Final
October 6, 1998

COST AND PERFORMANCE REPORT

Groundwater Extraction and
UV Oxidation Treatment
At the Bofors Nobel Superfund Site
Operable Unit 1
Muskegon, Michigan

October 1998

SITE INFORMATION

IDENTIFYING INFORMATION

Site Name: Bofors Nobel Superfund Site
Location: Muskegon, Michigan
Operable Unit: OU 1
CERCLIS #: MID006030373
ROD Date: September 17, 1990
Technology: Ultraviolet (UV) Oxidation
Type of Action: Groundwater Remediation

Figure 1 shows the location of the Bofors Nobel Superfund Site in Michigan.

TECHNOLOGY APPLICATION

Period of Operation:

September 1994 – Ongoing

Quantity of Material Treated During Application (to date):

Approximately 700 million gallons of contaminated groundwater has been extracted and treated at the site. Approximately 7,500 pounds of organic compounds have been removed from the groundwater. These quantities are cumulative through October 1997.

This application is part of an ongoing project to contain contaminated groundwater at the facility. Groundwater extraction and treatment has been performed at the site since 1978. The ultraviolet (UV) oxidation treatment application has been in operation since 1994. Additional contamination in site surface water, soil, and sediment is being addressed under a later phase of this Operable Unit (OU), and is not a direct part of this application.

BACKGROUND

Site Background:

- The Bofors Nobel Superfund Site is located on 85 acres in a chemical manufacturing area six miles east of Muskegon, Michigan in Egelston Township. The site includes an operating specialty chemical manufacturing plant that is currently owned by Lomac, Incorporated. The Muskegon, Michigan area is home to a number of superfund sites as a result of past chemical manufacturing production. The geological conditions at the Bofors Nobel site include a sandy soil horizon which allowed for the rapid infiltration of contaminated liquids generated by chemical wastes which were regularly discharged to ten separate, unlined surface impoundments at the site.

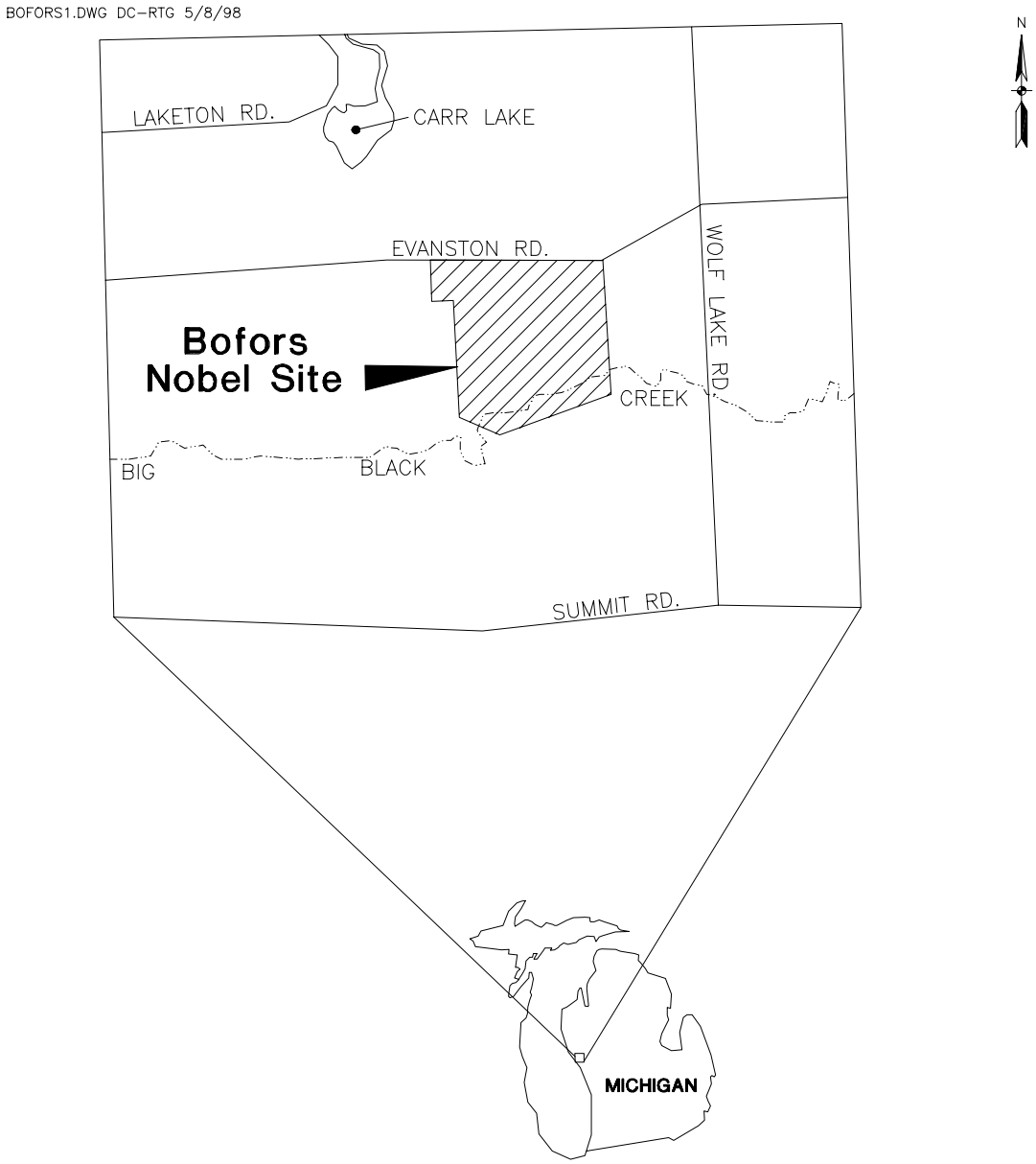

Figure 1. Site Location Map, Bofors Nobel Superfund Site, Muskegon, Michigan

- Prior to 1970, the facility produced chemicals such as 3,3-dichlorobenzidine (DCB), benzidine, and azobenzene for use in alcohol based detergents and as die intermediates. Raw materials used in the production of detergents included fatty alcohol, fatty ether alcohol, sulfur dioxide, aqueous ammonia and caustic. In the production of dye intermediates, raw materials utilized included muriatic acid, sulfuric acid, nitrobenzene, methanol, benzene, caustic, sodium chloride and zinc.

- Lakeway produced a lauryl alcohol base detergent, dye intermediates, pesticides, and herbicides during the 1970s.

- In September 1977, Lakeway Chemicals merged with Bofors Industries, Incorporated to become Bofors Lakeway, Incorporated. On December 31, 1981, Bofors Lakeway, Inc. merged with Nobel Industries of Sweden and the company name was changed to Bofors Nobel, Incorporated. In December 1985, the corporation filed for bankruptcy, claiming that the company had expended in excess of $60 million dollars for environmental cleanup.

- The Bofors Nobel, Inc. assets were sold to Lomac, Inc. in March of 1987. As a part of the sales agreement, an "Agreement and Covenant Not to Sue" was entered into between the State and Lomac for site contamination caused by previous facility operators. These agreements and covenants allowed Lomac to operate the facility independently of site remediation activities.

- In March 1989, the Bofors Nobel site was placed on the National Priorities List (NPL).

Figure 2 shows the layout of the Bofors Nobel facility.

SIC Code: 2869 (Industrial Organic Chemicals)

Waste Management Practices that Contributed to Contamination:

For approximately 20 years, chemical process waste liquids and sludge were routinely disposed in ten unlined surface impoundments at the site. In addition, lagoon berms occasionally failed, releasing impoundment sludge into nearby surface water bodies.

Site Operation History:

- Lakeway Chemicals, Incorporated began producing industrial chemicals at the site in 1960. During the late 1960s and 1970s, process wastes were discharged through open trenches to ten unlined Surface Impoundments located south of the plant area.

- During the 1970s, berm failures at the impoundments resulted in the discharge of sludge directly into Big Black Creek.

- Use of the surface impoundments for waste disposal was discontinued in 1976 when the facility began discharging its liquid wastes to the Muskegon County Wastewater Treatment System. At that time, the Michigan Department of Environmental Quality (MDEQ) requested that Lakeway perform hydrogeologic tests at the site to define aquifer characteristics and define extraction well placement to prevent migration of site contamination.

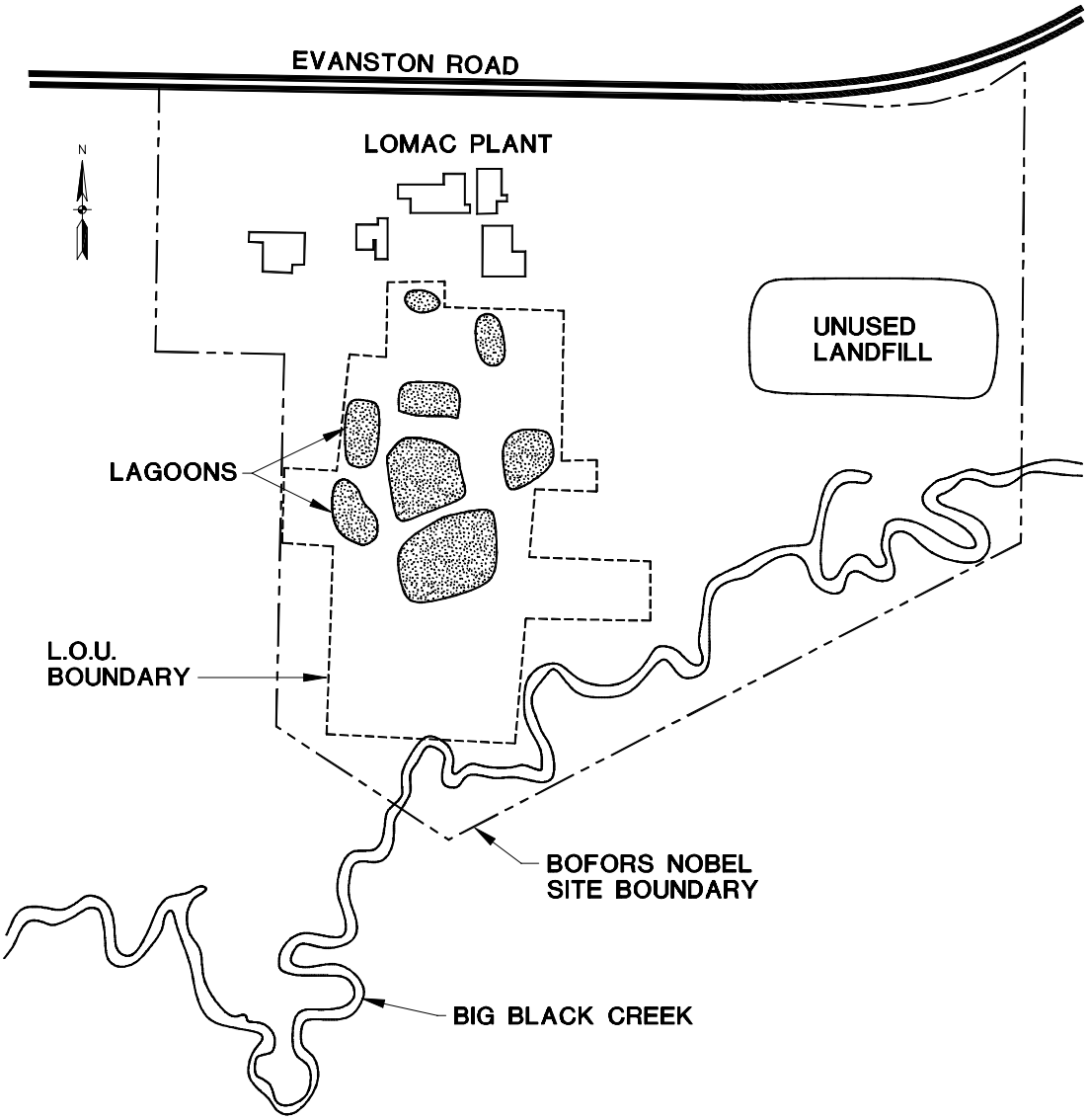

Figure 2. Layout of the Bofors Nobel Facility

- Groundwater extraction wells were installed along the southern boundary of the site and began operating in 1978.

SITE LOGISTICS/CONTACTS

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Site Investigations

- The site has been divided by the EPA into two operable units, OU 1 and OU 2. OU 1 consists of addressing soil and groundwater contamination in the lagoons area. OU 2 consists of addressing soil and groundwater contamination in the northern portion of the facility (The Lomac plant area).

- OU 1 has been subdivided into two phases. The first phase, termed the Groundwater Operable Unit (GOU), included installation of the Groundwater Treatment Plant (GWTP). The second phase, termed the Lagoon Operable Unit (LOU), will include remediation or containment of contaminated soil in the lagoons area of the facility. This report refers only to the first phase of OU 1 (The GOU).

- Because of the nature and extent of the contamination on the Bofors Nobel site, the State of Michigan contacted the U.S. EPA to evaluate the site for placement on the National Priorities List (NPL), pursuant to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA).

- The EPA conducted a site evaluation, and nominated the Bofors Nobel site to the NPL in July 1988, with listing occurring in March 1989. A Remedial Investigation/Feasibility Study (RI/FS) was initiated in August 1987 and was completed in June 1990.

- A Record of Decision (ROD) for the Bofors Nobel site was signed on September 17, 1990. The ROD addressed remediation of the sludge lagoons as well as restoration of the groundwater aquifer.

- Supplemental groundwater monitoring was performed by the USACE during the design of the GWTP and for design of an on-site landfill remedy. This monitoring was performed from March 1991 to June 1994.

MATRIX AND CONTAMINANT DESCRIPTION

MATRIX IDENTIFICATION

Groundwater (ex situ)

SITE GEOLOGY/STRATIGRAPHY

The regional geology of the Bofors site can be characterized as surficial Pleistocene sediments of varying compositions above Paleozoic sedimentary bedrock occurring on the margin of the Michigan Basin. These two different depositional age sediments rest on a Pre-cambrian basement complex.

The surficial geology is comprised of material deposited by the Wisconsin advance during the glacial periods of the Pleistocene Epoch. As the Wisconsinan glacier began to recede across Michigan, it re-established a lobate character subdividing into the Michigan, Saginaw, and Lake Erie lobes. During this general retreat, end moraines developed parallel to the margins of the several lobes with some local development of interlobate moraine. The development of these moranic systems impounded meltwater behind them and initiated the first stages of the Great Lakes. Continued retreat and advances of the glacial ice created additional moranic systems and lacustrine and outwash plains. The final retreat of glacial ice left Michigan with a complex landscape generally less than 20,000 years old, developed on drift deposits. The landscape is composed of low-relief features such as outwash, till, and lacustrine plains and greater relief features including moraines, drumlins, kame, kettles, eskers, wave-cut cliffs, and dunes.

Surficial geology near the Bofors site can be characterized as Pleistocene glacio-lacustrine sands, outwash sediments, and tills overlying the lower Mississippian Marshal Sandstone and Coldwater Shale Formations. These latter two formations are part of the geologic structure known as the Michigan Basin. Surficial geology consists of alluvium comprised of laminated sand and silt with peaty and fibrous material associated with Big Black Creek, and three glacially derived zones described below:

The uppermost zone is a predominately fine to medium grained sand with generally less than five percent fines passing the No. 200 sieve. Occasional coarser-textured beds with higher percentage of fines do occur, but these beds are sporadic. Low percent of fines, good sorting, uniform texture, and consistency of occurrence characterize this zone.

The next lower sequence consists of sand deposits that are variable in texture, generally greater than five percent fines, with some units containing more than 30 percent, commonly interbedded with units of silty clay. Occasional sand beds of the uppermost zone-type occur within this zone. However, these are generally thin and sporadic. General variability and lack of uniformity characterize this sequence, with represents a highly complex pattern of sedimentation.

The basal zone of the glacial stratigraphic section is a silty clay commonly containing 60 percent or greater fines. In addition, there are local minor beds of silt and sand with gravel. This zone appears to be related to deposits of the Morainal uplands because the total thickness of the two upper zones thins adjacent to the Morainal areas, and the basal unit is encountered at progressively higher levels.

Paleozoic rocks make up the majority of the structure known as the Michigan Basin. These sedimentary formations are bowl-shaped and tend to thin towards the basin's margins. Muskegon County is located on the margin of the Michigan Basin. The upper Paleozoic rocks in this region are the Osagean and Kinderhookian Series of the lower Mississippian age, consisting of sandstones and shales. Below the Osagean and Kinderhookian Series are Paleozoic age sedimentary rocks comprised in general of

mudrocks, sandstones, carbonates, and evaporates. The bedrock topography along the western margin of the Southern Peninsula of Michigan near Muskegon County increases gradually in elevation from the Lake Michigan shoreline.

The stratigraphic column beneath the Bofors site, beginning with the youngest formation, includes:

a) Recent sediments of alluvium and swamp deposits associated with Big Black Creek.
b) Quaternary lacustrine sand formation consisting of three subunits; the upper, middle and lower units.
c) Quaternary glacial till formation.
d) Mississippian Marshall sandstone formation.

The topography at the Bofors Nobel Superfund site slopes from a high elevation of approximately 660 feet Mean Sea Level (MSL) at the northern edge of the site to Big Black Creek, which flows along the southern border of the project boundary, at an elevation of approximately 617 MSL. Groundwater beneath the site is steeply sloping, and is located between elevations 621 and 625 MSL. Depth to groundwater at the site ranges from the ground surface at Big Black Creek, to approximately 34 feet below grade at the northern edge of the site. At the extraction well points, the estimated depth to groundwater ranges from 25 to 30 feet. It has been estimated that the primary aquifer at the site is 80 feet thick.

Local Climate

Regional climate characterization indicates a humid, continental climate influenced by nearby Lake Michigan. Lake Michigan influences Muskegon's climate by reducing summer maximum temperatures, and by moderating arctic air masses during winter. Strong north-westerly air flow during the winter months overrides the relatively warm water of Lake Michigan, producing snow squalls along the eastern shoreline. Consequently, snowfall in Muskegon is considerably higher than what is observed across the lake in Wisconsin or inland toward the center of lower Michigan. A thick snow cover results during winter months which may reduce the potential for wind-blown particulates. The influence of Lake Michigan is observed when comparing the Muskegon area with Grand Rapids, approximately 40 miles inland. The mean annual number of days with maximum temperatures of 90°F or greater is six at Muskegon, and thirteen at Grand Rapids. The mean number of days where minimum temperatures are below 32°F is 144 at Muskegon compared to 150 days at Grand Rapids. The mean monthly temperature in Muskegon during January is approximately 23°F, with total precipitation averaging three inches, including 33 inches of snow. Inland at Grand Rapids, the mean temperature is 21°F, with 2.5 inches precipitation, including 22 inches of snow.

CONTAMINANT CHARACTERIZATION

Primary Contaminant Groups:
Volatiles (Halogenated)
Semivolatiles (Halogenated)

Key Specific Contaminants:
Benzene
Benzidine
2-Chloroaniline
1,2-Dichloroethene
Trichloroethene
3,3-Dichlorobenzidine
Aniline
Vinyl Chloride

Over sixty contaminants have been detected in the groundwater beneath the site. The following table provides a partial list of contaminants of concern at the site.

Table 1. Partial Listing of Contaminants of Concern

Acetone	Aniline	Azobenzene
Benzene	Benzidine	2-chloroaniline
bis(2-Ethylhexyl)phthalate	Butyl Benzyl Phthalate	3-chloroaniline
Chlorobenzene	Chloroisophorone	Dichloroazobenzene
1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene
1,2-dichloroethane	Dichlorobiphenyl	1,2-dichloroethylene
Ethylbenzene	Isophorone	Phenols
Tetrachloroethylene	Toluene	1,1,1-Trichloroethane
Trichloroethylene	2-Methylphenol	Trimethylphenol
1,1,2,2-Tetrachloroethane	Vinyl Chloride	di-n-Propyl formamide
1,1-Dichloroethylene	Xylene	Trans-1,2-dichloroethylene
3,3'-Dichloro-2,4'-diaminobiphenyl	3,3-dichlorobenzidine isomer	

CONTAMINANT PROPERTIES

Table 2 lists selected properties for several of the most common contaminants present at the Bofors Nobel site.

Table 2. Contaminant Properties

Property	Units	Benzene	Benzidine	2-Chloro-aniline	1,2-DCE	TCE
Chemical Formula	-	C_6H_6	$C_{12}H_{12}N_2$	C_6H_6ClN	$C_2H_2Cl_2$	C_2HCl_3
Molecular Weight	g/mole	78.11	184.23	127.57	96.95	131.5
Specific Gravity	-	0.8765	1.250	1.213	1.28 (cis) 1.26 (trans)	1.46
Vapor Pressure	mmHg	76 (20°C)	0.83 (20°C)	0.17 (20 C)	200 (trans) (14°C)	57.8 (20°C)
Boiling Point	°C	80.1	402	208.8	60 (cis) 48 (trans)	86.7
Octanol-Water Partition Coefficient (K_{ow})	-	135	65	79	123 (trans)	339

NATURE AND EXTENT OF CONTAMINATION

Several environmental investigations have been performed at the Bofors Nobel site. In 1978, Bofors Lakeway, at the direction of MDEQ, completed installation and began operation of thirteen groundwater extraction wells, primarily located along the southern boundary of the property. The wells were designed to prevent the migration of contamination beyond the site boundaries. Operation of the extraction wells has continued since that time. Prior to 1994, extracted groundwater was treated at the Lomac facility and discharged to the Muskegon County Wastewater Treatment Facility. Since 1994, groundwater treated by the UV oxidation system has been discharged directly to Big Black Creek. No groundwater contamination has been detected down gradient of the project site. Modeling has indicated that the existing extraction system is capable of retaining the plume of contamination on the project site. It is estimated that termination of extraction well operation would allow contaminant migration offsite within three days of pump cessation.

Remedial investigation field activities at the site have included:

a) Surface soil sampling
b) Subsurface soil sampling
c) Groundwater sampling
d) Geophysical investigation
e) Air monitoring

Data from hundreds of soil boring and groundwater monitoring wells has allowed the development of numerous two-dimensional contour diagrams illustrating the surface areas, groundwater elevations, and contaminant concentrations profiles. These diagrams have been used to verify that current pumping scenarios are adequate to provide capture of the site contamination.

The hydrogeologic unit located beneath the project site is consistent in composition and exhibits a range of conductivity values commonly associated with a clean sand aquifer. The mean hydraulic conductivity for the wells tested at the project site was 4.4×10^{-2} cm/sec. The transmissivity at the site ranges from 43,000 to 60,000 gpd/ft, with an average value of 48,000 gpd/ft. These values are judged to be representative of the aquifer, based upon its characterization. The storage coefficient, also felt to be consistent for a sandy aquifer, was found to be approximately 0.27. Based upon the assumption that the aquifer is 80 feet thick and the average transmissivity of 48,000 gpd/ft, the coefficient of permeability was found to be 600 gpd/ft^2, or 2.8×10^{-2} cm/sec, which correlates well with the previously stated value of 4.4×10^{-2} cm/sec.

The most prevalent and highest concentration contaminants of concern at the Bofors Nobel site include benzene, benzidine, 2-chloroaniline, 1,2-dichloroethene, trichloroethene, 3,3-dichlorobenzidine, aniline and vinyl chloride. The highest groundwater concentrations detected for each of the contaminants listed above are shown in Table 3. These concentrations are all from groundwater samples collected prior to installation of the GWTP (pre-1994).

Table 3. Highest Detected Contaminant Concentrations (Pre-1994)

Constituent	Maximum Concentration (µg/L)	Well or Well Cluster ID
Benzene	60,000	WC-27
Benzidine	1,300	MW-108
2-Chloroaniline	63,000	WC-27
1,2-Dichloroethene	1,900	LW-3
Trichloroethene	43	PW-41
3,3-Dichlorobenzidine	2,600	PW-41
Aniline	10,000	WC-27
Vinyl Chloride	1,000	W-33

The average concentrations of the most prevalent groundwater contaminants over a 16-month period from November 1994 through February 1996 are shown in Table 4.

Table 4. Average Concentrations for Selected Contaminants (1994-1996)

Compound	Average Concentration (µg/L)
Benzene	350
Benzidine	315
2-Chloroaniline	270
1,2-Dichloroethene	180
Trichloroethene	100
3,3-Dichlorobenzidine	80
Aniline	40
Vinyl Chloride	33

As of October 1997, extracted groundwater contained approximately 1.5 mg/L of total organic compounds prior to treatment. The metals concentrations in the plant influent have not exceeded the regulatory limits established by the MDEQ.

OU 01 (GOU) was intended as a remedy for contaminated groundwater at the site. To summarize the aquifer parameters discussed in the previous paragraphs, the critical aquifer characteristics have been estimated as follows:

Table 5. Aquifer Characteristics

Unit	Apparent Thickness	Hydraulic Conductivity	Transmissivity	Flow Direction
Operable Unit 1	80 feet	600 gpd/ft^{-2}	48,000 gpd/ft	Southerly

Groundwater at the southern boundary of the project site and across the entire Bofors Nobel site acts as an unconfined aquifer.

TREATMENT SYSTEM DESCRIPTION

PRIMARY TREATMENT TECHNOLOGY

Pump and Treat with UV Oxidation

SUPPLEMENTAL TREATMENT TECHNOLOGIES

Pretreatment (water) – **Chemical** (chemical precipitation) and **Filtration**
Post-Treatment (water) – **Carbon Adsorption** and **Air Stripping**
Post-Treatment (solids) – Sludge Dewatering (filter press)

TIMELINE

Table 6 shows a timeline of significant activities that have occurred on the Bofors Nobel project.

Table 6. Project Timeline

Date	Activity
September 1991	Advanced Oxidation Treatment Demonstration Testing
September 1991 through April 1992	System Design
August 1992	Bid Submittal Deadline
October 1992	Contract Award
November 1992	Construction Mobilization
June 1994	Construction Complete
September 1994	Initiate Treatment Operations

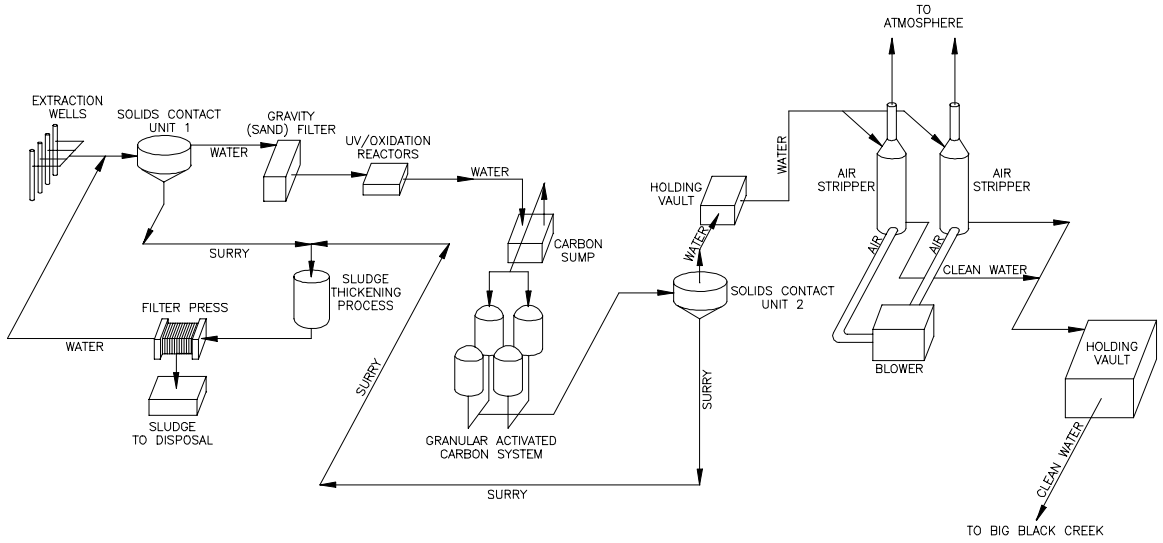
TREATMENT SYSTEM SCHEMATIC AND TECHNOLOGY DESCRIPTION AND OPERATION

Figure 3 shows a schematic diagram of the groundwater treatment system.

The extraction well network was constructed in 1978 as part of a proactive approach to site cleanup by the state of Michigan. No additional extraction wells were installed during construction of the groundwater treatment facility. Records providing extraction well details, pump types and casing/screen intervals are limited and were not available for the preparation of this document.

The facility design flow has been established as 782 gpm, with a maximum of 732 gpm derived from the wellfield, and 50 gpm as plant recycle. The current operating flow rate varies between 390 and 500 gpm, depending upon the season. Groundwater is discharged to the treatment facility from the extraction well network and was initially directed to a metals precipitation unit (solids contact unit 1) for pretreatment prior to organics removal. The metals precipitation unit was operated for approximately two years after system start-up. Because it was determined to be unnecessary at that time, it has since been taken out of service. Following solids contact unit 1, water is sent through a dual media gravity filter. Filtered water gravity flows through a UV Oxidation system to treat organic contaminants. Treated water gravity flows into a sump, from which it is pumped through four columns of granular activated carbon (GAC). GAC treatment is provided for polishing, and as a backup measure in the event the UV system is offline. Following polishing, the pH is elevated in solids contact unit 2 to convert ammonium ions (NH_4^+ - present at neutral pH) to strippable ammonia (NH_3), for removal within the ammonia stripping columns. The pH-adjusted water travels from solids contact unit 2 to the ammonia stripping sump, where it is then pumped through the ammonia stripping column. After stripping, the water is neutralized by acid addition, and the water is directed to the effluent holding vault. The holding vault also serves as a source of fire protection water at the facility. Water from the holding vault overflows through a weir and discharges to Big Black Creek at the southern edge of the site.

Solids generated in the two solids contact units are pumped to a sludge thickener. Thickened sludge is amended with lime to improve handling and dewatering, and is then pumped to a sludge filter press. The 25 to 35 percent solid sludge cake from the filter press is further processed to remove excess water using a sludge dryer. The solids content in the sludge is increased to approximately 90 percent in the sludge dryer. Sludge exiting the sludge dryer is transferred to bags and is disposed at a solid waste landfill. Water generated by the filter press is recycled to the head of the treatment facility.



• SOLIDS CONTACT UNIT 1	Removes metals from water by elevating pH and adding polymer to form a slurry mixture. Slurry sent to sludge Thickening Process; remaining water sent to Gravity Filter. Note: This unit was taken out of service in 1995 because it was not needed to meet discharge limitations.
• GRAVITY FILTER	Removes fine particles from water.
• SLUDGE THICKENING PROCESS/FILTER PRESS	Forms sludge by adding lime to slurry and forcing it through Filter Press. Sludge sent offsite for disposal, water recycled to Solids Contact Unit 1.
• UV/OXIDATION/GRANULAR ACTIVATED CARBON	Removes organic compounds from water.
• SOLIDS CONTACT UNIT 2	Elevates the pH for ammonia removal and adds a polymer to form a slurry mixture. Slurry sent to sludge Thickening Process.
• AIR STRIPPERS	Ammonia stripped from water prior to discharge to Big Black Creek.

Figure 3. Groundwater Treatment Process Schematic
Bofors Nobel Superfund Site, Muskegon, Michigan

KEY DESIGN CRITERIA

The expected operational lifetime of the treatment system is estimated to be greater than 60 years.

OPERATING PARAMETERS AFFECTING TREATMENT COST OR PERFORMANCE

The following table lists several of the key operating parameters for the GWTP. Where possible, design values are compared to actual values.

Parameter	Units	Design Value	Actual Value (1)
Pumping Rate	gpm	782	390 - 500
Water Temperature	---	---	---
Influent	^{o}F	NA	56
UV Oxidation Unit	^{o}F	NA	54
Effluent	^{o}F	NA	54
Influent and Effluent Contaminant Concentrations	---	---	---
Influent (9 Primary Contaminants)	µg/L	5,218	< 1500
Effluent (9 Primary Contaminants)	µg/L	43	< 9
Pressure Loss Through GAC Columns	PSI	1-3	NA
System pH (influent)	NA	7.0	7.3
Chemical Feed Rates	---	---	---
Caustic (50% NaOH)	gal/day	380	NA
Acid (96% H_2SO_4)	gal/day	687	NA
Polymer	gal/day	18	39
Hydrogen Peroxide	gal/day	NA	8.0
Ozone Generated	lbs/day	NA	49.7
Head Loss Through the Dual Media Filtration System	Feet	2.57	NA

(1) - 1998 Information
NA - Not Applicable

TREATMENT SYSTEM PERFORMANCE

PERFORMANCE OBJECTIVES

The overall objective of the GOU at the Bofors Nobel Superfund Site is to control the offsite migration of contaminated groundwater, and to reduce the contaminant mass remaining in the aquifer. Limitations have been established by the MDEQ for discharge of treated groundwater from the site. Table 7 lists the MDEQ limitations for water discharged from the GWTP to Big Black Creek. Weekly sampling is required for all parameters listed in the table.

TREATMENT PLAN

The treatment strategy for OU 01 at the Bofors Nobel site is to first address the contaminated groundwater beneath the project site by preventing offsite migration. After successfully achieving this goal, the source of the site contamination (soil and sludge in the lagoons) must be addressed in order to allow the site to be remediated. Contaminated soils at the project site have not yet been addressed through any type of remediation activity, therefore, a continuous source of contaminant loading to the aquifer remains at the site. To date, alternatives that have been considered to address the contaminated soils include incineration, excavation with consolidation in an onsite landfill, and placement of a slurry

Table 7. Discharge Limitations for the GWTP

Parameter	Limitation
COD	20 mg/L
Ammonia Nitrogen	---
12/1 - 4/30	29 mg/L
5/1 - 9/30	2.0 mg/L
10/1 - 11/30	12 mg/L
Purgeable Halocarbons	---
Each	5 µg/L
Purgeable Aromatics	---
Each	5 µg/L
Aniline	10 µg/L
2-Chloroaniline	20 µg/L
Carbon Disulfide	5 µg/L
2-Butanone	500 µg/L
2-Methylphenol	5 µg/L
Benzidine	0.12 µg/L **(1)**
3,3-Dichlorobenzene	0.18 µg/L **(1)**
2,4-Dinitrophenol	29 µg/L **(1)**
1,1-Dichloroethane	5 µg/L
1,1-Dichloroethene	5 µg/L
Total Copper	62 µg/L / 38 µg/L **(1)**
Total Lead	11 µg/L **(1)**
Total Mercury	0.0013 µg/L **(1)**
Total Zinc	320 µg/L / 185 µg/L **(1)**
Dissolved Oxygen	---
5/1 - 9/30	6.5 mg/L (minimum)
10/1 - 4/30	4.0 mg/L (minimum)
pH	6.5 - 9.0 (acceptable range)

(1) - Allowable Monthly Average Concentration

wall combined with installation of an impermeable cap at the site. At the time this report was prepared, no final action had been selected to address the issue of soil and sediment contamination.

In 1991, treatability testing was performed to assess the performance of several groundwater treatment technologies. Technologies tested included: UV/peroxide oxidation, UV/ozone oxidation, and carbon adsorption. Test results indicated that UV/ozone oxidation was the superior technology for treatment of groundwater at the Bofors Nobel site.

TREATMENT PERFORMANCE DATA

The concentration of contaminants in the influent to the groundwater treatment facility has consistently been less than design values. As previously indicated, the total concentration of organic compounds in extracted groundwater is approximately 1.5 mg/L (versus a design estimate of greater than 5 mg/L), and has not varied significantly since project start-up. The consistency of the influent concentration is expected, since the source of soil and sediment contamination at the site has not yet been addressed. It is likely that future soil remediation at the site will include removal and/or capping of the contamination, ultimately leading to a reduction in the amount of contamination being carried to the site groundwater. It has been estimated that long-term cleanup of the site groundwater will take 50 to 70 years.

The groundwater treatment facility has consistently treated the target contaminants to concentrations below the limits established by the MDEQ. The site has not exceeded the permit limits for any individual contaminant since start-up in 1994. Toxicity testing was not required under the original operating contract, but has since been added to the facilities operating charter. Since initiation of toxicity testing, some difficulties have been encountered when testing 100 percent effluent on the target specie, *Daphnia magna* or *D. pulex*. Toxicity testing issues are currently being addressed at the facility, and should be closely coordinated with state regulatory personnel.

Since 1994, over 7,500 pounds of organic compounds have been removed from the groundwater at the Bofors Nobel site. The principal treatment technology employed by the groundwater treatment system at the site is UV oxidation. This technology treats organic compounds by destruction as opposed to phase transfer. Destruction treatment technologies function by converting (either by physical or chemical means) contaminants into less harmful substances, many of which can be discharged directly to the environment. Phase transfer technologies collect contaminants from one medium (e.g., water) and concentrate them in or on another medium (e.g., granular activated carbon). The concentrated contaminants are subsequently easier and less expensive to transport and dispose. Destruction technologies are typically preferable to phase transfer technologies because with destruction, the need for further handling or treatment of wastes is minimized or eliminated.

As of October 1997, the Bofors Nobel groundwater treatment facility has processed approximately 700 million gallons of contaminated groundwater without exceeding any of the discharge limitations established by the state of Michigan. The treatment facility has been operating since September 1994, effectively preventing migration of the site contaminants. The facility has treated an average of six pounds of organic compounds per day since startup, with little variation in the contaminant plume configuration. There have been no adverse air emissions caused by the operation of the treatment facility. The system is able to operate with no downtime (100% operability) as a result of system flexibility and operating flow rates below system design flow rates. During an average monthly operating cycle in 1997, the facility used between 190,000 and 200,000 kwhrs of electricity, and approximately 10,000 CCF (therms) of natural gas, depending upon ambient temperature and treatment flowpath. In 1997, treatment system chemical usage rates averaged 500 gallons per month for hydrogen peroxide, and 2500 pounds per month for ozone. Pretreatment prior to the UV oxidation system is not currently being practiced, with no adverse findings.

Since system startup, there have been periodic shutdowns for scheduled maintenance activities. The replacement of six concrete C-5000 reactor vessels with stainless steel reactor vessels has been completed. This change was required as a result of leakage that was occurring along cracks in the concrete vessels and at the piping entry points.

Hydrodynamic Performance

Thirteen extraction wells are located along the southern boundary of the project site, adjacent to Big Black Creek. All extraction wells are not operated simultaneously. Typically, nine wells are sufficient to provide capture of the contaminant plume. Selection of operating extraction wells is based on total system flow rate. The extraction wellfield has a history of problems associated with the development of biomass around the well screens and within the well packs. A proprietary rejuvenation process, blended chemical heat treatment (BCHT), has been implemented to improve flow rates in the wells. The flow rates from individual wells vary significantly, and can range from 40 to 100 gpm, depending upon the degree of fouling and aquifer characteristics. It is estimated that the contaminant plume at the site has been contained horizontally and vertically by the extraction well network.

Treatment System Cost

PROCUREMENT PROCESS

The Feasibility Study and the project ROD called for Ultraviolet Oxidation (UV Oxidation) as the selected technology for destruction of organic contaminants present in the groundwater. UV/ozone oxidation was determined to be the most appropriate treatment technology for this site based on a treatability study that evaluated UV/ozone oxidation, UV/peroxide oxidation and GAC. The ROD also directed final effluent discharge to a cold water trout stream located on site (Big Black Creek). Rapid and complete evaluation of the chosen technology was performed by the Corps to determine whether the low discharge standards established by the state could be achieved. The evaluation results indicated that the selected technology would allow the discharge limitations to be met. One of the primary concerns was the contracting effort related to the procurement of the selected treatment system. The number of vendors capable of meeting the treatment performance requirements was limited, and the proposed life cycle costs for the various vendors was an important consideration.

The relatively recent development of the oxidation technology (mid 1970s) is one of the reasons that corporate competition was limited. At the time design was initiated on the groundwater treatment facility (September 1991), only three vendors had exhibited the capabilities necessary to effectively treat a groundwater contaminated with both volatile and semivolatile constituents on a high flow rate (greater than 1 MGD) basis. Because it was anticipated that the treatment system would operate for a long period of time (greater than 30 years), it was anticipated that operation and maintenance (O&M) costs might be more significant than capital costs. Based on this, consideration was given to procurement of the UV Oxidation system based upon life cycle cost rather than capital cost. Based upon the outcome of the predesign testing, a sole source justification was used to procure the UV Oxidation vendor most appropriate for this specific groundwater application. Justification was contingent upon two primary criteria: the capability of the process to treat the contaminated groundwater to acceptable levels, and life cycle cost for the end user. The outcome of this logical progression was a “treat-off” between three vendors to allow the government to obtain the services of the vendor that could most cost effectively address the contaminants present in the site groundwater.

The contract to construct and operate the GWTP for one year was awarded on a firm fixed-price (FFP) basis to Sverdrup of St. Louis, Missouri. The O&M period was later expanded from one year to 2.5 years. At that time, the O&M contract was awarded to Ayers, Lewis, Norris and May of Muskegon, Michigan.

TREATMENT SYSTEM COST

Cost data for the Bofors Nobel project has been developed using available records at the facility. It is estimated that 7,500 pounds of organic compounds were removed from extracted groundwater between September 1994 and October 1997. It is also estimated that 700 million gallons of groundwater have been extracted from the site over the same time period. The following tables list capital and annual O&M costs for the project.

Capital Costs:

DIRECT COSTS	
System Mechanical	
Ultraviolet Oxidation System	2,200,000
Granular Activated Carbon	420,000
Ammonia Stripping	1,200,000
Solids Contact Units	600,000
Filter system	300,000
Sludge Handling	400,000
Chemical Feed	60,000
Chemical Storage	50,000
Hydrated Lime Feed System	150,000
Tankage and Pumps	150,000
System Plumbing/HVAC	900,000
Miscellaneous Equipment	250,000
Architectural/Structural	1,500,000
Electrical/Controls	800,000
Civil/Site	520,000
One Year O&M and System Startup	2,700,000
Contract Amount	**$12,200,000**

Operating Costs:

1997 Average Values	
Staffing/Labor	260,000
Offsite Laboratory Testing	160,000
Process Chemicals	70,000
Parts Replacement and Onsite Lab	20,000
Extraction Well Maintenance	10,000
Interior/Exterior Maintenance	40,000
Miscellaneous Expenses	5,000
Utility Usage	
Electricity (at $0.06 per kwh)	138,000
Natural Gas (at $0.50 per therm (CCF))	60,000
Annual Operating Cost	**$763,000**

Based on these costs, it can be calculated that $13,726,000 has been spent over the first three years of treatment system operation. This total cost translates to treatment costs of $1,830 per pound of contaminant removed, or $19.61 per 1000 gallons of groundwater treated. If removals are compared to annual O&M costs, yearly treatment costs are equal to $305 per pound of contaminant removed, or $3.27 per 1000 gallons of water treated.

REGULATORY/INSTITUTIONAL ISSUES

Surface water discharges from the treatment system are regulated by MDEQ. Discharge limitations for the site are listed in a previous section of this report (Treatment System Performance).

Groundwater cleanup criteria have not yet been established for this site. It is expected that the USEPA will develop these criteria in September 1998 in the form of a second amendment to the ROD for the site.

OBSERVATIONS AND LESSONS LEARNED

Procurement Issues:

It appeared that a FFP contract worked well overall for this project. It is possible that a cost-reimbursable contract would have allowed a higher level of responsiveness to field modifications (especially smaller modifications) to the system during the construction phase. These modifications might have been processed and implemented more rapidly under a cost-reimbursable contract.

Implementation Considerations:

A preliminary understanding of the site characteristics was obtained through the operation of the groundwater extraction system, which went online in 1978. It was recognized that until a remediation decision is made on the source of the contamination (the sludge lagoons), significant headway into reducing the volume of contamination annually treated would be difficult to achieve. It is anticipated that it will be easier to reduce the volume of contamination in the groundwater at the site following a capping or removal action. A preventive maintenance program to insure uninterrupted operation of the groundwater extraction system has been implemented to reduce downtime associated with biofouling and plugging of the well screens.

During selection of the principle treatment technology (UV Oxidation), it was recognized that water quality parameters associated with deposition of various species on the ultraviolet light quartz sheaths could impact system performance, and ultimately increase treatment cost if not addressed during system design. As a result of these concerns, pretreatment components were included in the treatment system to minimize the possibility of poor performance in the principal treatment units.

The establishment of effluent discharge criteria early in the design process is critical in order to provide a treatment system that will be capable of meeting all requirements. Toxicity testing of the plant effluent was stipulated following completion of construction. It is important that the designer be aware of the potential for chronic and acute toxicity testing, so that consideration may be given to alternative treatment schemes that may be necessary to meet toxicity requirements. At a minimum, the designer should closely consult and coordinate with the regulatory personnel responsible for developing the permit requirements to ensure that issues relative to specie selection and dilution concentrations are appropriately addressed for the specific site characteristics.

The concept of having the construction contractor perform initial (first year) O&M of the treatment system appeared to be a good idea. This allows more continuity and a smoother transition from the construction to O&M phase of the project.

Consideration should be given on future projects to the possibility that more system operators will be required during the early stages (first 2 years) of O&M. After this period, it is likely that most operational issues will have been addressed, and that less system troubleshooting will be necessary.

Technology Limitations:

Until an overall remediation strategy is developed to address contamination still present within the ten onsite lagoons, this technology is not expected to reduce the in-situ contamination in the site groundwater to below the levels required by MDEQ. The inability of the constructed system to rapidly reduce the level of site groundwater contamination is a result of the presence of a contamination source area overlying the impacted aquifer. Until the source area is addressed under a separate remediation action, contaminants will continue to leach to the groundwater. No alternative systems have been recommended or identified to improve upon what is currently in place at the Bofors Nobel superfund site for treatment of the contaminated groundwater.

While continuing plume containment appears to be successful, the overall concentrations of VOCs, SVOCs and metals have not been significantly decreased after several years of extraction and treatment.

Future Technology Selection Considerations:

The following observations were made based on conversations with the construction contractor, various vendors, the site construction manager and the using agency.

Perhaps the most important aspect of any project is communication. Maintaining open lines of communication between different agencies insures that the needs of all parties are incorporated into the final product. This aspect of the project was important not only in relation to the UV Oxidation process, but also in regard to items such as establishment of discharge criteria for the completed groundwater treatment facility. Due to the complexity and uniqueness of the selected contracting vehicle, communication was especially critical in this project.

The Treat-Off test associated with the predesign stage of the project required a concerted effort by the designer to insure that the goals of the "treat-off" were clearly communicated to the vendors. This was necessary to insure that the vendors realize that the "treat-off" test is the vehicle by which the selection of the full-scale process will be made. As a lesson learned, communication between the designer and the UV Oxidation vendors regarding the ultimate goals of the pilot testing should be emphasized.

Following selection of the most appropriate vendor for the UV Oxidation system, it was important that good communication was maintained during the design process. Items such as electrical connections, system control, cooling water requirements, system placement, foot print sizing and a host of other technical issues had to be presented to the supplier of the UV Oxidation system.

It is always important, when developing any proprietary specification, that an equitable project cost be maintained, and that cost increases following notification to the vendor of choice be minimized. During predesign activities, it should be emphasized to the prospective suppliers that the final report that they supply to the using agency will be used as the basis of selection for the finished product. It should also be emphasized that the vendor will be held to the costs presented within the report for the full-scale system, provided the final design assumptions do not change. It may be appropriate to enter into a legally binding agreement with the selected vendor to establish capital and operating costs. It should be recognized that operational costs for the full-scale system are an integral part of the projected system costs, and little can be done other than estimate the costs based upon supplier projections. The project designer should review the vendor costs for accuracy. Another potential option is to provide a fixed cost line item within the bid package, so that all prime contractors are aware of the costs associated with the UV Oxidation package.

Following award of the contract, it is important to develop a strong working relationship between the contractor, supplier, and designer, so that a quality product will be supplied. As a part of this process, it is very effective to hold pre-submittal conferences on all major equipment packages to insure that the contractor, supplier, and designer are all fully aware of the requirements of the specific process, and are aware of the responsibilities of each individual. The pre-submittal conferences will set the tone for the subsequent dealings between all of the parties.

REFERENCES

Major Sources for Each Section:

Site Characteristics:	Source #s (from list below) - 3, 4
Treatment System:	Source #s - 6, 8
Performance:	Source #s - 1, 2
Cost:	Source #s - 1, 2
Regulatory Institutional Issues:	Source #s - 4, 7
Schedule:	Source #s - 5
Lessons Learned:	Source #s - 7, 8

Chronological List of Sources and Additional References:

1. 1997 Annual Monitoring information - Facility Operations
2. Monthly Operating Reports 1994 - 1997
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5. Record of Decision, Bofors Nobel Superfund Site, Muskegon, Michigan; September 1990.
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