermo-mechanical spall. So if that **[00:15:00]** happens to be the inside of your plutonium pit in a warhead, you may not have a pit anymore, so you have to protect it.

Or the electronics. With the electronics you have what's called systems-generated EMP [Electromagnetic Pulse]. That is, the X-rays and gamma rays come in and they excite other electrons from the heating of the atoms, and of course in turn they give off Compton free electrons which create the systems-generated electromagnetic pulse which can destroy things, but then you also have the neutrons which create transient radiation electronic effects, or TREE. Those can destroy things. You have dose-integrated EMP. There's all sorts of phenomena. It's extremely complex, very hard to model.

And you probably are thinking, why did we test them underground in tunnels with a nuclear device? You notice I keep saying "nuclear device" or "nuclear source." I don't say "bomb." We didn't use bombs. We took devices designed by our national laboratory friends. Again, we would present them with a list of requirements saying, we would like something that's going to be less than 20 kt that is going to give us this kind of radiative output that really is simulating something that might be a few hundred kilotons to a few megatons. Now that's a real trick for the designers to do that at a few kt, and even lower yields. And incidentally, our Russian friends were doing exactly the same, because again they were prohibited from testing out in space or the atmosphere. Mostly space again, the whole revolution of the last frontier out there, but also the new battlefield became space.

*So even at the same time that you've got a treaty that says nothing in space or in the atmosphere, there's concern on both sides that eventually it will get into space, obviously, or you're not doing these tests—?*

Well, the concern is, they're putting more and more of their national assets in space, and they want to know, is it going to survive in that nuclear battlefield, both from direct radiation and on the ground from the electromagnetic pulse. So again, we tried to build these above-ground simulators, and we have, and we have some pretty good ones. The problem is, in order to create that much energy, to create hot X-rays, for example, you only produce a very small beam, so you might be able to expose a few square centimeters. Well, think about warheads. They're a meter or so long and a third of a meter in diameter. Satellites are up to twenty meters across, some of the big ones, the big communications satellites, by the time they deploy all their antennae. All of those are collecting surfaces for radiation. So while we can test components and piece parts above ground, and we do, it was always nice to do the integrated tests underground.

The other problem is, when you test in an above-ground simulator, you're only exposing to the X-rays, or you're only exposing to the gamma rays, or you're only exposing to the neutrons, separately. Very, very hard to do combined effects, which is the real-world environment. Our Russian friends know this better than we do. They have a number of above-ground combined-effects simulators, especially for gamma and neutrons together. We sort of have one down at White Sands. Even the French have one. The French had radiation simulators. The Brits did for a while, but our British friends used ours rather than continue theirs. They also had experiments on our line-of-sight pipes, just as we conducted development tests, twenty-four of them to be exact, in the underground environment. Prior to that, they did their own atmospheric testing at Maralinga [Australia], Montebello [Islands, off Western Australia], and also up at Christmas Island. You know, they developed their own H-bomb with no help from this country because the McMahon Act strictly prohibited passing any of that information to them. **[00:20:00]** There's a great book out there called *Britain and the H-Bomb* [Palgrave, 2001]. It's by Lorna Arnold who was a researcher there.

*AWE is—*

Atomic Weapons Establishment. It's the British AEC. But you have to remember, it works for MOD. The Brits don't have a separate civilian oversight for the production. It's all under MOD. Whitehall. But the British have always—you know, it wasn't until 1985 that the United States passed a thing called the Goldwater-Nichols Defense Reorganization Act [of 1986], which put civilians firmly in control of the Department of Defense, made the Chairman of the Joint Chiefs [of Staff, JCS] and the Joint Chiefs directly responsible to the SECDEF [secretary of defense].

*I didn't know it was that recent.*

That's why [Secretary of Defense Donald] Rumsfeld is taking all this stuff right now. Yes, really. Prior to that, the Chairman of the Joint Chiefs reported to the president of the United States, not through the SECDEF, and it was not until the Goldwater-Nichols Reorganization—I think it was ’85, might’ve been ’84, ’85, did that. And so now in fact some members of Congress tried to put NNSA under the Department of Defense. You could do that, legally, and not be in violation of the Atomic Energy Act. So that was the difference, whereas MOD, all of the British military commanders report to civilians. They report to the Minister of Defense and his deputies, who are all civilians. So the British never had that civilian control quandary that we did. And let me just tell you bluntly, when Truman wanted the Atomic Energy Commission created and in civilian control because he didn’t trust the military, guess who was his strongest supporter? George C. Marshall. Leslie Groves. They both testified secretly at the time that they did not want the production of weapons under the services. They wanted the control of special nuclear material, the design, and the production to remain totally a civilian enterprise.

*Now I don’t know that. Are those things in Herken’s book?*

Not in Herken’s book, but they’re in other books.

*And what was, just briefly, because I do want to get to Mighty Oak before we run out of time, but what was their reasoning there again? Was it the knowledge?*

No, their reasoning was, is they just felt that the military shouldn’t be in control of such awesome power, that the Constitution had basically said civilians should be in power, and so this way it made it very positive. I think had the Goldwater-Nichols Act been in place where the secretary of war and the secretary of the Navy had control over the CNO and over the chief of staff of the Army who at that time reported directly to the president. It would’ve been different. But the Defense Department really didn’t gain the civilian control power until ’85. It was informally there but it was not—

**[00:25:00]** *It would be interesting to speculate because of course with nuclear weapons the military is integrally involved because they are doing the war planning, and yet it'd be interesting to speculate what difference that that has actually made over time, that there was—*

Well, you know, there were changes, and the biggest change to the Atomic Energy Act was '54, when the military was allowed to have custody of special nuclear material. Prior to that it was always under the control of the AEC, and that was because we were going to these sealed designs, and even where the what's called the capsule ball assembly was not inserted into the high explosive, it was still carried on the weapon; it was integral to the weapon and you couldn't manually insert it in flight, it was automatically inserted in flight, and as a result, you had to grant the custody—plus the response times were getting less and less and less. You know, the late forties, three days. By the time you were in '54, you were getting down to three-or-four-hour kind of response times, about half the time it takes to fly over the poles. By the time you were in the late fifties, you had missiles. Of course we didn't know the missile gap was sort of nonexistent, but in '58 the response time was getting down to thirty minutes. And by the time you were in the '66-'67 time frame, when the Russians had their first fleet ballistic submarines, you were now down to fifteen-minute response time. That's why the Cuban missile crisis in '62 was such a huge thing, because now you were looking at seven-or-eight-minute response times. Well, the best you could ever do with the B-52s was get them airborne in about seven or eight minutes. That's the best.

*So let's turn briefly to containment. I was reading parts of* Caging the Dragon*. One of the most interesting things to me about that whole discussion was how much you don't know about the way the earth moves. So what happens in Mighty Oak? It's brought up so much in these discussions and I don't really understand what happened there.*

All right. For a tunnel shot, Mighty Oak was in a sense, I won't say a Baneberry, but it was an eye-opener. But let's step back just a tiny bit. We went underground in '57, and at that time there weren't too many people worrying about the containment factor. Underground shots routinely released to the atmosphere, but you're only talking one, two, three, even the worst were at the most 10 percent of the total fission products while we were still testing in the atmosphere. So that was pretty good. Even though the Limited Test Ban Treaty said, radioactive debris will not cross your national borders: the Russians take one interpretation of that to mean particulate material but not gaseous material; we took it to mean everything. That was pointed out, incidentally, before the treaty was signed and basically [President John F.] Kennedy said, `I want the treaty signed; we'll change it later.`

So anyway, containment really was pretty much in its infancy. The operational guys still kind of determined what was going to be done, and we were trying to keep containment, the goal was still there, but the staffs were small. At Los Alamos it was mostly Bob Brownlee and a couple of other people. At Livermore it was Jim Carothers and a couple of other people. Cliff Olsen was heavily involved. Billy Hudson. But it really wasn't a lot of effort. The DOE was doing their own tests, and you're going to talk to the guy who worried about that, Wendell Weart. And they were doing tests with us, or on their own, and they did Cypress and Camphor in tunnels, and that was for the DOE equipment, for its ability to **[00:30:00]** survive radiation effects. That was before they decided after Camphor in 1971, which leaked, that they would get out of that business and just piggyback on our tests.

So our first underground tests, a lot of them leaked, even the tunnel shots. Basically you did Marshmallow; it leaked a little bit. Didn't get past the gas-seal door which was a 75 psi [pounds per square inch] door, but it seeped through stemming. Then we came back and did Gum Drop [1965]; it did the same thing. Double Play [1966] leaked a little more. OK, we were all the time trying to do these different things and its phenomena that's very hard to model and calculate.

And at the same time the labs, which started off in tunnels, quickly moved down into vertical drill holes, and several things allowed them to do that, and one was we improved our ability to drill shafts rather dramatically in a short period of time. But also, the age of the transistor, the age of the integrated circuit made your detector packages much smaller and consumed much less power. And so the guys at EG&G [Edgerton, Germeshausen, and Grier] and the laboratories were really wizards in designing all this packages that could fit on a diagnostic rack and go underground. That's why Los Alamos back in the fifties said no way. It was the big equipment, the fact that you had vacuum-tube technology and all that stuff. And Livermore wasn't sure how they were going to do it either. So that's why they started in tunnels, because a tunnel, you had enough space to do that. It wasn't a three-foot-diameter hole, then later a four-foot-diameter hole, then a six-foot-diameter hole, then eight, ten, and twelve-foot-diameter holes. By then you really didn't need the twelve-footers much. You could go back to mostly eights because everything was getting smaller, integrated circuits, fiber-optics, you didn't have to have one cable per channel of data. Now you could have one cable with maybe twenty channels of data on it. So you can see, they go hand in hand, the electronics revolution with how we were doing things.

So some of them contained; a lot of them leaked. There's a great little report out there that Brownlee and Higgins put together—Gary Higgins was very big into containment; he's not with us, unfortunately—of how we could contain these things.

Baneberry, which was sort of a disaster waiting to happen, you had three factors that caused Baneberry to leak. You take any one of the three away and at least calculationally, Baneberry wouldn't have leaked. And there's still one phenomenon about Baneberry. With the best of calculations, we can calculate everything and say, yeah, it leaked, but we still can't figure out why it took three-and-a-half minutes to get to the surface. If it was going to be a dynamic hydrofract [hydraulic fracture], it should've been there in three or four seconds.

*So the three factors were?*

A scarp in the Paleozoic surface beneath the working point. This was a hard limestone or dolomite which reflected a lot of the shock wave energy back. At the same time, a thing called the residual stress field was forming around the cavity. At one time we referred to it as the magical mystic membrane because we didn't understand that phenomena. The other thing was the two faults that came off those scarps that went through the cavity into the surface. But probably most importantly was the fact that the media in which the shot was an altered tuff which had about 50 percent swelling clay within it which has no sheer strength, so you couldn't set up that residual stress field very well. Take any one of those away, calculationally Baneberry contains. It was 10 kt, a thousand foot roughly. It actually had a line-of-sight pipe on it for a Livermore experiment. But in the post-shot investigation, the line-of-sight pipe contained well. It did not contribute to the failure. Because that's the first thing everybody thought about.

**[00:35:00]** Now, Wendell Weart was the Sandia rep, along with Larry Germain and Bob Brownlee, in the investigation of Baneberry. Germain still lives here in Albuquerque but he suffered a stroke about six years ago—

*Yes. I saw him last year because I interviewed his wife.*

And incidentally, Larry, who was the technical director on Baneberry, was probably the toughest guy of the CEP [Containment Evaluation Board] later on. He and Brownlee both, and Wendell to some extent. Brownlee and Germain would get fairly aggressive. Wendell was always the gentleman that he truly is, but he would still ask the most difficult of questions.

So Baneberry, we suddenly took a great interest. Again, in the tunnel shots, we were actually getting pretty good. We had the first four that kind of leaked. We got out of 16 Tunnel. We went to N Tunnel. We went to T Tunnel. We had a pretty good record, and when I say "pretty good record," enough that we were able to recover the experiments. It's one thing to expose a warhead and get the active measurements off of it; it's another thing to be able to go in and recover it and physically look at it. Now we had some big failures, as bad as Mighty Oak I the sense—there was one called Door Mist which was in T Tunnel, blew out rather badly. That was a '67 shot. We had another '70 shot called Hudson Moon that was very hard to recover any experiments because again it failed. What was happening is we were not closing off that line-of-sight pipe such that we could keep the cavity gases, because the bomb goes off in a few microseconds, and all this hot energy, radiative energy has to be converted to mechanical energy. Only about half of it gets converted to mechanical energy; the other half is what we call internal energy and I won't even go into that. But any physicist will know exactly what I just said. So the earth really doesn't know anything has happened in a sense for almost a millisecond. By then you've created a shock wave. The shock wave is so intense, about a hundred million atmospheres pressure. Its shock vaporizes about seventy tons of material per kiloton of yield. In turn, that vapor is still at very high pressures, in excess of a megabar, a million atmospheres. It will shock-melt another 700 tons or so of material per kiloton of yield. That gets you out to a radius for a kt of about three to four meters. Now you've got a breakaway shock wave which is traveling faster than the cavity growth, and you'll push outward in the kinds of media we have, it depends on the strength of the rock, anywhere from ten to thirteen meters per kiloton to the one-third. That's the cavity. And it does that. For example, a kiloton shot creates a cavity at the Nevada Test Site, which is fairly soft rocks, it'll create that roughly eighty-foot-or-so-diameter cavity, and it does that in about 140 milliseconds.

*So what are like the biggest cavities out there, would you say?*

Well, just a typical cavity, you know, the formula is well-known if you want to calculate it. The radius of the cavity is 70.3 x $W^{1/3}$, where $W^{1/3}$ is divided by the overburden density x the depth of burial to the one-quarter power.

*So you're not going to tell me what the biggest cavity out there is.*

The biggest shot we did out there was 1.3 megatons, 1,300 kilotons.

**[00:40:00]** *Right. And which test was that?*

That was Boxcar [1968]. And if you take the cube root of 1,300—well, let's take the cube root of a megaton, that's easy, that's 10. OK, 10 x about 13 meters, so 130 meters radius, 260 meters diameter. So the biggest cavity up on Pahute Mesa is probably on the neighborhood of about 900 feet across. Big. And that probably took about 800 milliseconds or so to form. Now it overshoots, it rebounds. The rebound sets up this strong hoop stresses around the cavity called the residual stress field. Now if you perturbate that or if you have an opening through it like a line-of-sight pipe, you have to figure out how to close that off and not perturbate that stress field in order to contain it.

We got pretty good up through about that Mighty Epic time frame in '76 and we had, sort of by chance and by calculational efforts which were crude at the best, had realized that if you put these closures to do two things—the closures are there for two reasons. The primary reason that they're there is for experiment protection, because the design of a line-of-sight pipe containment is you use the ground-shock energy to squeeze the pipe shut. That in turn, because we used circular cross-sectional area pipes, when you squeeze it at a megabar pressure, you vaporize the steel. You turn the steel into a plasma, and you shoot a jet of plasma down the pipe traveling as fast as 20 to 30 kilometers a second. To give you an idea, a 30.06 bullet is about 2 kilometers a second. So that's a very fast-moving material. It doesn't have a lot of mass, but remember, kinetic energy is one-half mv [mass times velocity] squared [½ $mv^2$], so it doesn't take a lot of mass to do a lot of damage. So we used to put these sliding doors, which Wendell was, you know, major a part of their design—they were originally called the Sandia Auxiliary Closures [SACs] and the DNA Auxiliary Closures [DACs], then the Modified Auxiliary Closures [MACs], then the Gas Sealing [Seal] Auxiliary Closures [GSACs], to put them across the pipe. Our later designs, we had a closure in front of that that was a big high-explosive cylinder-driven called the Fast Acting Closure [FAC]. That closed in about a millisecond. The doors would close in sixteen milliseconds for six feet in diameter, and actually fully close in thirty milliseconds where they were latched. They also were what we called the stemming anchor. They would prevent the grout that we poured around the pipe from being extruded into the LOS pipe, because you could only close the LOS pipe out to a certain distance where the stress wave, the ground shock wave, was strong enough to squeeze and swage that pipe shut. In actuality, there really wasn't much pipe to swage shut because all of the X-ray energy going down the pipe usually caused the pipe to blow up, expand and fail intention; so you were squeezing pieces of pipe back together but actually just filling it up with the grout. And then you wanted to compact it so that you didn't have a preferential path for this high-pressure gas left in the cavity to dynamically hydrofract, hydraulically fracture, around it.

On Mighty Oak [1986], what happened is—and actually we saw it before Mighty Oak, and this is a case in part personalities, you know, the whole world is driven by personalities—in order to reduce the costs of our tests, we started on an ambitious program, starting with Mighty Epic, to increase the test chamber size to accommodate more experiments. And you can basically **[00:45:00]** look at it as fluence time the square footage that you're going to expose, and so one of the ways to do that is to increase the taper of the pipe. You bring the test chamber in closer and it keeps the mining costs down, allows you to expose more experiments. The problem with that was, the size of those sliding gates couldn't be made any bigger than six foot. You probably say, why? That's because of the Reynolds Aluminum Company. Those doors are made out of forged aluminum, and the largest they could forge was seven feet by twelve feet, I think; don't quote me on the exact number. Wendell [Weart] might remember them better than I do, and I can sure go look them up for you.

So you brought the closures in close. And on Diablo Hawk we noticed our first problem, but it contained OK. Then we did Huron Landing [1982] and Huron Landing had some seepage and the grout pushed out the first one of those slide gates. [It] suggested maybe that there was a problem with the taper, but that really wasn't the problem. By the time we did Misty Rain [1985] and did the reentry on Misty Rain, it became very obvious to me that the closures were far too close to the working point. And then I did a little analysis of the strength of the closures, along with John Wydert from Sandia, and I said, wow, the ground shock is exceeding the strength of the closures, let alone putting a grout load against them from the extrusion from the cavity growth. And so we were basically taking out what was called our stemming anchor, and as a result, you were allowing a preferential path for a dynamic hydrofracture (hydraulic driven fracture) to occur. So you have to remember, we're executing one test and have the next one half-built or better. And at that time we were really busy in a number of programs involving the Peacekeeper, involving the Trident-2, and even Minuteman, the Mark 12-A, the Minuteman-3 warhead, and a lot of upgrades going on it, so there was a real active test program going on. And if you look at the underground weapons effects tests it's a function of how many new systems were coming on board. We went to one every two years for a while, and then the next thing you know, you're doing three in a year, which is why we had multiple tunnels, because you can't be doing two at once in the same tunnel.

Anyway, Huron Landing and Misty Rain and probably to some extent Diablo Hawk, containment was achieved because the earth helped us. We had a phenomena called block motion occur, which is where a fault moves, cuts the drift off, and actually provided the **[00:50:00]** stemming anchor. On Mighty Oak, even though block motion did occur, it occurred at such a late time that the stemming had already been pushed past it. And I kind of predicted that would happen. Wasn't sure it would happen, but kind of predicted it would happen. And that's exactly what happened. We knocked out the closures, we pushed all the stemming all the way down to the test chamber, and basically the cavity came down in the test chamber and then filled vessel two; vessel two got up a few hundred degrees Fahrenheit [F] and few hundred psi pressure, but the vessel two plugs—because we used to use this series of nested vessels, vessel one was the stemmed-in area where you would like to keep everything—vessel two, you had these plugs and enough tunnel volume that you could cool the pressure and the gases down but you would lose all the instrumentation that was underground, which is primarily digitizers, and then your belt to your suspenders was vessel three, which was another plug. Everything that went into vessel two was 1,000 psi, 1,000 degrees Fahrenheit for one hour. Everything that went into vessel three was 500 degrees Fahrenheit, 500 psi for an hour. In actuality, on Mighty Oak, we had a slight amount of seepage into vessel three and nothing beyond vessel three, so in terms of containment, it was a success. There was no release to the atmosphere. There was later on a controlled release of xenon.

*That's what that means in the NVOO 209 [*DOE/NV-209-REV 15*]. It was a controlled release of—because of what you'd had underground.*

It was a controlled release only of the Noble gases. There was no iodine released because the release was through what's called the HEPA [High Efficiency Particulate Air] filter, which filters out all the radioactive iodine. But in actuality, we waited until most of it was all decayed away anyway before we started pumping it to the surface, and then it was all through a HEPA filter. There's always been a question, was it ever even in the controlled release detected offsite? EPA [Environmental Protection Agency] said they got one little whiff of Xenon to the northwest of the test site. It's what's reported in NVOO-317, OK, if you look at NVOO-317, which you can get a copy from the [DOE] reading room. At least get it on CD [compact disc]. I don't know how many hard copies are left anymore, you know what I'm saying? But you know, then again there's certain EPA guys said it might've been a hiccup on the instrument, too. So we released I think it was 36,000 Curies [Ci: unit of radioactivity equal to $3.7 \times 10^{10}$ disintegrations per second] of xenon-133, which really is not very much. [Xe-133 has a 5.2d half-life, whereas Xe-135 has a 9.1h half-life.] A power plant during refueling can release three or four thousand. And they're licensed to do so. They're licensed to release on any given day 1,000 Curies. Because it's an inert gas, it's a Noble gas, it's biologically inert; you breathe it in, you breathe it out. And xenon has a pretty short half-life, too; by twelve-and-a-half days, it's pretty well gone. There is strontium there, but strontium is a beta emitter and it's not really much of a—I'm sorry, not strontium, I'll get it out right here, krypton 85, and the xenon-133 and -135 is a concern. All the strontium, all the particulate stuff is taken out in the HEPA filter. So nothing went out. And we had several controlled releases. Every time they did a drill-back on a cavity down on the flats, there's a controlled release. All of those are summarized in NV-317.

What happened on Mighty Oak is we still got 99.3 percent, if I remember correctly, say 98+ percent of all the data recovered. All the active data was recovered, all the thermal-couple measurements, all of the radiation measurements, all of that stuff. What you couldn't do is go **[00:55:00]** back and recover the experiments. Also Mighty Oak took out about thirty-five million dollars' worth of electronics, which had a very serious consequence on future testing, from the expense to replace it; at that time some of those high-speed digitizers, Tektronix only made three or four or five a month. They were I won't say "hand-built" but close to it, because the demand for them was only us and a very few other laboratories that were doing things primarily related to radiation phenomena, because not too many other phenomena out there required things that record at 3 and 4 gigahertz bandwidths. Today those recorders or, you know, those digitizers are more available thanks to the computer industry and its need for high-speed recorders, but at the same time there weren't a lot back in those days. And again Tektronix is still a source, but there are a number of other manufactures today. But again, you don't place an order and say, I want a thousand of those, and they're going to be delivered next week. They'd probably tell you there's a twelve-month lead-time on that. So it took a while to rebuilt our inventory, and we had a hard time fielding the next couple of experiments, with all the kinds of high-speed data particularly.

But all the data had been sent out of the tunnel over fiber-optics and was recorded outside of the tunnel, and the reason we had gone to that was for that simple reason. In some of those earlier tests I was talking about, Hudson Moon and the one over in G Tunnel, Door Mist, we lost a lot of the recorded data because it was recorded underground and the radiation either fogged the film or it demagnetized the tapes. That's why first we went to bubble memories when bubble memories first started coming into being and stuff like that.

So Mighty Oak was an absolute success containment-wise. Experimental-wise, it was a success. In terms of experiment protection, it was a dismal failure. It also then caused us to step back and re-look at things.

Now at the same time, we had something else going on, and that was at the time we did Mighty Oak, we had a source that we wanted to use for a certain kind of radiation output. I can't go into the details, and that source was at less than 20 kt but it was a lot higher yield than we would've liked to have used; so that we could reduce the ground motion so that the ground shock on those digitizers and everything would be less, and that way we could move the digitizers closer to the working point in the test chamber, keep the cable length shorter, reduce the signal-to-noise problem, get higher-quality data, et cetera. We had asked both labs to consider developing a much lower-yield source. Livermore succeeded in doing so. That became our source of choice, reduced the ground shock significantly, allowed us to use shorter test chambers, allowed us to develop the FAC concept.

So we went to a whole different test bed design after Mighty Oak, and that was just kind of coincidental. Today we could've done a Mighty Oak test without any problem just by changing the taper of the pipe, moving those closures back out, but in the meantime we also developed a much stronger slide closure called the STAC, the Stemming Anchor Closure. And that was after I came back. And I came back to work on that low-yield design and bring credibility back to the program; and during my watch we didn't have any leak. **[01:00:00]** Not quite true. Disko Elm [1989] had a slight leak on a cable, 4 Curies. Netted me a phone call with Admiral [James D.] Watkins. But we figured out what caused that and we never had that problem again. And the only other one was one of the cavity shots, Diamond Fortune [1992] and it was expected to perhaps seep into the tunnel, and we were very prepared for it. That one was around one Curie of xenon into the tunnels, krypton and xenon, krypton 85 and xenon 135. And you know it was gone by the next morning. We could no longer detect it. You have to remember that xenon 135, which is the primary gamma emitter, has a nine-and-a-half-hour half-life, so go through two or three or four half-lives, four in twenty-four hours, and it's gone. You just don't see it, unless you had a lot of it. Because the xenon we mostly kicked out after Mighty Oak was 133 ground and 133 metastable, I'd have to look it up, but it's several days' half-life. I think it's a five-day half-life. So it's going to still be there. And we could've waited till it all disappeared, but again it's not a biological threat. The EPA guys said go ahead and vent it. We waited on days when the meteorology was correct and all that. So again, I don't think it ever left the test site, and nobody was in the downwind areas at the time.

If we had to go back to testing today, there's a lot of concern about the erosion of the knowledge base. Tom Kunkle and I and Norm Burkhard at Livermore, Dr. Burkhard, we're all approaching sixty, and we're the whippersnappers. We're the youngsters. Fortunately, Norm Burkhard has understudies at Livermore and Tom has understudies up at Los Alamos, both for geology and containment phenomenology. The same way out at Livermore. But at the same time, it's just sort of one deep; for me, there's nobody behind me.

*Do you guys get together and talk in classified language and record things so that that stuff is there for the labs? Is there a program?*

We've done a fair amount of documentation, but still there's nothing like the experience, and yes, the CEP still meets. We recently met and sort of revised how the CEP would operate under the test readiness. We still try to maintain certification under the DOE's rules. Pretty hard to say when somebody's certified to—it's not like a welder, you know, and he can make a certain kind of weld and do all that. Basically we haven't archived everything but we've done a pretty good job, and it's there. The question is, will the new people know how to read it if they ever had to go back to it?

So yes, for the short term, I think we're still in good shape. For the long term, it's a hard thing to say. Will we return to testing? I don't know. I really don't. Will we see the potential use of a nuke in our lifetime? I think so. I think the world is getting—the proliferation of nuclear weapons is fairly easy. We might have aided some of that during our period of openness, but we also have a different world order with people very intent on getting nukes. Nobody has so far really wanted to use the poor-man nukes, the bio-weapons; they can be, they have been used, Iraq and Iran both, perhaps a couple of other countries. But you know it's scary, and what's scary is **[01:05:00]** the situation in the Middle East. Iran definitely is working its way toward nuclear weapons, just to be part of that community. North Korea may or may not possess nuclear weapons. Again, I don't think they would hesitate to use them in a combat situation if they thought it was a benefit to them.

*Even if the retaliation would just be so utter—there's not that fear anymore?*

I'm not so sure that they fear retaliation. What scares me with Iran, again this is my opinion, my speculation, is how long is Israel going to tolerate it? Is there going to be a preemptive strike? Especially with a country going around that refuses to acknowledge its existence, of it and the Holocaust and everything else. Things can change there, too. I think the five nuclear weapons states are very responsible. I think the two wannabe nuclear weapons states, Pakistan and India, are responsible. South Africa unilaterally disarmed, we think. Again, that's based on trust. They certainly did show us what their program looked like. Theirs was more a function of it costs a lot of money to have nuclear weapons. There are other countries in the world that have voluntarily stopped, sometimes just because of economics, but have the potential to start them up again. Japan definitely could have a bomb probably in six months if they wanted to. Germany could do it if they wanted to in a matter of months. But countries even in South America were pursuing active nuclear weapons programs at one time, and several other countries in the world, which that's why the P-5, the nuclear weapons states, try to extend their umbrella out to them and do that.

Yes, but Pandora's box is open, and there's no way to stop the hemorrhaging, and it's just a matter of time; I'm a little sometimes dismayed with this country that the Cold War threat is over so we don't have to worry about it. Our Russian and Chinese friends, let me assure you, don't think that way. They are modernizing, reducing, but still modernizing their arsenals because they are not thinking about them in the old Cold War mentality the way we do, that they may be used in an operational manner.

*But they're managing to modernize without testing, I guess.*

They may have done enough testing in the past. While we do subcritical experiments at the Nevada Test Site, and I emphasize subcritical, there is no way you can have criticality. There is no, even in the Comprehensive Test Ban Treaty [CTBT] as signed, not ratified, not entry into force, no definition of zero yield. The Russians have a definition of zero yield which would allow them to do things up into the tens, maybe hundreds of kilograms. The Chinese probably follow a similar policy. The Russians have publicly stated on numerous occasions that they're modernizing. They're developing a whole new generation of nuclear warheads. Sergei Ivanov [Russian Defense Minister] recently said that again, about a year ago.

But anyway, if we could do things, what are called hydronuclear experiments that we did during the moratorium period in which you might get a few pounds of yield (four pounds is sort of the magic number) that's a few generations of fission; or if you were able to do things up into let's say tens of kilograms, which is quite a few generations of neutrons, you'd have much more confidence in things working. I think what the Russians and the Chinese probably are doing are **[01:10:00]** variants on things that they were doing right at the end of underground testing, and that they can probably validate to their own satisfaction that they're doing it.

I'll just say one thing, that both Russia and China spend a lot of money, and I think while they both ratified the Comprehensive Test Ban Treaty, both have made public statements that they consider the treaty to be null and void because the United States did not ratify it. The Russians especially have made that statement. The Chinese made it about two years ago. Kind of interesting, too, when we did the subcritical experiments, in the interest of transparency we invited the Russian ambassador to visit the Nevada Test Site. He went down in U1a and was given the full tour. I think he was more interested (and this is a personal comment) in visiting Las Vegas than he was the test site, but that's beside the point. We expected a reciprocal visit to go to Novaya Zemlya to see what the Russians have been doing up there, which they again have publicly said is a mirror-image program of what we do. They just say, We are doing experiments similar to yours in Nevada. Not exactly, but similar. They didn't come forth with a reciprocal visit. We asked them, Can we have a visit? And they said, Certainly, as soon as you ratify the Comprehensive Test Ban Treaty.

So as a result, we're in a little stalemate with them. But, you know, things have been good with them and they recently came out strongly against Iran, even though they supplied a hell of a lot of the technology to the Iranian program. I don't think any of that was other than just to get good cold, hard cash. They have a huge nuclear industry in Russia that, while they're modernizing power plants and stuff like that, they aren't really building any new ones. They're going to start on an effort to build a bunch of new ones. Also build them in Europe for other countries. If the French don't beat them to the punch.

It's a strange world out there. But that's what we did, and on the seventeenth of May [Scheduled unclassified tour of NTS tunnels by UNLV researchers] you'll see all the engineering stuff that went into these, and in a sense they were huge. You didn't ask how much they cost. The fielding cost of a typical underground effects test when we stopped in 1990, for an line-of-sight pipe, the radiation effects tests, was about seventy million dollars. For a cavity test, which we didn't talk much about, where we did high-overpressure blast and shock or energy coupling, part of that related to the cratering program, which helped to validate all of that, those were typically in the neighborhood of about thirty-five to forty million dollars.

**[01:13:53]** End Track 2, Disc 2.

**[00:00:00]** Begin Track 2, Disc 3.

*Thirty-five to forty, so about half as much.*

If you want to look at it this way, it was half as many channels of data, too. A channel of data used to cost about $125,000 a channel. That's amortizing all those costs. So much of that was manpower. Could it have been done cheaper? Yes, if you weren't operating under the work rules of the Nevada Test Site, because in order to have no-strike rules out there, as you well know, they had lucrative contracts and the unions got very good wages. There were a lot of guys out there, crafts in the tunnels, that made more money than I did by a long shot.

*Well, this has been a really good overview. I've learned a lot.*

I think you'll get similar from Wendell [Weart], from a different perspective. Again, his activities pretty well stopped in about '74 or '75 time frame.

*Right. But it's good to get that early—he's late [nineteen-] fifties, I guess, up until that period, so that will be useful for me. It's interesting to think about, and this will have to be a conversation we'll have to have another time, but when you look back at that early history and you're looking at Niels Bohr saying this weapon would have to bring an end to war, that was his belief, and then you see actually how war, the Cold War anyway, developed technologically, it came to mind because you said the genie's out of the bottle, which of course is what they were saying back then, and trying to get it back in and then—*

Well, that's why when Ben Benjamin was standing in the West Ten Thousand Station, 10,000 yards from Trinity, and he said to his boss, Julian Mack, the two of them were up on top operating these high-speed cameras, he said, `My God, it's beautiful`, and Julian said, `Oh, no, it's terrible.` And Dr. Mack realized that the genie was out of the bottle and that world history would never be the same. And that's exactly what's happened, and I'm sorry to say, I really strongly feel that in the next ten years, somebody's going to pop one off in some sort of a conflict. It may even be shorter than that. A lot of crazies out there in the world right now. And it's all about power, you know, and I point out to people, there was a book written back in the late sixties and it's called *The Population Bomb*. People ought to go back and read it again. It's just as true today as it was when [Paul R.] Ehrlich wrote it back then. It's the fact that the world's population is getting so large and the demand for all the basic resources forces people into war. When he wrote that book, the world population was, what, four-and-a-half billion. Now it's pushing eight and continuing to grow at an exponential rate, and it'll just keep getting worse until either some disease wipes half of us off the face of the earth—well, that's a real possibility. We had diseases like that in historic times. The Black Plague took out about, what, 20 percent of the population of Europe or something like that.

*Something horrendous, yes.*

**Patricia Chavez of DTRA:** Yes. Or biological warfare. I mean—

**Byron Ristvet:** Oh, I don't think it'll actually be biological warfare. It'll be something like this avian flu. Just look at the pandemic flu in 1917. Geez, it killed, what, 8 percent of Americans or something like that.

**[00:04:46]** End Track 2, Disc 3.

[End of interview]