any effect on the normal course of his life." HP-12 was 53 at the time of the injection and lived another 8 years before dying, in 1953, of heart failure. Late radiation effects, such as cancer, were not expected to develop for ten to fifteen years, if at all. For example, the induction period in humans for radium-induced cancer, especially malignancy of the bones, was about 10 to 30 years after exposure. Despite Langham's statement, we cannot, of course, discount the fact that HP-12 might have lived 20 or more years; although in 1945, fifty years of age was considered to be fairly advanced. On the other hand, the GIs at Los Alamos who were heavily exposed to plutonium in 1945 while working in D Building under poor industrial hygiene conditions (see "On the Front Lines" on page 124) were in their early twenties and were at greater risk of developing late radiation effects than was HP-12.

HP-12 was injected with 4.7 micrograms of plutonium (0.29 microcuries) in the chemical form of the +4 citrate salt. The material had been sent to Dr. Friedell at Oak Ridge by Wright Langham, along with directions for its use on a human subject. Langham stated that citrate was chosen "to produce the maximum deposition in the bone . . . [so as to] produce an excretion rate comparable to that of a worker having absorbed the material at a slow rate." Urine samples were collected almost continuously for the first 42 days, and then intermittently until the 89th day after injection. Regular stool samples were collected as well over a 46-day period. In accordance with the plan, the Manhattan District Medical Office conducted the clinical part of the experiment, and the urine and fecal samples were sent to Los Alamos for analysis.

Langham also reported at the May conference that "the excretion during the first day was surprisingly low [0.1 per cent in the urine] and . . . the leveling off of the excretion rate was much slower than with rats." Langham sug-

Polonium Human-Injection Experiments

In 1944, in response to concerns for the risk associated with occupational exposures to polonium, the Army Medical Corps authorized Rochester to undertake a study of the biological behavior of that element. The program was started in August 1944 with animals, and by November, studies with humans had begun. Eventually, tracer amounts of radioactive polonium-210 were injected into four hospitalized humans and ingested by a fifth.

Polonium, the first element isolated by Marie and Pierre Curie from pitchblende in 1898, is an alpha emitter. When alpha particles from polonium-210 collide with beryllium atoms, neutrons are ejected, and polonium-beryllium combinations had already served physicists as a convenient source of neutrons. During the Manhattan Project, it was decided to use that neutron source as an initiator of the chain reaction in the atomic bombs, thus making polonium (and beryllium) an occupational health hazard for the people who needed to develop and build the initiators.

In the Rochester work, the subjects of the excretion studies were volunteers. The problem had been outlined to patients at the Rochester Hospital, who were told that it would involve the intake of tracer amounts of a radioactive substance followed by analysis of their excreta. Because polonium was not classified at that time,* the doctors may have even told the patients what substance they would be injected with. From the group of volunteers, four men and one woman were selected for the studies. They ranged in age from the early thirties to the early forties and were being treated for a variety of cancers (lymphosarcoma and various leukemias). One patient died from his cancer six days after the injection.

Four of the volunteers were injected with doses of polonium in a soluble form that ranged from 0.17 to 0.3 microcurie per kilogram of body weight. The fifth patient drank water containing 18.5 microcuries of polonium chloride, equivalent to 0.19 microcuries per kilogram of body weight. The amount of polonium excreted in urine and feces were analyzed, and blood samples were taken to determine the amount freely circulating in the blood. Autopsy tissue samples were taken from the patient who died to determine the distribution of polonium throughout the body.

Polonium-210 has a short half-life (138 days) and very high activity (4,490 microcuries per microgram). The high activity meant very small quantities (of the order of nanograms, a factor of 1000 less than for plutonium) could be administered and detected, so concerns of chemical toxicity were minimal. The short half-life meant the substance would not remain in the body so that concerns about long-term radiation effects were also minimized. In 1945, urine assays corresponding to the tolerance limits were 7 counts per minute for plutonium-239 but 1500 counts per minute for polonium-210.

Such metabolic studies were possible at Rochester University in 1944 because polonium was available at that time. The research yielded important information for the Manhattan Project on the hazards of polonium and helped develop techniques for the similar but later studies of plutonium.

*Polonium was classified in July 1945 and given the code name "postum."