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Case Studies

Endotoxin Exposures During Potato Processing

Dawn Tharr, Column Editor

Reported by Lynda M. Ewers and Loren C. Tapp

The National Institute for Occupational Safety and Health (NIOSH) received a confidential employee request for a Health Hazard Evaluation (HHE) at a potato processing facility. The requesters expressed concern regarding possible health effects, especially respiratory problems, which they believed may be associated with exposures to carbon monoxide (CO), chlorine gas (Cl_2), and unknown chemicals.

Two site visits were conducted by NIOSH investigators. A preliminary investigation focused on the potential for Cl_2 and CO exposures, and a limited number of worker interviews were conducted. During the second site visit, researchers collected data to investigate whether workers' health effects were related to bioaerosol exposures, such as bacteria, fungi, or their products. In addition, personal breathing zone (PBZ) concentrations of airborne particulates were estimated, and a health questionnaire was administrated to all available workers on two shifts.

Background

Production of potato products at the facility occurred throughout most of the year. To achieve this year-round schedule, spoilage of the autumn-harvested potatoes was reduced by applying a carbamate herbicide (Clean Crop Sprout Nip 7A, Platte Chemical Co., Fremont, NE) and by storing the potatoes in climate-controlled bunkers. On a typical day, about three million pounds of potatoes were transported from the bunkers to the plant. At the loading dock, located in an isolated building, potatoes were rolled out of inclined semitrailers onto a conveyor for preliminary sorting. They entered the main processing building through a water-transport pipe. After skin removal in the blanching/peeling/scrubbing machines, the potatoes were transported to a trim room for manual "specking," i.e., trimming black spots. Further sorting occurred before the potatoes entered cutting machines of various types, depending on the desired product. Two main lines (Lines 1 and 2) sliced the potatoes into french fries, which were partially fried before freezing and packaging. Packaging occurred within the same building as processing, but in a separate area. About two million pounds of potato products were distributed per day to commercial outlets and grocery stores by an independent company.

Central to the manufacturing process was the water-transport system, which moved potatoes into the building and between some processing steps. About two and one-half million gallons of chlorinated water per day was needed in this system. Water was recycled in some machines, notably the blanching machine, which required heated water (140–160°F). Wastewater generated during the water transport was captured in a gutter system covered by an open metal grid. The grid extended throughout the Line 1 and 2 processing areas, but not the packaging area. The gutter system included pumping stations that forced water to a treatment facility.

Throughout the day, floors and machinery were sprayed with water containing various disinfection products (e.g., Ultra Foam and Ultra Foam B, both chlorinated liquid detergents; Can D Dairy Hi Foam, a phosphoric acid foam wetting agent; Q-K, a quaternary ammonium disinfectant and sanitizer; Kelly Foam, a neutral detergent; and ALAS-478 acid anionic cleaner—all products of Chaska Chemical Company, Inc., Savage, MN). The resulting wastewater was flushed into the gutters. According to management, potato processing was halted at intervals ranging between 10 and 24 hours while the gutters and blanching machines were flushed, a process requiring about one hour. On the first Saturday of each month, or during a holiday period, production was halted for 24 hours while the entire plant was disinfected by washing machinery and floors with the above-mentioned products.

The plant operated 24 hours a day, seven days a week, and employed approximately 850 people; 180–200 employees worked in the Line 1 and 2 processing areas, and about 200 worked in the packaging area. There were four 12-hour shifts; shifts A and C alternated working 6 a.m.–6 p.m., and shifts B and D alternated working 6 p.m.–6 a.m. Each shift worked a total of seven 12-hour shifts over 14 days. The primary manual tasks performed in the processing areas were: (1) specking, performed by "grade one" workers (8–10 per shift); (2) cleaning floors and machinery, performed by "cleanup" employees (12 per shift); and (3) machinery operation, performed by "operators" (at least 2 per shift).

The company has acquired, and operates, several potato processing plants throughout the United States, of which this facility is the largest. Since the facility's acquisition in 1997, a general policy to standardize processes among plants has resulted in phased modifications to the physical plant and its operations. For example, prior to the NIOSH site visits, walls had been removed throughout the factory, machines had been vented to the outside, and plans to remove the gutter system were under discussion.

Methods

Medical

During NIOSH's initial site visit, 12 employees working in the Line 1 or 2 processing areas were systematically chosen from the areas having the greatest number of employees reporting health concerns and symptoms to be interviewed. Nine of the 12 had a history of shortness of breath at work, six had tightness in the chest, four had cough, four had sore throat, four had eye irritation, and one had wheeze. Four had a history of symptom(s) worsening after 4 to 6 hours at work, and improving 2 to 3 hours out of work. Two reported an increase in symptoms when they worked around the gutters. Based on this information, a questionnaire was designed to be administered at the second site visit.

During the second visit, all employees working in the Line 1 and 2 processing areas and the packaging areas were invited to participate in the survey. Employees working in the packaging department were chosen as the comparison group because of their minimal exposure to the processing areas of the plant. The purpose of the questionnaire was to determine the prevalence of symptoms among participating employees and to address the question of whether reported symptoms were related to workplace exposures. The questionnaire focused on the following issues: symptoms and illnesses, and their potential relationships to work exposure; demographic factors (age, gender, etc.); medical and work history; and nonoccupational exposures that could affect the health symptoms being experienced.

During the first site visit, company injury/illness records were reviewed. The Occupational Safety and Health Administration (OSHA) Log and Summary of Occupational Injuries and Illnesses Form 200 (OSHA 200 log) was also examined.

A statistical analysis to assess the relationship between reported symptoms and illnesses and occupational exposure to potato processing was performed. Employees who reported spending at least 50 percent of their total work time in the processing areas were defined as "exposed" workers; those with less than 50 percent of their work time in processing were defined as "unexposed." The magnitude of difference was assessed by the prevalence ratio (PR): a 95 percent confidence interval that excluded the number 1 was considered to indicate a statistically significant finding. The PR represents the prevalence of the symptom in the exposed group relative to the prevalence in the unexposed group. A PR of 1 suggests that no association between the symptom/illness and exposure has been found. A PR greater than 1 means that an association has been found; for example, a PR of 2 would indicate that a person in the exposed group is two times more likely to have reported the symptom than a person in the unexposed group. We considered the following list of nonoccupational factors to see if they had an effect on the prevalence ratios: age, cigarette smoking, farming, and exposure to birds, welding, glues, woodworking, and isocyanates.

Industrial Hygiene

Area air samples were collected for screening purposes using a bellows pump and associated colorimetric detector tubes (Dräger®, Inc., Pittsburgh, PA) for Cl_2 and CO. Specific processes and areas of the plant identified by the requesters as possible sources of these gases were sampled. Detector tubes have an accuracy of ± 25–30 percent and a measuring range of 0.3–5 parts per million (ppm) for Cl_2, and 5–150 ppm for CO.

Twenty-three full-shift personal breathing zone (PBZ) samples and eight area air samples were collected for analysis of total airborne particulates and endotoxin, which is a component in the cell walls of Gram-negative bacteria (GNB). All workers on the day and night shifts (B and D crews) were eligible to volunteer and participate in the study. Endotoxin samples collected from the processing side of the plant were considered to be from the "exposed" side, and background samples were collected from the packaging side. Area samples were distributed throughout the packaging and processing work zones. The samples were collected on tared 5.0 μm pore size, 37-millimeter (mm) polyvinyl chloride filters using a calibrated flowrate of two liters per minute (Lpm). Samples were weighed using NIOSH method 0500,[(1)] which has a limit of detection of 0.02 milligrams (mg). The filters were subsequently analyzed for endotoxin content using the Kinetic-QCL Limulus Amebocyte Lysate (LAL) assay kit (BioWhittaker, Walkerville, MD), according to the manufacturer's recommended procedures. For these analyses, 10 endotoxin units (EU) are equivalent to 1 nanogram of endotoxin. The limit of detection (LOD) for the endotoxin analyses was 0.5 EU per sample, which results in a minimum detectable concentration (MDC) of 1.06 endotoxin units per cubic meter (EU/m^3), based on a sample volume of 0.471 m^3, the minimum volume of the PBZ air samples. Results of endotoxin air monitoring and PBZ particulate levels were compared to relevant evaluation criteria, if available, and between the processing and packaging areas of the plant. Statistical analysis was performed using SAS® software.[(2)]

In addition to air sampling for endotoxins, bulk wastewater samples from the gutters running throughout the plant were analyzed for endotoxin and cultured for aerobic bacteria and fungi. All bulk samples were chilled and sent to the laboratory within 24 hours of collection. Fungi were grown on malt extract agar (MEA), and bacteria were grown on R2A agar. The MEA and R2A plates were incubated at room temperature (23°C ± 3°C) for 7 days, and 4 to 7 days, respectively. The number and characteristics of all fungi and the three most predominant bacteria were recorded. Fungi were identified to the genus level by direct microscopic observation. Bacteria were identified to the genus level by standard Gram-staining techniques and biochemical tests (i.e., catalase, oxidase, oxidation, and fermentation of glucose). Specific human pathogenic bacteria that require a selective medium and elevated incubation temperatures, such as *Legionella*, are not detectable using these tests.

Evaluation Criteria

Microorganisms

Acceptable levels of airborne microorganisms have not been established, primarily because allergic reactions can occur even with relatively low air concentrations of allergens, and because individuals differ with respect to immunogenic susceptibilities. The current strategy for on-site evaluation of environmental microbial contamination involves an inspection to qualitatively identify sources (reservoirs) of microbial growth and potential routes of dissemination. Air samples for microorganisms, endotoxins, or other microbial components can be collected to document the presence of suspected microbial contaminants.

Endotoxins, lipopolysaccharide compounds from the outer cell wall of GNB, are released from the bacteria when they die.[3,4] GNB are ubiquitous in the environment. In experimental studies, human volunteers exposed to high levels of endotoxins via inhalation experience airway and alveolar inflammation, as well as chest tightness, fever, and malaise, and have an acute reduction in lung function as measured by the forced expiratory volume in one second (FEV_1).[5,6] Airborne endotoxin exposures between 45 and 400 EU/m^3 have been associated with acute air flow obstruction, mucous membrane irritation, chest tightness, cough, shortness of breath, fever, and wheezing.[7–9] Chronic health effects that have been associated with airborne endotoxin exposures include chronic bronchitis, bronchial hyperreactivity, chronic obstruction of airways, hypersensitivity pneumonitis, and emphysema. A permanent decrease in pulmonary function, along with respiratory symptoms, has been reported in several cross-sectional epidemiological studies.

While a causal role for endotoxins in human health effects has become more generally accepted in recent years, a dose-response relationship has not been established. One reason for this is that the most commonly used method for analyzing endotoxins, the LAL assay, is a comparative bioassay. In other words, changes in the LAL test procedures themselves can erroneously appear as changes in the measured endotoxin activity levels. Until problems with the LAL test are resolved, it is not possible to compare endotoxin samples collected at different times or analyzed by different laboratories. For these reasons, the American Conference of Governmental Industrial Hygienists (ACGIH®) has proposed that Relative Limit Values (RLV®s), rather than the more usual Threshold Limit Values (TLV®s), be used as a reference for endotoxin.

RLVs require that samples be collected from an area considered to represent background levels of endotoxin, and that they be analyzed at the same time as the samples of interest. The RLV is expressed in terms of a comparison between the exposed and background areas. ACGIH proposes that, if there are health effects consistent with endotoxin exposure, and if the endotoxin exposures exceed 10 times the simultaneously determined background levels, then the RLV action level has been exceeded. When exposures exceed the RLV action level, remedial actions to control endotoxin levels are recommended. It is important to note that the nature of the relationship between the RLV and health effects has not been elucidated at the time of writing this report. Consequently, our recommendations are based only on whether the RLV action level has been exceeded, not on the magnitude of the endotoxin level.

Results

Medical

The 163 OSHA 200 log entries for 1996 through July 1999 included musculoskeletal injuries, eye injuries, burn injuries, and one case of heat exhaustion. No cases of respiratory illness were recorded. Review of company injury records revealed five reports of chest pain, six of dizziness or lightheadedness, and three of respiratory symptoms, including one asthma exacerbation.

The facility's health unit was staffed by an occupational health nurse from Monday through Friday during the first shift. All employees undergo a baseline health assessment that includes a medical history and an audiogram, followed by yearly audiograms. Those employees who are part of the Hazmat Team (e.g., first responder, boiler and refrigeration workers, and team leaders) also have an annual medical assessment, which includes a respiratory fit test, an OSHA respiratory questionnaire, pulmonary function testing, an electrocardiogram, a chest x-ray, blood tests, vision testing, and a physical exam, performed by a contracted off-site medical clinic.

Of the 188 employees working in the processing and packaging areas during the site visit, 115 (61%) completed a questionnaire. Of the 115 participants, 113 could be categorized as "exposed" or "unexposed," based on questionnaire responses. ("Exposed" is defined as working at least 50% of the time in processing areas; "unexposed" is defined as working less than 50% of the time in processing areas.) Fifty-six (50%) of the 113 were considered "exposed," and included 46 processing, four lab quality assurance (QA), three packaging, one salaried, and two "other" employees. Fifty-seven (50%) of the 113 employees were considered "unexposed," and included 49 packaging, four processing, one lab QA, and three "other" personnel. The participating employees represented workers from two of the four rotating shifts. The numbers and percentages of self-reported symptoms and illnesses are given in Table I. The most commonly reported symptoms among all participants included sinus problems (56%); persistent cough (50%); irritation of eyes, nose, or throat (44%); and unusual tiredness or fatigue (42%). A symptom was defined as being work-related if the respondent answered "yes" to the following question: "Do you think it [the symptom] is related to work?" The percentages of work-related

TABLE I
Self-reported symptoms and illnesses reported on questionnaire

Symptom/illness	Number (% of 113 participants) who reported symptom/illness	Number (% of participants with symptom) who reported symptom as work-related[1]
Sinus problems	64 (55.7%)	25/61 (41%)
Persistent cough	58 (50.4%)	20/57 (35.1%)
Irritation of eyes, nose, or throat	50 (43.5%)	39/48 (81.3%)
Unusual tiredness or fatigue	47 (42%)	32/47 (68.1%)
Ache all over	44 (38.6%)	27/41 (65.9%)
Chest flu or pneumonia	42 (36.5%)	NA[2]
Unusual shortness of breath	34 (30.1%)	23/33 (69.7%)
Tightness in chest	30 (26.1%)	19/29 (65.5%)
Wheezing or whistling in chest	28 (24.3%)	14/26 (53.8%)
Cough with phlegm	18 (15.7%)	NA
Fever, sweats, chills	17 (15%)	7/16 (37.5%)
Rash or skin irritation	12 (10.5%)	6/10 (60%)
Asthma diagnosed by physician	10 (8.7%)	NA
Symptoms consistent with chronic bronchitis[3]	7 (6.2%)	NA
Asthma now	6 (5.2%)	NA

[1]Answering "yes" to the following question: "Do you think it (the symptom) is related to work?"
[2]Not applicable.
[3]Symptoms consistent with chronic bronchitis were defined as a productive cough occurring more than three months out of the year, for more than two consecutive years.

symptoms were greatest for irritation of eyes, nose, or throat (81%); unusual shortness of breath (70%); unusual tiredness or fatigue (68%); ache all over (66%); and tightness in chest (66%).

The prevalence of reported symptoms by exposure category are given in Table II. Among the statistically significant findings, chest tightness was 2.8 times more prevalent in the exposed group than in the unexposed. Exposed employees also had 2.5 times the prevalence of shortness of breath; twice the prevalence of pneumonia or chest flu episodes; 1.7 times the prevalence of eye, nose, or throat irritation; and 1.5 times the prevalence of persistent cough. Although not shown in Table II, the prevalence of work-related shortness of breath (36%) and work-related chest tightness (34%) in the exposed workers was more than double that in the unexposed workers (18% and 11%, respectively); for work-related shortness of breath, PR = 2.2 (95% CI = 1.00–4.78), and for chest tightness, PR = 2.6 (95% CI = 1.10–6.17). No meaningful effect was found after considering nonoccupational factors; therefore, it was considered unnecessary to adjust the prevalence ratios for these factors.

Among the different job titles, grade I spec employees (also known as "trimmers"), operators, and cleanup employees had the highest prevalences of most symptoms, particularly respiratory symptoms, as shown in Table III. These jobs are located in the processing areas. The highest prevalence of respiratory symptoms reported to be work-related were among cleanup and grade I spec employees. The prevalence of symptoms by area are shown in Table IV. Employees working in the Line 2 processing area had the highest prevalence of most symptoms.

Industrial Hygiene

Chlorine was not detected in the screening samples collected at any location; the LOD was 0.3 ppm. Sampling for CO was generally negative; a slight atypical color on one sample may have been due to interfering compounds in that location. If the color was due to the presence of CO, the concentration indicated was less than 5 ppm, well below the occupational exposure limit.

Table V lists the taxa of bacteria cultured from the wastewater moving through the gutter system, including samples from the pump pit, distribution area, blancher, two peelers, sp3 area, and the main sump leading to the wastewater treatment facility. Many of the taxa are commonly found in soil or vegetable matter, which is prevalent at a potato processing plant. Counts of the colony-forming units of bacteria and fungi ranged from 8.1×10^6 to greater than 3.0×10^7, and from less than 10 to 3.2×10^4, respectively.

Table VI displays the PBZ-TWA concentrations of total particulates and endotoxin, and Table VII displays these results for the area samples. Total particulate concentrations were low. A t test of the log-transformed PBZ-TWA particulate concentrations indicated that PBZ-TWA concentrations from processing area employees were significantly higher than those for employees in the packaging area, with geometric means (GMs) of 0.221 mg/m^3 (geometric standard deviation [GSD] = 1.66), and 0.096 mg/m^3 (GSD = 1.88), respectively. PBZ endotoxin concentrations for processing workers averaged 168 EU/m^3, while concentrations for packaging employees were all less than 1.06 EU/m^3, the lower limit of detection for the endotoxin method. In other words, the ratio of endotoxin concentrations in the processing area to those in the packaging area greatly exceeded the RLV action level of 10 times background proposed by the ACGIH.

Discussion

During the initial site visit, the primary consideration was the potential for health effects due to chemical exposure, especially to Cl_2 and CO. However, no detectable exposures to those

TABLE II
Reported symptoms/illnesses among "exposed" and "unexposed" employees[1]

Symptom/illness	Number of exposed (% of 56) reporting symptom/illness	Number of unexposed (% of 57) reporting symptom/illness	Prevalence ratio[2] [95% confidence interval]
Persistent cough	34 (60.7%)	23 (40.4%)	1.5 [1.03–2.20]
Irritation of eyes, nose, or throat	31 (55.1%)	19 (33.3%)	1.7 [1.07–2.57]
Pneumonia or chest flu	27 (48.2%)	14 (24.6%)	2.0 [1.16–3.33]
Unusual shortness of breath	24 (42.9%)	10 (17.5%)	2.4 [1.29–4.63]
Tightness in chest	22 (39.3%)	8 (14.0%)	2.8 [1.36–5.75]
Sinus problems	36 (64.3%)	27 (47.4%)	1.4 [0.97–1.90]
Unusual tiredness or fatigue	25 (46.3%)	22 (39.3%)	1.2 [0.76–1.82]
Ache all over	24 (43.6%)	20 (35.1%)	1.2 [0.78–1.98]
Wheezing or whistling in chest	15 (26.8%)	13 (22.8%)	1.2 [0.62–2.24]
Cough with phlegm	12 (21.4%)	5 (8.8%)	2.4 [0.92–6.48]
Fever, sweats, chills	10 (18.5%)	6 (10.7%)	1.7 [0.68–4.43]
Rash or skin irritation	5 (9.1%)	7 (12.3%)	0.7 [0.25–2.19]
Asthma diagnosed by physician	5 (8.9%)	5 (8.8%)	1.0 [0.31–3.32]
Asthma now	4 (7.1%)	2 (3.5%)	2.0 [0.39–10.67]
Symptoms consistent with chronic bronchitis[3]	3 (5.5%)	3 (5.4%)	1.0 [0.22–4.83]

[1]"Exposed" defined as working at least 50 percent of the time in processing areas; "unexposed" defined as working less than 50 percent of the time in processing areas.
[2]Exposed group compared with the unexposed group.
[3]Symptoms consistent with chronic bronchitis were defined as a productive cough occurring more than three months of the year, for more than two consecutive years.

TABLE III
Reported symptoms/illnesses by job

Symptom	Operator (L) (20)[1]	Cleanup (L) (13)	Grade I spec (17)	Packaging (53)	Lab QA (6)
Cough	14 (70%)	8 (62%)	10 (59%)	19 (36%)	4 (67%)
Wheeze	2 (10%)	3 (23%)	7 (41%)	14 (26%)	2 (33%)
Chest tightness	5 (25%)	5 (38%)	9 (53%)	10 (19%)	1 (17%)
Shortness of breath	7 (35%)	5 (38%)	11 (65%)	10 (19%)	1 (17%)
Irritation of eyes, nose, or throat	6 (30%)	9 (69%)	13 (76%)	18 (34%)	3 (50%)
Sinus symptoms	8 (40%)	9 (69%)	12 (71%)	27 (51%)	4 (67%)
Pneumonia/flu	9 (45%)	4 (31%)	10 (59%)	14 (26%)	4 (67%)
Fever/chills	3 (15%)	1 (8%)	4 (25%)	8 (15%)	1 (17%)
Ache	5 (25%)	7 (54%)	9 (56%)	19 (36%)	2 (33%)
Tired/fatigued	5 (25%)	6 (50%)	12 (71%)	22 (42%)	1 (17%)
Rash	1 (5%)	0	4 (24%)	6 (11%)	0
Phlegm	2 (10%)	1 (8%)	6 (35%)	7 (13%)	1 (17%)
Chronic bronchitis	0	0	1 (6%)	5 (9%)	0
Diagnosed asthma	3 (15%)	0	0	6 (11%)	1 (17%)
Asthma now	3 (15%)	0	0	2 (4%)	1 (17%)
One or more respiratory symptoms	17 (85%)	10 (77%)	15 (88%)	25 (47%)	4 (67%)
One or more work-related respiratory symptoms	9 (45%)	8 (62%)	13 (76%)	21 (40%)	4 (67%)

[1]Number of respondents.

TABLE IV
Reported symptoms/illnesses by area

Symptom	Line 1 (11)[1]	Line 2 (21)	Line 1 and 2 (25)	Packaging (51)
Cough	5 (45%)	17 (81%)	11 (44%)	19 (37%)
Wheeze	1 (9%)	8 (38%)	5 (20%)	14 (27%)
Chest tightness	2 (18%)	11 (52%)	7 (28%)	9 (18%)
Shortness of breath	4 (36%)	12 (57%)	8 (32%)	9 (18%)
Irritation of eyes, nose, or throat	5 (45%)	14 (67%)	11 (44%)	16 (31%)
Sinus symptoms	5 (45%)	16 (76%)	14 (56%)	25 (49%)
Pneumonia/flu	4 (36%)	10 (48%)	12 (48%)	13 (26%)
Ache	4 (36%)	10 (50%)	9 (36%)	18 (35%)
Fever/chills	2 (18%)	5 (26%)	2 (8%)	7 (14%)
Tired/fatigued	2 (20%)	13 (65%)	10 (40%)	20 (40%)
Rash	1 (9%)	1 (5%)	3 (12%)	5 (10%)
Phlegm	0	6 (29%)	4 (16%)	6 (12%)
Chronic bronchitis	0	1 (5%)	1 (4%)	4 (8%)
Diagnosed asthma	0	4 (19%)	0	5 (10%)
Asthma now	0	4 (19%)	0	2 (4%)
One or more respiratory symptoms	7 (64%)	19 (90%)	17 (68%)	24 (47%)
One or more work-related respiratory symptoms	6 (55%)	14 (67%)	13 (52%)	20 (39%)

[1]Number of respondents.

substances were identified, even during specific tasks that employees identified as causing symptoms. The possibility of occupational exposure to bioaerosols as a cause of work-related symptoms was then considered. It is difficult to rigorously establish causality in any industry such as potato processing, where there is a complex mixture of exposures to chemicals and biological agents. Nevertheless, in this case, several lines of evidence led to the conclusion that the health symptoms experienced by many of the workers were caused by bioaerosol exposures, especially to endotoxins, resulting from the growth of microorganisms within the gutter system.

TABLE V
Bacteria identified in gutter water

Taxa	Gram-stain	Possible origin[1]
Aeromonas-like	Negative	Fresh water and sewage
Acinetobacter	Negative	Naturally occurring in soils
Corynebacterium-like	Positive	Mucous membranes and skin of mammals and other species; occasionally other sources
Curtobacterium-like	Positive	Plants, soil, oil brine
Enterobacteriaceae	Negative	Widely distributed in nature
Klebsiella-like	Negative	Common in soils, foodstuffs, seeds, plant roots, etc.
Pseudomonas fluorescens group	Negative	Common in water or soil
Streptococcus, not *pyogenes*	Positive	Vertebrates, especially mouth and upper respiratory tract
Unidentified rod	Negative	No information
Unidentified rod	Positive	No information

[1]From: Holt, J.G.; Krieg, N.R.; Sneath, P.H.A.; et al.: Bergey's Manual® of Determinative Bacteriology, 9th ed., Williams and Wilkins Co., Baltimore, MD (1994).

First, conditions observed within the plant, particularly the gutter system, appeared to be ideal for the growth of microbes and their subsequent aerosolization. Transport water was chlorinated; however, the soil, starches, proteins, etc., released from the potatoes during processing produced a very high organic load, which would reduce the effectiveness of chlorination in inhibiting microbial growth. Hot water was recirculated within some of the machines, possibly concentrating potato nutrients prior to the water's release to the gutters. Heated water was added to the wastewater stream, increasing its temperature. In the pumping pits, the wastewater was highly agitated, producing aerosols. Throughout most of their lengths, the gutters and pumping pits were covered with an open metal grid, readily allowing the escape of the aerosols into the work areas.

Second, reported health effects were more common among employees in the processing area, which contains the gutter system. Personal and area air sampling data revealed significantly higher endotoxin levels in the processing areas of the plant compared to the packaging area. Although seasonal health effects data were not collected, higher microbial activity levels during the late spring and summer, when temperatures are higher, and when the last of that year's potato crop is being processed, could possibly aggravate symptoms in some affected process workers. During the summer (the time the NIOSH bioaerosol sampling occurred), more decomposing potatoes are brought in from the storage bins, and higher levels of bacteria may exist in the potato transport water.

Third, prevalences of respiratory symptoms (up to 60%) reported by the potato processing employees at the facility are too high to be fully

TABLE VI
Personal breathing zone concentrations of total particulates and endotoxin

Area	Job title	Sampling time (minutes)	Particulate concentration in air (mg/m^3)	Endotoxin concentration in air[1] (EU/m^3)
Packaging	Floater	286	0.070	ND[2]
	Forklift operator	263	0.194	ND[2]
	Forklift operator	252	0.121	ND[2]
	Line operator	295	0.068	ND[2]
	Line operator	275	0.073	ND[2]
	Line operator	266	0.038	ND[2]
	Line operator	267	0.094	ND[2]
	Packer (hashbrowns)	336	0.075	ND[2]
	Packer (hashbrowns)	304	0.316	ND[2]
Processing	Blancher (L2)	330	0.159	83.9
	General cleaner	326	0.204	287
	General cleaner	360	0.304	111
	Cleaner (L1)	353	0.527	184
	Cutter operator (L1)	259	0.098	55.9
	Cutter operator (L2)	347	0.200	73.3
	Operator (peeler)	264	0.425	161
	Specialist (L1)	398	0.380	822
	Trimmer (trim room)	267	0.115	103
	Trimmer (trim room)	242	0.149	187
	Trimmer (trim room)	384	0.157	54.5
	Trimmer (trim room)	368	0.205	82.4
	Trimmer (L1)	381	0.198	51.8
	Fry operator (L1)	390	0.371	87.7

[1]The limit of detection (LOD) for the endotoxin analyses was 0.5 endotoxin units (EU) per sample, which results in a minimum detectable concentration (MDC) of 1.06 endotoxin units per cubic meter (EU/m^3), using a sample volume of 0.471 cubic meters, the minimum volume of the personal breathing zone (PBZ) air samples.
[2]Nondetectable.

TABLE VII
Area concentrations of dust and endotoxin

Area	Location	Sampling time (minutes)	Dust concentration (mg/m^3)	Endotoxin concentration[1] (EU/m^3)
Packaging	Entrance	453	0.056	ND[2]
	Rear of plant	448	0.045	ND[2]
	Near french fry conveyers	438	0.040	ND[2]
Processing	French fry area	442	0.197	ND[2]
	L1—near sorting machine	511	0.222	130
	Blancher	504	0.141	180
	L2	506	0.345	205
	Trim room	498	0.104	121

[1]See Table VI.
[2]Nondetectable.

explained by an allergic mechanism. Approximately one out of every six individuals in the U.S. is reported to have allergies,(10) with about 30 percent of the population having atopy, or the predisposition to becoming allergic.(11) It is well-known that individuals exposed to airborne organic dust containing fungal, bacterial, plant, or animal antigens can develop hypersensitivity illnesses, including hypersensitivity pneumonitis (HP), allergic rhinitis, and allergic asthma to airborne organic materials.(12–15) The high prevalence rate of some symptoms among the workers, however, implies something more than an allergic etiology and could be explained by the wide range of biological endotoxin activity, including inflammatory, hemodynamic, and immunological responses.

Finally, studies of other potato processing plants support the hypothesis that bioaerosols, particularly endotoxins, are a cause of health effects at the facility. These studies found that 16–46 percent of process workers reported work-related respiratory symptoms, particularly shortness of breath and chest tightness.(16–18) More recent studies of workers exposed to various types of organic dust have focused on the possibility of endotoxin exposures as causal agents for health effects. For instance, a U.S. study on cotton textile workers clearly established that endotoxin, but not dust, exposure levels were related to worker respiratory symptoms. A study of the potato processing industry in the Netherlands found that workers exposed to high endotoxin levels had lower measured lung function at baseline, and underwent a greater loss in average FEV_1 over a work shift, than the low endotoxin exposure group. Also, those workers with work-related respiratory symptoms had a threefold larger cross-shift decrease in lung function (forced vital capacity [FVC] and FEV_1) than asymptomatic workers.(19) Several researchers have attempted to distinguish the health effects of dust exposure, endotoxin exposure, and potato antigen exposure in dust. While process workers in one study were found to have specific antibodies for potato antigens, prevalence of these antibodies was not correlated with reported respiratory symptoms, i.e., antibodies were formed but were not associated with reported symptoms. A study conducted in a potato processing plant in Poland found that airborne endotoxin levels peaked dramatically after a blanching process, and the authors postulated that the process of steaming potatoes may enhance the biological activity of endotoxin by changing its physical structure. Almost 50 percent of the Polish workers in this study reported work-related respiratory symptoms, and employee FVC and FEV_1 decreased significantly over the work shift. Another study found that bacterial and endotoxin levels are higher in warmer and more humid environments, and exposure appeared to be strongly related to process water temperatures.[20]

Although results indicate that the high endotoxin levels in the processing areas of the facility were associated with the increased prevalence of work-related respiratory symptoms, certain study limitations must be noted. These limitations include sampling only two of the four shifts working at the facility, the potential for miscategorizing exposure groups, and sampling exposures over a very short time span, which may not give an accurate picture of the average work exposures. In addition, "transfer bias" may be occurring. A transfer bias occurs when those workers who enter a job and develop health problems remove themselves from the job they feel is causing their problems; those workers who remain tend to have fewer health effects and symptoms. When studying worker populations, the influence of the transfer bias may weaken the associations found between exposure and symptoms, and could lead to an underestimation of exposure-effect relationships. A recent study found a transfer bias when evaluating potato processing workers five years after an initial survey; workers who had been employed more than five years had fewer respiratory symptoms, higher lung function, and less atopy than those employed less than five years.[21]

Conclusions

Although it is not possible to establish a definitive causal link between the reported health effects and endotoxin exposures, this link is plausible, based on NIOSH findings at the plant, and on the scientific literature. Potato processing employees reported significantly more respiratory symptoms than packaging employees. Average endotoxin concentrations in the processing area were significantly higher than those in the packaging area and greatly exceeded the ACGIH-proposed RLV action level of 10 times background. Clearly, steps to reduce the endotoxin levels in the processing area of this plant are warranted and can likely be achieved through modifications to the gutter system.

Recommendations

1. National Institute for Occupational Safety and Health engineering modifications to the present gutter system should be implemented to reduce the time that wastewater remains within the gutters and to reduce escape of aerosolized water or steam into the work environment. An experienced engineering firm should be consulted to determine the best way to accomplish this.
2. Local exhaust ventilation or covering of the gutter and water-transport systems should be considered in those areas where worker exposure to the transport water or wastewater is possible, e.g., in the trim rooms, the area near the blanching machines, and the pumping pits of the gutter system.
3. Cleaning and maintenance procedures should be improved for the gutter system by establishing regular, frequent, and thorough flushing.
4. Care should be taken that, in the process of reducing exposure to water, excess potato dust is not generated. Potato dust might provoke other health problems, such as allergic reactions to potato antigens, unacceptable levels of nuisance dust, or even exposure to endotoxins that are present on the surface of the potatoes before they enter the plant.
5. Recycled water should be considered highly contaminated with endotoxins, and worker exposures to the water should be minimized.
6. Employees should report health effects thought to be caused by work exposures to the plant's medical facility. Those employees found to have potential work-related health effects should be referred to a physician who is knowledgeable in occupational medicine.
7. As part of its safety and health program, the company should monitor health problems in a systematic manner designed to identify particular job duties, work materials, machines, or areas of the plant that may be associated with particular health effects. A periodic health assessment, including respiratory symptom history, should be offered to employees working in production areas of the plant. Those with new-onset and/or work-related respiratory symptoms should be evaluated by a physician who is knowledgeable in occupational medicine. Individuals with occupational illnesses should be protected from exposures to agents presumed to cause or exacerbate those illnesses, primarily by using engineering (e.g., isolation, ventilation) and/or administrative (e.g., work and hygienic practices, housekeeping) controls, if feasible, and through the use of personal protective equipment (PPE), secondarily. In some cases, workers may have to be reassigned to areas where exposure is minimized or nonexistent. In such cases, the reassigned worker should retain wages, seniority, and other benefits that

might otherwise be lost by such a job transfer.

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