Case Study

U.S. Chemical Safety and Hazard Investigation Board

Explosion at Biochemical Facility: Liquid Nitric Oxide Release

No. 2003-15-C-OH
August 2004

ISOTEC
a wholly owned subsidiary of Sigma–Aldrich Corporation
Miami Township, Ohio
September 21, 2003

KEY ISSUES:

- Process Hazards Analysis
- Incident Investigation
- Land Use Management
- Emergency Response

Introduction

This Case Study describes an explosion in a cryogenic nitric oxide (NO) distillation process at the Isotec facility in Miami Township, Ohio. Remarkably, only one employee was injured. More than 2,000 local residents were evacuated for 24 hours.

INSIDE . . .

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U.S. Chemical Safety and Hazard Investigation Board
Office of Investigations
2175 K Street NW
Suite 400
Washington, DC 20037-1848
202-261-7600
www.csb.gov

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1.0 Incident Description

On Sunday, September 21, 2003, at about 7:30 am, the Isotec on-call system operator received an automatic pager alert indicating an alarm condition in a cryogenic nitric oxide (NO) distillation unit.[1] Arriving at the facility at about 7:50 am, he observed reddish-brown gas venting from the distillation unit vacuum pump exhaust—which indicated a breach in the column piping within the vacuum jacket.

Nitric oxide—a toxic gas—was venting to the atmosphere and reacting with air to form nitrogen dioxide (NO_2), also a toxic gas.

The responding employee immediately notified his supervisor, who called the 911 dispatcher. Isotec management and Sigma–Aldrich, the parent company of Isotec, were then notified.

The reddish-brown gas cloud was observed drifting southwest from the site and slowly dissipating. By 8:15 am, employees secured the leak by closing the vacuum pump suction valve. Shortly thereafter, the vapor cloud was no longer visible.

The operations manager and the other five Isotec employees believed they could safely remove the nitric oxide from the N3 distillation column and vacuum jacket, and proceeded with the necessary preparations.[2] Their position was based on successful application of the same strategy to a column malfunction on September 18, 1998. Distillation column N4 (same design as N3) had developed an NO leak into the vacuum jacket and vented nitric oxide from the vacuum exhaust.[3] While closely monitoring pressure and temperature, operators successfully emptied the nitric oxide from the column and vacuum jacket.

Once the September 21 leak was secured, personnel began installing temporary tubing to empty the nitric oxide in the malfunctioning column. Concurrently, they closely monitored the pressure inside the column, which was behaving as in 1998 when column N4 leaked nitric oxide.

The pressure stabilized at no more than 130 pounds per square inch (psi)—well below the vacuum jacket calculated burst pressure of 1,645 psi. Isotec personnel noted that the

[1] Cryogenic fluid is a liquid with a boiling temperature below -150 degrees Fahrenheit (°F [-101 degrees Celsius (°C)]) at atmospheric pressure.

[2] For simplicity, the distillation columns referred to in this Case Study are N1, N2, N3, N4, N5, and N6 (i.e., the Main Column, CONO, TNO, NO4, NO5, and NO6, respectively).

[3] Although damaged column N4 was inspected, Isotec never located the source of the leak or determined the cause of failure.

condenser was "vigorously venting nitrogen vapor," which indicated increased heat load in the column.

At 10:15 am—with no warning—a violent explosion destroyed the distillation column, the blast containment structure, and nearby buildings (Figure 1). Windows were blown out of the main office building, about 140 feet from the explosion; and glass shards lacerated the hand of an Isotec employee. No other injuries were reported.

Small chunks of concrete and metal shards were propelled as far as 1,000 feet and fell on adjacent property. Three houses north of the facility were struck by debris, causing minor damage to two roofs and a picture window.

A large steel panel from the blast containment structure struck and dislodged a 52,000-pound gaseous carbon monoxide (CO) storage vessel, pushing it about 10 feet off its foundation (Figure 2). A second steel panel severely damaged adjacent equipment (Figure 3). A ruptured fill line vented CO gas, which then ignited and burned for about 1 hour, until the vessel was empty (Figure 4).

As a precaution, the fire department requested that the police evacuate a 1-mile radius to protect the community from metal shards or other debris in the event that the CO vessel exploded. The evacuation order was lifted after 24 hours.

Figure 1

20-foot-diameter, 8-foot-deep crater and structural damage caused by NO process unit explosion

Figure 2

52,000-pound, 42-foot-tall CO vessel pushed 10 feet off foundation (right arrow) by blast panel (left arrow)

. . . The fire department requested that the police evacuate a 1-mile radius to protect the community from metal shards or other debris in the event that the CO vessel exploded.

Figure 3

Blast containment structure damaged by steel blast panel

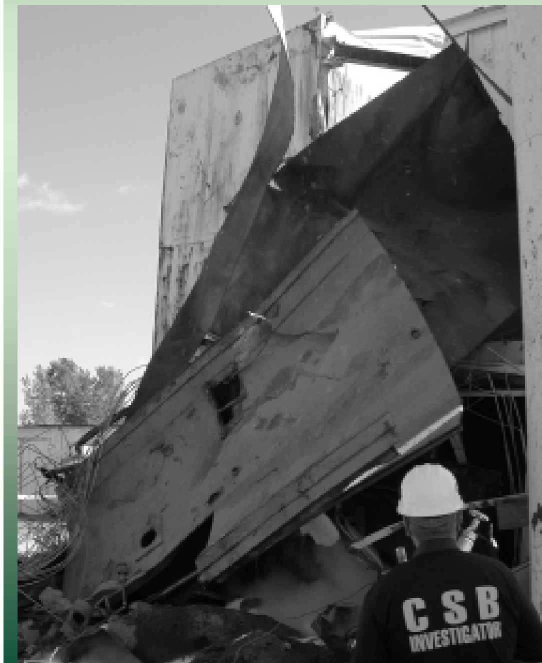

Figure 4

CO gas venting from ruptured fill line (arrow) on displaced vessel

2.0 Nitric Oxide Hazards

At ambient conditions, nitric oxide is a colorless, odorless gas. The vapor is highly toxic and is an irritant to the pulmonary tract. Nitric oxide quickly reacts with air in the atmosphere to produce more stable nitrogen oxides, including NO_2, which presents similar health hazards. The presence of a reddish-brown gas with strong odor (i.e., NO_2) is a clear indication of NO release.

Liquid nitric oxide is a cryogenic fluid. Hazards associated with handling cryogenic fluids include freezing and frostbite on exposed human tissue. Special handling is required to prevent injury.

In liquid and solid form, nitric oxide is an unpredictable, highly shock-sensitive explosive. System design and operating procedures to minimize the possibility of liquid NO detonation are not well understood.[4]

[4] In the mid 1960s, National Aeronautics and Space Administration (NASA) studies determined that liquid nitric oxide may generate damaging explosions. The U.S. Department of Energy (DOE) Los Alamos National Laboratory (LANL)—developers of the NO distillation technology in use at Isotec—operated a system from 1963 until the late 1970s. In 1975, a small explosion was attributed to the detonation of liquid/solid nitric oxide in a small system device. As part of the LANL investigation, the U.S. Bureau of Mines determined that "liquid NO is comparable to nitroglycerin in sensitivity to weak shock waves" (Ribovich, Murphy, and Watson, 1975; pp. 275–287).

Isotec management personnel recognized the toxic hazards of gaseous nitric oxide and the human tissue freezing hazards associated with handling cryogenic liquids. They were also aware that solid and liquid nitric oxide are considered high explosives, but concluded that the probability of explosion in their application was low.

Discussions with Isotec management and review of documents confirmed that the Los Alamos National Laboratory (LANL) provided operating history and explosion hazard studies to Isotec when it acquired the distillation technology in the mid 1970s. In 1982, Isotec experienced one explosion involving liquid nitric oxide, which was attributed to impurities or system plugging. It was thought that this incident was similar to a 1975 LANL explosion.

In 1995, Isotec experienced a second incident in another distillation column. Although the Isotec investigation team concluded that a detonation had occurred in the distillation column assembly, they were unable to recover the damaged section to identify the cause or exact location of the failure (Section 5.1).

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3.0 Isotec Operations

The distillation units separate the stable NO isotopes . . . from high-purity liquid nitric oxide in specially designed columns.

Sigma–Aldrich Corporation, doing business as Isotec, is a multinational life science and high technology company headquartered in St. Louis, Missouri. Sigma–Aldrich purchased the Isotec facility (Figure 5) in 2001 from Matheson Gas Products.

Isotec has manufactured chemical products for the diagnosis of disease and for scientific and genetic research since 1979. It was the first company to apply cryogenic distillation technology[5] to the commercial production of stable isotopes[6]—carbon-13 (^{13}C), nitrogen-15 (^{15}N), and oxygen-18 (^{18}O).

The Isotec facility is located 12 miles south of Dayton and 0.5 mile west of Interstate 75, on an 11-acre parcel in Miami Township, Ohio. Over the past two decades, the adjacent land use has changed from rural farmland to established residential development; more than 500 homes are located in the surrounding area.

Isotec employs about 75 full-time personnel working on an 8-hour, 5-day schedule. Ten employees are involved in distillation unit operations.

The distillation units separate the stable NO isotopes (containing ^{15}N and ^{14}N) from high-purity liquid nitric oxide in specially designed columns. Two NO distillation units—N3 and N6—were operating at the time of the explosion. Two other NO distillation units were installed but not operational.

[5] LANL developed isotope separation using NO distillation technology. Isotec acquired the technology for commercial use.

[6] An isotope is one of two or more atoms of the same atomic number but with different numbers of neutrons, thus with a different mass number. A radioactive isotope is an atom containing an unstable nucleus that decays—emitting alpha, beta, or gamma rays—until stability is reached. The stable end product is a nonradioactive isotope of another element.

Figure 5

Isotec facility (residential areas north, across Benner Road [top left], and adjacent to south property line)

. . . The adjacent land use has changed from rural farmland to established residential development; more than 500 homes are located in the surrounding area.

Nitric oxide is generated by reacting sulfur dioxide, nitric acid, and water in the NO boiler.

High-purity NO gas from the purifier feeds the main column—a 300-foot-tall, multipipe assembly sealed inside a 16-inch-diameter insulating vacuum jacket.

4.0 Isotope Production

4.1 Process Description

NO isotope enrichment is a continuous distillation process that concentrates enriched stable isotopes. The NO process—which operates 24 hours a day, 7 days a week (Figure 6)—is described below:

1. Nitric oxide is generated by reacting sulfur dioxide, nitric acid, and water in the NO boiler. The nitric oxide is then combined with isotope-depleted nitric oxide from the distillation column. The dryer and purifier remove water and impurities. The nitric and sulfuric acid waste generated in the boiler is neutralized and discharged to the sewer.
2. High-purity NO gas from the purifier feeds the main column—a 300-foot-tall, multipipe assembly sealed inside a 16-inch-diameter insulating vacuum jacket (Figure 7). The column piping and vacuum jacket are stainless steel. NO tubing, instrument tubing, and wiring—and electric power wiring to the boiler—are routed through the top and into the vacuum jacket. The assembly is suspended in an 18-inch-diameter carbon steel well casing below ground.

   A condenser on top of the column and an electric reboiler at the bottom control the NO temperature for proper distillation.[7] The condenser uses liquid nitrogen and liquid oxygen for coolant. Ten percent isotope-enriched nitric oxide is extracted and converted into other products in a different area of the facility.
3. Stable isotope-enriched nitric oxide feeds the high-enrichment column located in the center of the main column. A separate condenser is mounted on top, and a separate electric reboiler is located at the bottom. The high-enrichment column operates under the same principle as the main column.[8]

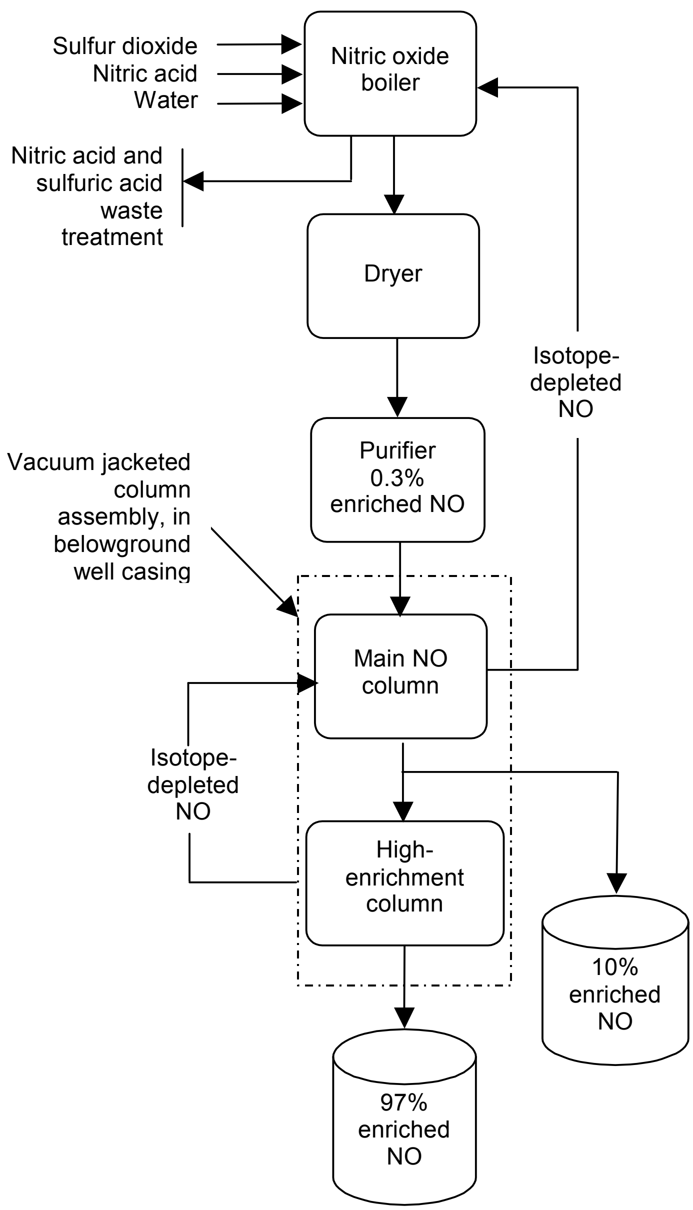
   The 97 percent stable isotope-enriched nitric oxide is removed from the bottom of the high-enrichment column through stainless-steel tubing. It is converted into other products in another area of the facility.

[7] At ambient pressure, nitric oxide boils at -241°F (-152°C) and freezes at -262°F (-163°C).

[8] Because nonisotope-containing molecules have a lower molecular weight than isotope-containing molecules, they boil at a slightly lower temperature. The nonisotope-containing NO molecules vaporize and rise to the condenser. The isotope-containing molecules remain in liquid form at the bottom of the distillation column.

Figure 6

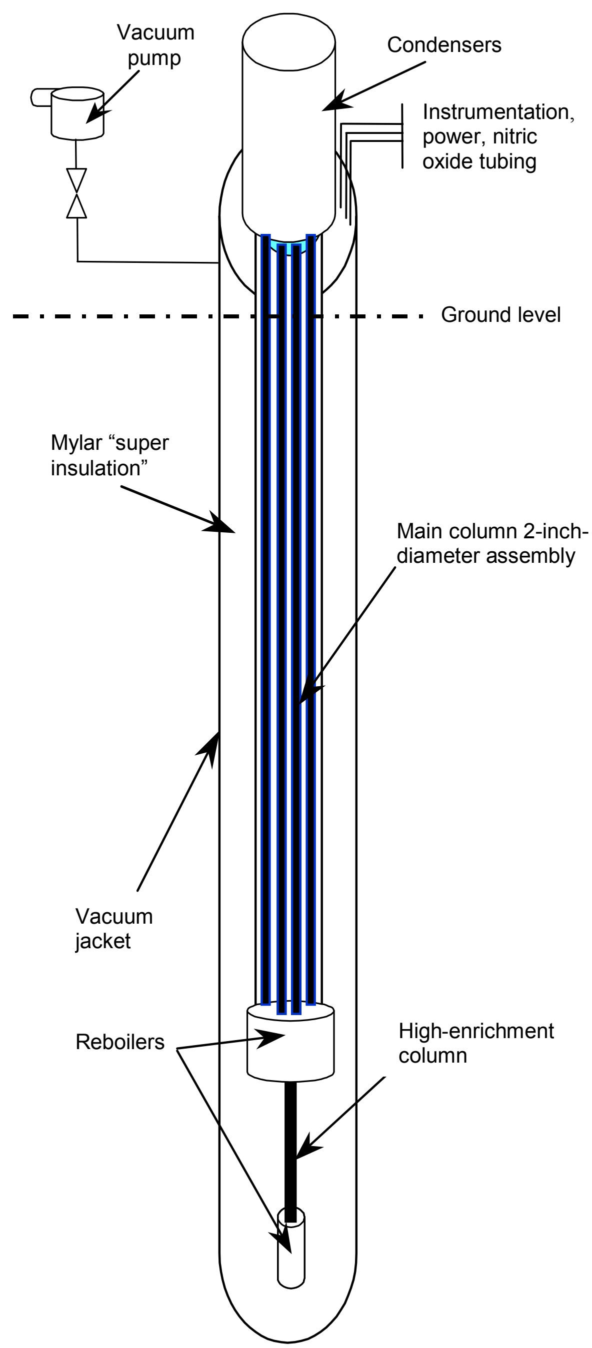
NO distillation process flow diagram



Stable isotope-enriched nitric oxide feeds the high-enrichment column located in the center of the main column.

Figure 7

NO distillation column configuration



4.2 Safety Systems

4.2.1 Chemical Hazards

The NO distillation units incorporated NO detectors and alarm systems. These systems and temperature and vacuum jacket pressure alarms were integrated into an automatic dialing pager system to alert key personnel of a process upset.

Unit controls were automated—the column went into full reflux (closed system recirculation) in the event of an automatic shutdown signal due to a system upset condition. Operators would then evaluate the system status to determine what followup action was necessary to return the system to normal operation or to safely terminate all process operations.

4.2.2 Physical Hazards

Nitric Oxide Explosion

As discussed in Section 2.0, liquid nitric oxide is an unpredictable, highly shock-sensitive explosive. Passive protective devices are the primary means of minimizing the effects of an NO explosion.[9]

[9] A passive protective device/configuration requires no physical action by the system and no human intervention. Examples include physical fire barriers, dikes around storage tanks, and engineered blast shields.

The Isotec distillation system design incorporated two passive protective elements:

- The portion of the column installed in the well casing below ground to accommodate its extreme length provided a high level "shielding."
- The exterior blast shield structure (Figure 8)—installed in response to similar LANL upgrades—was intended to protect employees and equipment in the unlikely event of an NO detonation in the aboveground equipment.

The exterior blast containment structure was an open-top, four-wall rectangular carbon steel plate configuration. Each wall was fabricated using two unreinforced 0.5-inch-thick plates spaced about 4 inches apart. The gap between the plates was filled with sand; the wall panels were welded at the corner joints using structural steel angle shapes.

Although Isotec management reported that the shield was based on an LANL design, the Isotec structure omitted two key safety features:

- A heavy steel wire mesh top to capture debris.
- A wide top-to-bottom labyrinth opening in one wall to prevent pressure buildup, as depicted in Figure 9 and discussed in Section 5.2.3.

The Isotec distillation system design incorporated two passive protective elements . . .

Although the jacket was not intended to operate as a pressure vessel, it was equipped with a block valve—which, when closed, could result in significant pressurization.

Figure 8

Blast shield around N6 distillation column, similar to N3 blast shield

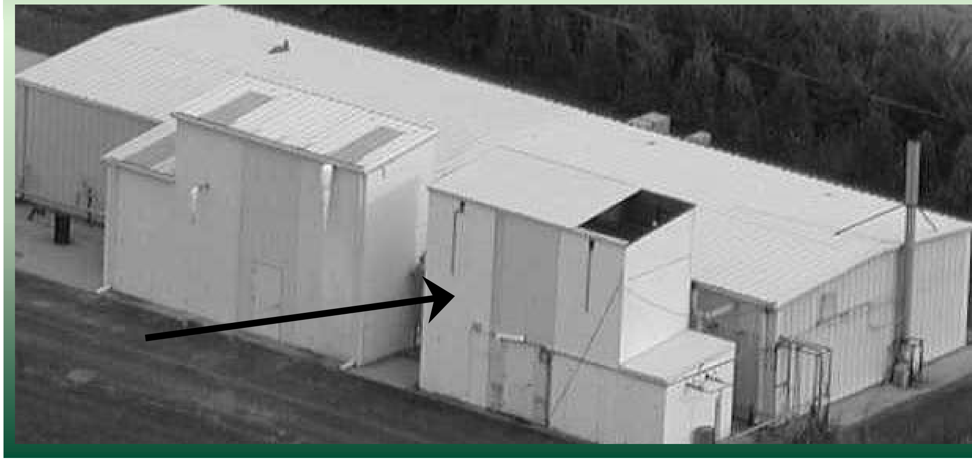
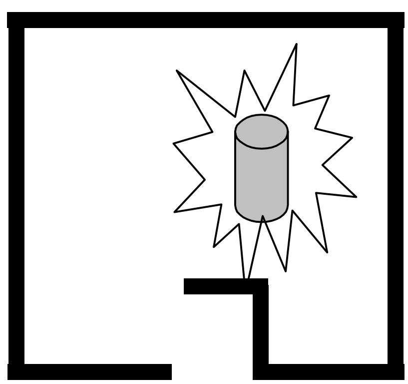


Figure 9

Labyrinth opening to release pressure and block projectiles



Piping/Vessel Overpressure

Pressure relief devices are designed to prevent mechanical equipment from overpressure damage by opening at a preset maximum pressure. The NO tubing attached to the distillation column was equipped with pressure relief devices.

However, no pressure relief device was installed on the vacuum jacket (empty volume in excess of 400 cubic feet). Although the jacket was not intended to operate as a pressure vessel, it was equipped with a block valve—which, when closed, could result in significant pressurization. On the morning of the incident, operators closed this valve to stop the NO release. [10]

[10] CSB estimated the explosive energy of the vacuum jacket when pressurized with air to the burst pressure limit. Assuming that the jacket was filled with piping and insulation up to 90 percent (10 percent empty volume), the failure energy is equivalent to about 11 pounds of trinitrotoluene (TNT).

5.0 Incident Analysis

5.1 Prior Incidents

Table 1 outlines the incident history of the Isotec NO distillation units. Isotec investigated each of these failures. However, the inaccessibility of damaged equipment in the belowground vacuum jacket and the limited ability to recover other evidence prevented conclusive identification of the causes of these incidents. If Isotec had been able to fully investigate each incident, the lessons learned would likely have prevented the catastrophic failure of the N3 distillation unit.

5.2 Failure Evaluation

5.2.1 Distillation Unit Failure

The remains of the belowground distillation column and vacuum jacket were inaccessible for post-incident analysis because of damage and debris from the cave-in at the upper section of the well casing. Therefore, CSB was unable to determine the precise location of the column piping leak or the specific failure mechanism that caused the leak. Possible failure mechanisms include corrosion, fatigue cracking, or other degradation.

Likewise, it was not possible to conclusively determine either the explosion origin inside the vacuum jacket or the cause of the shock load that initiated the explosion.

Distillation column components ejected from near the top of the well casing provided strong evidence that the column piping experienced high temperature and extreme crushing pressure, most likely from a high-energy explosion in the vacuum jacket (Figure 10). The debris from the vacuum jacket consisted of small metal shards (Figure 11), indicating high-order explosive failure.[11]

Figure 10

2-inch-diameter stainless-steel piping oxidized and crushed

Distillation column components ejected from near the top of the well casing provided strong evidence that the column piping experienced high temperature and extreme crushing pressure, most likely from a high-energy explosion in the vacuum jacket.

[11] NFPA 921 characterizes a high-order explosion as shattering of the structure, producing small, pulverized debris. Rapid rates of pressure rise splinter or shatter walls, roofs, and structural members; and the building is completely demolished.

Table 1

Isotec Incident History, NO Distillation Units

Incident Date	Distillation Column ID (a)	Incident Description	Status
1982	N1 (Main Column)	Control system failure, nitric oxide frozen, small explosion in trap; unknown cause	Repaired, traps redesigned, returned to service, decommissioned 1995
12/29/1995	N2 (CONO)	NO leak from column piping into vacuum jacket, small detonation 200 feet below ground; unknown cause	Abandoned-in-place 1995
9/18/1998	N4 (N04)	NO leak from column piping into vacuum jacket; unknown cause	Leak contained, column stabilized, de-inventoried, column extracted and inspected, abandoned-in-place
9/21/2003	N3 (TNO)	NO leak from column piping into vacuum jacket, major detonation below ground; unknown cause	Column, associated equipment, adjacent buildings, blast containment structure destroyed

(a) Isotec designation in parentheses.

Figure 11
Stainless-steel shard, likely from vacuum jacket

5.2.2 Failure Scenario

CSB identified the following failure scenario from analysis of available physical evidence:

- A leak developed in the distillation column piping, releasing nitric oxide into the vacuum jacket. NO gas vented to the atmosphere through the vacuum pump discharge. Loss of vacuum in the jacket seriously degraded its insulating capacity, thus increasing the heat load on the column.
- Closing the vacuum jacket isolation valve to stop the NO leak into the environment pressurized the vessel as the liquid nitric oxide began to boil. The maximum observed vacuum jacket pressure did not exceed 130 psi, which is well below the predicted failure pressure of the jacket.
- Nitric oxide continued entering the vacuum jacket through the leak in the pipe and detonated, crushing the column piping and bursting the jacket.
- A shock load of sufficient energy to detonate liquid nitric oxide could result from one of two mechanisms:
    - Rapid vaporization of liquid nitric oxide as it entered the vacuum jacket.
    - Collapse of a reboiler from pressure buildup in the vacuum jacket.

5.2.3 Blast Shield

The rectangular blast shield structure directed a significant quantity of small debris vertically up, most likely preventing serious injury to the employees and emergency responders in the vicinity.

However, the total destruction of the structure caused major damage to the surrounding facility, including dislodging the CO vessel and rupturing the CO piping—which resulted in the community evacuation, as discussed in Section 1.0.

A more effective blast shield structure would have included a labyrinth opening (Figure 9) and a steel wire mesh top similar to the LANL blast structure. This configuration would be much less likely to catastrophically fail.

A more effective blast shield structure would have included a labyrinth opening and a steel wire mesh top similar to the LANL blast structure.

Although at least two PHAs documented that detonation of liquid nitric oxide is a "credible scenario," neither analysis comprehensively addressed the previous incidents . . .

Because the specific causes of the N4 column failure and NO release in 1998 were not determined, no appropriate corrective actions were implemented to prevent a similar failure in the N3 column . . .

5.3 Process Safety Management

CSB identified deficiencies in the implementation of process safety management at the Isotec facility. The Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) Standard (29 CFR 1910.119) was promulgated in 1992 to prevent or minimize the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals.

The NO distillation units were PSM-covered processes.[12] Furthermore, process safety best practice guidelines are available through trade and professional associations, such as the American Institute of Chemical Engineers, Center for Chemical Process Safety. Effective process safety programs—regardless of whether they are a regulatory requirement—would most likely have prevented this incident or minimized its consequences.

5.3.1 Process Hazard Analysis

The Isotec/Sigma–Aldrich process hazard analysis (PHA) team[13] acknowledged that liquid nitric oxide presented an explosion hazard; however, the team did not understand the significance of the risk to employees.

Although at least two PHAs documented that detonation of liquid nitric oxide is a "credible scenario," neither analysis comprehensively addressed the previous incidents involving NO detonation (see Table 1). The PHAs did not thoroughly review administrative and engineering controls or the consequences of postulated and actual failures. There was no system in place to track PHA findings and associated followup actions.

5.3.2 Incident Investigation

Isotec management did not adequately investigate the two previous NO detonation incidents involving the other distillation units. Because the specific causes of the N4 column failure and NO release in 1998 were not determined, no appropriate corrective actions were implemented to prevent a similar failure in the N3 column—which is essentially identical to N4. There was no record of actions taken to apply lessons learned from the N4 incident, or the failure of column N2 in 1995, to the design and operation of the N3 distillation unit.

[12] Each of the three operating distillation units contained approximately 500 pounds of nitric oxide. The OSHA PSM threshold for nitric oxide is 250 pounds. The U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) threshold is 10,000 pounds.

[13] Sigma–Aldrich management reported that it participated in the 2001 PHA.

5.4 Adjacent Land Use

When the Isotec facility was constructed in 1979, it was surrounded by farmland, with only a few houses located directly across Benner Road to the north. By September 2003, more than 500 homes, places of worship, and a municipal golf course were located in the immediate vicinity. A 50-foot buffer on the south property line provides the only separation between the facility and residential areas.

Zoning changes involving the undeveloped property around Isotec did not adequately consider the public safety risks posed by facility operations. In 1997, the township approved a zoning change that allowed residential development of a 40-acre tract adjacent to Isotec; however, Isotec opposed the change on the basis of public safety concerns.[14]

5.5 Emergency Response

Shortly after the system alarm—but prior to the explosion—the NO venting was contained, and the gas cloud rapidly dissipated. The township fire department on-scene incident commander, in consultation with the Isotec operations manager, decided that a community evacuation was not necessary at that time.

[14] The approved zoning change deleted two lots to increase the buffer between the Isotec facility and the development.

Emergency responders remained at the scene while Isotec employees monitored the status of the distillation unit and began planning activities for transfer of the nitric oxide out of the column. Two hours later, without warning, the column exploded.

Immediately following the explosion, the incident commander, Isotec management personnel, city and township authorities, and the fire department discussed their concerns about the possibility of catastrophic failure of the 26-ton CO storage vessel that was damaged by the explosion. The incident commander ordered an evacuation of the community within a 1-mile radius.[15] The evacuation affected more than 2,000 residents, a church, the golf course, and nearby businesses.

Police officers went door-to-door notifying residents of the evacuation. The City of Miamisburg activated a new automatic dial-up system to place a voice notification to some city residents.[16] The local television public access channel broadcast the evacuation notification. Network television channels displayed a banner with the evacuation notice on the bottom of the screen.

[15] The 1-mile evacuation zone was based on the *Emergency Response Guidebook* recommendation for a CO railcar or tank truck (USDOT–Transport Canada, 2000).

[16] The City of Miamisburg automatic call system is intended for locating lost children. It was used on a limited trial basis during the evacuation.

Zoning changes involving the undeveloped property around Isotec did not adequately consider the public safety risks posed by facility operations.

Isotec/Sigma–Aldrich informed CSB and the community that they would not restart NO distillation and would decommission the remaining NO unit, N6.

A few weeks after the incident, CSB investigators collected observations from residents in the evacuation zone. Findings included:

- Some police officers conveyed extreme urgency to evacuate, while others only recommended evacuation.
- Some residents received no notification to evacuate.
- Some residents were alerted of the order to evacuate by neighbors.
- Some residents were unclear about where to go, or what emergency shelters or other support services were available.

5.6 Post-Incident Activities

CSB, Isotec/Sigma–Aldrich, and the city and township participated in community meetings to discuss the incident response. The city and township managers conducted separate post-incident critiques of their emergency plan response.

The following key actions resulted:

- Isotec/Sigma–Aldrich informed CSB and the community that they would not restart NO distillation and would decommission the remaining NO unit, N6.[17]
- The City of Miamisburg established an emergency response review committee composed of police and fire department personnel and the assistant city manager. The committee identified the following emergency response plan improvements:
  - Emergency operations exercises will be conducted with the school district and Miami Township.
  - One-hundred emergency frequency two-way radios will be provided to the local school district to improve communication with emergency responders.
- Miami Township post-incident activities included:
  - Approval of the construction and full-time staffing of a new emergency operations center adjacent to the fire department and township offices.
  - Review of available automated telephone call-out systems for possible implementation.
  - Review of the existing zoning code to consider:
    - Requiring chemical companies to obtain a conditional use permit when operating in areas zoned for light industrial use.
    - Expanding the buffer zone around light industrial areas.

[17] Sigma–Aldrich reported that all nitric oxide has been removed from column N6 and that NO distillation has ceased at the Isotec facility.

6.0 Lessons Learned

6.1 Process Hazard Analysis

Although Isotec and Sigma–Aldrich PHA records acknowledged the explosive potential of the NO system, there was no written documentation that action had been taken to minimize this potential.

A comprehensive PHA program thoroughly investigates all identified hazards, documents and tracks actions taken to minimize the hazards, and evaluates safety systems design basis records (e.g., blast shielding and overpressure protection calculations) and process design information.

6.2 Incident Investigation

Although Isotec experienced two previous NO distillation unit failures involving the detonation of liquid nitric oxide, the investigation records were incomplete. There was no record of the cause of the incidents and no documentation of corrective actions to prevent recurrence.

Incidents must be thoroughly investigated to identify causes and to implement corrective actions to prevent recurrence. Results of incident investigations are key inputs to the PHA process.

6.3 Land Use Management

Neither the township zoning process nor the township and city permit approval processes adequately considered the hazards of preexisting industrial chemicals. Likewise, neither authority prescribed steps for addressing potential public consequences from the accidental release of chemicals.

As part of the land use approval process, authorities should evaluate the public risk from preexisting chemical industry facility operations. City and county jurisdictions should coordinate review activities.

6.4 Emergency Planning and Notification

A number of residents were not informed of the evacuation in a timely manner; others received no notification. Information was sometimes inconsistent or incomplete, causing confusion among evacuees.

Community emergency plans prepared by local governing authorities should include instructions on evacuation protocols. Training should include simulated emergency drills and directly involve the public.

Public awareness campaigns should be used to inform the community of notification in the event of an emergency.

Results of incident investigations are key inputs to the PHA process.

As part of the land use approval process, authorities should evaluate the public risk from preexisting chemical industry facility operations.

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