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Hazardous Waste Engineering
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Project Summary

Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites: Worker Health and Safety Considerations

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The full report was developed as an aid in evaluating costs associated with worker health and safety at hazardous waste cleanup sites. Previously available cost data were inadequate to identify health and safety costs consistently.

Six hypothetical cost scenarios were developed based on composites of existing sites. Experienced cleanup contractors were requested to prepare detailed cost estimates for the six scenarios. Cost estimates included both the base construction costs that would be incurred if no hazardous wastes were involved and the costs for each of four degrees of hazard. The hazardous conditions were patterned after the four levels of personal protection that have been established for workers on hazardous waste sites. The impacts of temperature variations were also estimated.

Separate cost estimates were obtained for transportation and disposal. Transportation costs were estimated based on information from transportation firms. Disposal costs were obtained from an existing report.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 requires the determination of remedial action costs for uncontrolled hazardous waste sites. Two basic methods are available for determining such costs:

1. Engineering cost studies that base their estimates on standard guides such as the Dodge and Means construction cost manuals.
2. Extrapolation of costs from bids and case study reports involving similar activities and problems for other sites.

The available cost figures seldom identify and often do not include additional costs associated with protection of worker health and safety. Ten categories of health and safety cost components are presented in Table 1.

The purpose of this project was to determine the incremental health and safety costs associated with worker protection at hazardous waste sites. The basic factors evaluated were the impacts of different degree-of-hazard conditions and the effects of temperature variations on total remedial action costs. Costs and impacts were evaluated for distinct remedial action activities, referred to as unit operations.

Approach

Six remedial action scenarios were developed to obtain and quantify estimates from cleanup contractors for costs associated with worker health and safety on hazardous waste sites. This approach provided a consistent format for estimating costs, and addressed the concerns of contractors for confidential and proprietary information. Each sce-

nario was composed of a number of distinct unit operations. A combination of these unit operations represented a complete remedial action program for each of the hypothetical sites. The site characteristics and a total of 16 different remedial action unit operations were based on cleanup operations at actual uncontrolled hazardous waste sites. The resulting scenarios were reviewed by selected site contractors to ensure that they reflected realistic site conditions and provided a reasonable format for developing cost estimates. The six scenarios developed were:

1. Surface removal at above-ground storage sites (drums and bulk tanks).
2. Surface removal at above-ground storage site (PCB electrical equipment).
3. Subsurface removal at a trench burial site.
4. Containment of landfill by leachate collection and surface sealing.
5. Containment of landfill by surface sealing and slurry trench.
6. Closure of a surface impoundment using solidification.

The site contractors that provided cost estimates for the six scenarios were selected because of their (1) past experience with sites similar to those presented in the scenarios, (2) willingness to participate, (3) availability of personnel routinely involved in cost estimates, and (4) familiarity with health and safety requirements on hazardous waste sites. Each scenario was estimated by two different contractors, except for Scenario 5, which had only one estimate.

Contractors provided cost estimates for four degrees of hazard and base construction costs (i.e., costs associated with performing the required tasks on a site that did not involve hazardous wastes). The four degrees of hazard described reflect the conditions associated with the use of a personal protective equipment. Table 2 summarizes the levels of protection used in defining scenario conditions.

Because of the impact of ambient temperature on the degree of hazard and the potential use of these data for cost estimates in different climates or seasons, contractors were also requested to estimate the impact of three temperature ranges on their total cost estimates for unit operations and remedial action scenarios. The temperature ranges used were:

- Moderate temperatures ranging from 0 to 18°C (32 to 65°F)

Table 1. *Worker Health and Safety Cost Components**

1. *Personal Protection*
   a. *Levels of protection*
   b. *Types of protection*
      - *foot*
      - *hand*
      - *eyes*
      - *body*
      - *head*
      - *respiratory*
      - *hearing*
      - *entry/communications*
   c. *Mobile and stationary equipment storage and operation stations*

2. *Medical Services/Surveillance*
   a. *Medical examinations*
      - *baseline physical*
      - *respirator program*
      - *follow-up to baseline*
      - *unscheduled due to illness or accident*
      - *follow-up to highly toxic exposures*
   b. *On-site*
      - *first aid (explosions, animal/insect bites, falls, exposure, etc.)*
      - *emergency communication*
      - *medical personnel*
      - *rescue equipment*
      - *emergency showers/eye washes*
      - *emergency medical facilities/equipment*
      - *periodic or continuous monitoring while working*
   c. *Off-site*
      - *transportation (ambulance)*
      - *medical facilities*
      - *fire department*
      - *life squad*
      - *coordination with health/medical services and authorities*

3. *Personnel Training*
   a. *Waste handling*
   b. *Emergency procedures*
   c. *CPR and first aid*
   d. *Protective gear/equipment*
   e. *Monitoring equipment*
   f. *Communication equipment*
   g. *Special/seasonal equipment*
   h. *Rehearsals*
   i. *In-house training*
   j. *Outside programs*
   k. *Safety and health practices*
   l. *Entry and exit procedure*
   m. *Technical orientation—basic sciences*

4. *Manpower Inefficiencies*
   a. *Restricted mobility*
   b. *Waste handling procedures*
   c. *Monitoring requirements*
   d. *Buddy system*
   e. *Pre- and post-work activities*
   f. *Heat stress*

5. *Record Keeping*
   a. *Management requirements*
   b. *Labor union requirements*
   c. *Governmental*
   d. *Medical*
   e. *Training*
   f. *Work history*
   g. *Site safety/maps*
   h. *Manifests, receipts, and permits*

6. *Decontamination*
   a. *Personnel*
   b. *Protective gear*
   c. *Cleanup equipment*
   d. *Monitoring equipment*
   e. *Required facilities, equipment, structures, etc.*
   f. *Change rooms/facilities*

7. *Site Security*
   a. *Restriction of access by personnel or vehicles*
   b. *Signs and tags*
   c. *Security personnel*
   d. *Security systems/equipment*
   e. *Coordination with law enforcement agencies*

8. *Insurance*
   a. *Comprehensive general liability*
   b. *Environmental impairment liability*
   c. *Workman's compensation*
   d. *Specific coverage*
   e. *State and federal requirements*

9. *Emergency Preparedness*
   a. *Fire fighting*
      - *chemicals*
      - *extinguishers*
      - *turnout gear*

Table 1. *(Continued)*

b. *Spill containment/control*
- *absorbents/chemicals*
- *containers and collection equipment*
- *oil booms/containment devices*

10. *Hazard Assessment*
a. *Sample packaging and shipping requirements*
- *special containers*
- *chain-of-custody*
- *special packing materials*
- *manifests and bills of lading*
- *labels, markings, and placards*
- *waste product information sheets*
- *authorized transporters*

b. *Monitoring equipment*
- *oxygen detectors*
- *radiation detectors*
- *combustible gas detectors*
- *field test kits*
- *organic vapor analyzers*
- *specialized laboratory equipment*

c. *Sampling equipment*
- *disposable sampling equipment*
- *specialized equipment*
- *special material construction*

d. *Analytical costs (field and contract laboratories)*
- *qualitative*
- *quantitative*

e. *Review and interpretation of data*
- *establishment of levels of protection*
- *source identification*
- *assessment of contaminant migration*

**This table is the list provided to contractors. Suggested additions to components include cost of maintaining an industrial hygienist or other qualified and safety expert on-site, computer ready data for medical and hazard assessments, and epidemiology studies for illnesses that may occur.*

Table 2. *Conditions Associated with Levels of Personal Protection*

1. *Level A—requires full encapsulation and protection from any body contact or exposure to materials (i.e., toxic by inhalation and skin absorption).*
2. *Level B—requires self-contained breathing apparatus (SCBA), and cutaneous or percutaneous exposure to unprotected areas of the body (i.e., neck and back of head) is within acceptable exposure standards (i.e., below harmful concentrations).*
3. *Level C—hazardous constituents known; protection required for low level concentrations in air; exposure of unprotected body areas (i.e., head, face, and neck) is not harmful.*
4. *Level D—no identified hazardous or toxic substance present, but conditions are monitored and minimal safety equipment is available.*
5. *No hazardous or toxic substances on site—standard base construction costs.*

- High temperatures ranging from 18° to 38°C (65° to 100°F)
- Low temperatures ranging below 0°C (32°F)

Health and safety and base construction costs per unit were calculated for each of the remedial action unit operations included in the scenarios. Health and safety costs per unit are summarized for the remedial action unit operations in Table 3.

To calculate increased costs resulting from health and safety considerations, the ranges of total costs (per unit) for each of the four degrees of hazard were divided by the base construction costs (per unit) for each of the unit operations. Cost multipliers for estimating increased costs are shown in Table 4. The range of values shown, particularly for unit operations that involve direct handling of contaminated materials and wastes, reflects the contractors' different approaches and experiences involving protection of worker safety and health.

Estimates for unit operations not included in the six cost estimating scenarios can be determined by comparing potentials for worker exposures in similar unit operations. The average variations for health and safety costs of similar unit operations can be used to estimate those for other unexamined unit operations.

Average variations in remedial actions costs were calculated for each of the three temperature ranges under the four degrees of hazard. These cost variations were then compared for the three temperature ranges to determine the effects of temperature changes on costs. Table 5 provides a cost multiplier which can be used to estimate health and safety costs when applied to the base construction cost for the same temperature conditions. A multiplier for base construction costs is also provided to adjust estimates of base construction costs for the three temperature conditions that are not related to health and safety considerations (e.g., viscosity of hydraulic fluid at cooler temperatures may reduce equipment efficiency). Finally, a percent increase in health and safety costs for higher and lower temperatures is provided relative to the health and safety costs at moderate temperatures.

Average cost rates for hazardous waste transportation are listed in Table 6. Disposal costs were obtained from another EPA document and are summarized in Table 7 which provides an average of the reported cost ranges.

Applicability of the Data

The incremental costs of health and safety considerations can be used to evaluate alternative remedial actions. Cost estimates for designs of remedial action unit operations can be adjusted to reflect the anticipated degree of hazard. This step will permit a more accurate estimate of relative costs for alternative remedial action plans.

Though cost multipliers calculated from this project cannot be considered all inclusive, they can estimate the impact of health and safety considerations on costs (see Table 4). The relative impact of temperature (or the percent increases in variations) can also be estimated using the cost multipliers or the percent increase provided in Table 5.

Cost estimates obtained from engineering cost studies using standard guides can be adjusted to reflect health and safety costs. Standard cost reference guides such as Means and Dodge

Table 3. *Median Cost Per Unit Operation*

Unit Operation	Unit of Measure	Base Construction Cost Per Unit	Incremental Health and Safety Costs Per Unit				No. of Cost Estimates
			Level D	Level C	Level B	Level A	
Surface Water Controls:							
Surface Seal—Synthetic Membrane	m^2	$17.03 ± 2.62	$2.56 ± 1.43	$3.35 ± 1.29	$3.95 ± 1.54	$4.21 ± 1.73	2
	sq yd	$20.37 ± 3.13	$3.06 ± 1.71	$4.00 ± 1.54	$4.72 ± 1.34	$5.03 ± 2.06	2
Surface Seal—Clay	m^2	$2.74	$0.26	$0.52	$0.66	$0.74	1
	sq yd	$2.29	$0.22	$0.43	$0.55	$0.62	1
Revegetation	ha	$63,701.00 ± 57,329.00*	$30,587.50 ± 30,245.50*	$37,112.50 ± 35,897.50*	$38,082.50 ± 36,867.50*	$39,926.00 ± 38,711.00*	5
	acre	$25,480.50 ± 22,931.50*	$12,235.00 ± 12,099.00*	$14,845.00 ± 14,359.00*	$15,233.00 ± 14,747.00*	$15,970.50 ± 15,484.50*	5
Contour Grading	m^3	$4.63 ± 1.41	$1.24 ± 1.86	$1.70 ± 0.97	$1.99 ± 1.03	$2.34 ± 1.37	3
	cu yd	$3.31 ± 1.09	$0.95 ± 0.66	$1.30 ± 0.74	$1.52 ± 0.79	$1.79 ± 1.04	3
Surface Water Diversion	m^3	$8.98 ± 7.07	$4.68 ± 4.55	$5.55 ± 5.17	$6.40 ± 5.94	$6.91 ± 6.44	2
	cu yd	$6.87 ± 5.41	$3.58 ± 3.41	$4.25 ± 3.96	$4.90 ± 4.55	$5.28 ± 4.92	2
Basins and Ponds	m^3	$6.36 ± 1.84	$1.87 ± 1.46	$2.66 ± 1.73	$2.87 ± 1.59	$3.09 ± 1.50	2
	cu yd	$4.87 ± 1.41	$1.43 ± 1.12	$2.03 ± 1.32	$2.20 ± 1.22	$2.36 ± 1.15	2
Dikes and Berms	m^3	$14.30 ± 1.52	$7.72 ± 6.38	$10.08 ± 7.43	$10.28 ± 7.24	$11.47 ± 8.12	2
	cu yd	$10.94 ± 1.16	$5.53 ± 4.88	$7.71 ± 5.68	$7.89 ± 5.56	$8.78 ± 6.21	2
Ground-Water Controls:							
Well Point System	m^2	$113.36	$11.70	$19.63	$24.06	$31.34	1
	sq yd	$11.50	$9.78	$16.41	$20.12	$26.20	1
Drain System	m^3	$44.05 ± 5.18	$13.15 ± 9.84	$17.96 ± 11.79	$19.99 ± 12.48	$22.33 ± 11.73	2
	cu yd	$33.68 ± 3.96	$10.06 ± 7.53	$13.74 ± 9.02	$15.28 ± 9.54	$17.07 ± 8.97	2
Bentonite Slurry Trench	m^3	$50.96	$4.46	$6.97	$16.40	$18.24	1
	cu yd	$38.97	$3.41	$5.33	$12.54	$13.94	1
Waste Controls:							
Chemical Fixation (Solidification)	m^3	$83.36 ± 58.30	$23.79 ± 21.04	$31.10 ± 26.98	$32.08 ± 27.79	$35.27 ± 30.63	2
	cu yd	$63.53 ± 44.57	$18.19 ± 16.09	$23.77 ± 20.62	$24.52 ± 21.24	$26.96 ± 23.41	2
Excavation of Contaminated Soil	m^3	$17.53 ± 14.73	$58.55 ± 44.03	$71.55 ± 65.65	$91.75 ± 67.05	$104.51 ± 75.52	6
	cu yd	$121.61 ± 119.24	$44.78 ± 33.67	$54.71 ± 50.20	$70.16 ± 51.28	$79.92 ± 57.75	6
Treatment of Contaminated Water	1/day	$7.11 ± 7.02	$2.68 ± 2.67	$2.73 ± 2.72	$3.08 ± 3.06	$3.50 ± 3.48	3
	gpd	$26.92 ± 26.57	$10.15 ± 10.12	$10.23 ± 10.27	$11.64 ± 11.58	$13.23 ± 13.15	3
Drum Processing	208 l (55 gal drums)	$304.86 ± 268.68	$447.98 ± 396.04	$564.65 ± 495.02	$682.11 ± 593.22	$796.83 ± 694.15	4
Bulk Tank Processing	30,280 l (8,000 gal tanks)	$2,627.00 ± 1,405.00	$2,604.50 ± 1,557.50	$3,743.00 ± 1,817.00	$6,314.00 ± 644.00	$8,394.00 ± 40.00	2
Transformer Processing	Transformer	$270.00 ± 60.00	$--	$622.29 ± 573.72†	$--	$--	2

*Higher than likely costs shown here are result of one contractor's costs being far higher than balance of cost figures obtained for this unit operation.
†This unit operation was deemed appropriate for performance only at level C. Costs at Levels D, B, and A were not provided.

construction cost manuals do not include additional costs for health and safety considerations. Thus these cost estimates represent base construction costs. They can be adjusted by using the health and safety cost multipliers for the anticipated degree of hazard and by adding those costs to the base construction costs.

When cost estimates are based on case studies of other sites with similiar activities, costs of health and safety considerations are generally included. To adjust these costs, for a specific site, the degree of hazard would have to be determined. For case history reports, the temperature range would also need to be determined. The costs could then be adjusted on each unit operation to reflect the differences in costs above base construction costs for the degree of hazard associated with the case study sites, versus the anticipated degree of hazard of the site being examined.

Cost differences for various regional and seasonal temperature conditions can be calculated by using the cost multipliers or percent difference of health and safety costs for the temperature conditions provided in Table 5.

Limitations of the Data

Several factors that affect cost were identified but not addressed in this project. These include scale economies, regional differences, management policies and procedures, and type and size of company.

Previous studies have shown that scale economies and regional variations are significant factors in construction costs, and they can be assumed to have significant impacts on health and safety costs as well. The existing data made it impossible to quantify the impacts of these factors.

This project identified differences in management procedures and policies that affect cost estimates. Such differences currently exist because regulatory standards and guidelines are evolving and are not uniformly enforced on hazardous waste sites. Thus the safety management policies and procedures of individual contractors can significantly affect health and safety costs. These costs can also be affected by the emphasis that a contractor places on using equipment instead of manpower to accomplish a task. The reason is that workers operating machinery have a smaller potential for exposure than workers directly handling containers and contaminated materials.

Guidance was provided to minimize differences in the assumptions on

Table 4. *Cost Multipliers for Total Costs at Four Degree-of-Hazard Levels*

Unit Operation	Degree-of-Hazard Conditions: Level D Avg. Cost Multiplier*	Level D Range	Level C Avg. Cost Multiplier*	Level C Range	Level B Avg. Cost Multiplier*	Level B Range	Level A Avg. Cost Multiplier*	Level A Range	Number of Estimates
Surface Water Controls:									
Surface Sealing—Synthetic Membrane	1.14	1.80—1.20	1.19	1.14—1.24	1.22	1.17—1.28	1.24	1.17—1.30	2
Surface Sealing—Clay	1.09		1.19		1.24		1.27		1
Revegetation	1.16	1.05—1.50	1.24	1.12—1.60	1.26	1.13—1.62	1.28	1.14—1.65	5
Contour Grading	1.23	1.09—1.46	1.33	1.17—1.57	1.40	1.22—1.65	1.46	1.24—1.80	2
Surface Water Diversion Structures	1.35	1.12—1.57	1.44	1.20—1.67	1.51	1.24—1.77	1.54	1.24—1.83	2
Basins and Ponds	1.25	1.09—1.41	1.37	1.21—1.53	1.41	1.28—1.54	1.46	1.35—1.56	2
Dikes and Berms	1.47	1.07—1.86	1.66	1.21—2.11	1.68	1.24—2.11	1.75	1.26—2.24	2
Ground Water Controls:									
Well Point System	1.09		1.15		1.18		1.23		1
Drain System	1.28	1.09—1.47	1.38	1.16—1.60	1.43	1.19—1.66	1.48	1.27—1.69	2
Slurry Trench	1.09		1.14		1.32		1.36		1
Waste Controls:									
Chemical Fixation (Solidification)	1.22	1.11—1.32	1.29	1.16—1.41	1.30	1.17—1.42	1.33	1.19—1.47	2
Excavation of Wastes/Contaminated Soil	3.08	1.33—6.45	3.37	1.44—7.13	4.09	1.50—8.85	7.29	1.56—20.90	6
Treatment of Contaminated Water	1.19	1.07—1.38	1.21	1.13—1.38	1.26	1.14—1.43	1.28	1.14—1.49	3
Drum Processing	2.01	1.34—2.66	2.28	1.44—2.92	2.64	1.52—3.77	3.17	1.58—4.53	4
Bulk Tank Processing	1.95	1.86—2.03	2.48	2.38—2.58	4.19	2.73—5.64	5.49	3.07—7.90	2
Transformer Processing	—†		2.93	1.23—4.63	—†		—†		2

*Values given include 100 percent for base construction costs.
†This unit operation was deemed appropriate for performance only at Level C. Costs at Levels D, B, and A were not provided.

Table 5. *Health and Safety Cost Multipliers and Percent Increased Costs at Different Temperatures*

Temperatures °C	Temperatures °F	Base Construction Multiplier†	Level D H/S Multiplier†	Level D % Increase#	Level C H/S Multiplier†	Level C % Increase#	Level B H/S Multiplier†	Level B % Increase#	Level A H/S Multiplier†	Level A % Increase#
0-18°	32-65°	1.00	0.60	0	0.89	0	1.07	0	1.27	0
18-38°	65-100°	1.06	0.64	8	0.94	14	1.19	17	1.44	19
<0°	<32°	1.09	0.82	11	1.12	15	1.44	15	1.87	17

*H/S (i.e., Health and Safety) cost multiplier of base construction costs at the same temperature.
†Base construction cost multipliers of base construction costs at 0-18°C (32-65°F).
#Increased health and safety costs from costs at 0-18°C (32-65°F).

which cost estimates were based, but some variation was apparent. For example, different contractors apparently allocated capital expenditures and depreciation of equipment at different rates, depending on their past experience. Though none of the estimates were based on 100 percent allocation of new equipment costs, the rate of depreciation and allocation of capital expenditures seemed to vary for each contractor.

Estimates of increased costs resulting from health and safety considerations can be obtained by applying the cost multipliers provided in this Summary to

Table 6. *Average Transportation Costs by Type of Transporter*

Type of Transporter	Rate* ($/km)	Rate* ($/mile)
Treatment, Storage, and Disposal Facilities Providing Service to Customers	$1.66	$2.67
General Freight Transportation Companies Which May Haul Hazardous Waste on Request	$2.24	$3.60
Hazardous Waste Transportation Companies Specializing in Hazardous Waste	$2.30	$3.70

*Rates based on fully loaded trucks.

Table 7. *Averages of Hazardous Waste Management Quoted Prices for All Firms in 1980 and for Nine Major Firms in 1981**

Type of Waste Management	Type or Form of Waste	$/Metric Ton		$/English Unit	
		1980	1981	1980	1981
Landfill	Drum	$144.00	$204.00	$30/55 gal drum	$42.50/55 gal drum
	Bulk	$ 49.50	$ 69.00	$45/ton	$62.50/ton
Land Treatment	All	$ 14.50	$ 14.50	$ 0.06/gal	$ 0.06/gal
Incineration	Relatively clean liquids, high Btu value	$145.00	$ 33.00†	$ 0.55/gal	$ 0.13/gal†
	Liquids	$145.00	$145.00	$ 0.55/gal	$ 0.55/gal
	Solids, heavily toxic liquids	$521.50	$593.00	$ 1.80/gal	$ 2.25/gal
Chemical Treatment	Acids/Alkalines	$ 47.50	$ 56.50	$ 0.18/gal	$ 0.22/gal
	Cyanides, heavy metals, highly toxic wastes	$290.50	$428.50	$ 1.10/gal	$ 1.63/gal
Resource Recovery	All	$130.50	$165.00	$ 0.50/gal	$ 0.63/gal
Deep Well Injection	Oily wastewaters	$ 28.00	$ 28.00	$ 0.11/gal	$ 0.11/gal
	Toxic rinse waters	$198.00	$198.00	$ 0.75/gal	$ 0.75/gal

*Interviews were conducted in May of 1980 and February of 1982.
†Some cement kilns and light aggregate manufacturers are now paying for wastes.

Source: US EPA, Review of Activities of Major Firms in Commercial Industry: 1981 Update, SW-894.1, Washington, D.C., May 1982.

current estimates of base construction costs. However, because of inflation and market changes, the original 1982 cost estimates will soon be outdated. Ongoing efforts are needed to validate and update the costs provided in this Summary.

The full report represents a starting point for identifying the impacts of health and safety considerations on the cost of remedial action at the hazardous waste sites. Future activities should include continued efforts to update and validate estimating methods that accurately reflect the impacts of regional variations, scale economies, health and safety considerations, inflation, and market changes.

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The complete report, entitled "Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites: Worker Health and Safety Considerations," (Order No. PB 86-176 344/AS; Cost: $16.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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The EPA Project Officer can be contacted at:
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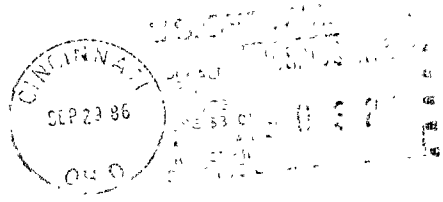

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