ON THE FRONT LINES

Plutonium workers past and present share their experiences

a roundtable organized by Bill Inkret and Guthrie Miller under the auspices of the Environmental Safety & Health Division

Plutonium metal is one of the major legacies of the Cold War—about 89 tons of it can presently be found in the pits of stockpiled nuclear weapons. The entire world ardently hopes that most of that nuclear fuel will be retired to some safe place in some benign form. A small fraction will inevitably continue to be used in the remaining nuclear stockpiles. Both aspects, retirement of the fuel and maintenance of the stockpile, require a place to handle plutonium and people who are willing and able to do the work safely.

Los Alamos was the place where, in 1944, reactor-produced plutonium in gram quantities was first fashioned into the pure metallic form needed to build an atomic bomb. Today the Laboratory remains one of the few places in the world where that very dangerous material can be handled safely. The town is also the present or former home of many men and women who worked with plutonium on a daily basis. Some of those people had accidents, and as a result, now carry in their bodies small quantities of plutonium.

For this issue of *Los Alamos Science*, which is dedicated to radiation protection and the story of the human radiation experiments, we asked a small group of past and present Laboratory employees to tell their stories of what it was and is like to work with plutonium. All of them have been involved in significant accidents or uncontrolled situations that led to significant internal exposure to plutonium. Some of their exposures are among the most serious that have occurred in the history of the Laboratory. Today, vastly improved working conditions have made accidents much less common than in the early days, but a small number of unlikely events are bound to happen even now. The personal experience of such events and their aftermath is presented in what follows.

Open hood in D-Building–1944

The participants represent all eras of the Laboratory from the Manhattan Project days to the present. A few are members of an informal group known as the UPPU club (translated as "You pee Pu!"), which was established at the Laboratory by Wright Langham in 1951. One had to have accumulated a significant plutonium body burden to qualify for voluntary membership. Those volunteers agreed to be monitored periodically and are being monitored to this day.

A plutonium body burden usually cannot be detected by an external radiation monitor because the alpha particles emitted by the plutonium are completely absorbed and never leave the body. The most reliable detection scheme is to measure the small fraction of that burden that is excreted in the urine daily. So starting in the forties, the urine of a plutonium worker was monitored on a regular basis. The amount measured in the urine is then related to the amount retained in the body using data and methods derived from a series of animal and human experiments. Wright Langham, who was responsible for the protection of workers during the early days at Los Alamos, was instrumental in the design and analysis of some of those experiments (see "The Plutonium Injection Experiments"). If urine assays and models like the Langham equation indicate that a worker has retained an amount near or above the limit set by radiation protection standards, then he or she is not allowed to work with plutonium again.

The roundtable was organized into several distinct parts. The participants were first asked to describe their personal experiences working with plutonium and their concerns about safety. That discussion illustrates the evolution of attitudes and practices from the Manhattan Project through to the present. For the second part, the participants were asked to describe the accidents that led to their intakes of plutonium. Next, they were given the opportunity to ask questions of the health experts that were present, and finally, they were asked to give their views of the plutonium injection experiments.

We want to thank them for sharing their feelings and experiences and for their essential contributions to the mission of the Laboratory.

The Participants

Here we introduce the ten men who agreed to share their stories of plutonium intakes. It is their belief that open communication will help the Laboratory, the community, and the whole of society to understand the human factors associated with managing our plutonium legacy.

These ten individuals are representative of a variety of plutonium intakes that have occurred in the history of the Laboratory. The magnitude of each individual's intake is expressed as the estimated committed effective dose-equivalent in rem, which is the dose that will be accumulated over a fifty-year period from the time of intake. These rem doses are divided into classes as follows: Class I: 10–30 rem, Class II: 30–100 rem, Class III: 100–300 rem, Class IV: 300–1000 rem.

Although the rem dose is meant to be a universal measure of the cancer risk from radiation exposure, the rem doses for plutonium accumulate slowly and may not have as large a cancer risk as an equal acute dose of gamma and x radiation. Therefore, the doses quoted here are most useful in comparing with other plutonium intakes.

To put these doses in perspective you may recall that the average background dose is about a third of a rem per year, or about 15 rem over a fifty-year period. Thus, for example, a person whose body burden of plutonium corresponds to a Class-I dose will receive a total radiation dose somewhat greater than background.

Ted Magel (Class III) and **Nick Dallas** (Class I) arrived at Los Alamos in early February 1944. They are credited with the first production of plutonium metal at Los Alamos. Ted received a puncture wound, and both Nick and Ted inhaled plutonium dust, which resulted in high nose counts. (Each nostril was swiped with moistened filter paper, which was put in an alpha counter to measure the amount of radioactivity in terms of counts per minute (cpm), or disintegrations per minute (dpm) when corrected for counter efficiency.)

Bill Gibson (Class III) came to Los Alamos in June of 1944 and worked in the plutonium recovery laboratory. From 1944 to 1945, Bill received exposures that resulted in four high nose counts (over 1000 cpm from one nostril, a level rarely seen in recent years) and one plutonium-contaminated wound, which was surgically excised. He was removed from plutonium work in 1954.

Ed Hammel (Class II) came to Los Alamos in June 1944 to replace Ted Magel as section leader for the plutonium metallurgy laboratory. The relatively primitive working conditions in D Building, as opposed to specific incidents, account for Ed's intake of plutonium.

Harold Archuleta (Class I), a lifelong resident of Espanola, came to work at the Laboratory's metal fabrication group in the plutonium research facility at DP site in 1958. In 1971, Harold suffered a plutonium-contaminated wound, which required excision, and in 1987, he inhaled plutonium dust, which resulted in a high nose count (over 1000 dpm from one nostril). Howard was removed from plutonium work in 1990 and retired from the Laboratory in 1993. He is now an escort for a Laboratory contractor.

Arthur Beaumont (Class III) arrived in Los Alamos in 1946 to work as the recreation director in Theater #2. In 1951, he began working at DP site on weapons components and later worked on the artificial heart program. Art's intakes occurred in the 1970s and involved both plutonium-239 and plutonium-238. Art was removed from plutonium work in August 1973.

Jose Gonzales (Class I) was born in El Rancho and spent summers on his father's homestead on Barranca Mesa in Los Alamos. In 1958, he began work at DP site as a radiation-protection technician. Jose relates numerous incidents in which intakes have occurred.

James Ledbetter (Class I), a native of Oklahoma, came to Los Alamos in 1969 and began working on plutonium heat sources for the Jupiter fly-by mission. Jim was one of the workers exposed in the infamous CMR-Building airborne plutonium accident of 1971 in which a malfunction of the ventilation system transported airborne plutonium out of the hot cell into the cold operations area.

Michael Martinez (Class I) began working in the metal production laboratory at TA-55 in 1980. TA-55 is the site of the state-of-the-art plutonium facility that was completed in 1978. John was involved in an airborne release of plutonium-239 in 1993. Michael was removed from plutonium work that same year.

Jerry Taylor (Class IV) began working at TA-55 in 1980. In April 1981, Jerry cut his left hand with a plutonium contaminated knife while working inside a glovebox. The wound was surgically excised twice, and chelation therapy was administered for a period of over one year. Jerry was removed from plutonium work and continued to work at the Laboratory until 1985.

Setting the Stage in Chicago

Ed Hammel: As background for this discussion, I'd like to read a paragraph from the diary of Glenn Seaborg. As most of you know, Seaborg, in collaboration with Art Wahl and Joseph Kennedy, was the first to isolate plutonium and to demonstrate that it was a new man-made element heavier than uranium. [*Trace quantities of the new element were made by placing samples of uranium in the Berkeley cyclotron and bombarding them with either neutrons or deuterons. When uranium-238 absorbs a neutron, it transforms into neptunium-239, which rapidly decays to plutonium-239, the isotope used in nuclear weapons.*] That work was done in 1941, two years after the discovery of nuclear fission and just as the possibility of making an atomic bomb was first being seriously considered by the United States following communications from Great Britain.


Ted Magel in 1944

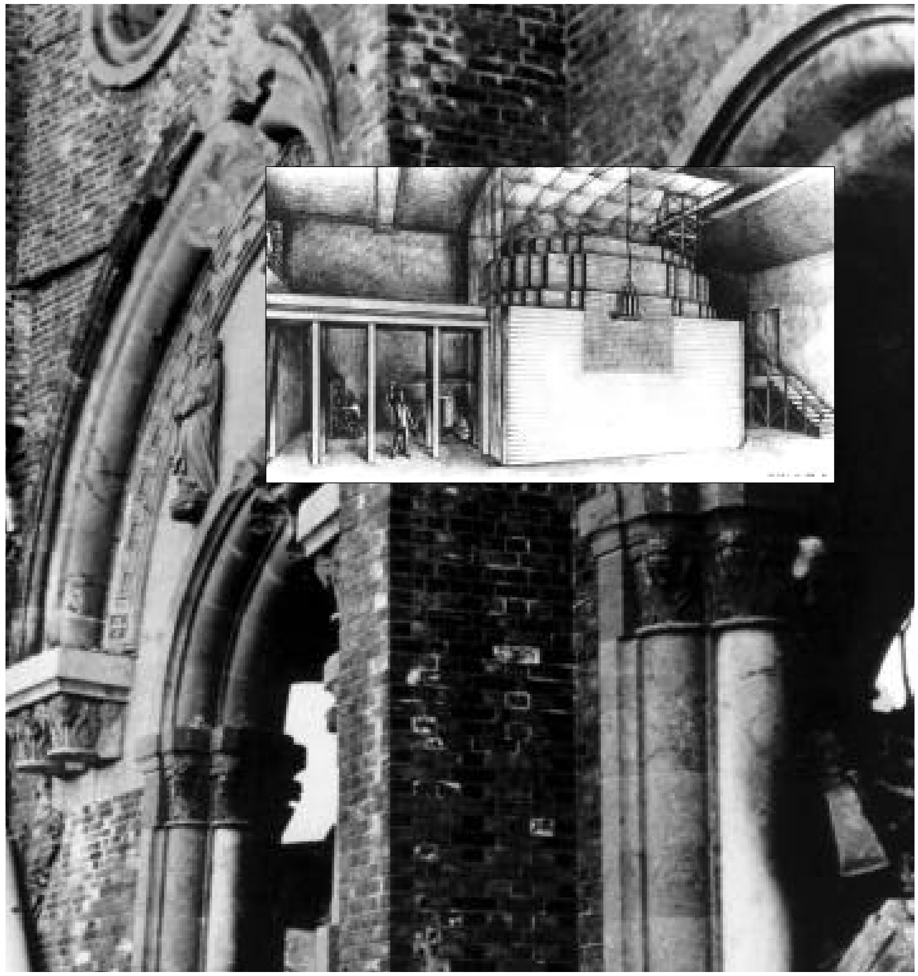
By April 1942, the decision to build the bomb had been made, and Seaborg and his Berkeley colleagues had joined the Plutonium Project at the Metallurgical Laboratory [Met Lab] at the University of Chicago. They were charged with developing chemical methods for isolating and purifying reactor-produced plutonium. Nuclear reactors were still just a dream—Enrico Fermi was under the west stands of Stagg Field, the University of Chicago's athletic stadium, building the uranium pile in which he hoped to demonstrate the first self-sustaining nuclear chain reaction (he did not succeed until December 1942). Nevertheless, Arthur Compton, the initiator of the Plutonium Project, was fairly certain that uranium reactors like Fermi's could be used to manufacture the kilogram quantities of plutonium needed for a bomb.

In January 1944, accelerator-produced plutonium in milligram quantities was just becoming available to the Berkeley chemists, but gram quantities were soon to be delivered from the pilot production reactor in Clinton, Tennessee. On January 5, Glenn Seaborg wrote:

> *As I was making the rounds of the Laboratory rooms [at the Met Lab] this morning, I was suddenly struck by a disturbing vision. I pictured in my mind the expanded scale of work with solutions containing plutonium that will soon result from the large quantities of plutonium soon to be received from Clinton Laboratories. I visualized beakers of plutonium solutions throughout the laboratory rooms, and it struck me forcibly for the first time that plutonium handling will now no longer be confined to micro quantities manipulated by specially trained experts. Recalling the health problems incurred by workers in the radium dial-painting industry, I realized clearly that similar hazards face those of us working with alpha-particle-emitting plutonium-239. I was struck by the fact that despite the great care in planning by the Project medical people, no one has anticipated and made special provision for the wide-scale handling of alpha-active material which presents special hazards of ingestion. It became clear to me that our rather ordinary laboratory hoods are inadequate for this task and that rather extensive rebuilding of our laboratory facilities to emphasize adequate air flow and extraordinarily clean operations will be necessary. I am determined that none of the people for whom I am responsible shall be subjected to any avoidable dangers from handling alpha-active plutonium.*

That note was written nine months after the Los Alamos Laboratory (Site Y) was established and a month before any plutonium arrived at Los Alamos. From the Met Lab and other sources, we knew that we would be working with a very hazardous substance. But we had a tremendous job to do in terms of making this material into a metallic fuel for the bomb. Nobody had ever seen pure plutonium metal. Nobody knew any of its properties. Nobody knew its density, its melting point, or how hard or brittle it was. Nobody knew how to fabricate it. All we knew was that we had to do it. And we had to do it as carefully as we could.

Los Alamos Science: *Ted Magel, you were the first person to isolate*



Inset: Fermi's pile under the stadium at Stagg Field, University of Chicago

plutonium in a pure metallic form. Tell us how you came to work with plutonium in the first place.

Ted Magel: Well, I was actually at Berkeley when plutonium was discovered. I was doing my graduate work in chemistry under Professor G. M. Lewis, and Seaborg, Art Wahl, and Joseph Kennedy were just across the hall. I had no part in their discovery, but I knew about it. Then when Seaborg went to Chicago to set up the Met Lab, I was the fifth chemist that he asked to join him. At first, we were working with tracer amounts of plutonium—and finally with microgram amounts that could only be observed under the microscope.

Los Alamos Science: *What was the purpose of the work at the Met Lab?*

Ted Magel: The laboratory was called "The Metallurgical Laboratory" to disguise the real nature of our work. In actuality, we were developing chemical techniques for separating the plutonium that was going to be produced in a uranium pile. We worked with a big load of uranyl nitrate that had been bombarded with neutrons for weeks and weeks at the cyclotron at Washington University in St. Louis. That material was supposed to mock up the material that would eventually be sent from the Clinton reactor. We managed to precipitate out a plutonium compound from this big mixture; it was the first plutonium compound seen under the microscope.

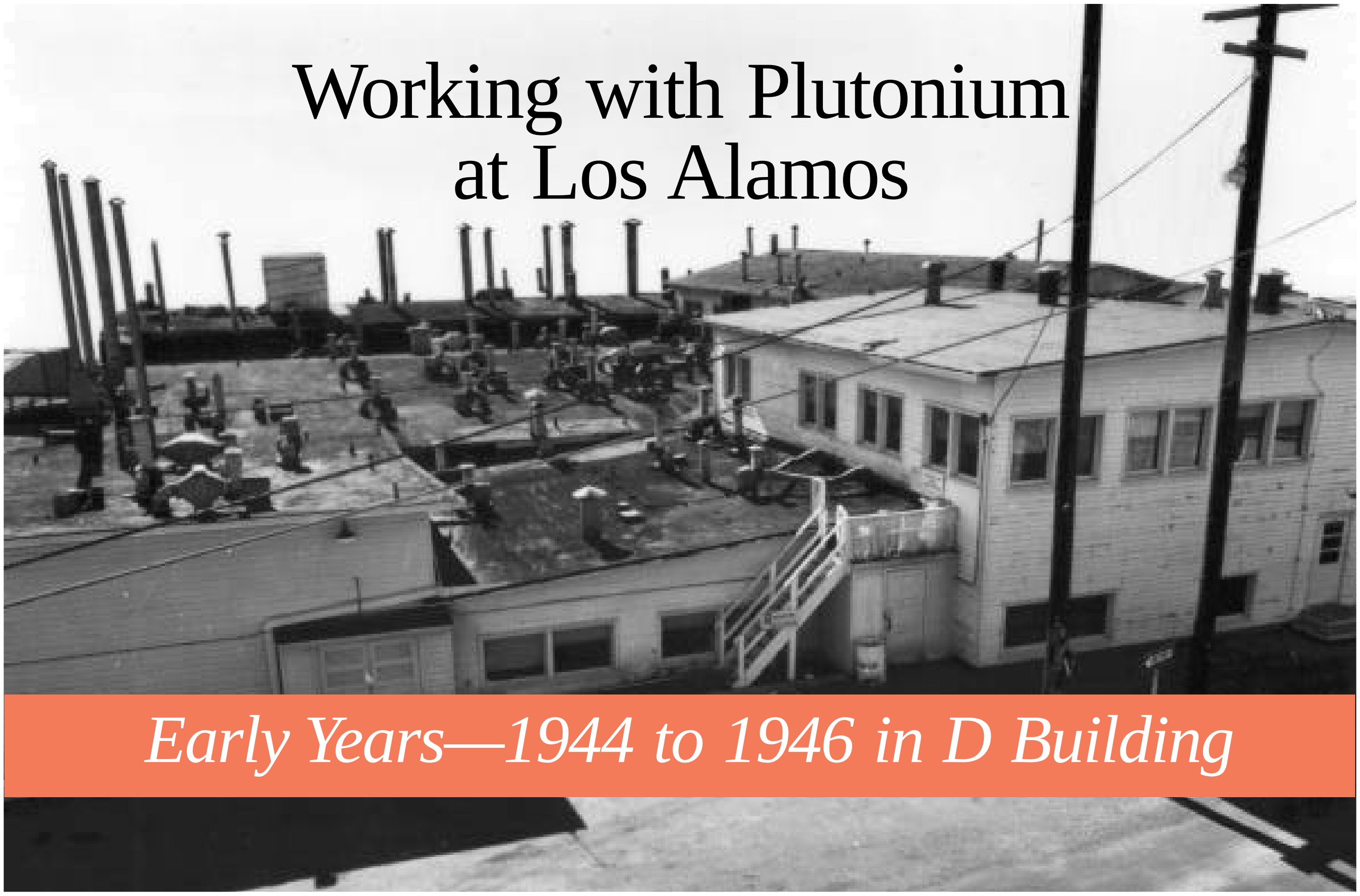
For various professional reasons, I decided to leave Seaborg's chemistry group and work for Dr. Chipman. He had been brought out from MIT to head up some metallurgical operations needed for the plutonium-production system. In 1943, Chipman asked me to go over to Site B, an old brewery on the south side of Chicago near the University, and set up a group to work on techniques to produce plutonium metal from the very small quantities of plutonium compounds that would initially become available. Nick Dallas and I went to site B. I recall that we spent all of our efforts during 1943 on small-scale reduction techniques for making pure metal buttons.

There wasn't any plutonium around at that time, so we used stand-in elements like uranium, alloys of uranium, manganese, and so on. During that year Nick and I developed the hot-centrifuge procedure for making small-scale good-yield reductions of uranium fluoride to uranium metal.

Anyway, one night I was awakened by Chipman at about 11:00 o'clock and asked to go immediately to a meeting where they said, "We want you and Dallas to pack your things right now and go down to Los Alamos. They want to see if you can reduce uranium, and they want you to get ready to reduce plutonium on the one-gram scale." So we packed up our equipment and went to Los Alamos.

At that time, everybody was having trouble producing tiny quantities of uranium and plutonium metal using standard procedures. And the difficulty was pretty obvious. The smaller the quantity of material, the greater the surface effects that cause the metal to hang up on the walls of refractory crucibles. As a result, it's very difficult to get a good yield of solid, nonporous metal. But that was the goal, to make a solid button that could be used for measuring the bulk properties of the metallic phase.

Working with Plutonium at Los Alamos



Early Years—1944 to 1946 in D Building

All plutonium chemistry and metallurgy at Los Alamos was done in D Building, one of the most elaborate and costly structures at Site Y. It was designed to minimize contamination of plutonium by light-element dust particles in the air. According to official descriptions it had five miles of piping, a complex air-conditioning system with special provsions for air washing and electrostatic dust removal, very complex laboratories serviced with water, air, gas, and electricity, and "deluge shower baths" to wash off contamination.

Ted Magel: Nick and I arrived at Los Alamos about February 3, 1944 and went immediately to the metal-reduction area in D Building. Well, the place seemed like a morgue to us; everyone was quiet and working in isolation. I guess they were discouraged. Dick Baker was having a great deal of difficulty with his metal-reduction work, and morale was low. Nick and I quickly transformed the place and got everyone excited. Within a week, we had set up all the equipment that we'd brought with us from Chicago and were making 1-gram reductions of uranium in our hot centrifuge.

On March 2, the chemists gave us a 50-milligram quantity of plutonium fluoride to reduce to metal. That's a very small amount of material but that was all that was available. Nick and I worked with it, and in our second attempt at reduction, we were able to make a tiny coherent sphere of plutonium metal weighing 20 milligrams. That was a 40-per-cent yield, better than we expected after our first failure.

We continued to refine our methods and to wait, along with everyone else, for the arrival from the Clinton Laboratory of the first gram samples of plutonium. When they finally came, Eric Jette and Cyril Smith decreed that Dick Baker would get the first crack at a reduction, but Dick's stationary-bomb method yielded only a black cokey mass rather than a coherent button of plutonium metal. A few weeks later, a second sample became available, and this time, it was given to us.

Nick Dallas: Ted, you really should tell the whole circumstances of that reduction.

Ted Magel: The reduction of a gram quantity of plutonium was considered a very big deal because that amount of metal would allow much improved measurements of many crucial material properties. The reduction was supposed to take place on March 24, 1944, and General Groves and several top administrators had been specially invited to observe us as we did it.

Well, when does everything go wrong—when you have a whole lot of observers, right? So on the 23rd, I said to Nick, *Well when does everything go wrong—when you have a whole lot of observers, right? So on the 23rd, I said to Nick, "Let's go up to the lab and make the reduction tonight before all these people get here."*

"Let's go up to the lab and make the reduction tonight before all these people get here." Nick agreed, and we carried out the reduction using the hot-centrifuge bomb method [*see "Plutonium metal—the first gram"*]. When it was done, we cut open the bomb, dropped the little button of plutonium metal in a glass vial and put it on Cyril Smith's desk with a note that read:

Here is your button of plutonium.
We have gone to Santa Fe for the day.

Everyone was pretty mad at us and claimed that we had contaminated the lathe and the back shop when we had opened the bomb to retrieve the plutonium button. I don't believe that we had, but I understood how they felt. In any case, once they had the button, they immediately started measurements of density and so forth. Also, Dick Baker continued his work on the stationary bomb and eventually developed excellent procedures for working with the larger quantities of plutonium that continued to arrive from the Clinton pile.

Nick Dallas: Ted, after we made the first button, I believe we started working on plutonium purification techniques.

Ted Magel: Right Nick. After about eight more 1-gram reductions, we went to work on developing ways to make super-pure plutonium. We needed to remove all light-element impurities. The worry was that alpha particles from the plutonium would hit light-elements and produce neutrons. The high neutron background would then cause the bomb to pre-initiate and fizzle before the critical mass was fully assembled.

Well, just as we were getting off the ground on light-element purification, it was discovered that plutonium from the production piles at Hanford would contain substantial quantities of plutonium-240, an isotope that produces neutrons as it undergoes spontaneous fission. Since plutonium-240 cannot be removed chemically, the gun method for assembling the plutonium bomb was abandoned and the project turned to the implosion method. That meant Dallas and I were no longer needed to make super-pure plutonium.

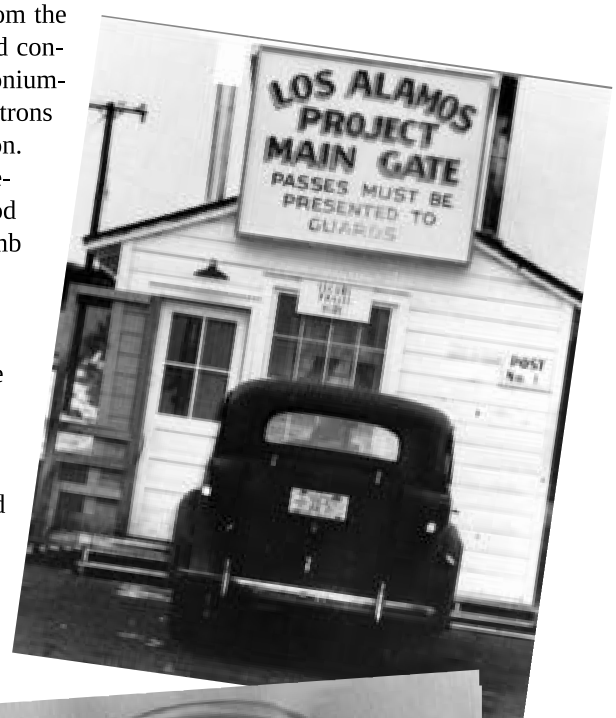
Oppenheimer told the chemists that we were welcome to stay and find jobs elsewhere in the Laboratory. Nick and I elected to leave. I think we were the first ones ever to leave Los Alamos and still remain on the Manhattan Project. We went to work for Dr. Chipman at MIT where we produced nonporous, highly sintered crucibles of pure magnesium-oxide—3 inches in diameter and about a foot high—for holding molten uranium and plutonium. And we shipped large numbers to Dick Baker's group out at Los Alamos.

Los Alamos Science: *Was the fact that you both had body burdens of plutonium one of the reasons for leaving?*

Ted Magel: Not at all. We did have a few mishaps with plutonium, and we were being monitored by Dr. Hemplemann and Wright Langham, but that's not the reason we left.

Los Alamos Science: *We'll want you to discuss the accidents in the second half of this discussion, but let's go back to Ed.*

Ed Hammel: I started work on the project in 1941 back in Princeton, on the heavy water part of the project.



Bill Gibson in 1944

Technical area around Ashley Pond

Ed Hammel in 1944

My wife had serious sinus problems, and someone told me that there was a place on the project out west where it was really dry. I managed to get transferred, and I arrived at Los Alamos at the end of June 1944. I was the replacement for Ted Magel in the plutonium metallurgy lab. My section got the reduced buttons from Baker and was responsible for remelting them, alloying them, and then casting them. We did that from June 1944 to the end of the war. I hadn't worked with radioactivity before I came to Los Alamos, and I learned shortly after arriving that Magel had received a large dose, but there was a job to be done.

Los Alamos Science: *Were you concerned about the health risks of working with plutonium?*

Ed Hammel: I think that everyone in D Building was aware of the risks. But there was a war going on. We didn't know exactly what was happening in Germany, but we knew their capabilities. We learned about the raid on the heavy water plant in Norway. We feared the worst, and I think that everyone working in D Building was primarily concerned with not being responsible for some stupid accident that would in any way delay completion of the overall operation.

Los Alamos Science: *What were the working conditions in D building? Were they very primitive in terms of containment of plutonium?*

Ed Hammel: We worked with wooden dry boxes, which were pretty primitive, and we worked in open hoods for some procedures. But we tried to be very careful. We wore respirators and special protective clothing, and nose counts were carried out for all personnel working with plutonium.

Los Alamos Science: *What is a nose count?*

Ed Hammel: Usually twice a day members of the health group would turn up to take nose swipes. They would swab the inside of the nostrils of each worker with a damp, rolled strip of filter paper that was attached to the end of a swab stick. After completing the collection, each nose swipe would be placed in an alpha counter to see if there was any radioactivity.

Los Alamos Science: *Bill Gibson, you were here about the same time as Ed. What was your experience?*

Bill Gibson: I came here the same month as Ed, June 1944, to work in the plutonium recovery lab. And like Ted Magel and Nick Dallas, I'm a member of what is called the UPPU club. All of us in that club got an appreciable amount of plutonium inside us during World War II. I won't say how much, and nobody was really sure until about 1954. By then, analytical techniques had improved to the point that inconsistencies in the analysis had been materially reduced and the data appeared to be more meaningful. I was taken off my job and not allowed to work with plutonium or put my hand in a glove box again.

And I began to think of the science fiction pieces that I'd seen in the Sunday newspapers and thought, "Oh my God, are we entering a new age?"

Los Alamos Science: *What did you think about this material at the time?*

Bill Gibson: I was in an Army combat unit at the time I was assigned to Los Alamos and I didn't have a clearance, so at first, I didn't know what I was working with. The characteristics of the material were reasonably close to uranium but not quite the same and not the same as any other element of the periodic table. And I began to think of the science fiction pieces that I'd seen in the Sunday newspapers and thought, "Oh my God, are we entering a new age?" After a month, I received my clearance and was told what it was all about, including that I was working with a new man-made element plutonium. Of course, I knew about radioactivity, and I knew that in the old days the people who had painted the radium watch dials had suffered from radium poisoning and died some pretty terrible deaths. But Wright Langham was a very sharp man, and he cautioned us about the hazards of plutonium. He and Louis, Dr. Louis Hempelmann, kept pretty close watch over us.

But the conditions were primitive. Like Ed said, we worked in open hoods. There was a table with a glass top that resembled a slanting shelf, and we put our hand under the glass to work. We worked with all kinds of chemical residues and with all kinds of crucibles. We had to recover plutonium from almost every element in the periodic table. Sometimes things got pretty sloppy. As a matter of fact, the first eight grams that we worked with was called our jinx batch. After it had been ether-extracted and was in its purest form, one of my compatriots put it in a petri dish and put the petri dish in an oven to speed evaporation. When he tried to pull out the glass dish, the bottom fell out, and the whole thing, plutonium and all, went on the floor. We cleaned up the spill, it was about 8 milliliters of liquid, and got it almost to the final purification. That is, we had it in the centrifuge at the precipitation stage, and while it was whirling around like mad, one of the centrifuge cones broke, and the stuff came out all over the inside of the centrifuge and out through the ventilation of the centrifuge onto the floor. Again we cleaned it up, got it purified and sent it to the dry-chemistry operation where their controller got stuck, and the stuff burned to a cinder. So we had to start again for the fourth time. We finally did get out most of the eight grams and gave it back to the dry-chemistry section, who prepared it for metal reduction.
As I said, the conditions were not the very best. When we spilled the solution, we had to get down on our hands and knees and clean it up. But we were able to recover almost all of it, and that was what we were after.

Los Alamos Science: *Were you concerned about your own health when you were in these situations?*

Bill Gibson: The combat unit that I came from wound up in the Battle of the Bulge, so my philosophy was that if I died twenty years later from working with this stuff, I would be lucky compared to my compatriots who hadn't had the chance to live that long. My attitude was to be as careful as possible and to do the best I could as a soldier of the United States Army.

Ed Hammel: What was paramount in our minds was not the danger of radioactivity, but rather that this stuff was extremely valuable, at least 100 times more valuable than gold, and for gosh sakes, we better take care not to lose any of it.

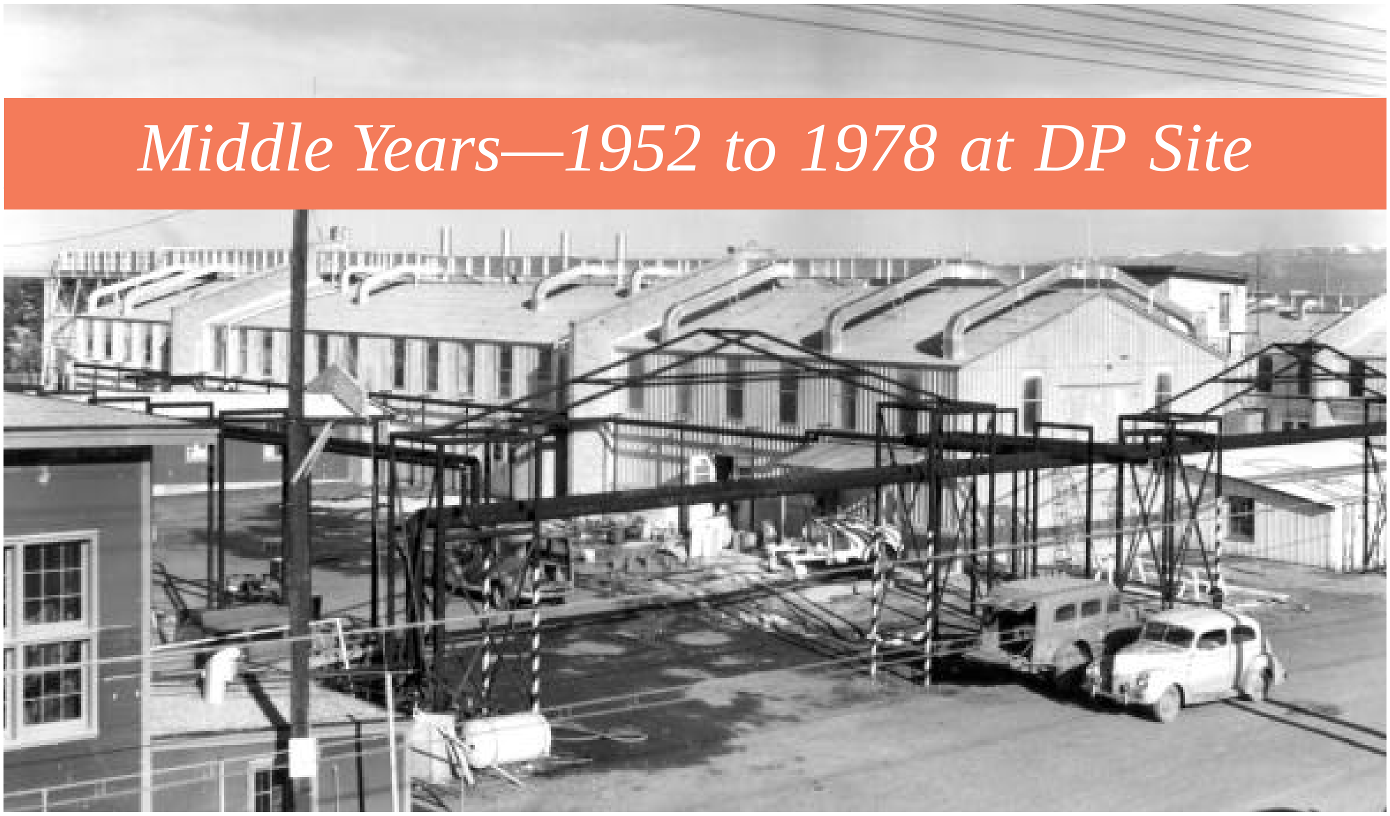
Bill Gibson: We did try to protect ourselves from inhaling plutonium microparticles by wearing dust masks, the kind that miners use. But they weren't very effective. I don't think there were many days during World War II when I was without a positive nose count of between a few hundred and 20,000 disintegrations per minute.

Los Alamos Science: *Bill, we'll wait until our discussion of accidents and health consequences to hear more of your story. But now we turn to another period in the story of plutonium workers marked by the move to DP site and less primitive working conditions.*

Infirmary

Covered bridge across Trinity Drive connecting technical areas

Middle Years—1952 to 1978 at DP Site



By late 1944, the need for a safer and larger facility to handle fabrication and recovery of plutonium was evident. The site selected for the new complex, originally called "D Site," was on a mesa across from the modern-day airport and down about a mile from the original technical area of the Laboratory, which is now the center of the town. The new complex was officially named "DP Site" on March 16, 1945, to avoid any confusion with the existing "D" Building. Although many theories exist about the exact meaning of DP, the minutes of the Plant Building Committee, headed by J. E. Burke, suggest that P stood for Plant. (In a 1981 article, however, Burke stated that the P stood for polonium). The buildings at DP site are made of metal and were built with elaborate ventilation systems, closed hoods, and all kinds of features to keep exposures to a minimum. Operation began at the site in 1945.

Los Alamos Science: *Art, your experiences began in DP Site, didn't they?*

Art Beaumont: Yes. But I first came to the Santa Fe area back in 1946. I came to look up a gal I had met when I was with the 10th Mountain Division. We really hit it off, and I decided to stay. In April, I got a job up here on the mesa first with the U.S. Army Corps of Engineers, and then with the Zia Company, as recreation director of Theater Number 2. By July of that year, my wife and I were married. A bit later, I went back to school at the University of New Mexico and earned a masters degree in educational administration. Then, in May 1951, I was hired by the Laboratory. Although I didn't have a degree in chemistry, I had enough coursework in science that they hired me to work on the fabrication of plutonium parts for weapons.

Los Alamos Science: *What did you know about plutonium when you first started?*

Art Beaumont: I didn't know anything. I just walked down to Building 5 at DP Site and started to work. There was no education; I wasn't even sure what I was working with, to be very honest. There was a stainless steel glove box with weapons components, and one of the first things I did was use a piece of sandpaper to make a certain tolerance for a weapon item. It was really kind of amazing. I would be sanding away and all of a sudden I would see a little fire in front of me. Plutonium dust had accumulated and caught on fire. I would use graphite to put out the fire or just take a piece of sandpaper and smother it.

Los Alamos Science: *The plutonium would catch on fire?*

Art Beaumont: Yes, small pieces of dust with lots of surface area are pyrophoric; it starts burning by itself.

Los Alamos Science: *Were you concerned about the health hazards?*

Art Beaumont: Not at all. From Building 5, the fabrication unit, I went to Building 2, which was recovery, and

I worked there for a long time. We were like a family down there. Everybody cooperated with everybody. I worked with people like Dr. Baker, who everybody probably knows about, and it was just fun working with him. I had absolutely no fear of plutonium, but one afternoon about 3:30 P.M., I was asked to go to the administration building. There they told me, “You’ve reached the threshold of allowed plutonium in your body; we have to transfer you.” I still have the letter from Dr. Baker that said I was being reassigned from DP West to DP East. Since that day, I’ve felt that if there was somebody like me, whose count was building up, the one thing the Laboratory could do would be to tell that person and give them a choice of being reassigned before they acquire their limit. Instead, out of the clear sky, I was told I had reached the threshold. I hope the Laboratory is doing things differently with the people who are working today.

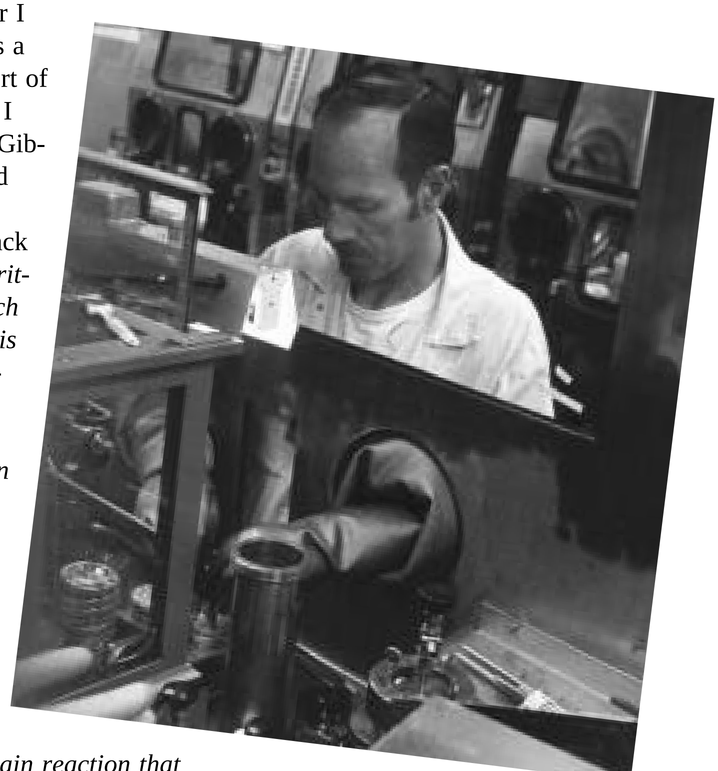
Jose Gonzales: I understand what Art is saying. It’s hard not knowing exactly what’s going on. Back in the early days the Laboratory people would transport plutonium in convoys only fifteen feet from my kitchen door down the hill in El Rancho. I remember hearing those convoys passing our house at 1:00 A.M. in the morning. It would have been nice if they had told us what was in them. The family knew there was a secret project, but they didn’t know anything else. My father had had a homestead on what is now called Barranca Mesa. It’s the most northerly mesa in Los Alamos. In the early forties, the Federal Bureau of Investigation came to our home and condemned the property for war purposes. They gave us 30 days to move out, and that’s when we went down to El Rancho. My father worked at D Building during the war and was there during the early stages of the plutonium work. He lived a happy life and died at the age of 85.

Los Alamos Science: *Jose, what made you decide to work at Los Alamos?*

Jose Gonzales: I had a business down in Pojoaque, and when it went down the tubes because the highway department was widening the road, I decided to apply to Los Alamos. That was 1958. Dr. Thomas Shipman in the Health Division called me for an interview and explained the field of radiation monitoring to me. He explained what my duties would be, and then I wound up being assigned to DP Site. There I had a chance to work with some of the pioneers in plutonium work—like Bill Gibson, Art Beaumont, and Bill Maraman. I felt comfortable from the start even though I didn’t know exactly what was going on in the experiments. I guess what made me feel good was that I had the equipment to protect myself and to protect those people that were out there. A lot of elderly people of Spanish descent were working there as laborers, electricians, craftsmen, and so on, and I was able to communicate with them in Spanish.

Then just a month after I started work, there was a fatal accident. That sort of shook me up, but then I went to guys like Bill Gibson, Bill Maraman, and Dr. Shipman, and they were able to put me back on track. [*This fatal criticality accident in which Cecil Kelly was killed is one of three such accidents that have occurred at Los Alamos; the others took place in 1945 and 1946. A criticality incident, or the accidental initiation of a nuclear chain reaction, usually occurs by collecting a mass of fissile material into a small space. The nuclear chain reaction that results releases a lethal flood of gamma rays and neutrons.*] I learned from the experience that people can die from radiation—you can plan for a job for three weeks, and it only takes one second to mess it up. After that, I felt good because I understood even more why I was needed, and I liked being part of a supporting group. We were there to help in whatever manner we could. Safety was number one, and we always tried to be prepared.

Back in the early days, the Laboratory people would transport plutonium in convoys only fifteen feet from my kitchen door down the hill in El Rancho. I remember hearing those convoys passing our house at 1:00 A.M. in the morning.



Glovebox at DP Site

Los Alamos Science: *What exactly was your job out there?*

Jose Gonzales: In my first years, I did routine radiation monitoring. I posted the dose rates, and I helped people with routine operations, like getting dressed in protective clothing and then changing back to their own clothes when they left the area. Also, I made sure the right equipment was there. Over the years, I worked in all the labs at DP Site. I assisted with the first batch of plutonium-238 that came there. It was going to be used as an energy source for a heart pacemaker. I also worked with the people who did metal reductions, turning compounds into pure metal. They worked in a long line of glove boxes called the MPL, the metal prep line. In 1978, when we were preparing to move to the new facility at TA-55, I was the only one left with any experience on that line. That's when Larry Mullins, Dana Christensen, and Art Morgan asked me to run the system. I was upgraded to a chemical technician, and I worked on that line for 13 years until I retired in 1991. I helped assemble the laser-reduction apparatus, and I made the first laser-reduction of plutonium. Conventional reductions took 18 to 20 minutes; the laser method reduced the time to 6 seconds and also reduced the neutron exposure. You know back in 1978 when I was upgraded, my first job was to help decommission the metal prep line before it was moved to TA-55. Now the Lab is about to decommission it again, and they have asked me to work as a consultant preparing a set of safety checks on their procedures for decommissioning. It feels good that I can still help.

Los Alamos Science: *Did you enjoy your work?*

Jose Gonzales: Yes, I did, but I enjoyed it most when we were back at DP Site. We all called each other by our first names; there was none of this mister stuff. We were one united family. When something happened, everyone went in as one unit to take care of it. Also, they gave me the opportunity to go out to the Nevada Test Site. I made about ten trips out there, and at one point, I worked on the Rover program, which was a program to develop a nuclear-powered rocket that could travel to Mars. I really enjoyed that experience. I worked for the Laboratory for 33 years, and I don't have any grudges against the Laboratory or the people I worked for or the people I worked with, and that makes me comfortable.

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Los Alamos Science: *Jim Ledbetter, you also worked on the Rover program in the 1960s, didn't you?*

Jim Ledbetter: Yes, my first experience as a radiation worker was at the Nevada Test Site. I was employed as a technician in the Nuclear Rocket Development Program in the Advanced Space Program. President John F. Kennedy was the champion of that program. He wanted to promote research that would enable manned space missions to distances beyond the moon, more precisely, to Mars. My job was on the Rover reactor, which was to be used as the fuel source for the manned spacecraft. I was responsible for the mechanical arms that were used to disassemble the reactor parts and prepare them for diagnostic tests. The work involved very high radiation fields.

All of us were very highly trained by outside contractors before we were pressed into service. I spent a number of years out at the test site doing postmortem examinations on various reactor designs built by Los Alamos and Westinghouse.

Los Alamos Science: *Why did you come to Los Alamos?*

Jim Ledbetter: Following President Kennedy's death, subsequent administrations determined that there would be no mission to Mars in the foreseeable future, and in 1969, the Nuclear Rocket Research for the Advanced Space Program ended. At that time, I was offered a job at Los Alamos. It was similar to the past work in the Rover Program. I was involved in robotics and hot cells providing postmortem operations on experimental fuels and components for breeder reactors. We were a team of engineers, technicians, and scientists who, in a six-month period, developed the primary containment and the robotics to do the job.

In 1970, the Laboratory informed us that we were going to participate in an assessment of the heat source for the Jupiter fly-by experiment. The unit used plutonium-238 as the heat generating material and a thermocouple package from TRW to generate power for the on-board components. It was in this manner that signals would be transmitted back to earth. Our task was to disassemble two of the units so Los Alamos scientists and engineers could assess the performance and recover the components and materials.

Following receipt of the first unit and removal of the TRW thermocouple package, the hot-cell process began. We completely dismantled the plutonium heat sources and rewelded the components into tantalum containers. They were then removed from the hot cell and stored for reuse. The first disassembly went very smoothly with no malfunctions and no unusual occurrences. The process went very well even though a sense of urgency surrounded our efforts. The experiments were being pressed to meet NASA schedules, so we quickly prepared for the second disassembly. It was during the second disassembly that we encountered problems. Despite those problems, the people at Los Alamos persisted, and the NASA schedule for the fly-by was met. It was very rewarding to us that we could be involved and see success as the spacecraft transmitted data from Jupiter several years later. After the project, we were informed that the heat source had transmitted signals far beyond Jupiter, to distances as far away as Pluto. Its performance exceeded expectations and provided data for a much longer period.

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Los Alamos Science: *It sounds like the years at DP Site were a very expansive era in the history of the Laboratory. New energy sources, interplanetary space travel, all kinds of dreams were in the air. Now we'll go on to the opening of the modern facility at TA-55 and the practices and attitudes of today.*

Modern Times—1980 to the Present at TA-55

The modern plutonium facility at TA-55 was authorized in 1971 following a devastating fire at the Rocky Flats Plant in Colorado. The Los Alamos facility was designed to withstand all natural disasters, accidents, and terrorist activities, and to protect workers under unusual circumstances such as power failures. Its modular construction has permitted continual upgrades so that it remains a state-of-the-art facility to this day (see "The Modern Role of the Plutonium Facility").

Los Alamos Science: *Jerry Taylor, you worked at TA-55. What was it like when you first came to the job?*

Jerry Taylor: I was in awe when I first walked into TA-55. It was like entering the spacecraft in *2001 Space Odyssey*. There were all these stainless-steel valves and pipes everywhere. The whole facility was awesome.

Los Alamos Science: *You knew people who worked there, didn't you?*

Jerry Taylor: Yes. My uncle worked there, and his brother-in-law was a group leader. My father and some of my cousins also worked there. In fact, my grandparents had been in Los Alamos since 1943. My grandfather worked on the first bomb.

When I first started, I went to a safety course and learned about criticality and radiation hazards. I saw all the procedures we had to go through, all the safety precautions, all the monitoring to protect us. But it never scared me. I really enjoyed learning the work at TA-55. We got to go and see what they did in some of the other labs and down to the vaults where they store plutonium and all kinds of things containing plutonium. There are a few fuel rods down there in a pool of liquid, and they are the most beautiful aqua color I have ever seen.

It was really amazing to me that we could make this material. Lots of times, we started from contaminated trash, and all of a sudden, we ended with a piece of plutonium metal. I was always in awe of all of it. I enjoyed the work. It never did scare me until the day of the accident. But then it got to me, because I knew the health hazards. That was fourteen years ago, and I still worry to this day about what the long-term exposure to internal radiation will do to me. I know Bill Gibson, I used to work with him. He had an exposure almost fifty years ago, and he's still around. And Art Beaumont is still here, even though he's been exposed. But I still have questions about it.

Los Alamos Science: *Did anyone else in your family ever have any internal exposures to plutonium?*

Jerry Taylor: My uncle had a very small exposure, but my dad never has. I don't know if my grandfather ever had one. He was a machinist up here. My family has worked here all these years, and I'm the only one that has a contamination besides my uncle, and I think his is very small.

Los Alamos Science: *How did you feel about the fact that plutonium is used to build bombs?*

Jerry Taylor: It never really bothered me. When scientists first came up with the bomb, there was a lot of dying going on in the war. The scientists, the bomb, they stopped the war, so I think it was a good thing. Plutonium is a dangerous material, and it can make a very dangerous weapon. I hope we won't have to see it used again. There is a lot of good work that goes along with the radiation work. I would love to work at the Lab again. There's a lot of neat stuff going on all the time. It's not boring.

Los Alamos Science: *Jerry, can you describe what it's like to work in a glove box at TA-55?*

Jerry Taylor: At first it's very awkward, it's like you don't have any hands. You keep dropping things. Once you get used to it though, it becomes pretty easy.

Bill Gibson: You certainly don't want to try to set your watch while you're working in the glove box. The gloves are inside the box and are attached to a pair of openings in the walls. You put on the gloves by putting your hands through the walls, so when you work in the box, your hands are always in the gloves. There's a big window in front of you to let you see what you're doing. The glove box is totally enclosed so nothing can escape. Not only that, any ventilation at all is inward since there's a slight negative pressure in the box.

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Jerry Taylor: It was hard at first to manipulate your hands while you're in those heavy gloves, but it soon became pretty easy, and I always enjoyed it. I wish I could have done more of it. It was a good experience except for the accident. After the accident, I wasn't allowed to do that kind of work anymore. The exposure was too big.

Los Alamos Science: *Michael Martinez, you have been working at TA-55 for a long time.*

Michael Martinez: Yes, I came to the Lab in 1980 and worked in the metal production room at TA-55. There you convert an oxide to a fluoride and then to a metal. Like Jerry was saying, it was very interesting when I first went in there. Everything—the pipes, the valves, you name it—it was all interesting. And it was hard to get your hands in the glove box at first. It was hard to do anything inside the glove box with leaded gloves. Once in a while, you would catch yourself grabbing your hand and trying to pull off the gloves. But of course you can't. You're taught how dangerous the material is, and you learn a lot of safety precautions. You know what you can do and what you can't do. It never did scare me; even after the incidents that gave me some exposure, I wasn't scared.

Los Alamos Science: *How did you end up working with plutonium?*

Michael Martinez: A friend of mine who was working with plutonium asked me if I would like to take a similar job. He wanted to know whether I would be scared, and I told him, "No." So I got the job. At first I didn't know much about radioactivity, but I learned as I went along. One October during the first three years of working there, I was pulled out of the plant to work on salt casting and other jobs, because I had already received the exposure that I was allowed for that year. When the next year started, I was allowed to go back into the plant and work with plutonium again. But now, after this last incident, I was told I would never be able to work with plutonium again.

Los Alamos Science: *What did you like about the plutonium work?*

Michael Martinez: I'm not happy about having to stop this work. Plutonium is what made us a free country. I'm proud that I worked with it, and I wish I could continue.

Los Alamos Science: *Do your family and friends share your feelings?*

Michael Martinez: They worry some about the dangers, but I tell them it was just as dangerous when I worked on cars. If I stick my arm in the fan, my arm is going to go. If I get under the

Of course incidents did happen and you dealt with them. If you tore a glove, you changed it. If the window cracked, it had to be changed. And sometimes you would get contaminated.

Safety excercise at TA-55

car and the jacks are not set right, the car is going to fall on me. Working with plutonium is the same. There are a lot of rules you have to obey, so you don't initiate a criticality accident. If you're going to be doing something, you do it safely. If you're not careful, something is bound to happen.

Los Alamos Science: *How frequently were you monitored for contamination?*

Michael Martinez: You're supposed to check yourself with a hand probe every time you pull your hands out of the glove box, and then again as you leave the room, you check your hands and your feet. Finally, before you leave PF4 (the plutonium area of TA-55), there's a monitor, a person, who checks you completely. Most of the time you're clean, but once in a while, you get a couple of clicks. You check your gloves—the surgical gloves that you wear under the big leaded gloves in the glove box. You can't see anything, but you know they're hot, they're contaminated with radioactivity. You call the monitor to see if you should change the gloves or whatever. It's kind of weird because you can't see anything, you can only hear the clicks.

Los Alamos Science: *Harold Archuleta, what was your experience in becoming a plutonium worker?*

Harold Archuleta: I came to work in 1967 at the old DP Site in group CMB-11. That was the metal-fabrication group where castings of various shapes and sizes were produced. I had to be highly trained because the work was totally hands-on. At first, I had to just watch; they wouldn't let me do anything for the longest time. Then I started making ingots. Later, I moved up to rods and then finally to hemi-shells. The hemi-shells had to be perfect. The group relocated to TA-55 in 1978. There I worked as head caster and tech supervisor. I was also responsible for training technicians as well as staff members, young and old. Just as I had been trained, I would always emphasize that safety was the number one priority. Of course incidents did happen, and you dealt with them. If you tore a glove, you changed it. If the window

Most of the time you're clean, but once in a while you get a couple of clicks. You check your gloves—the surgical gloves that you wear under the big leaded gloves in the glove box. You can't see anything, but you know they're hot, they're contaminated with radioactivity. You call the monitor to see if you should change the gloves or whatever. It's kind of weird because you can't see anything, you can only hear the clicks.

cracked, it had to be changed. And sometimes you would get contaminated.

The present facility is different from the old DP site. It's not like a family anymore where everyone cooperated and helped each other out.

Bill Gibson: There's a good reason for the change. When we were at DP Site we were a group of about 50 or 60 people. At TA-55, the group suddenly grew to about 300, and the only people you knew well were the people in your own area.

Los Alamos Science: *Were you proud of your work? Did you enjoy your job?*

Harold Archuleta: Overall, my job experience was a positive one. I enjoyed the research and production. We were in competition with Rocky Flats, and we would always come out ahead.

Accidents with Plutonium

In this part of the discussion the participants were asked to describe the accidents or incidents that led to their plutonium intakes.

Harold Archuleta: My first incident occurred after opening a freezer in the attic at DP West, Room 500. Plutonium was stored in freezers because the cold temperature keeps it from oxidizing. One particular Monday morning, I was given a casting ticket to retrieve plutonium buttons for casting. Upon opening the container, I noticed the buttons were oxidized. I then realized the freezer was not in operation. After reporting the problem, a nose count was taken immediately. A high count was found in both nostrils. Contamination was also found on my gloves. Shortly after this incident, Harold Ide who was in charge of H-1 contamination incidents, informed me that I was required to give fecal samples. I did so for a few months.

The second incident occurred while casting plutonium rods. During the filling of the molds, a slight overflow occurred, causing a sliver to form. While I was unloading the molds, I felt a pin prick on my right middle finger. I immediately stopped and reached over with my left hand and held the neoprene glove bringing my right hand out to the edge of the glove port opening. I called to a monitor who happened to be close by. He checked, and no contamination was found. But at the wound counter, it was found to be contaminated. I was taken to occupational medicine where I was told, "There are two things we can do. We can let you heal over, in which case you'll have a body burden, or we can take you over to the hospital and cut it out." I chose excision. At the hospital they gave me a shot and then they started to cut. I could see the blood run. They checked it with the wound counter, and it was still hot. They cut some more, and they kept cutting until it was below background on the instruments. Then they stitched it, about six or seven stitches on my finger. I was removed from plutonium work while I recuperated.

The third incident involved another nasal intake. I was changing a thermocouple tube in a pressurized furnace. Due to a faulty helium valve, the furnace had not been properly depressurized. Upon removing the thermocouple, some contamination was released. My nose count was found to be very low. I think that what I have in my lungs is a result of the first incident. It is americium that is detected when a lung measurement is taken. [*Weapons grade plutonium has about a forty-year biological (residence in the body) half-life. Americium-241, which is a decay product of plutonium-241, is more easily detected in the lungs than plutonium-239, because it emits higher energy gamma rays.*]

Los Alamos Science: *Have you worried about that over the years?*

Harold Archuleta: I didn't worry until about three or four years ago. I started to get this discomfort in my left side around my pectoral muscles. I didn't think it was the plutonium. We had to lift a furnace that was inside the line, and I grabbed it with my left arm. It was pretty heavy. After that, I started to have a lot of weakness in my left arm. I went to all kinds of doctors. I thought it might be my heart. But the doctors determined that it wasn't my heart, it was the design of the glove boxes. All those years of working there had affected my neck, elbows, and lower back, and something in the fifth vertebrae in my neck was sort of pinching a nerve that would bring this weakness to my pectoral muscles. There's nothing I can do about it.

Los Alamos Science: *Did that explanation satisfy you, or do you still have questions?*

Harold Archuleta: No, I asked the doctors at Lovelace whether the problem could be from the plutonium in my lungs, and they said no, they don't think it could be that. But when I talk to other people, they all say, "I bet it's the amount of exposure in your lungs." But I don't know—I don't think so.

Los Alamos Science: *Michael Martinez, will you be next?*

Michael Martinez: My first incident was about 1984. There were six of us in the vault getting ready to send a shipment to Rocky Flats. We sent materials in containers that resemble pressure cookers, and we use those units over and over again. This time we removed the bolts and took the lid off, and the stuff inside went airborne. This unit was empty, but it was hot, and we didn't know it. Nothing was marked on the outside to say it was contaminated, but it was. Another person and I, who were right by the container, had the highest nose swipes. That was my first intake.

The second incident was in 1993. We were doing reductions in the induction furnace, and we had just started working with the laser. If I remember correctly, it was right after a three-day weekend. We were doing a laser reduction. When the reduction took off, it sounded kind of funny compared to what we were used to hearing. We checked to see if our vent line inside the glove box was open. We had an argon line hooked up to the laser window, which separates the laser from the reduction chamber. We used the argon to clean the window after the reduction was done. This time we turned on the argon, and it broke or cracked the window. The plutonium that was airborne in the chamber went through the window, and we picked up quite a bit. After that incident, they shut the line down for a while, and I transferred out of TA-55 to the Chemical and Metallurgy Research building.

Los Alamos Science: *What happened after you knew you had an intake? Were you concerned?*

Michael Martinez: I wondered how bad it was. At first, they gave me urine kits and fecal kits once a day, and then once a month. I'm still giving urine samples. Awhile after the incident, they called me to the Health Division, and the doctor gave me the numbers relating to my exposure. And now you've given me another set of numbers.

Harold Archuleta

One particular Monday morning, I was given a casting ticket to retrieve plutonium buttons for casting. Upon opening the container, I noticed the buttons were oxidized. I then realized the freezer was not in operation. After reporting the problem, a nose count was taken immediately.

Los Alamos Science: *How was it having to fill all the bioassay kits? How did you feel bringing all that stuff home? Did your family ask questions?*

Michael Martinez: I never told them. I've never told anybody. I didn't want them to worry.

Jose Gonzales: I've got a long story, because as a monitor, you're always looking for the unknown. At least that was what it was like during my early years at DP Site. My first episode was at the waste-disposal site where they were treating americium in 55-gallon drums. I opened the door, and to my surprise, I could see the americium coming out the door. All I could do was call "Mayday!" and rope the area. Everything in the building was contaminated. The area eventually got cleaned up, but I probably picked up a dose there.

The second place where I might have picked up some dose was in the filter house. It wouldn't have been from inside the filter house, because I was wearing a respirator. But while undressing afterwards, I could have gotten some dose from contaminants that had fallen on my clothing. Another incident was in the electrorefining unit. We used to transfer 350-gram metal buttons in plastic bags. The technician was putting a button in the bag, and we were putting on our respirators to prepare for making the transfer. Suddenly the seams on the plastic bag gave out, and the button rolled on the floor. I held my breath, got a glove, put the button in the glove, and threw it back inside the hood. That was the only thing I could do. If the door had been open, the button probably would have rolled to the airport. Thank God it didn't. There are so many incidents I could relate. They weren't intentional errors. We were just doing things in the best way we could.

I'll tell just one more. It was 1977 on the metal prep line. I was holding a radiation-monitoring instrument close to where a metal reduction was being done. When the pressure surge came during the reduction reaction, a gasket blew on the reduction vessel. At that point in the reduction, the vessel was

Michael Martinez

There were six of us in the vault getting ready to send a shipment to Rocky Flats. We sent materials in containers that resemble pressure cookers, and we use those units over and over again. This time we removed the bolts and took the lid off, and the stuff inside went airborne.

under 2,000 pounds of pressure, so when it blew, it blew the gloves right out of the glove ports and caused the whole room to become contaminated. The only thing I could do was to yell as loud as possible for everyone to evacuate the room. We assembled on the outside, and thank God, everyone was safe. But we picked up a dose. I became a permanent fixture in the In Vivo Lab where gamma-ray lung counts are done. That incident bothered me a bit more than the others. I called my wife to tell her we had an incident and that I wouldn't be home as early as I had said. And sure enough, at ten o'clock it came on the news that there had been an accident at DP Site, and that five people were involved. My wife was concerned about it. But we got it straightened out. We put a safety valve on the pressure cylinder of the vessel so the same thing wouldn't ever happen again.

I had an incident at TA-55 when I was doing a reduction myself. The pressure in the reduction vessel—actually we call it a bomb—was 2,200 pounds per square inch. About 18 minutes into the reduction, four bolts that hold the reduction bomb in place came loose; I yelled for everyone in the room to evacuate. I saw some sparks so I held some wet cheesecloth close to the glove ports to keep the gloves from catching fire and waited to see if the reduction would stay inside the vessel. We didn't have time to go for respirators. Thank God we were able to keep everything contained inside the glove box. We had a 4-inch opening at the bottom of the box, but the negative pressure pulled everything back into the box and saved us.

All these incidents happened, and still, I didn't want to quit my job. I have pride in my work. When I felt kind of bad, I talked to my family. I have two healthy children and two grandchildren, and they understand. There were a few times when I had to leave my underwear at work, and my son would say, "Mom, daddy's hot again!" I'm so grateful that I can joke about those things today. At the time it happened, it was something serious. Today, I feel better physically, mentally, and spiritually than I ever have in my life. I'm still working at the Lab, helping to write a Lab report on the decommissioning of the metal prep line. I'm really proud to be doing that.

Art Beaumont: In about 1964, some 13 or 14 years after I came to DP West and began to work with plutonium-239, I started to work with plutonium-238. It was for the artificial-heart program. We had just produced the first plutonium-238 metal in a regular glove box, and I was up on the ladder to open the top of the furnace. I reached in with tweezers, pulled out a 25-gram button of plutonium-238, and then sparks started to fly all over the place. The plutonium-238 was oxidizing so rapidly because the atmosphere in the glove box was just the normal atmosphere. I handed the button to Larry Mullen who was working right next to me, and he dropped it, and then somebody else dropped it, and then finally we got it back into the furnace. That taught us that we had to work in an inert hood, one without any oxygen or nitrogen. But I don't believe I got any dose at that time.

Jose Gonzalez

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There was an incident, though, on another line in a room called 401. It was about 1972, and I was working in a set of gloves right next to another fellow. All of a sudden his glove ripped off from the glove port. He had this whole glove on his arm, and we were both looking into the glove box through the open port where the glove had been. We didn't hardly breathe. We yelled for our respirators, and the monitor came quickly and put them on our faces. That's the one incident in which I believe I could have gotten a dose, because I wasn't wearing a respirator. The whole room got contaminated. It took several weeks to clean it up.

I was told I couldn't work with plutonium in August 1973, about 23 or 24 years after I started, but I was never informed about any doses. I would send in urine samples, but they never gave me any of the results. I worked full-time at the Lab until 1985 when I retired, and I came back to work part-time as a Lab Associate until last year.

Ed Hammel: I have a suspicion that what Art is saying is not that unusual. Probably, there were a lot of people who were not informed of their internal exposures because they were considered too insignificant. And I suspect that the reason we are having this discussion today is because now it has suddenly become significant. The culture has changed, and the whole country is worrying about these things. Everybody is trying to play catch up.

Art Beaumont: If I was a person with a body burden, it would seem to me the Lab would be interested in it. At one point after I moved to DP East, I questioned Bill Maraman about why they weren't asking for urine samples. After a big discussion, it turned out that a secretary had taken me off the list.

Jim Ledbetter: The only incident I recall in which I picked up an exposure was in 1971 during the disassembly of the plutonium-238 Jupiter heat

Art Beaumont

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source. We were working in a hot cell with three-foot shielding. The atmosphere inside the containment was argon-purged and was maintained at a very low oxygen content, less than fifty parts per million.

The first disassembly was 100 per cent successful. We disassembled the source and welded the plutonium-238 metal into tantalum cans. Then we began preparing for the second source. By then, we'd gathered a lot of attention, and some of the renowned people involved in the heat-source program were present at the site for the second disassembly. Harold Agnew was there, Dick Baker was there, and so were the principal investigators, Stan Bronitz and Bob Mulford.

Once you start a disassembly, you can't stop until you have all the parts disassembled and packaged no matter how long it takes. Sometime late in the evening, odd things began to happen. For example, during the machining, we would get rings of fire around the plutonium capsule. We checked the oxygen level. It was low enough that oxidation shouldn't have been happening. We kept working, and we kept getting spontaneous bursts of flame. Somebody said, "We've got to switch to helium." So we hooked a helium trailer to the manifold and began purging the primary containment with helium. And then more strange things began to happen. The gas boots collapsed around the manipulators and wouldn't stay expanded.

Bob Mulford and I decided to go into the hot cell to do the welding. We were right next to the primary containment, and I was doing the welding. After a few minutes, a *cam* (continuous air monitor) alarm went off outside, within six feet of us. We called in the monitor, and he checked the cam. "I think we got a blip in power. There's nothing back here." So we went back to work. Shortly after that, the cam went off again. We decided to stop and check things out. Several people came into the hot cell, including our Division Leader, Dick Baker. We found a minor leak around a vacuum connection, repaired the leak, and went back to work. Finally, the alarm went off again, and Bob Mulford and I decided we shouldn't take a chance, so we put on our face masks. We were hurrying to weld the capsules and put them away. And while we worked, I could hear the floor monitor outside the three-foot wall starting to pick up a signal. I could hear it clicking away, and I recall saying, "Boy, something has got to be wrong here!" The clicking got worse and worse, and we kept working faster and faster. Inside the hot cell where we were working, we weren't picking up anything on the radiation monitors. But when we looked down the corridor of the hot cell to the operating area outside, the personnel that had been in the operating area had taken off their clothes and were walking around in undershorts. They were trying to figure out what was wrong, and we were frantically trying to weld the plutonium containers.

As it turned out, the helium had caused a positive pressure in the boot around the manipulator so that the airborne plutonium was being sucked out through a puncture in the boot into the operating area outside. The people out there, including the TRW person who was asleep on the bench, received exposures. Ironically, we were the lucky ones who picked up the least exposure, because we were working inside the hot cell. It took about ten weeks of intensive decontamination to clean up the whole facility. We worked as a team, including Dick Baker. Even the group leaders and scientists were in coveralls. All of us were examined pretty carefully for internal contamination. We gave urine samples, and they put us through the whole-body counter a number of times. That's the only time I have ever received an uptake of plutonium, though I have worked with it in the form of breeder-reactor fuels prior to that experience and for many years after.

Jerry Taylor: I remember my accident to the day. It was April 1981, on Good Friday. I had been working on a process in which I had ended up with two one-liter bottles of fluid. When I came in on Good Friday, the bottles were collapsed. I decided to empty them before they collapsed all the way and made a mess over everything. I found a sharp pointed knife in the glove box, which, I learned later, should never have been there. I picked up the knife to vent the lids of the bottles, and as I made the puncture, the knife went through the lid like a piece of hot butter and right through my left glove into my left hand. I pulled my hands out of the glove box and told the supervisor, "I just got a puncture wound." We went to the decontamination sink and sat there for about 45 minutes trying to scrub off the surface contamination. The wound was still hot, so we went over to H-2, Occupational Medicine, and they did the first excision. There were a lot of celebrities there, Dr. Grier and Dr. Voelz. I started using the chelating agents that day. They're supposed to help remove the plutonium. About a month later, I had to get another excision.

James Ledbetter

By then we'd gathered a lot of attention, and some of the renowned people involved in the heat-source program were present at the site for the second disassembly. Harold Agnew was there, Dick Baker was there, and so were the principal investigators, Stan Bronitz and Bob Mulford.

Los Alamos Science: *Were you aware at the time it happened that you had had a serious accident?*

Jerry Taylor: Yes. I knew what I was working with. But I didn't know how much I had received internally. Most everybody here received their doses by inhalation. I received mine internally right then and there. It was just like playing with a pocket knife. Usually you poke a hole in your hand, and you don't think much about it. There was plutonium on this knife. It's funny to think about. At first, I didn't think the dose was going to be that high. I hadn't been worrying about working with the material. But right after the accident, I started wondering how much of a dose I'd gotten. That first day the count on my wound was very high, and that's when I started worrying. It was very scary to me.

Los Alamos Science: *How did they explain the chelation process to you?*

Jerry Taylor: They just said that plutonium and americium are bone seekers, so they would give me DTPA [the chelating agent] either with zinc or calcium. These metals would more or less trade places with the plutonium, and the plutonium would come out in my urine. They gave me a shot of this chelating agent three times a week for almost a month. Then we went to an inhalation method because I was starting to look like a junkie with so many holes in my arms. Dr. Voelz gave me his card and said to show it to the police and have them call him at home if they ever stopped me and looked at my arms and thought I was a junkie. He said he'd get me out of trouble.

As far as my family went, they were pretty frightened. Even my best friend wouldn't come close to me for a couple of months, wouldn't even shake my hand. Actually, we were the type of friends that would give each other a tug or a hug, but he was frightened of what I had gotten in me and what I still had in my hand. So he would talk to me at a distance. That really bothered me psychologically. But it's not like that anymore. For about a month, I went around wearing a surgeon's glove to try to sweat out the surface contamination.

I was only off work for a couple of days, and when I went back, I worked in the front office. They had to tell me to stay out of the hallway and away from the doors to the vault because I kept setting off the alarm just by walking near them. That first year was very long. I had a lot of chelating agents. A lot of urine kits. I saw a lot of numbers. Irene did a lot of whole-body counts.

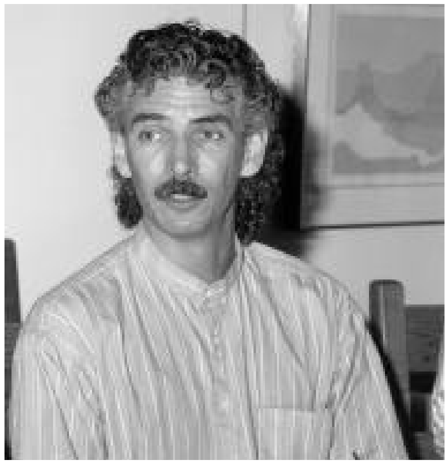
Los Alamos Science: *Did the chelating agents do any good?*

Jerry Taylor: Yes. From the numbers I remember seeing, my body burden went down by 90 per cent. That's including the amount they took out in the two excisions. The chelation did get to me. It made me kind of shaky and upset my stomach. I don't know if it was just the stress or the calcium in the chelating agent. Even to this day, if I take a multivitamin with calcium, I get a little shaky for an hour or so. I seem to be overloaded with calcium, but the numbers show that it worked real good.

I still have a fairly substantial contamination, but I don't think about it much—unless something like this meeting brings it up. It happened fourteen years ago. I've put it to the back of my mind. But when I first moved to Albuquerque eight years ago, it did concern me. My wife had gotten pregnant, and I worried that the radiation in me might have affected the baby. That was a pretty stressful time. My son was born, and he was fine. It was a concern then. But I don't think about it much anymore. I go on with my life, and I've been feeling healthy.

Los Alamos Science: *Do you think the Lab took good care of you since the time of the accident?*

Jerry Taylor: I think they could improve. During the first year they watched me very carefully, and it felt like almost too much with all the wound counting and the urine analysis. But after that, I always wanted to hear more. I wanted to know what had happened to other people who were contaminated. I wanted to know if any new studies had come out. I was hoping that if a similar thing did happen to someone else, they could use my experience to help that person. They did keep track of me for the five years I was at the Lab. The accident happened only six months after I started at the Lab. After I left, I didn't hear anything unless I called Dr. Voelz and asked for another body count. And then they would do it. I appreciate that, but I think they should be contacting me annually at least. The fact that I haven't been monitored regularly is one of the reasons I decided not to volunteer for the Transuranium Registry.



Jerry Taylor

It happened fourteen years ago. I've put it to the back of my mind. But when I first moved to Albuquerque eight years ago, it did concern me. My wife had gotten pregnant, and I worried that the radiation in me might have affected the baby. That was a pretty stressful time. My son was born, and he was fine.

Los Alamos Science: *Would you explain what the registry is all about?*

Jerry Taylor: It's a way to donate your body for study following your death so they can see what actually happened to the intakes of plutonium or uranium or other nuclear materials that you had. [*For a discussion of the work done on autopsy tissues see "A True Measure of Plutonium Exposure—The Human Tissue Analysis Program at Los Alamos."*] I like the idea that they are doing those studies, but I feel I've already given enough of my body.

Los Alamos Science: *Do you have full use of your hand?*

Jerry Taylor: Pretty much. I can't spread it as far as the other guy. If I catch a baseball, it hurts near the area of the wound, because they took out all the fatty tissue around it. But there's nothing really wrong with it. I have full use of my hand.

Bill Gibson: My experiences with contamination had less to do with particular accidents and more to do with the very crude conditions under which we worked. We worked essentially in the open, and as a result, we were constantly exposed. Those old Wilson respirators just didn't do us much good. We kept working with larger and larger quantities of plutonium. As I said earlier, when I first came, we were working with the first 1-gram quantity ever made, but then we worked with 8 grams, then 16, then 64, and on up to kilogram amounts.

Wright Langham and Louis Hempelmann kept us pretty well posted on our exposures. They were taking urine counts by 1945, and we saw the counts continue to be positive. When we started working with peroxide precipitations, things got worse. You know, that stuff bubbles, and we were working in the open. There was a fine mist of plutonium nitrate in the air all the time. We thought we were protected by our respirators, but we weren't, and boy, our urine counts just zoomed. It was about that time that I had an incident. I was shoving a piece of rubber tubing onto a side arm of a filter flask when the arm broke and a piece of glass got jammed into my thumb. As I pulled the glass out I could see a little trace of green under the skin. Green was the color of the plutonium hydroxide that was in the flask, so I knew I was contaminated. I told my supervisor immediately, and they rushed me over to the hospital and excised the wound. That was the only dramatic incident that ever happened to me, but I don't know that it added very greatly to my overall count. It was the crude conditions under which we worked—horrible by today's standards although they looked very reasonable to us at the time—that were responsible for my high count. I went over the allowed limit, and I wasn't the only one; there were three or four of us at the time who had to stop doing plutonium work because of excessive urine counts.

Most of us were in the army, and a soldier, you know, is expendable. But Wright Langham didn't think so. He expressed considerable concern over our rapidly rising urine counts. There were about three or four of us who went over the so-called limit, and we were kicked out of the laboratory. Wright and Louis were very concerned. Counts were rising so rapidly that a couple of us were measured as having about three times the limit, but those measurements may have been false.

Los Alamos Science: *Do you remember what the limit was at that time?*

Bill Gibson: As I recall, it was 7 counts per minute in a 24-hour urine sample. Supposedly, that rate meant we were carrying 1 microgram of plutonium. How accurate that is I have no idea. All I know is that today I'm healthy. The past is history. What happened, happened, that's all.

Bill Gibson

It was the crude conditions under which we worked—horrible by today's standards although they looked very reasonable to us at the time—that were responsible for my high count. . . . Most of us were in the army, and a soldier, you know, is expendable. But Wright Langham didn't

Los Alamos Science: *At that time, in 1945, no one knew exactly what the count meant. The calibration that was needed to relate the counts in your urine sample to the amount of plutonium in your body had not been done yet. In fact, Langham's and Hempelmann's rationale for the human injection experiments was to obtain the data for that calibration. They were very anxious to have a valid basis for interpreting those counts and taking people off the job at the appropriate time.*

What do you think of the assertion that having plutonium in your body prevents colds?

Bill Gibson: I don't know about that. It's true that I've only had about one cold in the last twenty or thirty years, but it may not have anything to do with the plutonium. The interesting thing—which Dr. Voelz knows all about—is that the members of the UPPU club have better health and greater longevity than the national average, significantly greater. In other words, plutonium exposure doesn't seem to have hurt us, and if anything, it might have helped us a little.

Los Alamos Science: *How about you, Ed? What was your experience?*

Ed Hammel: I mentioned earlier that my section was responsible for remelting, alloying, and then casting plutonium. Essentially all the plutonium at Los Alamos, both recycled and original, passed through our section from the time we had gram quantities to the end of the war. We used open hoods when we had to; we used wooden dry boxes when we had to. But as far as I can remember, during that period, we didn't have any incidents of punctures or anything like that in our group. I don't think any of my people managed to be in the UPPU club.

Los Alamos Science: *But you could have been. Do you remember the circumstances when you received an intake?*

Ed Hammel: Not really. There was no specific instance. I knew I was

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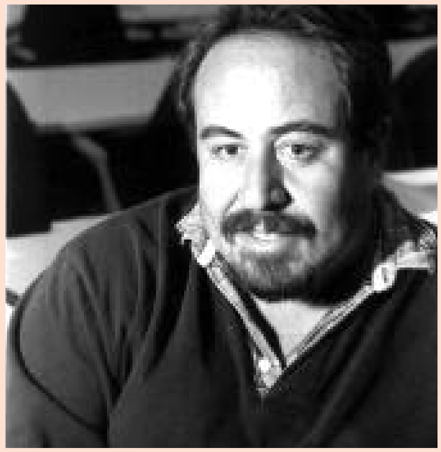
A Recent Incident

Several weeks after the roundtable, Johnny Montoya was involved in an accident at TA-55. At our request he has been gracious enough to share his personal feelings and emotions connected with that accident. His words show the human side—separate from the technical risk, the media-hype, the political agendas, and the operational tasks. That is the side we, the health protection professionals, must always be aware of and must address in an accident—care of the mind, the emotions, and the body of the affected individual. Bill Inkret

I have worked at TA-55 for 14 years doing various aspects of plutonium processing. My accident occurred late in April 1995. I've always thought of plutonium as kind of a friend, but I'd placed boundaries on that friendship—as long as we stayed on our respective sides, we'd get along just fine. When the accident occurred, my first reaction was extreme anger. Our borders had been crossed, and I felt outraged and betrayed. I was also very scared when the busy activity of medical personnel started unfolding around me.

Nose swipes indicated that I'd inhaled plutonium. A chest count, taken at the In Vivo lab, indicated that it was substantial. It was frightening to hear I might have received a large dose. Dr. Lowrey suggested a treatment called chelation that would help if my intake was extensive. One of the staff explained the process and how it would enhance removal of plutonium from my body. I recalled my father telling me about chelation agents at his feed store. I was also told that prompt action was vital, and based on the information, I decided to go ahead. I remember asking Gina Rey about her thoughts. She lifted my spirits immeasurably by saying, "You're doing the smart thing—if you have what the numbers are showing, you're better off chelating." The procedure was explained in great detail, and shortly thereafter, I was prepped.

I'm sure I was in shock because several attempts to get an IV into one of my veins failed—the veins in my arm had collapsed. It was a nightmare, but Gina remained at my side, telling me to be strong and to ask the Lord for help, and her faith gave me faith. Without Gina, I'm not sure I could have held together as well as I did. Everyone did a good job, and the chelation went smoothly.



Johnny Montoya

Still, I was *totally* freaked out, and the most difficult part was about to begin: I had to tell my family. How do you explain this to people who have never worked with plutonium? People who love you and are concerned for your welfare. That was when Dr. Inkret gave me courage and support. I asked him, "How do I tell my wife and children?" He made suggestions, but he also gave me his home phone number in case I needed to talk. Well, believe me, I took *full* advantage of his generous offer. He explained that the emotional stress would do me *more* harm if I wasn't careful how I dealt with it. And he said, "In the long hours and days to come, I'll do my best to explain it all to you. Don't worry, I'll be with you every step of the way." Believe me, he was. But that first night was the hardest of my life; I was living a nightmare.

It was obvious the next morning that the anger hadn't left me. Driving up for another chest count at 7:00 A.M., I approached one of the trucks that bring plutonium shipments to TA-55. Again, I felt the intense anger of being betrayed by someone I'd worked with for the last 14 years. When I got to the lab, Dr. Inkret was waiting, and I described my emotional state as I'd approached that truck.

I showered and entered the counting chamber. It was the longest 30 minutes of my life. When I came out, I saw Dr. Inkret, Bruce Matthews, Tim George, Dave Post, and others. They were jubilant. I knew instantly they had good news. I was on top of the world. Dr. Inkret called his colleague, Dr. Smith, to explain the results. I got on to express my feelings of jubilation. Dr. Smith said, "Before you get too happy, let me say, we have a good result along with the initial bad one. Let's do the count again to see which it really is." Boy, it was as if someone had hit me over the head with a bat. I was at square one again.

To make a long story short, I had several more chest counts in the days to come, which were all favorable. I was then told that the true test would be the fecal and urine assays. I'd need to wait several days for those. As you can imagine, I went though hell. Finally, they determined that the dose was nowhere close to what had first been thought. The rest of the testing period has been a long wait. I've spent numerous hours educating myself and gaining valuable information on the implications of my intake. I now understand better what it means to my body. But most important, the anger is gone. More than likely, the positive way things turned out has had a lot to with this. My tests have all been low compared to what was first believed.

I hope my experience can, in some way, do some good. Perhaps I can help someone through similar circumstances, though I hope I will never have to. ■

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carrying some plutonium, but it wasn't enough to worry about.

Los Alamos Science: *OK, we're back to the beginning, Ted and Nick, and we want to hear about your intakes.*

We called Wright Langham, and Hempelmann said, "Hey, do you want to excise this thing and get it out of here?" We went to the hospital, and they thought they had cut it all out, but they hadn't—I still have some plutonium in one finger.

Ted Magel: Within weeks of making the first 1-gram button, I had an incident in which I was working in a dry box scraping the slag from another of those 1-gram buttons, and the needle I was using slipped, went through the rubber glove, and embedded in my finger. Nick would remember that incident. I could see some black stuff in my finger. OK, I thought, that's plutonium oxide. We called Wright Langham, and Hempelmann said, "Hey, do you want to excise this thing and get it out of here?" We went to the hospital, and they thought they had cut it all out, but they hadn't—I still have some plutonium in one finger. They began taking urine samples in 1945, which was when the procedure for measuring excreted plutonium was first available.

Sometime between March and July of 1944, they developed a method of monitoring how much plutonium we were getting from breathing. The nose counts were the primary method for that. This girl would come around and swab our nostrils. One time I was getting ready to do a reduction, and I decided to take a last quick look inside this little tiny crucible to make sure I had put all the ingredients into it. I bent down close to it and lifted the lid without bothering to put on my respirator. Apparently I got a very high nose count from doing that. But the big dose was from the needle stick. Dr. Voelz told me recently that I have the fifth highest dose of the 26 members in the UPPU club.

Los Alamos Science: *Were you worried about having plutonium in you?*

Ted Magel: I didn't get too excited or worried about it. I'm not super patriotic or anything like that, but it was war, and we had a job to do. Nick took the same stand, and we continued to work together to get the buttons made.

Nick Dallas: The day Ted got his high nose count, I got one too, but it wasn't as high as Ted's because I was wearing my respirator. Mackenzie would do nose counts twice a day, and she would give us calcium phosphate pills to enrich the calcium in our bones.

Ted Magel: By then, they knew from animal studies that plutonium goes to the bone. They thought that if we built up our calcium content, there would be less reason for plutonium to want to reside there. They had to develop health procedures from scratch, because there was no plutonium before that time and, of course, no experience working with it. Nick and I were there, so we were the guinea pigs for trying out new health procedures. We are also two of the original 26 members of the UPPU club. We've been monitored by Los Alamos since that time for any damage that plutonium might cause. Every year, I would send them a gallon of urine from a 24-hour period so they could measure the plutonium content.

Ed Hammel

Essentially all the plutonium at Los Alamos, both recycled and original, passed through our section from the time we had gram quantities to the end of the war. . . . As far as I can remember, during that period we didn't have any incidents of punctures or anything like that in our group. I don't think any of my people managed to be in the UPPU club.

Follow-up Studies, Expert Opinions, and Future Prospects

Los Alamos Science: *This is a good time to switch the focus from the accidents to the questions and concerns you may have about possible health effects and about the way the Laboratory has treated you over the years. We have several experts here to answer your questions. They're probably all familiar to you. First is Dr. George Voelz, who was the head of the Health Division at the Laboratory for many years and is a recognized leader in the field of plutonium epidemiology. Next is Don Petersen, who was trained as a pharmacologist and served as George's deputy for many years. Next to Don is Mario Schillaci, a physicist who recently joined the radiation dosimetry group. And of course, there are Bill Inkret and Guthrie Miller, who organized this meeting and prepared the dose estimates you received before coming here today.*

Ted Magel: I can't speak for all UPPU members, but in 1971, they decided to bring all 26 of us back to Los Alamos to do complete physical examinations and to get whole-body counts, urine counts, x rays, and blood work. They were using the urine data to measure the long-time excretion rate of plutonium compared to the amount retained. They're still collecting basic chemical and medical information on the rate at which the body rids itself of plutonium once there is an uptake.

They've also worked very hard to measure the amount in our lungs and to monitor our lung performance. They were looking for any effect that might confirm or dispute the news media claim that one speck of plutonium will kill the population of the Earth. The media keeps writing that story over and over to the point that I get very very mad. I've been after George Voelz to write an article and stop this nonsense. Sure, it's a hazardous material, but there are at least twenty-six of us who've been carrying it around for decades, and eighteen of us who, after fifty years, are still healthy and just getting older.

Nick Dallas: I think the main medical worry after carrying this stuff in you for many years is that you may get bone cancer.

Ted Magel: Nick, tell them about your lung problem and what they saw under the microscope.

Nick Dallas: In about 1970, a lump was discovered in the lower third of my right lung, and I went to the City Hospital at Johns Hopkins University to have it removed. Dr. Hempelmann, who was then at the medical center at Rochester, came down especially for the operation. The biopsy showed that the tumor was nonmalignant. It was what they call a hamartoma, [*hamartoma is a congenital nonmalignant collection of various cell types*]. The medical people claim that those types of tumors can grow on any of your internal organs and are not caused by radiation. Dr. Hempelmann arranged to have the lung tissue packed in dry ice and mailed to Los Alamos for analysis. He also sent along a bone sample, a piece of my rib that they had removed during the operation, and also a lymph node. I believe they wanted to see how much plutonium I really had in me and to check that against the amount they'd predicted on the basis of my urine counts.

Wright Langham was the one at Los Alamos directing the analysis. He took a thin section of the lymph node and wrapped it in photographic film to make an autoradiograph. Sure enough, you could see a few stars on the film. Those stars were evidence of radiation—they're the alpha tracks emanating from each small particle of plutonium, and they form what looks like a star at the spot where each particle is located [*see autoradiograph, page 152*].

The Los Alamos medical people have collected certain organs from other people, like myself, who were operated on and analyzed them to determine the fraction of plutonium that goes to the liver, the lungs, the bone, and so forth. That information allows them to predict strictly from the urine samples how much radioactive material you have in other parts of your body.

George Voelz: Los Alamos has sponsored a tissue-analysis program since 1959 to study the deposition of plutonium and other actinide elements in the body. So your samples became part of that study.

Nick Dallas: You know, I wasn't told until after the operation that they'd taken extra tissue samples, and I was quite upset at first. But Ted calmed me down, and now I'm kind of proud that I've contributed to a greater understanding of how plutonium distributes itself once it gets into the body. But it was upsetting that they didn't ask for my consent ahead of time.

Ted Magel: That reminds me of something. A long time ago, Hempelmann and Voelz gave me a consent form to fill out and sign that gives them permission to do this kind of analysis on my organs after I die. I'm in favor of it, but I haven't signed the form yet because my wife is still not sure she wants it to happen. Nick, did you sign yet?

Nick Dallas: To tell you the truth, my wife doesn't particularly care for that either, and since I've already given some of my lung tissue, some of my bone, and my lymph node, I think they've got enough data from me.

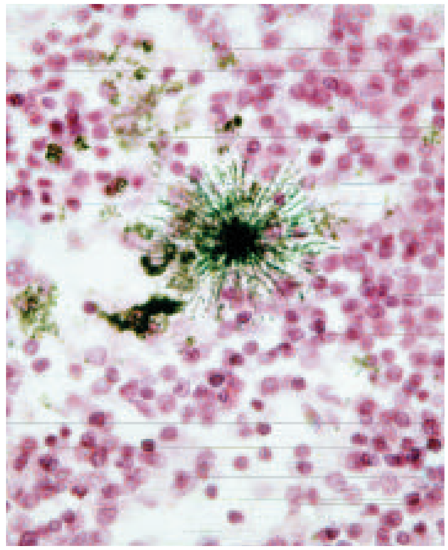
Los Alamos Science: *Ted, have you had any symptoms associated with your body burden?*

Ted Magel: Not that I'm aware of. I'm in very good health, and I've fathered six healthy children, three boys and three girls.

Nick Dallas: And I've had four healthy girls.

Los Alamos Science: *How about you, Bill?*

Bill Gibson: I've lived fifty years in good health, and I have two healthy children. I'm 74 now, and I don't see any reason that I shouldn't get to 84 or 94. I don't really have any concerns about the plutonium in me.



The image is an autoradiograph of a tracheobroncial lymph node from a former worker at the Laboratory. It shows an alpha track radiating in a typical star pattern from tiny alpha-active clumps of material.

Los Alamos Science: *Well, Bill, Ted, and Nick, all members of the UPPU club, seem sanguine about their health prospects. But maybe George Voelz, our resident expert on the epidemiology of plutonium workers, would like to tell us what the data says. George?*

George Voelz: Let me begin with a few very simple facts. Each one of us in this room, without considering the possible effects of occupational exposures, has a one-in-three chance of getting cancer in our lifetime. And we each have a one-in-five, or 20-per-cent, chance that we'll die from cancer. That means of the 21 people in this room, 7 of us will probably get cancer, and 4 of us will probably die of cancer.

Now if your occupational exposure is within the limits set by the Department of Energy, or even if your exposure is well above those limits, your increased risk of getting cancer is not so very great compared to this basic rate. The problem is that if you do get cancer you begin to wonder, "Did I get it from the radiation exposure?" And there's no way to answer that question because there's no way to tell whether radiation was the cause. As a physician responsible for the health of radiation workers, that bothers me a great deal.

Another thing that bothers me is our past failures in communication. Art Beaumont spoke about that earlier. The medical people were doing a lot of worrying and studying and thinking behind the scenes, but we probably didn't share enough of our thinking with the workers who were getting exposed. We had a particularly hard time monitoring inhalation exposures, because once plutonium gets in the lung, it may be anywhere from 6 months to several years before any of that material migrates to other parts of the body and shows up in the urine. In some autopsies, we've seen that 30 or 40 years after the exposure, 75 per cent of the inhaled plutonium is still in the lung.

It's similar for Jim Ledbetter's accident. His urine count didn't show anything until several months after the inhalation, and then the counts rose for a period of 3 to 5 years as the material gradually got deposited in other parts of the body and was excreted in proportion to the amount deposited. We didn't communicate very well with either Art or Jim, and I'd like to apologize for that.

I think we did much better with the members of the UPPU club. Those were the people who had unusually high exposures in the old D Building. Wright Langham started keeping track of those folks in about 1948 and 1949. The first official examinations were done by physicians in the areas where they were living in about 1952. It's been about fifty years since most of them had their major exposures in 1945, so this is a sort of golden anniversary for them.

As Ted alluded to earlier, they've fared pretty well as a group. Of the original 26, only 7 have died, and the last death was in 1990. One was a lung-cancer death, and two died of other causes but had lung cancer at the time of death. All three were heavy smokers. In fact, 17 of the original 26 were smokers at the time they worked in D Building. Smoking was a very social activity during World War II. The military offered free cigarettes, and if you turned someone down when they offered you a cigarette, it was almost taken as an insult.

In any case, there were the three deaths involving cancer, which is consistent with the national cancer mortality rate for a group of this size and age. Then there were three deaths due to heart disease and one due to a car accident. According to the national mortality rate, one would have expected 16 deaths in this group by this time, so the mortality rate for the group is about 50 per cent lower than the national average. That's due to good lifestyle more than anything else. People who are well-behaved, predictable, and responsible generally live longer than the average, and those are the characteristics selected for in plutonium workers.

We compared the mortality rate of the twenty-six UPPU Club members with the rate of unexposed Los Alamos workers from the same period. This comparison eliminates the so-called healthy-worker effect, the fact that the employed population has a lower frequency of disability and disease than does the general population. The risk ratio for all causes of death was 0.60 and for deaths from all cancers was 0.82. A risk ratio of less than 1.0 indicates the risk of death in the exposed group is less than in the unexposed. Because of the small number of people in the exposed group, even these low risk ratios were not statistically significant. Nevertheless, it is of some considerable comfort that they are low.

George Voelz

I think we did much better with the members of the UPPU club. Those were the people who had unusually high exposures in the old D Building. Wright Langham started keeping track of those folks in about 1948 and 1949. The first official examinations were done . . . in about 1952. It's been about fifty years since most of them had their major exposures in 1945, so this is a sort of golden anniversary for them.

We recently published a study of all the males who have been employed at the Los Alamos Laboratory during the period from 1943 through 1977. That is some 15,000 people. The important finding from the standpoint of radiation exposure is that we did not find any increase in the rate of leukemia or other blood-cell cancers that tend to increase with increasing exposure to radiation. We did a trend analysis that showed the rate of three cancers (esophagus, brain, and Hodgkin's disease) correlated statistically with increasing exposures to doses of external radiation. These particular cancers, however, have not been known to be caused by low-dose radiation in other studies. This inconsistency, plus the absence of excess leukemias, made us conclude that the significance of the observed findings was indeterminate. We also compared cancer rates in workers exposed to plutonium with those in unexposed workers. There were no statistically significant elevations of cancers in the plutonium-exposed workers.

So far, we have not seen any significant health effects from plutonium, but that doesn't mean that plutonium isn't very hazardous. It is. But we've taken great care from the beginning to operate with conservative limits on the permissible body burden for plutonium workers, and those limits are not special for plutonium but rather are equivalent to the occupational limits placed on all types of radiation exposure.

Los Alamos Science: *George, can you explain what that limit is in a way that everyone will understand?*

George Voelz: I used to be able to explain the limit quite easily, because it was based on the amount of plutonium you had retained internally. That amount had a definite activity, or gave rise to a definite number of alpha particles per second. For many years, the maximum permissible body burden for plutonium was an activity of 40 nanocuries, which corresponds to 1,480 disintegrations per second. That body burden by weight is 0.65 micrograms.

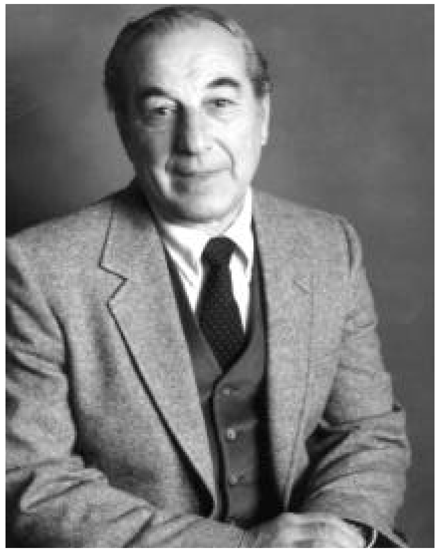
The health-physics community has now gone to another system for computing doses. In the new system, all doses are given in rem, which is related to the energy deposited by the radiation and the effectiveness of the type of radiation at causing biological damage. Now you can add external doses and internal doses to come up with the total dose without doing any conversions along the way.

The complication with the new system is that we are computing committed doses. That computation is simple for external doses—whatever exposure you received is the committed dose because that's all the dose you will get from that source. But for internal exposures, the committed dose is much more complicated. For every additional amount of material that you retain in your body in a particular year, the health physicists compute the dose you will receive from that material over the next 50 years. That 50-year total is called the committed dose, and it is added to your recorded dose in the year that the material is deposited in the body. That means that if you retain, say, one additional nanocurie [*one billionth of a curie or about 16 billionths of a gram of plutonium-239*] in a period of less than a year (which gives you a yearly dose of about a tenth of a rem), you will be taken off the job because your committed dose increased by about 5 rem, the maximum allowable dose increase per year. In terms of risk, this procedure equates the health risk from a 50-year internal exposure to a nanocurie of plutonium with the health risk from a 5-rem, external, whole-body exposure to x rays or gamma rays accumulated over one year.

Jerry Taylor: I used to understand the numbers when they were expressed in terms of body burdens. Now that they've changed the system, I'm really confused, and it makes me wonder whether they are telling me everything.

Los Alamos Science: *Jerry may be particularly concerned because he has the highest dose in this group. George, perhaps you could tell us whether you have ever seen a direct effect of plutonium exposure?*

George Voelz: The only thing we've seen is one case of a bone tumor in the UPPU group. Statistically we can't say that the tumor was due to the plutonium exposure, but it's certainly suspicious. That's the kind of tumor we see resulting from animal exposure to higher amounts of plutonium. But occupational exposures are kept so low in the United States that I don't expect we will be able to see any extra risk associated with plutonium exposure. We are beginning to see some things coming out of the Russian experience. They've had rather poor working conditions for a long time, the equivalent of fifty years of D Building, whereas D Building lasted only a little over a year in this country. There are Russian plutonium workers with lung disease, breathing problems, fibrosis, and so on, the kinds of things we've never seen here. So the Russian experience is likely to give us some definitive data on which to base our risk estimates.



Nick Dallas

You know, I wasn't told until after the operation that they'd taken extra tissue samples, and I was quite upset at first. But Ted calmed me down, and now I'm kind of proud that I've contributed to a greater understanding of how plutonium distributes itself once it gets into the body.

Los Alamos Science: *What have you learned from monitoring the UPPU club members over the years?*

George Voelz: It's been pretty interesting to watch. We've seen their plutonium levels go down to about half of the original levels over those fifty years. Up until about 20 years ago, it was thought that very little of the plutonium would come out of the body. We thought the bone half-time (the time for the amount of plutonium in the bone to be reduced in half) was 100 years, but now we believe the half-time is 50 years. We thought the liver half-time was 50 years, and now we believe that it's only 20 years. By monitoring the UPPU members, we've learned that plutonium moves out faster than we had expected.

Jerry Taylor: I've been wondering why people like myself who had a lot more exposure than the UPPU guys are not being monitored.

George Voelz: There is no simple answer to that question, Jerry. The UPPU Club study was set up in the late 1940s and early 1950s when knowledge about the plutonium dosimetry and health risks was very limited. Dr. Louis Hempelmann and Wright Langham thought it was essential to follow these men, most of whom had left Los Alamos after the war. They decided it was a good thing to do, and it was done. There were no proposals for approval by agencies, no human-study review boards, and no funding problems in those days. By 1974, other studies were started that included the more highly exposed persons to plutonium.

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Laboratory Initiates New Voluntary Plutonium Monitoring

Roundtable participants Jerry Taylor and Art Beaumont voiced concern that several groups of plutonium workers with significant depositions were being followed by epidemiology studies. However, Jerry and Art were not being followed even though they both have depositions as large or larger than many of the persons in the study groups. The reason they were not included is simple, although not necessarily acceptable. Two groups are being followed at Los Alamos to compare their morbidity and mortality to unexposed populations, and those groups were identified before Jerry Taylor's accident occurred and Art's deposition was identified. Following single individuals would not yield significant information for an epidemiology study.

However, the question raised by Jerry and Art brings into focus the most important aspect of monitoring for plutonium (or any other toxin)—letting the individual understand their own risks so they can make personal decisions about the acceptability of those risks. The single most important theme of the Human Studies Project is that the individual has a right to know what is happening to his or her body, has a right to judge the acceptability of any workplace-related risks for themselves, and then can accept or reject employment based on that judgement. The other information we garner from our measurements, such as increased understanding of risks, are secondary to the information requirements of the individual.

As a result of Jerry's and Art's questions, the Laboratory will now provide bioassay monitoring to individuals who have been identified as having significant body depositions of plutonium or americium but are no longer employed at the Laboratory. The individuals will be encouraged to participate, and they will be provided with all data, analysis results, and the opportunity to discuss these results with the dosimetry and medical staff at the Laboratory on an annual basis. ■

Jerry Taylor is being measured at the Los Alamos In Vivo Measurements Laboratory for the presence of various radioisotopes. The device, part of which is being placed over his chest, has four separate detectors that work together to measure the energies of the photons being emitted by radioactive materials. In this way, the staff are able to identify the type and amount of the plutonium, uranium, americium-241, and a wide range of fission products that may be present in the person's chest, liver, or other organs. A whole-body assessment can be made as well. Such information will help workers, past and present, understand the type and level of the exposures they have experienced while working with radioactive materials at the Laboratory.

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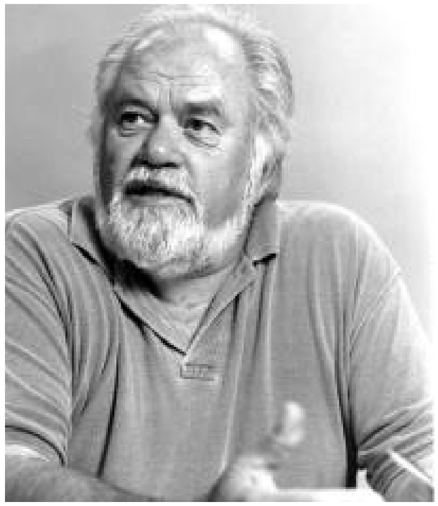
Again, it was just done without outside approvals, budgets, or funding. The overall findings (not identified by individual results) have all been reported in the scientific literature.

By the 1980s, we had gathered a significant body of information on plutonium. Medical examinations were not giving us as much information as epidemiologic studies involving hundreds and thousands of people. By then, we were doing studies of the entire worker populations at several DOE locations. The larger population studies are necessary to give us data that can be analyzed statistically. They have the potential to give us information on health risks that we cannot get from doing medical monitoring of an individual or a small group of individuals. In fact, the trend now is going toward pooling data from multiple studies to get still larger statistical sampling. Earlier this year, Los Alamos scientists participated in preparing a paper that analyzed the combined data on over 95,000 workers from nuclear facilities in the United States, the United Kingdom, and Canada. We have also continued the long term follow-up of the small UPPU Club, which has now reached 50 years since exposure, but we have not initiated new medical follow-up studies on individuals.

I realize that this history is not a very satisfactory answer for an individual who wants to know how things are going for them personally. A few months ago, we proposed a follow-up project to help former employees of the Laboratory. The program included a telephone information line, newsletters, epidemiological surveys, and the potential for doing some additional individual studies of special merit. It is under review by an outside agency for a possible funding grant. We think the proposal is great, but the odds for funding are poor.

In the meantime, we have had an interest in getting periodic urine samples and lung counts on some individuals with high internal depositions of plutonium. In fact, we have been extremely pleased that you, Jerry, have volunteered for those studies on several occasions since you left the Laboratory. We hope to keep working with you in the future.



Don Petersen

The take-home message from this experiment is that radiation injury is much more likely to cause a lethal event than to cause a change in the genes that will be perpetuated through the generations. . . . Only in experiments with fruit flies, bacteria, and molds, where you can get billions of them in a jar, do genetic effects of irradiation show up. With people, it apparently doesn't show either because there are simply too few of them or bad genetic material gets weeded out by natural processes.

Los Alamos Science: *What about the chance of hereditary effects from internal exposures? Do plutonium workers need to worry that they may affect their potential offspring through exposure to plutonium?*

Don Peterson: The notion that radiation exposure will lead to genetic effects goes back to experiments with fruit flies. There, the populations are huge, the number of progeny are huge, and one can follow many successive generations in just a few months, so the genetic effects of irradiation can be seen. However, the absolute rate of genetic change is very low.

I'd like to tell you about one particular experiment with mice, because I think it may provide you with some reassurance with regard to the dangers of genetic effects in irradiated people. Jake Spaulding over in the Los Alamos Health Research Lab did a multi-generation experiment with mice in which the matings were restricted to brother-sister matings.

To understand the experiment you need to have a little birds-and-bees information. Sperm cells have a lifetime of only about 75 days. In other words, if you're a male you have a full turnover of sperm in about 75 days. If you're a female, you're born with all the reproductive cells you are ever going to have, and so you can accumulate radiation damage in those egg cells.

In the mouse experiment, the idea was to expose members of each generation of males to half of a lethal dose of radiation. An exposure of 400 rem kills a mouse, so those males were exposed to 200 rem. After radiation, a waiting period was given to allow new adult sperm cells to grow in from the basic stem cells. This eliminates any effects from direct damage to adult sperm, but not the mutations induced in stem cells.

The irradiated male mice were then allowed to breed with nonirradiated females. As a control, nonirradiated males were also bred with nonirradiated females. Now the catch in this experiment was that it started out with only a few mice from a single litter, and all the matings in each generation had to be brother-sister matings. Jake and his coworkers bred these mice through 87 generations, which in human terms takes you back to the time of the Ptolemies in Egypt, to Cleopatra and the like. The total dose to the germ cell line was 87 times 200 rad, or 17,400 rad. Now the Ptolemies believed that brother-sister mating was the way to go; all the pharaohs were married to their sisters. Genetically, this practice may get the family line into trouble in a hurry. We have laws against the practice. However, the addition of irradiation to the mouse reproduction failed to show radiation damage detrimental to the well-being or continuance of the species. There were no gross abnormalities and the litter sizes and survival rates were equal in the two populations.

The take-home message from this experiment is that radiation injury is much more likely to cause a lethal event than to cause a change in the genes that will be perpetuated through the generations. Usually, if mutations occur, they are rapidly eliminated by spontaneous abortion, and you don't see them survive in the population. Only in experiments with fruit flies, bacteria, and molds, where you can get billions of them in a jar, do genetic effects of irradiation show up. With people, it apparently doesn't show either because there are simply too few of them or bad genetic material gets weeded out by natural processes.

Mario Schillaci: Even in the case of the Japanese atomic-bomb survivors, a population of over 80,000 individuals, some of whom were exposed to very large doses, there have been no hereditary effects seen. That null result is consistent with the extremely low rate of radiation-induced hereditary changes seen in animal studies.

Mario Schillaci

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Bill Gibson: I particularly appreciate these comments because my son was born with cancer. He still survives now; he is 45 years old and has his own business. But at the time he was born, I was quite concerned that my radiation exposure may have affected him.

Ed Hammel: I have a question regarding the size of doses. Many people are familiar with the tragedy of the radium-dial painters, who ingested quantities of radium as they sucked on their paint brushes to make a nice sharp point. Many of those workers developed radium poisoning and died very horrible deaths. I was wondering if you could tell us the size of the radium doses compared to the doses of the people around this table.

George Voelz: The radium data are sort of mind boggling. Among 4,000 dial painters, essentially all women, there were several hundred cases of bone tumors. Of those, I believe there were only two who received cumulative doses to the bone of less than 20,000 rem.

Now for plutonium. Like radium, plutonium is a bone seeker. It is not surprising then that beagles given high amounts of internal plutonium developed an excess number of bone tumors compared with the number observed in unexposed dogs. The cancer induction is dose dependent; the higher the dose, the higher the excess cancer risk.

The average effective (whole-body) dose among the members of the UPPU club is about 125 rem, and the person with the highest plutonium deposition has received a little over 700 rem. Because plutonium is not uniformly deposited in all tissues, the doses vary for different organs. For example, the average bone dose for the group is estimated to be about 45 rem. Plutonium deposits initially on the surface of the bone, which is also the area where the active bone cells are located. Bone cancers arise from those cells; thus, the dose to that specific area is most important. In humans, the dose to the bone surface from plutonium is about 20 times higher than the dose averaged over the whole bone mass. Thus, the average bone-surface dose among the UPPU men is calculated to be about 900 rem, and the man with the highest deposition has an estimated bone surface dose of 5,000 rem. They sound high, but those doses are much less than even the lowest radium doses that induced bone tumors.

The current risk estimate for plutonium exposure indicates 15 excess bone cancers would be expected for each million person-rem. A million person-rem could consist of, say, 1,000 people each having a dose of 1,000 rem to the bone surface. If the risk estimate holds true, there would be 15 cases of bone cancer among the 1,000 persons; each individual would have a risk of 15/1,000 or 1.5 per cent. As a physician, I like to think of this problem in the reverse. There is a 98.5-per-cent chance for a person with a 1,000-rem dose to the bone surface to escape without an effect.

Los Alamos Science: *As a result of fallout from atmospheric testing, a large fraction of the general population is carrying around some plutonium in their bodies. How large is the dose from that source?*

George Voelz: I just looked this up recently. About 6 tons, or nearly 6 thousand kilograms of plutonium, fell to the earth throughout the world as a result of nuclear testing. That's kind of astounding when you think that today we've been talking about body burdens of millionths of a gram. Of course, a great fraction of the plutonium fallout was dispersed in the oceans and didn't get to any of us. But we know from autopsy studies of the general population that we all carry detectable levels of plutonium, mostly in the lung, the bone, and the liver. The main route for intake was inhalation of tiny particles that were in the air. Some may have been ingested through the food chain, but plutonium has a very low rate of absorption in the GI tract. Unlike radium, it goes right through your gut with very little absorption into the blood stream. So whatever was retained in the body probably entered through inhalation and was initially deposited in the lung.

The Los Alamos autopsy studies and other research show that the 50-year dose commitment to the lung from plutonium fallout is about 40 millirem. That's for a person who was alive from the beginning of nuclear testing in 1945 through 1970. This 50-year dose is a tiny fraction, actually less than 0.3 per cent of the average annual dose (300 millirem) that we receive from natural background and other man-made sources over a 50-year period. To put it another way, the lung now receives less than 1 millirem per year from internally deposited plutonium, and the bone receives about 5 per cent of that, or 0.05 millirem per year, an entirely negligible amount compared to our average annual radiation dose.

I should mention the complication of smoking. Data suggest that the risk of dying of lung cancer from smoking a pack of cigarettes a day is 20 times greater than that of a non-smoker, or the risk increases by 1,900 per cent. In contrast the increased risk of a lung cancer death from the maximum allowed committed dose from plutonium is only a small fraction of 1 per cent. Since most plutonium workers of the 1940s and 1950s were smokers, it's very difficult to separate out the plutonium risk from the much greater smoking risk.

Harold Archuleta: When you have plutonium in your lung, does it ever get out? Is it expelled out?

George Voelz: If you first breathe in plutonium particles that are fairly large, most of them will be deposited on the cilia, the tiny hairs on the lining of the air passages in the bronchi. During the first few weeks after inhalation, the natural action of the cilia will bring much of this material up to the throat, and you end up swallowing the particles. They then pass through the gastrointestinal tract and come out in the feces. That's one reason we take fecal samples after an accident involving inhalation.

However, if the particles are very small, say a micrometer or less in diameter, which are the size you get in a fume or a small fire, they will travel deeper into the lung. Their fate then depends on their solubility. Nitrates and other soluble forms will dissolve in the body fluids, go into the circulation, and be deposited primarily in the bone and the liver.

If the particles are an oxide form produced at high temperatures, then they are not very soluble, and they remain for very long periods of time in the lung tissue or the lymph nodes, the filter system around the lung.

We have examined autopsy tissues from five of the seven deceased members of the UPPU club, and to our amazement, we found that in three of them 35 to 60 per cent of the plutonium in the body at the time of death was in the lung or the tracheo-bronchial lymph nodes and had evidently remained there for the 30 to 40 years following inhalation.

Now plutonium, like radon, is an alpha-particle emitter, and therefore, the accumulation in the lung causes us to worry about the risk of lung cancer. In fact, the risks of plutonium exposure are presently based on radon, on the correlation between lung cancer and radon exposure in the mining industry. My feeling, however, is that the risk of lung cancer from plutonium may turn out to be lower because the mechanics of deposition and difference in half-lives from those of radon and its products. When you breathe in radon or its radioactive daughters, those nuclei dump their alpha activity very, very quickly. Their half-lives are very short, on the order of 30 minutes. So within 30 to 60 minutes, they have dumped into the linings of the lung airways one-half to three-quarters of all the energy (radiation) that they're ever going to emit. And lung tumors start from the linings of those airways.

Plutonium, in contrast, has a very long half-life, 24,000 years. Its radioactive emission is slow and steady over many years. Moreover, it stays only a short time in the airways before it's redistributed in lung tissue and lymph nodes, areas that are not targets for lung cancer. Therefore, I expect that the present estimates, which are based on radon, may be substantially reduced if we ever get sufficient data.

I should mention the complication of smoking. The risk of dying of lung cancer from smoking a pack of cigarettes a day is 20 times greater than that of a nonsmoker, or the risk increases by 1,900 per cent. In contrast, the increased risk of a lung-cancer death from the maximum allowed committed dose from plutonium is only a small fraction of 1 per cent. Since most plutonium workers of the 1940s and 1950s were smokers, it's very difficult to separate out the plutonium risk from the much greater smoking risk.

Mario Schillaci: Although there may not be a direct correlation between radon and plutonium, I think everyone might be interested in a new study regarding radon in the home and the incidence of lung cancer. In more than half the counties in the United States., representing 90 per cent of the population, this study found that the incidence of lung cancer *decreased* with increasing concentrations of radon. That anticorrelation between cancer incidence and radon exposure held up to a radon concentration that produces a dose equivalent of 3 to 4 rem per year (ten times the average annual dose from all sources). So there's some evidence that small doses of radiation might not be that harmful and, more speculatively, might even be beneficial.

Art Beaumont: I have a question about the dose calculation you've done for me. It suggests that I got an intake at a time after I had stopped working with plutonium. Can you explain that?

George Voelz: I mentioned before that if you have inhaled some plutonium and if it's in an insoluble form, it will migrate very slowly to other organs in the body. Therefore, the amount that shows up in the urine may increase very slowly over time or may not even be measurable until a year or two after the inhalation. That could explain the discrepancy between the dose reconstruction and your experience.

Los Alamos Science: *As I think you all know, Guthrie Miller and Bill Inkret in our Dosimetry Group are the ones who prepared the dose information that you received in preparation for this meeting. Guthrie, do you want to comment on the dose calculations?*

Guthrie Miller: I would like to remind everyone that doses are estimated from the amount of plutonium in the urine samples that you give us. That data is used along with a mathematical model, describing the rate at which plutonium is excreted from the body. The combination allows us to predict the amount of plutonium that was originally taken into the body. This is a difficult inverse problem, and there are significant uncertainties in the results.

George Voelz: In the early days, say before the mid-fifties, the data had huge errors. First, there were errors in the chemical separation methods, in the analytical techniques used to precipitate the plutonium from the urine. Second, there was the problem of contamination: the urine sample was often accidentally contaminated by the sample bottle or by contaminated hands or clothing or what not, and there was no way to tell. Some of you may recall that around 1946 or 1947, Wright Langham created the health-pass ward at the local hospital to get around this problem. Anyone thought to have had an intake was given a 48-hour health pass and asked to report to the hospital where uncontaminated samples could be collected. I understand that the guys got to drink their share of beer on those health passes. They had some sort of beer delivery system from the PX that Wright was never able to figure out. He didn't work very hard on the problem.

Opinions about the Plutonium Injection Experiments

Guthrie Miller: *You all have personal experiences with plutonium intakes. I think many people would be interested in your opinion of the plutonium injection experiments that were done in 1945-1947. Recall that Langham and other people of that era wanted to be able to determine how much plutonium a worker had retained, and at the time, they had no definitive experiments to relate the amount of plutonium in the urine to the amount in the body. They only had data from animal experiments. So they decided to do an experiment in which small quantities of plutonium would be injected into the bloodstream of some eighteen hospitalized individuals. The earliest subjects were diagnosed as terminal and a few of them were given quantities well above the allowed dose for plutonium workers in order that the deposition pattern of plutonium in the body could be determined at autopsy. Most of those individuals were indeed terminal and died of expected causes. One individual was misdiagnosed and lived for many years. He apparently never had any symptoms from the plutonium that had been administered.*

A number of nonterminal patients were also involved. They were given a dose of 5 micrograms, which, based on the experience of the radium-dial painters, was considered to be small. Neither acute nor long-term effects were expected, nor were any seen, but the dose was large enough to allow reasonable measurements of the amount of plutonium excreted in urine and feces. The idea of the experiment was to measure the rate at which the injected plutonium was excreted in the urine. Those data could then be used to interpret the excretion data of people, such as yourselves, who were working with large quantities of plutonium and needed to be taken off the job if the contamination got too large.

There has been a huge outcry about these experiments. What's your opinion about the experiments, and specifically, do you think that they were morally wrong?

Bill Gibson: My personal opinion is that as long as the people were informed of the experiments there was no wrong done. Many of these people were fatally ill anyway and were expected to die within a short period of time. But if some of the people were not informed, I believe that was pretty reprehensible. There's no reason why a person should be included in such an experiment without being told what the experiment is about and given a chance to decide not to participate.

Ted Magel: Those experiments were essentially tracer experiments, and they did no harm. But Hazel O'Leary and others in our government went off the wall. They made a big deal out of nothing because they were ignorant of the facts. The news media is the same. They don't have the background; they don't research their stories. They hear a rumor, and they put it in the news. The problem is that we've been dumbing down the schools. Nobody gets any science education nowadays. From the teaching colleges to the school boards to the parents, we've got to revamp the whole system.

Ed Hammel: I believe there are no moral absolutes. What's moral at one time in history may be immoral at another. Looking back on what was done fifty years ago, it seems very immoral. Today's physicians would not perform an experiment on any individual without first getting his or her informed consent in a written document. But during wartime, many things were done that were just considered urgent under the circumstances. But you can't apply a set of moral criteria from one era to a completely different era. It doesn't make sense to do that. I believe that the people who did those experiments believed they were doing what was best for the country at the time.

Bill Gibson: The same is true of the bombings of Hiroshima and Nagasaki. At the time, it was considered a moral imperative; it was something that had to be done. Now people are saying how immoral it was. That's because we are living in a different era with different circumstances, moralities, requirements, and so on.

Harold Archuleta: I believe that if the people were told what was being done and if someone explained to them what might happen after being injected, then the experiment was OK. It would have been up to the individual to decide whether or not to go through with it. But if it had been me, I wouldn't have done it.

Michael Montoya: That's the same way I feel. If people were told about it, then things were fine. But if the doctors went ahead without those people knowing what was happening, then it was bad. It would be very hard to be used as a guinea pig.

Jose Gonzales: It's immoral to put people on the electric chair, but we see it happening. Now here's the word plutonium. We who have worked with it understand what it is, and we accept the consequences of our mistakes.

Also, I think the Laboratory has done everything it could to get the data it needs to keep us from having too much contamination. But I think it's immoral to be fooling around with people who don't know what the word "plutonium" means. And it's immoral to do something without letting a person know the effects that might happen.

Art Beaumont: I also feel the same way. I sincerely believe that all the people that participated should have been told what was happening and what the consequences might be. Otherwise, it was immoral.

Jim Ledbetter: Under the circumstances of those times, the doctors and scientists were probably justified in what they did. And I think the benefits gained were worthwhile. I don't know whether the people were informed or not. Perhaps, they just didn't understand. In fifty years, you can forget a lot of things. I've had a doctor tell me about the injection I was getting, and even though I didn't understand totally, I still accepted his judgment. And maybe fifty years later, I'll be saying, "This is really bad news." So I believe the experiments were all done under the highest morals and with a national need in mind. I don't believe the doctors deliberately set out to misrepresent what they were doing. I believe the people knew but just didn't understand it.

Jerry Taylor: Well the experiments needed to be done. The question of what happens when you get exposed—that question had to be asked as they started making plutonium. It was a new material. But nobody has the right to play God with anybody else. So I agree with everyone else. The experiments were all right as long as the people were informed and still wanted to do it. Otherwise, it wasn't right. We may find that out some day. It's being investigated. But you don't know if the truth is going to come out. It's like the OJ Simpson trial. I don't know that we'll ever know who did what. And again, I don't know if you can really say that the experiments were morally right or wrong. It's funny to ask that question. Look at the morals in our country today. Instead of looking at those, the press and the public are going back fifty years and finding wrong in something that we needed to do back then. But the bottom line is that if the people were not informed and were being used as human guinea pigs, then it wasn't right in my eyes. ■

William C. T. Inkret joined the Laboratory in 1986 as a postdoctoral fellow, and his research included development and application of computer algorithms for analysis of chest-count data to detect plutonium and americium and the development and application of methods for estimating internal dose from gamma-emitting radionuclides based on whole-body count. Bill also led the design, construction, and dosimetry of a plutonium-238 alpha-particle irradiation system used in radiation biology studies at the Laboratory, and later, he assisted Harvard University in building an identical system. In 1991, Bill became team leader of the Radiological Dose Assessment Team. In 1995, he took over leadership of the Laboratory's Human Studies Project and brought the project to closure. Bill received his B.A. in biology in 1979 from Carroll College in Montana. After a two-year tour as a ski-area avalanche-control specialist and a union laborer in high-rise construction, he earned his M.S. in health physics from Colorado State University. In 1986, he earned his Ph.D. from Colorado State University, College of Veterinary Medicine and Biomedical Sciences. Bill serves on several national radiation protection committees, including the National Council on Radiation Protection and Measurements Scientific Committee on plutonium-238 power sources for space applications. Bill enjoys yardwork, tending the family farm in Nebraska, skiing, finding antique collectibles, and teaching his children about these interests.

Guthrie Miller received his B.S. in physics from the California Institute of Technology and earned his Ph.D. in high energy physics from Stanford University. His thesis was part of the work awarded the Nobel prize for physics in 1990 (to Taylor, Friedman, and Kendall) for the first experimental verification, by electron scattering, of the quark model of the nucleon. He came to Los Alamos National Laboratory in 1974 to work in the Controlled Thermonuclear Research Division (magnetic fusion energy). In 1991, Guthrie joined the dose-assessment team and continued the research on plutonium internal dosimetry of James N. P. Lawrence after his retirement. With William Inkret and Harry Martz, Guthrie has pioneered the use of Bayesian statistics in health physics. He currently chairs the American National Standards committee on plutonium internal dosimetry. Guthrie has two sons, Geoffrey 16 and Owen 12. His outside interests, aside from parenting, include wilderness activities, co-counseling, dance, and music.

Plutonium Metal

Ted Magel

Nick Dallas

In 1943, the Manhattan Project was pursuing two routes to a nuclear bomb, both dominated by the problem of acquiring the necessary nuclear materials. One route involved isolating the rare isotope uranium-235 from the abundant uranium-238 in sufficient quantity to build a weapon. The two isotopes are chemically identical and differ in mass by only about 1 per cent. Somehow the slightly lighter uranium atoms would have to be teased away from the heavier ones. Several separation techniques were under study—gaseous diffusion, electromagnetic separation, thermal diffusion, and the use of a centrifuge—but it was very uncertain whether any of them could produce the required kilogram quantities in a reasonable amount of time.

The second route to the bomb involved plutonium-239, an isotope that physicists predicted would support a nuclear-fission chain reaction at least as well as uranium-235. But only insignificant traces of plutonium occur naturally on Earth. Large quantities would have to be made in a uranium-fueled nuclear reactor. When the reactor was operating, some of the neutrons from the chain reaction would be absorbed by uranium-238 to produce the unstable isotope, uranium-239. Almost immediately after being formed, uranium-239 would emit a beta particle (electron) to become a new element, neptunium-239, which would emit a second beta particle to become plutonium-239.

The total amount of man-made plutonium in existence in 1943 was the approximately 1.5 milligrams that had been made in accelerators. Not until February 1944 could gram quantities become available from the uranium reactor under construction at Clinton, Tennessee, and the needed kilogram quantities could not be expected to become available from the production reactors being built at Hanford, Washington until sometime in 1945.

In the meantime the metallurgists needed information as soon as possible on the bulk properties of the metallic form of plutonium including its melting point, its hardness, and especially its ductility and density. After all, they would be responsible for fabricating the metal into the shapes specified by the bomb designers. Solid pieces of pure plutonium metal large enough for metallurgical experiments—that is, not much less than a gram—were required to make the measurements.*

The need was so urgent that chemists at the University of Chicago's Met Lab and at Los Alamos began research in 1943 on chemical techniques to reduce plutonium compounds to pure metal. Compounds of other metals, particularly uranium, were used as stand-ins in the experiments.

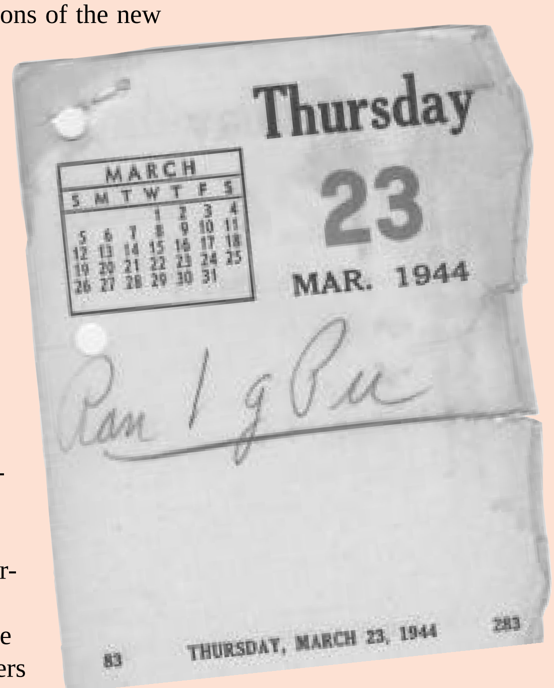
Two young men at the Met Lab, Ted Magel and Nick Dallas, (see the plutonium-worker roundtable, "On the Front Lines") were the first to solve the plutonium metal reduction problem on a scale larger than a few micrograms. Since parallel work at Los Alamos was going poorly and gram quantities were soon expected

*The first unequivocal production of plutonium metal was carried out on November 6, 1943, at the Met Lab by H. L. Baumbach, S. Fried, P. L. Kirk and, R. S. Rosenfels (Manhattan Project Report CK-1143, December 1943). It was in the form of a few small globules of silvery metal weighing 1-3 micrograms each, scarcely large enough to permit any meaningful measurements of physical properties.

The First Gram

by Ed Hammel

from the Clinton reactor, Oppenheimer wrote a memo on January 18, 1944 requesting that Magel and Dallas come to Los Alamos. About a month after their arrival on February 3, 1944, they produced a shiny 20-milligram button of plutonium easily visible to the naked eye, and three weeks later they prepared a 520-milligram button of pure plutonium metal. These were the first amounts of plutonium metal produced at Los Alamos as well as the largest single buttons of the new element produced anywhere in the world. The technical story of their work is recounted here to illustrate the science and the intense atmosphere of the early plutonium metallurgy work and also to give them long overdue recognition for their contributions.



One basic reaction for reducing a plutonium or uranium salt to a metal is a metallothermic reaction. For uranium, a typical starting compound is uranium tetrafluoride and a typical reduction reaction is:

$$UF_4 + 2Ca \rightarrow U + 2CaF_2,$$

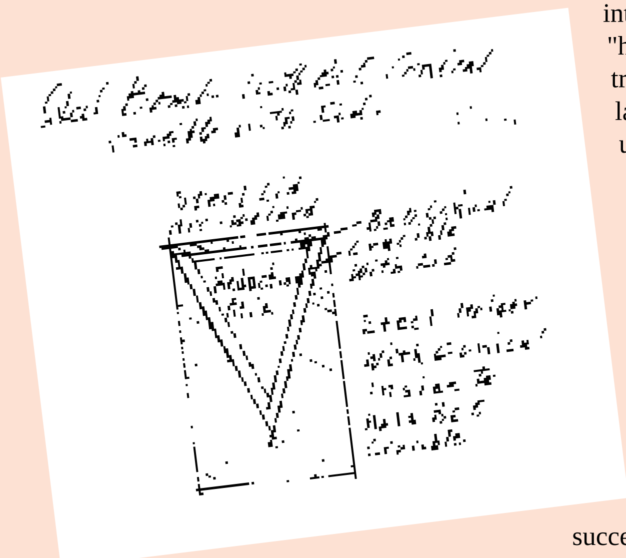
where calcium is the reducing agent. Heating the reagents to temperatures in the vicinity of 400 to 500 degrees centigrade initiates the reaction, which proceeds in the direction shown because fluorine has a much higher affinity for calcium than for uranium. At the same time, and for the same reason, the reaction gives off a great deal of heat—hence the name "metallothermic." Because of the high temperatures and pressures and the high reactivity of the reducing agent, the reaction was run inside a sealed metal container, which the Manhattan Project researchers called a “bomb.” The bombs were lined with crucibles made of refractory materials such as metal oxides that would remain intact at the thousand-degree-centigrade temperatures produced in the reaction.

To maximize the yield and purity of the metal product, chemists had to optimize many parameters: the form of the initial uranium or plutonium salt, the reducing agent, the layering of the reagents in the bomb, their mesh sizes (the reagents were powdered), deviations from the stoichiometric proportions, the refractory material for the liner, the rate of heating, the optimum temperature required for initiating the reaction, the time spent at the maximum temperature reached, and finally, whether or not to add other materials that would simultaneously react, thereby producing additional heat (so-called boosters).

Yet another choice was how to separate the pure molten metal from the slag formed by the reaction products (CaF_2 in the above example). One way was to leave the bomb alone during the heating and let gravity do the work. Uranium and plutonium are far denser than the slag and should therefore naturally coalesce into a single molten globule of metal at the bottom of the crucible. Dick Baker’s group at Los Alamos used this “stationary bomb” approach.

But the first batches of plutonium compounds would be very small indeed. The smaller the scale of the reaction, the worse the stationary-bomb approach could be expected to work. A smaller bomb has more interior surface area in proportion to its volume than a larger bomb and is therefore more likely to lose a larger proportion of the reaction heat through the liner and bomb walls to the external environment. The reaction products might solidify before the new metal could flow through them and coalesce at the bottom of the liner.

Magel and Dallas, while working at the Met Lab in Chicago under Dr. John Chipman, recognized this problem and decided to assist the separation by performing the reduction inside a graphite centrifuge. The bomb was placed on its side in the centrifuge and rotated rapidly as it was being heated. The rotation rate could be adjusted to make the centrifugal force on the molten metal about 50 times larger than the force of gravity, enough to propel the molten metal outward to the tip of the cone-shaped interior of the refractory liner where it would cool into a consolidated mass. The components and operation of their "hot centrifuge" are shown in the box “The Magel-Dallas ‘Hot Centrifuge’ Technique,” page 165. By the end of 1943 Magel and Dallas were using their new technique to make 1-gram buttons of pure uranium metal from uranium fluoride.



Meanwhile, the Los Alamos efforts in metal reduction, using stationary bombs and other methods, were floundering. Baker’s group tried to prevent the slag from solidifying too quickly by using an iodine booster which not only adds heat to the reaction but also adds reaction products with low-melting points to the slag. Both effects keep the slag in the liquid state for a longer time. The iodine booster improved the results, but the reductions on the 1-gram scale still produced finely divided metal mixed with slag rather than a coherent metal slug. In January 1944, Baker also tried the centrifuge approach, but his efforts were not successful. Consequently, J. W. Kennedy, the Leader of the Chemistry and Metallurgy Division, his Associate Director Cyril Smith, and eventually, as noted above, Oppenheimer himself requested Dr. Chipman to transfer Magel and Dallas to Los Alamos as quickly as possible.

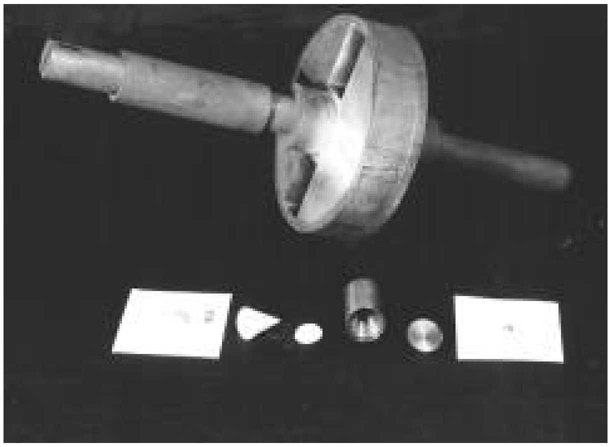
After Magel and Dallas arrived with their equipment, they immediately began performing centrifuge reductions of uranium. Reductions in a centrifuge worked best when the reducing agent was lithium and the liner was made of beryllium oxide. Magel and Dallas also concluded that an iodine booster had essentially no effect on reductions using lithium. Evidently the heat generated by the booster was of little value since the slag in lithium reactions had a sufficiently low melting point to permit plutonium and uranium metal to sink through it easily. Therefore, any further lowering of the melting point by adding iodine was unnecessary.

By March 2, an amount of fluoride (PuF_3) containing 50-milligrams of elemental plutonium was available for reduction. It had been prepared by Laboratory chemists from shipments of plutonium nitrate sent from the Clinton reactor. Magel and Dallas were given the material to reduce to plutonium metal. Probably with some reservations, they first followed the Los Alamos protocol of using calcium as the reducing agent and an iodine booster. The result was a grayish cokey mass containing no agglomerated plutonium. But on March 8, they tried again with another sample, this time using lithium (and iodine again). That experiment produced a shiny 20-milligram button of plutonium. Although the yield of 40 percent was disappointingly low, the result was the first plutonium metal made at Los Alamos and the first made anywhere in sufficient quantity to see without mag-

continued on page 166

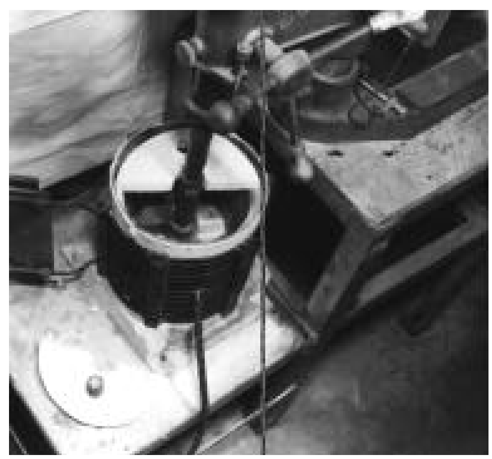
The Magel-Dallas "Hot Centrifuge" Technique

The photograph below shows the components of Magel's and Dallas's apparatus for small-scale metal reduction of plutonium and uranium compounds. On the paper in front of the centrifuge rotor is a charge of metal halide (such as PuF_4) and a reducing agent. To the right of the paper is a cone-shaped crucible or liner made by powdering BeO, forming it in a mold, and firing it as clay is fired. Magel and Dallas put the reducing agent into the crucible first and put the halide on top. They covered the crucible with a double lid (shown to the right of the crucible): the first layer made of either sintered NaCl, $BaCl_2$, or LiF, was topped with one made of MgO. They put the crucible inside the cone-shaped interior of the cylindrical steel bomb, displaced the air inside the bomb with argon, covered the bomb with a steel lid, and sealed it shut by welding.



They mounted the bomb into one of the slots of the rotor and packed it tightly in place with more MgO. The rotor was about 15 centimeters in diameter and was made entirely of graphite to give it both strength and heat resistance. It had four slots so that four reductions could be performed at once. (If the experimenters didn't have four charges, they put dummy bombs into the slots for balance.)

The photograph at right shows the centrifuge. The loaded rotor was placed inside a coil that was attached to a high-frequency electrical generator, and the shaft of the rotor was attached to a drill press through a slot-and-pin connector. When the generator was turned on, the coil would produce a rapidly alternating magnetic field, which would heat the rotor and bombs by induction. During the heating, the rotor would be spun by the drill press at 900 revolutions per minute, which made the force on the bomb's contents about 50 times that of gravity. Magel and Dallas found that the best procedure for plutonium reduction was to heat the spinning rotor and bombs to about 1,100 centigrade, which took somewhat less than five minutes, maintain that temperature for three minutes, and then turn off the generator and let the whole thing cool but continue the rotation until the temperature reached 400-500 centigrade. When the bomb cooled to room temperature, they sawed it open at the top and removed its contents for examination.



The photograph at left show a longitudinal cross section of a bomb that was fired in the graphite centrifuge. In this particular specimen, the layer of slag is clearly seen on top of a button of uranium metal. The button is located in the tip of the crucible. The black spongy deposit clinging to the upper part of the cone is metal mixed with slag, which meant that the yield of pure metal was low in this particular reduction.

continued from page 164

nification. Many other 50-milligram runs were made with PuF_4, PuF_3, and $PuCl_3$, as well as with other reducing agents. At this scale the results varied (about one third of them were successful).

Ted Magel

During the three weeks following the initial success, Laboratory chemists prepared in succession two samples of PuF_4, each containing a gram of plutonium. Much to the dismay of Magel and Dallas, Eric Jette, the leader of the Plutonium Metallurgy Group, and Cyril Smith decided to give the first 1-gram sample to Dick Baker for an attempt at reduction in the stationary bomb. The attempt produced only questionable microscopic droplets of plutonium dipersed in slag.

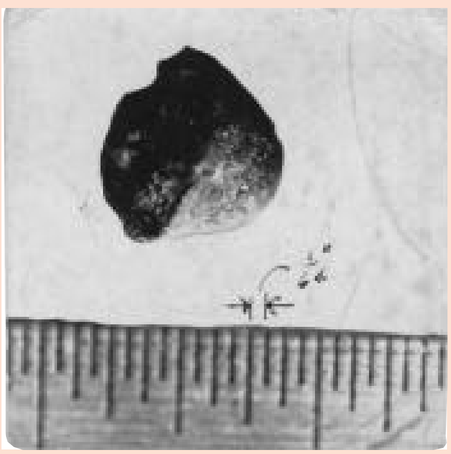


Figure 1. The first gram-scale piece of plutonium metal in history. It was made by Ted Magel and Nick Dallas at Los Alamos on the night of March 23, 1944 and weighed 520 milligrams.

When the second sample became available, Jette and Smith requested Magel and Dallas to attempt a centrifuge reduction on March 24th in the presence of a number of dignitaries. Magel decided on the 23rd to do the experiment without a crowd present. That night he and Dallas performed the reaction with lithium and no booster. When they cut open the bomb, they found a 520-milligram button of plutonium, shown in Figure 1. Again the yield was inexplicably low, but the metal was shiny and soft enough to cut with pliers; both qualities indicate purity. The button was immediately used for crucial metallurgical and chemical studies. From April to early June, Magel and Dallas made eight more buttons on the one-gram scale, all of which were successful, and four of which are shown in Figure 2. In total, they performed about 300 centrifuge reductions between February and June; twenty-five of them were plutonium reductions.

During the course of their work, both Magel and Dallas experienced various accidental exposures to plutonium, which later qualified them for membership in the so-called UPPU club, Wright Langham's follow-up study of wartime plutonium workers who received intakes of plutonium (see "On the Front Lines").

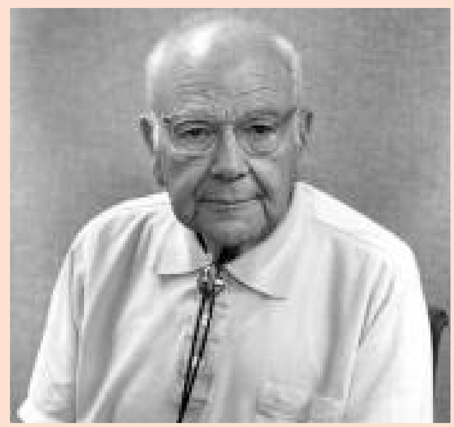
In the summer of 1944, Magel and Dallas started small-scale work on purifying plutonium, especially from light-element contaminants. They set up high-vacuum, high-temperature remelting systems to evaporate residual light element impurities from the reduced buttons of plutonium. Light-element impurities are a problem because they absorb alpha particles from the decay of plutonium and emit neutrons. The neutrons can then initiate a chain reaction in the plutonium before two subcritical assemblies have been able to come together to form the planned supercritical mass. The removal of light-element impurities was therefore considered crucial for minimizing the neutron background and preventing a preinitiation of the gun-type plutonium weapon.

During that summer, Baker made a systematic study of small-scale, stationary-bomb reactions. He found that $PuCl_3$ was a better starting material than PuF_4 and then went on to develop reliable techniques using this halide for producing gram-scale buttons of plutonium. Because stationary bombs were much more convenient than centrifuges and did not require lithium as a reductant nor the use of beryllium oxide crucibles (both of which contributed high levels of light-element impurities to the resulting plutonium), Baker's method turned out to be preferable for production of plutonium in quantities greater than one gram.

Figure 2. Four more plutonium metal buttons made by Magel and Dallas during the spring of 1944.

The availability of gram-scale quantities of plutonium permitted the Los Alamos metallurgists to attack in a multi-faceted and coherent way the so-called variable density and crystal-structure problems. Puzzling variations in density and crystal structure had been seen in different metal specimens since the time of plutonium's first production on the microgram scale at the Met Lab, and the possibility of allotropism had been raised as early as February 1944 by R. Mooney and W. H. Zachariasen at the Met Lab. Nevertheless, at Los Alamos, the results of specific attempts to settle this issue were ambiguous until June 1944. Research did finally show that plutonium has more complex allotropic behavior than any other known metal, and this property made the task of producing the necessary shapes for weapons even more difficult.

Toward the end of the summer of 1944, the light-element impurity problem suddenly became irrelevant: It was discovered that reactor-produced plutonium from Hanford would contain significant amounts of plutonium-240. That isotope undergoes spontaneous fission and therefore would add much more to the neutron background than the light elements ever could. Since there was no practical way to remove it, the project had to abandon the gun-type weapon and replace it with an implosion device in which the speed of the assembly would eliminate the possibility of neutron-induced preinitiation. It also meant that Magel and Dallas were no longer needed to solve light-element purification problems, and they decided to leave Los Alamos and join Dr. Chipman, who had moved to MIT. There they helped make large crucibles of various refractory materials for use by Baker's reduction section and Ed Hammel's remelting, alloying, and casting section. Thus their work for the Manhattan Project continued even after they left Los Alamos. ■



Edward F. Hammel joined the Laboratory in 1944 as a section leader in the Chemistry and Metallurgy Research Divsion, where his principal responsiblity was remelting, alloying, and casting plutonium metal. In 1945 he was appointed group leader of the Metal Physics Group, which was responsible for determining the pyhsical properties of plutonium. In 1948 Ed became group leader of the Low Temperature Physics and Cryoengineering Group and was responsible for organizing a program to study helium-3. During that year Ed and his collaborators were the first to liquefy helium-3 and to test its properties at low temperatures. They searched for superfluid behavior down to 0.7 kelvin, a remarkable feat for the times. Their search was unsuccessful because helium-3 becomes a superfluid at an unexpectedly low temperature of less than 3 millikelvins. From 1970 to his retirement in 1979, Ed held management positions in various energy related projects including the study of superconducting transmission lines and energy storage. In 1955 Ed was awarded the American Chemical Society gold medal for his work on helium-3. He received his A.B. in chemistry from Dartmouth College and his Ph.D. in physical chemistry from Princeton University.

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The Future Role of

From the time the first gram of reactor-produced plutonium was shipped to Los Alamos in 1944 to process into pure metal, the Laboratory was called upon to develop the knowledge base and the technology to handle, process, and utilize this man made material for both wartime and peacetime uses. Now, over 50 years later, the Cold War is over and difficult problems regarding the safe dismantlement of nuclear warheads and deposition of plutonium are requiring development of new technologies. Again the Laboratory is being challenged to fulfill this responsibility.

Leading edge research on special nuclear materials such as plutonium, enriched uranium, tritium, and others naturally requires specially designed and managed facilities. It is not an accident that those facilities exist at Los Alamos, nor that they are configured to meet constantly changing national needs as well as the highest safety, health, and environmental standards. In fact TA-55, the modern plutonium facility at Los Alamos, is touted as one of the "Crown Jewels" in the Department of Energy's inventory of facilities.

But things didn't start out that way. D Building, the first facility at Los Alamos for handling plutonium, turned out to be less than adequate. It had been specially designed in the spring of 1943 to minimize contamination of plutonium by light-element impurities. When that need disappeared (see "Plutonium Metal—The First Gram"), it became very clear that the more serious problem was preventing plutonium contamination of the workers. Unfortunately, D Building was not ideally suited to meet that need, and so very soon after the building was occupied and plutonium began arriving in larger quantities, plans were made for erecting a new facility at DP Site. The structures were standard prefab metal buildings outfitted with high-integrity metal gloveboxes and carefully designed ventilation and plumbing systems to insure material containment and worker safety, at least during normal operation.

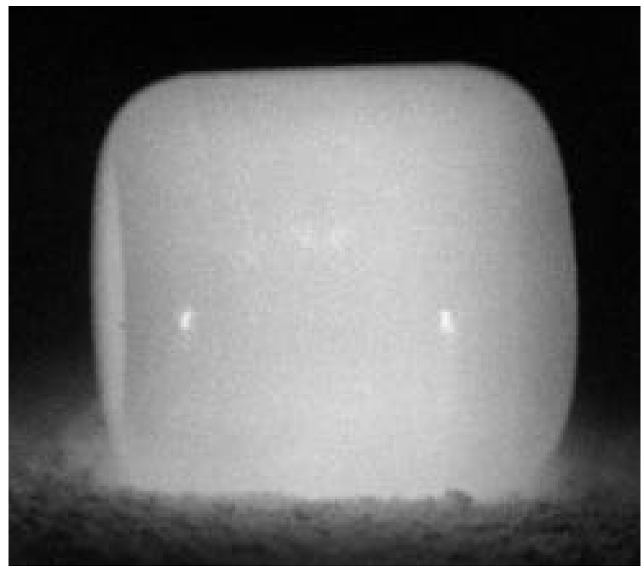
DP Site served as the nation's center for plutonium research and development through the 1950s and 1960s. The responsibility for fabricating plutonium weapon components, which Los Alamos had carried out during WWII, was transferred instead to the Rocky Flats Plant in north central Colorado starting in the early 1950s. In May 1969 a fire at the Rocky Flats facility, which was devastating to the physical plant, caused a temporary shutdown of the plutonium operations and prompted the Atomic Energy Commission (then in charge of nuclear technologies) to perform a "critical systems analysis" of the nation's plutonium infrastructure. The analysis pointed out that the infrastucture was fragile and shallow in nature. Improved handling practices as well as new facilities would be necessary to insure continuity of operation as well as the health and safety of workers, the public, and the environment not only under ordinary operations but also in the event of extraordinary circumstances (accidents, natural disasters, terrorist activities, and so on). The end result of the Commission's study was the decision by the U.S. Congress in January 1971 to build two new modern plutonium facilities, one to be located at Rocky Flats for the purpose of making of plutonium weapon components and the other to be located at Los Alamos for performing plutonium research and development.

The new plutonium facility at Los Alamos, referred to as TA-55 (TA stands for

Plutonium Technology

by Dana Christensen

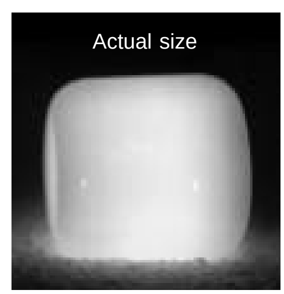
technical area), was designed to withstand earthquakes, tornadoes and all manner of natural disasters. It was also designed to protect workers under extraordinary circumstances such as power failures, fires, and other accidental occurrences. When it became fully operational in December 1978, the major activities in the facility revolved around support of nuclear weapons research, development, and testing. The materials work included purifying plutonium metal, developing and testing new plutonium alloys, performing mechanical and structural strength tests, and making measurements of physical properties such as the equation of state of the various complicated phases of the metallic form of plutonium. On the fabrication side, research was done on manufacturing technologies, and the results were directly applied to the fabrication of components for the new designs being tested underground at the Nevada Test Site. Small-scale recycling (about 200 kilograms per year) of materials and residues from research and development activities was another essential component of the effort, and the Laboratory became involved in developing more efficient and safer chemical separation techniques to carry out those recycling activities. Surface analysis and material-aging studies in support of stockpile-lifetime analysis were also carried out on a modest scale.



In addition to weapons-related work, the facility housed a modest capability in the design, fabrication, and safety testing for plutonium-238 heat sources. These are very compact, long-lasting power sources developed especially for space missions (see Figure 1). Although the heat sources were fabricated and assembled elsewhere, the safety, design, and fabrication parameters were developed and demonstrated at Los Alamos. Finally there was a modest capability to design, fabricate, and test advanced nuclear reactor fuels, such as mixed uranium and plutonium carbides, nitrides, and oxides. The entire population at TA-55, at the time of start-up in 1978, totaled less than 150 employees, including all of the health and safety, and operational support personnel.

Figure 1. Power Source for Deep-Space Applications

This long-lasting radioactive power source of plutonium-238 oxide is very compact indeed. Its 150-gram mass fits into a cylinder having a height and a diameter of only 2.75 centimeters. The initial power output of 62.5 watts decays with a half-life of 87.4 years. The heat from this type of source is converted to electricity through thermal-electric converters, and the electricity is then used to power instruments onboard a spacecraft .



Over the years, this facility, designed in a modular fashion for flexibility and change, has undergone significant modifications and upgrades in response to new demands. Some of those demands began to appear in 1980 when the DOE realized that its new production facility at Rocky Flats would not be on-line in time to meet weapon-component production requirements. Los Alamos was therefore asked to produce pure plutonium metal on an interim basis. By 1983 when it became clear that the new facility at Rocky Flats would not operate as designed, the DOE asked Los Alamos to assist Rocky Flats with the selection and installation of technologies so as to expedite the start-up of their facility. Los Alamos was also asked to continue providing production assistance so as to maintain component production.

A formal program funded by the Department's Office of Production and Surveillance was soon established to support these production-assistance activities. The new program represented a significant change in direction and an increase in the level of activity at the Los Alamos plutonium facility. Research, development, and demonstration of chemical-separation technologies for plutonium recovery became the cornerstone activity, and pure plutonium metal continued to be prepared at Los Alamos and shipped to the Rocky Flats Plant.

Figure 2. High-Purity Plutonium Ring
This ring of plutonium metal has a purity of more than 99.96 per cent. It is typical of the rings that were prepared by electrorefining at Los Alamos and shipped to Rocky Flats for weapon fabrication. The ring weighs 5.3 kilograms and is approximately 11 centimeters in diameter.

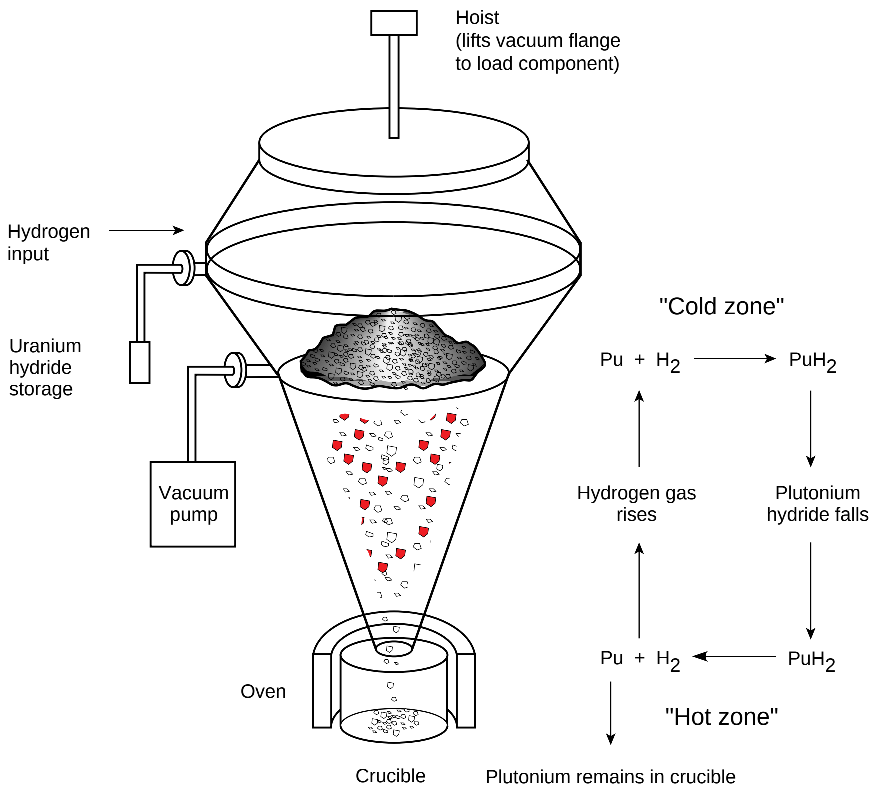
The new plutonium processing mission provided the seeds for innovation and discovery of new and novel separation/purification techniques. Dozens of patents were issued and an untold number of publications were prepared. The population of the facility grew rapidly to exceed 600 employees. Because of the facilities modular design, old technologies were easily removed and replaced by the latest technology available. Also, new health and safety features were easily incorporated as soon as the need was identified. As a result, the plutonium facility has been able to respond to constantly changing operational, and health and safety standards.

Today the combination of a very flexible facility and a very experienced staff is proving to be a tremendous asset in meeting the new demands on plutonium technology. It may come as a surprise that the demands have become more complex, not less, since the ending of the Cold War, and the Laboratory has been challenged more than ever to find innovative solutions. For example, the dramatic down-sizing of the nation's nuclear arsenal in accord with recent treaties requires new technologies to support safe, waste-free dismantlement of nuclear warheads under stringent regulatory conditions. The plutonium facilities ARIES project has become the approach of choice for cost-efficient, waste-free separation of plutonium from weapon components. This project is designed to bring in plutonium assemblies, remove the plutonium as either a metal ingot or oxide powder, and package the plutonium for long term storage according to the DOE Packaging Standard. Figure 3 shows the hydride-dehydride process, which is the centerpiece of the ARIES project. This technology base is being actively exchanged with our Russian counterparts.

The ultimate disposition of the excess plutonium, whether it be transmutation, energy conversion, vitrification as waste, or some other option must also be faced and will require a deep understanding of the fundamental science and technology involved in each as well as a definitive evaluation of the various trade-offs among them. The DOE has named Los Alamos the lead laboratory for plutonium stabilization, packaging, and storage research. The Laboratory is also involved in studying conversion of excess weapon materials into reactor fuels, transmutation of materials by either accelerators or nuclear reactors, stability of nuclear materials in waste forms such as glass or ceramics, and other long-term disposition options.

Surveillance of the remaining U.S. nuclear stockpile has also become more challenging. Since no new production of nuclear weapon components is taking place, the old approach of discovering manufacturing and material flaws at the time a weapon is retired and then correcting the flaws in the next-generation weapon is no longer acceptable. Now the goal is to understand phenomena that might cause changes in materials performance and to predict the rates of those changes so that deterioration in materials performance can be anticipated long before it affects the behavior of a weapon component . The plutonium facility has recently taken on the responsibility for the surveillance of all stockpile plutonium components. The idea is to implement a centralized cost-effective approach for determining safe and

Figure 3. Hydride-Dehydride Recycle System—An Elegant Technique for Nuclear-Warhead Dismantlement



The hydride-dehydride recycle process for extracting plutonium from a warhead exploits the fact that, when plutonium comes in contact with hydrogen gas, it reacts with the hydrogen to form a hydride at a rate that is thousands of times faster than that of any other metal. The diagram shows the vacuum chamber in which the process takes place. (The chamber is installed inside of a glovebox to insure that no plutonium escapes into the work environment.) The heated crucible at the bottom of the chamber is the "hot zone" and the upper part of the chamber, where the weapon component is placed, is the "cold zone." Hydrogen from a heated uranium-hydride storage bed flows into the cold zone where it reacts with the plutonium to form plutonium hydride. The hydride falls as a powder into the hot zone, and there it decomposes into hydrogen gas and pure plutonium. The released hydrogen rises to the cold zone where again it can combine with the plutonium and "carry" that plutonium down to the crucible below. The cycle continues until all the plutonium has been separated from the weapon component. The signal that the process is complete is a sudden rise in the pressure inside the chamber, indicating that all the hydrogen has been released. The hydrogen gas is then pumped out of the chamber and re-absorbed by the uranium-hydride bed. When the process is complete, 99.9 per cent of the plutonium in the weapon component is in the bottom of the crucible where it will be melted and incorporated into a storage-ready ingot. Thus plutonium recovery is contained from beginning to end within a compact unit that occupies a 36-square-foot glovebox.

Standard acid-leach plutonium recovery methods generate hazardous mixed chemical and radioactive waste that are very difficult kind to dispose of. In contrast, the new hydride-dehydride recycling method is essentially a zero-waste process—generating no mixed or liquid waste of any kind.

reliable stockpile lifetimes. A comprehensive program involving both destructive and non-destructive testing of stockpile weapon components and systems is being put in place. Also, new approaches and technologies are being developed that are predictive in nature so that the goal of predicting accurate lifetimes can indeed be realized. (For example, ultrasonic techniques can be used to pinpoint changes in physical dimension that occur over time as a result of radiation effects on various materials.) In addition to surveillance, the facility will also maintain the technology base for component fabrication so that, if weapon components need replacement, they can be refabricated quickly and efficiently.

Plutonium-238 heat-sources are still the best power sources for unmanned deep-space exploration. Recently the plutonium facility has been declared the nation's center of expertise in that technology, and its historic involvement in research and development has now been expanded to include the actual production of heat sources. Figure 4 shows elements of the latest project—the heat sources to power the deep-space probe to Saturn and the Saturn moon, Titan (Cassini mission). Future heat-source requirements for similar missions will be supplied out of TA-55.

Finally, the end of the Cold War has opened up new opportunities for technical exchange and collaboration regarding plutonium technology. Whereas in the past,

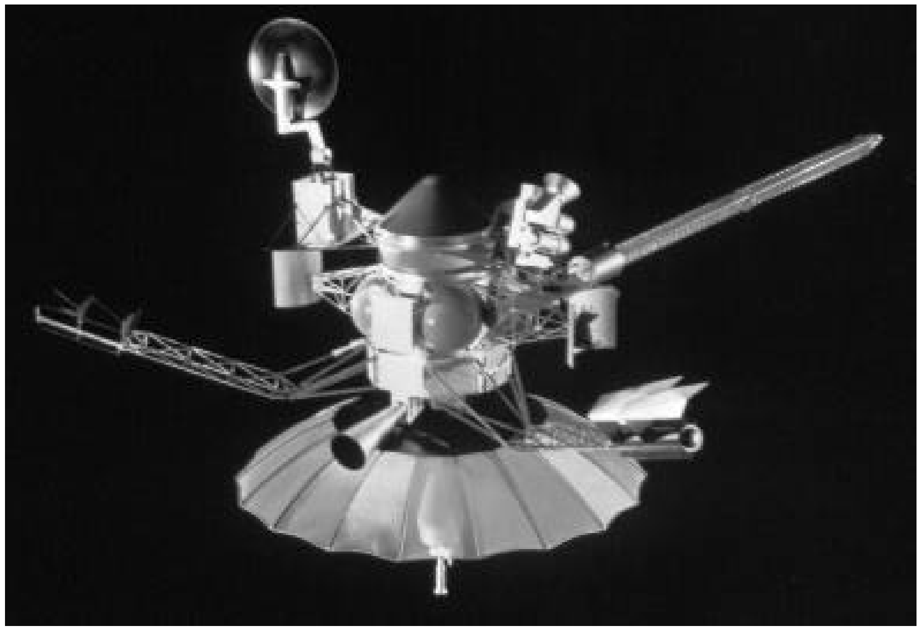
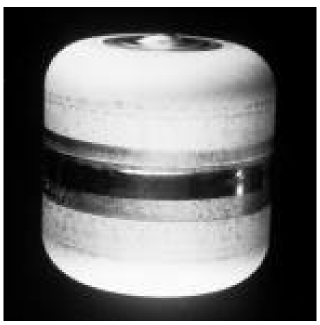


Figure 4. Plutonium-238 - Powered Deep-Space Probe
This deep-space probe (right) is typical of those that are powered by radioisotope thermoelectric generators. Those electric generators run on power from plutonium-238 heat sources like the one shown below. The Cassini mission to Saturn will require three thermoelectric generators, each loaded with 72 of those heat sources.



the plutonium technology base in each of various countries was kept secret and closed, today that knowledge is being more openly discussed. In particular, the states of the Former Soviet Union (principally Russia) are beginning to participate through interactions with the U.S. national laboratories in the control of nuclear materials and the stabilization of excess materials and facilities. This initiative enhances the non-proliferation of weapon technology and materials to non-declared states and terrorist organizations.

New cooperative agreements are being formulated to bring consistency to the way that nuclear materials such as plutonium are identified, controlled, stabilized, packaged, and stored. Indeed, most of the weapon production facilities of the past are no longer needed, and safe decommissioning and dismantlement can now begin. Those activities, however, require a significantly new technology base. Scientists at the plutonium facility have been working on those problems and have already developed several exciting new technologies including plasma and electrolytic methods for removing plutonium contamination from solid surfaces (see Figure 5). Those methods render the equipment free of contamination and therefore disposable through standard industrial routes rather than through transuranic-waste routes. Another demonstrated approach is liquid waste-stream polishing whereby liquid wastes can be stripped of plutonium and other noxious contaminant's prior to discharge. That technology is now being demonstrated in treating liquid effluents from TA-55.

The end of the Cold War has opened up opportunities to reduce nuclear arsenals and to minimize the availability of weapons-grade plutonium. It also means that the country and the world must wrestle with decisions on the clean-up of plutonium residues, facilities, and contamination, and on the eventual disposition of excess plutonium. Clearly a strong, reliable technology base is essential to implement the technical and political decisions as they are made. Realistically, the country will down-size its investment in nuclear facilities and infrastructure, which will make the remaining infrastructure even more important for future missions. A stronger investment in science and technology will be essential to overcome the inherent vulnerability associated with reduced production capacity. It will also be essential for solving the problems of the plutonium disposition and for making future generations free of this difficult Cold War legacy.

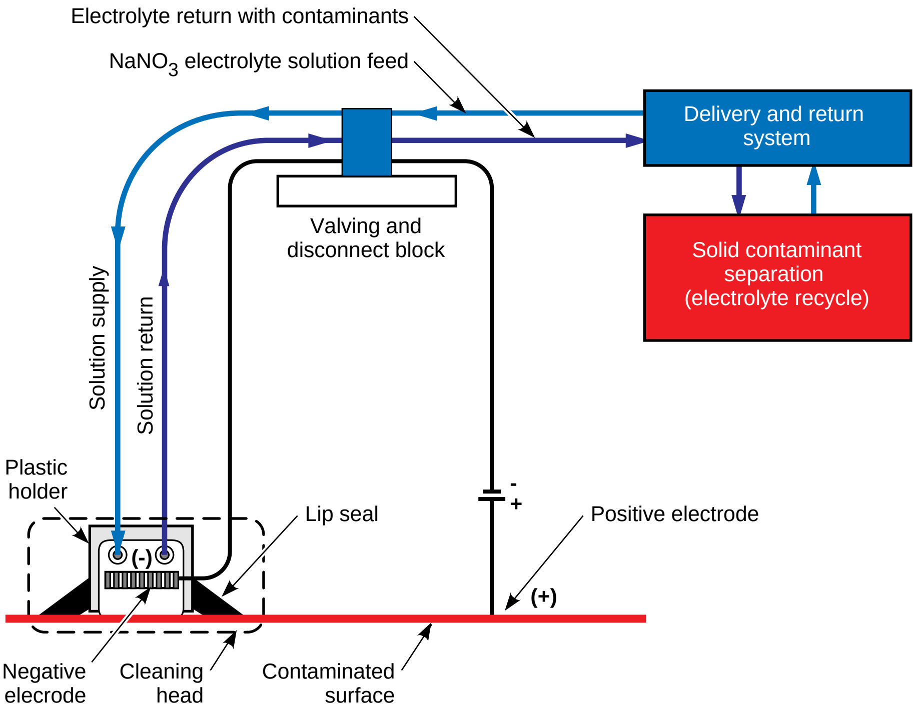


Figure 5. New Solution to Glovebox Decontamination

This new clean-up technology uses sodium nitrate as an electrolyte to remove plutonium and other contaminant's from metal gloveboxes. The surface to be cleaned functions as the anode and the cleaning head functions as the cathode. Plutonium ions and other contaminant's are pulled into solution by the voltage difference as the electrolyte passes through the layer between the cleaning head and the contaminated surface. The electrolyte then passes through a unit where the contaminant's precipitate out of solution. Thus there is no primary waste stream from this process. The system is designed to handle gram quantities of plutonium. Different cleaning heads are used to accommodate different glovebox-surface configurations. Numerous successful demonstrations of this methodology on a variety of surfaces have been done.

Dana C. Christensen is Deputy Division Director of the Nuclear Materials Technology Division at the Laboratory and is internationally known for his work in nuclear materials management, principally plutonium. Dana joined the Laboratory in 1979 after completing a research associate position at Battelle Pacific Northwest Laboratory. Since that time he has held a number of program and group management positions within the Laboratory, and has served on numerous national and international committees focused on chemical separations, waste minimization and pollution prevention, as well as facility design and operation, and weapon materials management. Dana has established and manages technology exchange activities in the field of actinide materials management with other DOE contractors and in foreign countries. Dana's research interest in the pyrochemical separation processes for extracting and purifying actinide elements led him to co-found the Actinide Pyrochemical Workshop, now in its fourteenth year. Dana received his B. S. and his M. S. in chemical engineering from New Mexico State University and earned a master's degree in business management from the University of New Mexico - Anderson School of Management.