Glenn N. Wagner,[1] *D.O., Cdr., M.C., U.S.N.;*
Michael A. Clark,[1] *Ph.D., M.D., Cdr., M.C., U.S.N.;*
Edward J. Koenigsberg,[2] *M.D., Col., U.S.A.F., M.C.; and*
Stephen J. Decata,[1] *PH2, U.S.N.*

Medical Evaluation of the Victims of the 1986 Lake Nyos Disaster

REFERENCE: Wagner, G. N., Clark, M. A., Koenigsberg, E. J., and Decata, S. J., **"Medical Evaluation of the Victims of the 1986 Lake Nyos Disaster,"** *Journal of Forensic Sciences*, JFSCA, Vol. 33, No. 4, July 1988, pp. 899-909.

ABSTRACT: A cloud of carbon dioxide gas, with an estimated volume of 1 km^3 was released from Lake Nyos, a volcanic crater lake in Cameroon, Africa, causing 1700 to 2000 human fatalities as well as killing thousands of livestock and wild animals. At the request of the Cameroonian Government, the Office of Foreign Disaster Assistance of the U.S. Department of State sent a multidisciplinary team which included 2 forensic pathologists to assist the Government of Cameroon in investigating this natural disaster. The medical evaluation was concentrated in 3 areas: the autopsy of human and animal fatalities, examination and interview of survivors, and examination of the scene of the disaster. Toxicologic specimens were obtained at autopsy, and numerous samples of lake water were collected. The autopsy findings were consistent with asphyxia. The results of chemical analyses excluded many volatiles but not carbon dioxide as the toxic agent. The exact source of this gas continues to be a subject of a heated geologic debate, but fermentation of organic materials in the lake water has been eliminated on the basis of C^{14} isotope studies. This investigation underlines the value of forensic pathologists in epidemiological studies and in the examination of living persons.

KEYWORDS: toxicology, asphyxia, carbon dioxide, postmortem examinations, human identification, mass disasters

In the early evening hours of 21 Aug. 1986, a large cloud of gas was released without warning from Lake Nyos, a volcanic crater lake in northwestern Cameroon. This gas cloud caused the immediate death of 1700 to 2000 persons and tens of thousands of animals, as well as displacing several thousand people—some of whom were injured. A similar eruption had occurred at Lake Monoun, approximately 95 km southeast of Lake Nyos, in August 1984, but no studies were performed until months after this event, which had caused 37 human fatalities. The Cameroonian Government was understandably most concerned with studying the phenomenon of "killer lakes," and they formally requested scientific and medi-

The opinions expressed herein are those of the authors and are not to be construed as official or as necessarily reflecting the views of the Departments of the Navy, Air Force, or Defense. Received for publication 11 Sept. 1987; revised manuscript received 16 Oct. 1987; accepted for publication 20 Oct. 1987.

[1]Staff pathologist, staff pathologist, and staff photographer, respectively. Department of Forensic Sciences, Armed Forces Institute of Pathology, Washington, DC.

[2]Agency for International Development, Office of U.S. Foreign Disaster Assistance, Washington, DC.

Copyright © 1988 by ASTM International

cal assistance from the Government of the United States. The Office of Foreign Disaster Assistance (OFDA) of the Agency for International Development responded with a multidisciplinary scientific team composed of volcanologists, limnologists, geologists, water chemists, environmental engineers, a photographer, and 3 physicians. The Lake Nyos disaster was unique in that it allowed for the 2 forensic pathologists on the team to study a natural disaster where the primary thrust of the investigation was the determination of the cause and mechanism of death of the victims. In most mass disaster situations, forensic pathologists have been primarily concerned with processing and identification of remains rather than with studying the event which caused the deaths.

The Republic of Cameroon is an independent democracy located in equatorial West Africa; it has an area roughly the size of California, and in 1984, had a population of 8.5 million. Approximately 70% of the population lives in rural areas and is employed in agriculture. The northwestern region of Cameroon is mountainous and covered by lush tropical vegetation. Approximately 20 volcanic crater lakes or maars are found in this area. Thursday evening, 21 Aug. 1986, began with torrential thunderstorms typical of the rainy season, but by 9:00 p.m. the weather had cleared and the temperatures were cool. Many residents of the village of Nyos and surrounding villages had retired for the night while others were engaged in their usual evening activities. Survivors who were on the high ridges above Lake Nyos reported a series of rumbling sounds originating from the lake, followed by bubbling. A large white cloud, later estimated as having a volume of 1.0 km^3, rose from the lake. It flowed over the geologic dam and a 100-m waterfall at the north end of Lake Nyos and followed the contour of the river valleys below as it gradually dissipated. When the first outsiders entered the area on Saturday morning, they found thousands of dead people and animals [*1*]. Many survivors remained comatose, while others were in a stuporous state. News of the catastrophe did not reach the outside world until Sunday and, by Monday, OFDA was assembling a multidisciplinary scientific team which arrived in Yaounde, Cameroon, on Thursday, 28 Aug. 1986. The results of the chemical and geologic studies have been reported elsewhere [*1*]. The following account details the studies of the forensic pathology team.

Method of On-Site Investigation

The Lake Nyos disaster created several unusual investigative problems for the medical team. Upon arrival in Cameroon, it was discovered that "representative victims" were not available for postmortem examination because of the lack of refrigerated storage in the remote locality where the disaster occurred. After consultation with Cameroonian officials and U.S. Embassy staff, it was agreed that the U.S. medical investigation would continue along three separate lines of investigation:

(1) examination and interview of survivors,
(2) postmortem examination of available human and animal remains, and
(3) scene investigation of Lake Nyos and surrounding areas where the fatalities occurred.

Much of the initial information available to the team came from the bush pilots of Helimission, a nondenominational missionary agency operating in Cameroon. These missionaries were the first outsiders to visit Lake Nyos after the eruption, and they photographically recorded their findings on 23 Aug. 1987 (Figs. 1 and 2). Their statements were later substantiated by the testimonies of survivors at Wum and Nkambe and by careful analyses of slides and 8-mm movies taken by the missionaries.

Examination of the photographic materials provided by the Helimission pilots indicated several important features: (1) the people and livestock apparently dropped in their tracks with little, if any, warning; (2) there was no evidence of an agonal struggle, that is, seizures; (3) the orderly arrangement of stacked food utensils, and so forth, in multiple dwellings mitigated against a seismic event; and (4) the descriptions of the deceased by lay people can

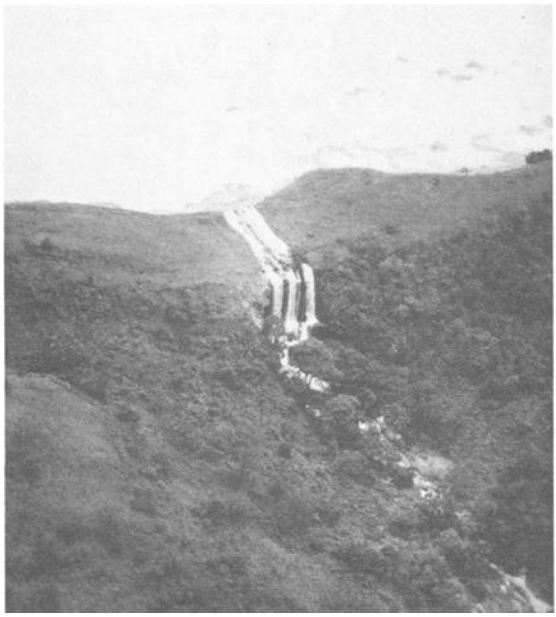

FIG. 1—*Aerial view of Lake Nyos. The lake drains through the waterfall to the valley below, where the village of Nyos is located. Floating vegetable debris is apparent in the lake. The surface water was opaque as a result of the formation of colloidal iron oxide (AFIP Negative 87-6122).*

FIG. 2—*Aerial view of Folani settlement near the village of Nyos. These huts contrast with the more Western appearing houses in the village. No seismic damage is apparent, and the vegetation appears normal (AFIP Negative 87-6128).*

be explained by postmortem decomposition. Descriptions of victims indicated quantities of blood and fluid protruding from the nose and mouth, incontinence, bloating, and multiple scattered blisters over the extremities and torso. Similar descriptions were used to describe the 37 victims of Lake Monoun, a nearby maar lake which erupted in 1984 after a landslide, but none of the victims in that event were autopsied [2]. Close-up photographs of the Lake Nyos victims show serosanguinous fluid protruding from multiple orifices characteristic of postmortem purging. Similarly, the blisters evident on the extremities show no vital reaction. These findings are best described as decompositional and entirely within the known postmortem interval (Figs. 3-7).

A large quantity of information came from the refugee camps located at the government hospitals at Wum and Nkambe. The statements of survivors indicated a changing pattern of signs and symptoms related to their distance from the lake. The few survivors from the village located 3 km from Lake Nyos reported collapsing when the cloud passed through the village. Upon awakening, they experienced a feeling of warmth as well as dizziness, difficulty in breathing, and confusion. These people were either in the second story of buildings or at higher elevations and were not exposed to the densest part of the cloud, which was heavier than air and traveled by following the contours of the ground. Periods of unconsciousness lasted anywhere from 6 to 36 h. One woman reported awakening to find her kerosene lamp out, but she was able to immediately restart it. These survivors do not recall any peculiar odor or unusual occurrence before the event, but 50% reported smelling a sulfurous odor they described as "gunpowder" after the event.

Survivors from Subum and adjacent areas, as well as survivors from villages located along the 10 km between Nyos and Subum, reported a similar experience upon awakening to the

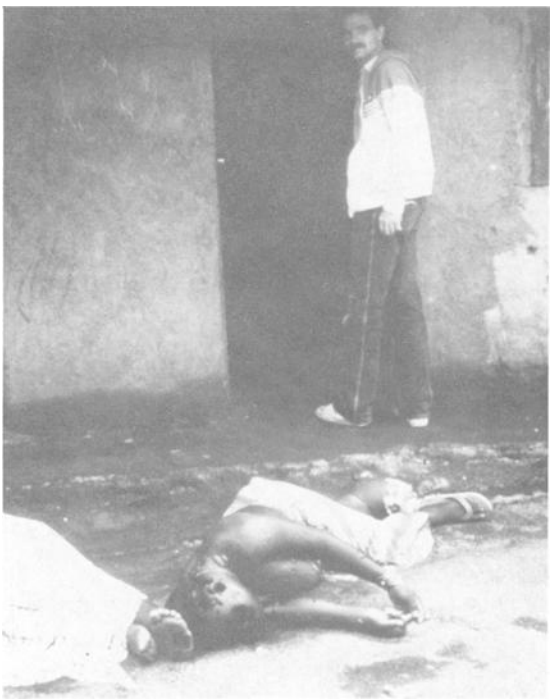

FIG. 3—*Scene in village of Nyos upon arrival of Helimission pilots on 23 August 1986. Bodies were lying both inside and outside homes. Note postmortem bullae on breast of female victim in foreground (AFIP Negative 87-6124).*

FIG. 4—*Interior of house shown in Fig. 3. Note two victims on floor. Furniture and belongings are undisturbed, as are dishes stacked in cabinet. These findings indicate a lack of significant seismic activity. Bodies are intact and in early stages of decomposition. No thermal effect is noted on bodies or furnishings (AFIP Negative 87-6119).*

FIG. 5—*Group of four child victims in bed at village of Nyos. Except for vomitus in the mouth of one victim, there is no evidence of agonal activity (AFIP Negative 87-6126).*

FIG. 6—*Group of victims clustered outside house in village of Nyos. There is no evidence of an agonal struggle. Also note that even though the victims have been dead 36 h, there is no evidence of insect activity (AFIP Negative 87-6121).*

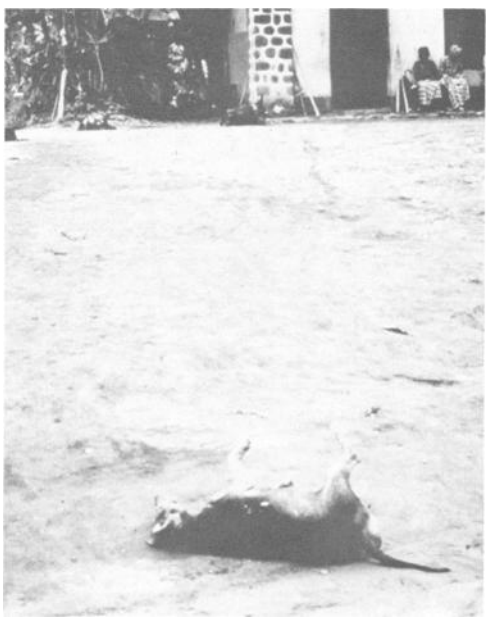

FIG. 7—*A dead dog is apparent in the foreground, and several human survivors are seen sitting in front of the house. Again, notice the absence of insect activity. Some observers reported that no small animals (for example, dogs and goats) had died, but subsequent investigation disclosed that they were buried in the mass graves with the human victims (AFIP Negative 87-6123).*

FIG. 8—*Survivor with severe burns of right hand and forearm which resulted from her losing consciousness from exposure to the gas cloud. She collapsed, and her hand and forearm lay in a smoldering cooking fire for a number of hours while the victim was in a comatose state (AFIP Negative 87-6125).*

gas. Their reports differed from those of the Nyos residents by their noting the strong odor of gunpowder or rotten eggs and feeling very heavy. Periods of unconsciousness ranged from several hours to 24 to 36 h; however, most awoke within 12 h of the event. Unlike the Nyos survivors, these survivors complained more of eye and gastrointestinal irritation. All survivors experienced a transient period of respiratory distress.

Laboratory studies conducted at the government hospitals were limited. Urinalyses showed a transient albuminuria, qualitatively determined. Blood counts and sedimentation rates were within normal limits for this population. Sedimentation rates are elevated in this population because of parasitic infections. Hemoglobin electrophoretic studies of survivors revealed no difference in sickle-cell trait (Hgb AS) in survivors, as compared to the general population.

A number of survivors sustained thermal burns and fractures or dislocations from falls. All of the individuals who had thermal burns were near or in open-fire pits (Fig. 8). While several individuals had partial extremity paralysis associated with fractures or dislocations or both, most also showed some degree of peripheral edema suggestive of compartment syndromes. These injuries, as well as the long periods of unconsciousness, accounted for most of the injuries noted. By December, the vast majority of these neurological deficits were resolved.[3]

Survivors with skin lesions were studied extensively and grouped into three categories: (1) those which preceded the gas release chronologically, (2) those with clearly thermal burns, and (3) those which looked like superficial chemical burns. Initially it was postulated that the skin lesions resulted from sulfur compounds in the gas cloud, since those patients

[3]CARE Communication on Status of Refugee Camps, 1986.

experienced a "rotten egg" or "gunpowder" odor upon awakening from their coma [*3–8*]. As the investigations progressed, it became apparent that sulfur compounds were not constituents of the gas. Carbon dioxide in sublethal concentrations causes olfactory hallucinations which many subjects described as an odor of "rotten eggs" or "gunpowder" [*4,8–10*]. An alternative explanation for these "chemical burns" and that currently favored by us is that the "burns" were pressure lesions from prolonged unconsciousness and immobility. Similar lesions are common in cases where prolonged comas resulted from barbiturate overdoses [*11*]. (They are more frequently seen with carbon monoxide poisoning, but that has apparently been excluded as a factor here.)

A total of three spontaneous abortions were reported among the survivors in the week following the disaster. Since then, regional health officials have not noted any increase in frequency. This concern, however, is reflected in the position that the Cameroonian Government has taken: the Ministry of Health has targeted the health status of female survivors of reproductive age, pregnant women, and newborns for prospective studies. We felt, based on the hundreds of refugees that we saw and talked with, that there would be few, if any, long-term physical handicaps. Later studies support the transient character of most of the presentations but do indicate continuing psychological trauma.[4]

Autopsy studies on human and cattle remains were nonspecific, supporting the probable cause of death as asphyxiation (Figs. 9–11). We relied on the toxicological analyses for clarification. There were no increases in carboxyhemoglobin saturation levels, no sulfhemoglobin, and minimally elevated methhemoglobin concentrations [*3,6,12–14*]. No drugs were detected except for low levels of alcohol in the human material. Through pathological and chemical analyses, we excluded cyanide, ammonia, carbon monoxide, halogenated gases, and sulfur compounds as major constituents of the gas cloud. Carbon dioxide analysis was not (and could not be) performed.

Photographic documentation included slide and color negative 35-mm formats of the lake and adjacent villages, select survivors at the government hospitals at Wum and Nkambe,

[4]CARE Communication to Cameroonian Government, Dec. 1986.

FIG. 9—*A group of dead cattle is seen on a hillside. There were many such cohesive groups of dead cattle seen (AFIP Negative 87-6131).*

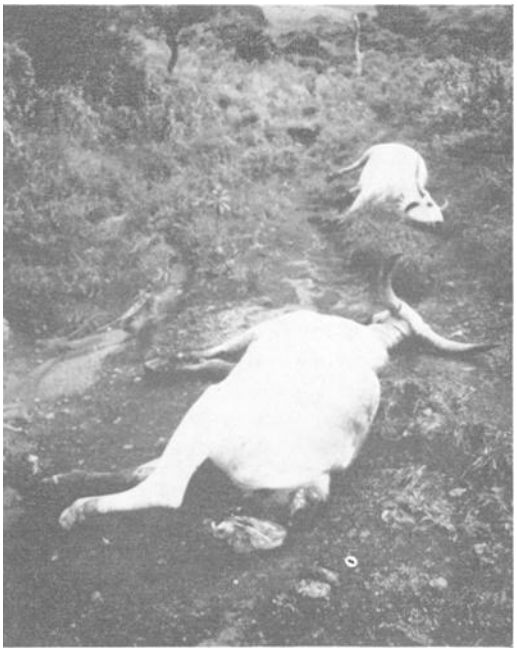

FIG. 10—*Close-up of dead cattle. Even though decomposition is proceeding, there is no evidence of insect activity (AFIP Negative 87-6129).*

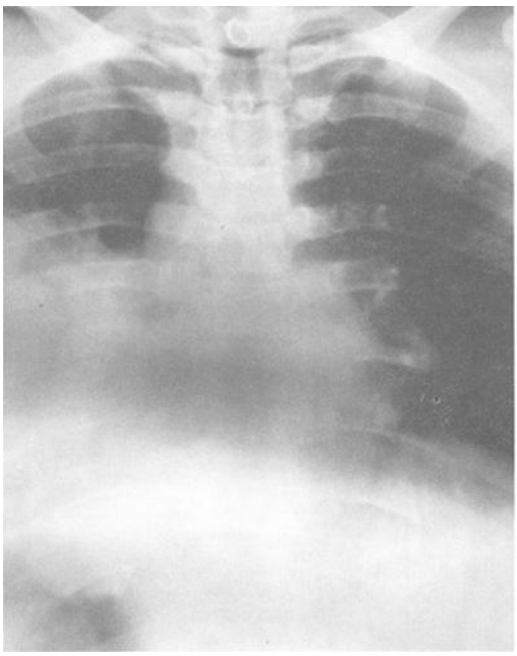

FIG. 11—*Only one victim of the disaster died after arriving at a hospital. He had a lobar pneumonia, as illustrated in this X-ray (AFIP Negative 87-6127).*

and on-site activities such as exhumations. Color infrared film was used to show any changes in plants (chemical, thermal, and so forth) and to try to pinpoint grave sites. In attempting to control infection, the Government elected to bury whole families together in a common grave, usually dug on the premises. Substantial quantities of lime were added. The color infrared film did not prove useful in identifying grave sites, presumably due to the heavy rainfall in the week following the disaster.

No small animal remains were available for autopsy, since house pets and smaller livestock were apparently buried with human remains. The Helimission pilots described all manner of animal life affected by the gas cloud. They saw dogs, cats, cattle, goats, chickens, snakes, and frogs "dead in their tracks" on 23 August. Insect activity was absent for at least 24 h after the event, presumably being anesthetized or killed. We saw living dogs, cattle, chickens, and goats about deserted homes during the week following the disaster.

A number of organizations have examined the survivors, visited the site, and issued reports. A CARE study released in December 1986 in Yaounde, the capital city of Cameroon, reported on the progress of the survivors. The investigators noted that most medical complaints resolved within 10 to 14 days. Refugee relocation problems remain.

Discussion

Lake Nyos occupies a volcanic crater formed by a violent explosion several hundred years ago. Underlying the lake is a volcanic pipe which serves as a conduit for gases. Over time, carbon dioxide dissolved in ground water has accumulated in the bottom water of the lake due to the relatively stable stratification. Chemical, isotope, and geologic evidence supports the hypothesis that the carbon dioxide was derived from deep-seated magmatic sources [*1*]. No direct volcanic activity was involved [*1*]. An undetermined mechanism triggered the gas release from the lake. The lethal cloud, heavier than air, flowed downhill into populated areas. Geochemical studies indicated continuing high levels of dissolved carbon dioxide in Lake Nyos' water specimens [*1*]. This observation, along with our findings, led us to conclude that in fact the toxic gas cloud was composed of carbon dioxide. The human and animal victims exposed to the cloud rapidly lost consciousness due to oxygen displacement in the air and high levels of carbon dioxide. Death was due to asphyxiation [*2-4,6,9,10,12,15*]. Skin lesions on many survivors are thought to represent arms of pressure necrosis from long periods of unconsciousness and immobility [*5,6,8,10,11*]. Residual morbidity in survivors is the result of thermal burns and neurological injury from fractures.

There does not appear to be any long-term health problems among the survivors as a result of the gas exposure. The Ministry of Health has targeted women of reproductive age, pregnant women, and newborns for long-term studies. As of the beginning of 1987, continuing health problems among the Nyos disaster survivors were the result not of toxic gas exposure but of living conditions (CARE communication). Present disease patterns in this group reflect those conditions and the disease patterns for the region. Kimbi, the largest of the "temporary" resettlement centers, has over 1000 refugees.

Lake Nyos continues to present a threat [*1*]. Scientists studying the lake in December 1986 were suddenly exposed to another release of gas. According to the *Cameroonian Tribune*, several French scientists and two Cameroonian marines working on the lake heard a rumbling sound followed by the release of gas by the lake. The blue waters turned rusty red from iron oxide, and gas monitors showed a significant increase in carbon dioxide. The geologists studying the lake point to another potential hazard—the spillway draining Lake Nyos. The waterfall is formed by relatively weak pyroclastic ash beds. A failure in these beds would result in a catastrophic flood which would inundate the villages of Nyos and Subum and the adjacent northern settlements.

There are no references in the medical literature relating to specific skin lesions from carbon dioxide exposure [*3-6,8-10*]. It is unlikely that the skin lesions resulted from a blast of

hot gas, based on the absence of hair singeing, flash burns, or damaged clothing. Also, none of the plants examined showed thermal damage. The effects of carbon dioxide are easily appreciated when one is exposed to a quantity of dry ice [*4*]. High levels of the gas often induce olfactory hallucinations, which may explain differences in survivors' statements [*4-6,8-10*]. Lethal concentrations are generally given as approximately 10% [*9*]. An estimated 1.0 km^3 of gas was released by Lake Nyos, based on measurements of gas saturation in studied lake water specimens. It is logical that those closer to the lake were exposed to a much higher concentration of gas than those more distant. This dilution of the gas by ambient air, over distance and time, could well explain the difference in perceptions among the survivors, as well as their distribution.

Finally, there has been considerable interest expressed in the role of forensic pathologists in the examination of living persons [*6*]. Clearly, this is not a new area, since many of us have engaged in such activities as traumatologists in the course of a routine working day. However, the continuing expanding role of the forensic pathologist in public health is seldom appreciated. In this disaster, clinical medicine collaborated and expanded the postmortem studies. Indeed, forensic medicine is an area where many practitioners should be involved and can contribute to the benefit of the public good.

References

[*1*] Kling, G. W. et al., "The 1986 Lake Nyos Gas Disaster in Cameroon, West Africa," *Science*, Vol. 236, 10 April 1987. pp. 169-175.

[*2*] Sigurdsson, H., Devine, J. D., Tchoua, F. M., Presser, T. S., et al., "Origin of the Lethal Gas Burst from Lake Monoun, Cameroon," *Journal of Volcanology and Geothermal Research*, Vol. 31, No. 1, 1987.

[*3*] Zugibe, F. T., Costello, J. T., Breithaupt, M. K., Zappi, E., and Allyn, B., "The Confined Space Hypoxia Syndrome," *Journal of Forensic Sciences*, Vol. 32. No. 2, March 1987, pp. 554-559.

[*4*] White, C. S., Humm, J. H., Armstrong, E. D., and Lundgren, N. P., "Human Tolerance to Acute Exposure to Carbon Dioxide," Report No. 1, *Aviation Medicine*, Vol. 439, Washington, DC, 1952, pp. 439-455.

[*5*] Kaye, S., *Handbook of Emergency Toxicology*, 3rd ed., Charles C Thomas, Springfield, IL, 1973.

[*6*] Thienes, C. H. and Haley, T. J., "Miscellaneous Depressant Vapors," in *Clinical Toxicology*, 5th ed., Chapter 7, Lea and Febiger, Philadelphia, 1972, pp. 57-60.

[*7*] Baselt, R. C., *Disposition of Toxic Drugs and Chemicals in Man*, 2nd ed., Biomedical Publishers, Davis, CA, 1982.

[*8*] Klaassen, C. D., Amdur, M. O., and Doull, J., *Casarett and Doull's Toxicology: Basic Science of Poisons*, 3rd ed., McMillan, New York, 1986.

[*9*] Sharp, G. R., in *Aviation Medicine: Physiology and Human Factors*, G. Dhenin, Ed., TriMed Books, London, 1972, pp. 202-203.

[*10*] Clayton, G. D. and Clayton, F. E., *Patty's Industrial Hygiene and Toxicology*, 3rd ed., Vol. 2A, 2C, Wiley, New York, 1981.

[*11*] Mandy, S. and Ackerman, A. B., "Characteristic Traumatic Skin Lesions on Drug-induced Coma," *Journal of the American Medical Association*, Vol. 213, 1970, pp. 253-256.

[*12*] Halliday, D. A., *Air Monitoring Methods for Industrial Contaminants*, Biomedical Publishers, Davis, CA, 1983.

[*13*] Sick, T. J. and Rieders, F., "Determination of Carboxyhemoglobin in the Presence of Other Blood Hemoglobin Pigments by Visible Spectrophotometry," *Journal of Forensic Sciences*, Vol. 30, No. 1, Jan. 1984, pp. 39-54.

[*14*] Evans, W. E. D., *The Chemistry of Death*, Charles C Thomas, Springfield, IL, 1963.

[*15*] Baselt, R. C., *Biological Monitoring Methods for Industrial Chemicals*, Biomedical Publishers, Davis, CA, 1980.

[*16*] Goldsmith, M. F., "Medical News & Perspectives: U.S. Forensic Pathologists on a New Case: Examination of Living Persons," *Journal of the American Medical Association*, Vol. 256, No. 13, Oct. 1986, pp. 1685-1691.

Address requests for reprints or additional information to
Glenn N. Wagner, Staff Pathologist
Armed Forces Institute of Pathology
Forensic Sciences Department
Washington, DC 20306-6000