The Cecil Kelley Criticality Accident

On December 30, 1958, an accident occurred in the Los Alamos plutonium-processing facility, where plutonium was chemically separated, or "recovered," from various compounds. In this facility, plutonium compounds were dissolved and mixed in a large tank with chemical reagents to concentrate and purify the plutonium. On the day of the accident, Cecil Kelley, an experienced chemical operator, was working with the large mixing tank. The solution in the tank was supposed to be "lean," typically less than 0.1 grams of plutonium per liter, but the concentration on that day was actually 200 times higher. In fact, the tank contained enough plutonium (3.27 kilograms) in an upper layer of organic solvent to be very close to criticality—that is, capable of sustaining a chain reaction. When Kelley switched on the stirrer, the liquid in the tank formed a vortex, or whirlpool. The lower, aqueous layer was pushed outward and up the walls of the tank, as if forming a bowl; the upper, plutonium-containing layer flowed into the center of this "bowl," which increased the thickness of the layer. In this new configuration, the plutonium went critical, releasing a huge burst of neutrons and gamma radiation in a pulse that lasted a mere 200 microseconds.

Kelley, who had been standing on a foot ladder peering into the tank through a viewing window, fell or was knocked to the floor. Confused and disoriented, he apparently turned the stirrer off and on again, then ran out of the building. The two other operators on duty at the time saw a bright flash of light, like that of a flash bulb, and heard a dull thud. Quickly, they rushed to help, and found Kelley outdoors. He was ataxic (lacking muscular coordination). All he could say to the operators was, "I'm burning up! I'm burning up!" Assuming he'd had a chemical accident, the two operators led Kelley to a shower. One operator turned the stirrer off as they went by.

Within five or ten minutes, a nurse, supervisors, and radiation monitoring staff were all on the scene. Kelley was evidently in shock and virtually unconscious, but rather innocently, the nurse noted that Kelley had "a nice pink skin." Because the nature of the accident was unknown at the time, it was not understood until later that Kelley's pink skin was erythema (a redness of the skin, like that from a sunburn) caused by his radiation exposure.

The possibility of a criticality accident had been considered so remote that the radiation monitoring staff began their investigation by searching for plutonium in the work environment with alpha detectors. They found no widespread activity. It was only as Kelley was leaving in an ambulance, eighteen minutes after the accident, that the circumstances of his accident became clear. The monitoring staff had just begun gamma radiation measurements. When they saw the high level of gamma radiation in the vicinity of the large mixing tank (tens of rad per hour), the investigators quickly realized what had happened.

The symptoms Kelley displayed at the plutonium-processing facility, characterized by collapse and mental incapacitation, were the first stage of his clinical course (what is now know as the most severe form of acute radiation syndrome). The second stage began when he arrived in the emergency room of the Los Alamos Medical Center. It was dire. Kelley was semiconscious, retching, vomiting, and hyperventilating. His skin was cold and dusky reddish-violet, and his lips had a bluish color that indicated poorly oxygenated blood. He was immediately wrapped in blankets and surrounded by hot water bottles. His blood pressure and pulse were at first unobtainable. He had shaking chills, and the uncontroled movement of his extremities and torso necessitated restraint by the nursing staff. Kelley's anxiety and restlessness were eased only by Demerol. After about ten minutes, the nurses were able to measure Kelley's pulse (160 beats per minute) and his blood pressure (80/40). His body emitted a small but measureable amount of gamma rays, and his vomit and feces were sufficiently radioactive to give a positive reading on the detector.

One hour and forty minutes after the accident, Kelley entered the third stage, which was both the longest and most encouraging. Kelley regained coherence, and although he complained of severe abdominal cramps and occasionally retched and vomited, he seemed considerably improved overall. He was transferred from the emergency room to a private room, placed in a bed that was on "shock blocks," and enclosed in an oxygen tent. Kelley's first blood samples were drawn at this time. Because Kelley had been irradiated with neutrons, the sodium and other light metals in his blood were "activated," or transformed into radioisotopes such as sodium-24. His average whole-body dose was first estimated by measuring the radioactivity of his blood. It appeared to have been massive—in the range of 900 rad from fast neutrons and 2,700 rad from gamma rays, giving a total of 3,600 rad—and certainly lethal.[1]

Six hours after the accident, the lymphocytes virtually disappeared from Kelley's peripheral circulation, which

[1] After his death, Kelley's radiation dose was better estimated, again using biological indicators of the neutron dose and inferring the gamma dose. The results were somewhat greater than the estimate made during Kelley's period at the hospital: 900 rad from fast neutrons and 3,000 to 4,000 rad from gamma rays, giving 3,900 to 4,900 rad.

The origin of the Los Alamos Human Tissue Analysis Program

was taken as a grave sign. Twenty-four hours after the accident, a sternal bone marrow biopsy was performed. The marrow appeared watery, rather than bloody, and no excessive bleeding occurred. The marrow was almost completely acellular, edematous, hemorrhagic fatty tissue. From that observation, along with the rapid onset of lymphopenia (depression of the lymphocytes in the bloodstream overall), it was clear that Kelley would not survive long.

During the second evening after the accident, Kelley entered the fourth stage. The pain in his abdomen became difficult to control. He became increasingly restless despite medication—so much so that the intravenous infusions were inadvertantly interrupted. He began to sweat profusely, his color became ashen, and his pulse irregular. About 35 hours after the accident, Kelley died.

Kelley had spent about half of his 11.5 years at Los Alamos as a plutonium-processing operator (from 1946 to 1949 and, again, from 1955 through 1958). During that time, he underwent several minor exposures to plutonium, including regular exposure to moderate levels of airborne plutonium in various chemical forms. Therefore, his tragic death became an opportunity to determine certain factors crucial to the protection of workers. By analyzing the tissues of his body, researchers could determine Kelley's total plutonium body burden and compare it with the result obtained from periodic urine assays during his life. Furthermore, they could determine the distribution of the plutonium in Kelley's body. Because certain tissues are more sensitive to radioactivity than others, the distribution of the plutonium was important in determining the effective dose. That result could be applied broadly to other individuals who were exposed to plutonium largely by inhalation over a prolonged period. Kelley's exposure record included 18 instances of high nose-swipe counts and 10 instances of minor exposures, such as being involved in the cleanup of a plutonium spill or getting a slight laceration. Urine assays taken during that period usually showed slight amounts of plutonium. Analysis of those assays indicated that Kelley's plutonium body burden was 19 nanocuries (see "The Human Plutonium Injection Experiments"). Kelley's records showed that all of his exposures occurred during his early plutonium work (1946-1949) and it was very likely that most of his plutonium burden was accumulated during this period from chronic inhalation exposure to low-level airborne plutonium.

Autopsy samples were taken from throughout Kelley's body to measure plutonium concentrations. (The accident itself, an exposure to neutrons and gamma rays, had no impact on the amount or distribution of plutonium in his body.) The tissue analysis showed that Kelley's total plutonium body burden was 18 nanocuries. This compared extremely well with the value of 19 nanocuries determined from urinalysis. Wright Langham stated that the above agreement "was so very satisfactory that it is undoubtedly fortuitous." In addition, it was found that about 50 per cent of the plutonium was in the liver, 36 per cent in the skeleton, 10 per cent in the lungs, and 3 per cent in the respiratory lymph nodes. Plutonium Injection Experiments in humans had shown a somewhat different distribution: 65 per cent in the skeleton and 22 per cent in the liver, for example, most likely the result of differences in the chemical and physical nature of the plutonium (the experiments used a soluble salt of plutonium whereas Kelley inhaled plutonium dust particles).

Another interesting factor in Kelley's analysis was that they were able to determine relative timescales for the movement of plutonium through the body and within organs. This was possible because changes in plutonium production methods between Kelley's first and second stints as a plutonium worker had considerably increased the ratio of plutonium-238 to plutonium-239 in the material being handled. This fact, coupled with the record of nose counts and exposures, enabled them to distinguish the "early" plutonium from the "late" plutonium and, thus, to trace qualitatively the movement of plutonium from the lungs to other organs. They found that plutonium cleared relatively rapidly from the lungs compared with the clearance from the bone and lymph nodes. Much of the plutonium in the lungs migrated to the liver whereas only a small percentage migrated to the bone and lymph nodes. Finally, the rate of clearance from the lungs to the liver must be relatively fast and the retention time in the liver must be longer than in the lungs.

A memorandum written by Jean McClelland and Bill Moss, chemists in the Health Division, presented the results of Kelley's tissue analysis. Those results showed that plutonium was retained in the lungs and pulmonary lymph nodes much, much longer than contemporary models had predicted. Because this was unexpected, it was decided to collect tissues from other exposed individuals to confirm this phenomenon. They also stated that tissues from non-occupationally exposed individuals would be collected as controls. Thus, the Los Alamos tissue analysis program was begun. ■

Further Readings

T. L. Shipman, C. C. Lushbaugh, D. F. Petersen, W. H. Langham, P. S. Harris, and J. N. P. Lawrence. 1961. Acute radiation death resulting from an accidental nuclear critical excursion. *Journal of Occupational Medicine: Special Supplement.* (March 1961): 145-192.