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THE SIGNIFICANCE OF SPILLS: HOW DO ENVIRONMENTAL EMERGENCIES AFFECT ENVIRONMENTAL QUALITY?

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Introduction

No one contests that large oil spills such as the EXXON VALDEZ or TORREY CANYON have severe effects on the local environment. Likewise, derailments of tank cars or accidents to road tankers that release hazardous materials can be locally devastating and frightening. Similarly, fires can release clouds of toxic materials that affect residents in the area. The manufacture, transportation, and storage of hazardous materials is a requirement of modern society, however, and accidents inevitably happen, even in the most carefully managed operations.

These environmental emergencies usually generate intense, but short-lived, publicity and the response is inevitably more attention given to the issue, inquiries as to cause, a tightening of practices, and even some research into prevention, remediation, and risk assessment. Regrettably, after a year or two, the incident is often forgotten and practices and practitioners gradually relax, at least until the next incident.

Much effort, however, has gone into reducing both the numbers and impact of environmental emergencies. There is now a greater degree of vigilance over processes and procedures that can lead to accidental spills. Ironically, this can mean that

This issue features an article by Don Mackay and Kang Qiang on the significance of spills to the total input of chemicals to the environment. The study shows that spills account for a significant portion of some chemicals' input to the environment. For other chemicals, the contribution of spills is not as important. Significantly, spills often result in high levels of a particular chemical in a specific area. This article puts into perspective the contribution of spills to overall pollution in relation to inputs from other sources.

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such activities as monitoring, reporting, surveillance, and continuing research into improved prevention practices become a lower priority. What may be forgotten is that, apart from the local disruption, environmental emergencies can also have significant impacts on overall environmental quality. The volume and magnitude of these impacts have not, to our knowledge, been fully assessed.

This article describes some of these impacts and begins to quantify them. This subject is growing in importance due to the success of recent measures designed to improve environmental quality, such as waste treatment, recycling, waste reduction, and "pollution prevention", which is a collective term for combined actions that reduce environmental impact. To appreciate this trend requires a little history of how environmental management has evolved over the years.

A Brief History of Our Environmental Times

There has been a significant change in focus in environmental management and regulation in the last two decades, especially since 1990. Early regulations were aimed at reducing the concentration of specific "priority" contaminants in effluents to ensure that the local receiving environment experienced tolerable concentrations, i.e., levels well below those that would cause toxic effects. Significant progress was made in "cleaning up" these sources of pollution. At the same time, concern about oil and chemical spills has resulted in improved transportation practices and faster, more effective remedial measures to mitigate the effects of the remaining "inevitable" spills. These situations were relatively simple to identify, and the remedies relatively simple to justify. In short, the obvious problems have been addressed, pollution has been reduced, and environmental quality has improved significantly.

Ironically, it seems that there has not been a corresponding reduction in public concern about environmental quality. In large measure, this is probably due to a greater realization that low levels of contaminants can have adverse effects on humans and on the environment at large. The insidious contaminants and their effects are not visible to the eye.

For example, CFCs may increase exposure to UV radiation, leading to skin cancer. Carbon dioxide may lead to global warming. Inhaled PAHs may cause cancer, while other chemicals such as PCBs may promote this disease. Certain estrogens may cause unexpected hormonal effects, reducing fertility and distorting sexual differentiation. We now realize that we were lucky in the 1960s and 70s that no major public health problems occurred. Some assert that these problems did occur, however, and remain with us even now (Colborn *et al.*, 1996). We tend to be more fearful of the invisible enemy which subtly affects our well being and that of our offspring than of more obvious problems.

Accordingly, the focus of environmental management has shifted from controlling concentrations (g/m^3) in the environment to controlling discharges or loadings (kg/h) to the environment. This is determined in part by the realization that when the large, obvious sources are controlled, a multitude of minor sources often remain. These sources consist of such small operations as dry cleaners and gas stations, and even consumer products such as window blinds containing lead.

Toluene may be rigorously controlled in the refinery effluent but the average person may be more exposed to it from domestic use of rubber cement and correction fluid. There seems little merit in reducing an effluent from 100 to 10 kg/year if, in the same region, 5000 kg/year are released from use of domestic products or if there are regular spills of 1000 kg.

What is obviously needed is a systematic evaluation of all sources of all chemicals of concern, followed by a rational program of source reduction. In some cases, international actions are required. Many of these reductions are likely to be achieved by "pollution prevention" measures rather than "end-of-pipe" treatment. An example is the substitution of chlorine dioxide for chlorine in pulp bleaching, which essentially eliminated dioxins from mill effluents.

This prevention approach is now more acceptable to corporations in part because of more enlightened attitudes at the corporate board level. These attitudes are perhaps prompted by concerns about public image, but also by a desire to **avoid** regulations rather than **satisfy** them with all the attendant legal complications and expense. Better to have no discharges of chromium or mercury by not using these metals at all, than to face the prospect of continuing, expensive monitoring of effluents to increasingly stringent levels. Even in the most carefully operated facilities, emergencies and chemical releases caused by weather or human error occasionally happen. These can result in painful, protracted litigation which wastes time and money, breeds distrust, and creates an impression of corporate disdain for environmental quality.

This philosophy, coupled with a belief that the public has a right to know what is being released and where it is being released, is at the heart of the U.S. Toxics Release Inventory Program, Environment Canada's National Pollutant Release Inventory (NPRI) (Environment Canada, 1995), and the Canadian Chemical Producers Association (CCPA) reports on "Reducing Emissions" (CCPA, 1993). The CCPA reports contain not only data on recent emissions, but also projections for the next five years, which are equally important. The NPRI data are particularly valuable as the major sources of emissions are identified, as well as how the chemical is discharged, i.e., to air, water, land or underground.

It is important to appreciate that these emission inventories are only estimates. There are severe technical difficulties in making such estimates and present figures are probably accurate, in most cases, only to a factor of 2 or 3. For example, according to the NPRI data for 1993, 30 tonnes of vinyl chloride were released, while the CCPA figure is 20 tonnes, which is in very good agreement. However, these data do not necessarily include emissions from environmental emergencies such as spills and fires, or fugitive emissions, such as evaporation from chemicals stored by numerous small users after purchase and perhaps lying "forgotten" in a warehouse or in leaky drums in a yard.

Are these unaccounted sources significant? If so, they greatly complicate the issue of environmental management of chemicals because we may fail to identify and control the key sources. This may undermine our ability to establish the link between discharges and environmental concentrations and, subsequently, between exposure and risk of effects. Establishing this link is one of the primary incentives for gathering the data in the first place. Regulating and reducing chemical contamination requires a full appreciation of all sources, just as the corporate accountant requires a full appreciation of all sources of income.

The Present Situation

To investigate this issue, a modest project was undertaken in which data were gathered from Environment Canada's Environmental Emergencies Branch, the NPRI, and other sources. The aim was to compare the quantities (tonnes/year) that are released industrially with amounts released in emergency incidents.

Environment Canada's National Environmental Emergency Centre and Environmental Technology Centre generously provided data on all spills in Canada from 1974 to 1984. The "Spill List" is impressive, naming more than 250 substances that were spilled and a large number of incident reports from many sources and jurisdictions.

There were 68 spills of sulphur (which is more a nuisance than a threat), totalling 69 720 tonnes, 107 spills of ammonia (which can be devastating), totalling 466 tonnes. There was one spill of a negligible quantity of zinc stearate (which is probably a useful skin ointment). There were 334 spills of PCBs, or fluids containing PCBs (which are viewed as very nasty) totalling 89 tonnes.

The Environment Canada NPRI data and the CCPA data for the same chemicals were obtained and Table 1 was compiled for those chemicals that appear on the "Spill List" and on either or both of the other lists. The result is a list of 47 chemicals for which spill and emission data exist. The 10-year spill total was divided by 10 to give an annual average. It should be noted that the "Spill List" and emission data are from different time periods, an issue which is addressed later.

The data show some interesting features.The CCPA reports emissions of 8 tonnes of ammonium sulphate in 1993, but the NPRI figure for that year is over 1500 tonnes. Apparently, there are careless distributors! The NPRI figure for mercury in 1993 is 2.9 tonnes, but an average of

Table 1 Chemical Spills and Emissions

Chemical	Spills from 1974 to 1984			CCPA-reported emissions (tonnes)		NPRI-reported inventory (tonnes)	Ratio of NPRI / Spill
	Spill #	Amount (tonnes)	Annual Avg.	1992	1993	1993	
Acetone	4	9.930	0.993	1 900	1 900	3 341.649	3 370
Acetylene	1	0.013	0.0013	120	66		
Acrylonitrile	1	4.600	0.460	21	19	26.350	57.3
Ammonia anhydrous	107	466.200	46.620			27 505.032	590
Ammonium nitrate	63	4 237.640	423.764	1 000	98	1 464.388	3.46
Ammonium sulphate	8	261.700	26.170	0.01	8	1 534.344	58.6
Aniline	1	0.100	0.010			< 0.500	
Asbestos	15	310.470	31.047	490	220	294.064	9.47
Benzene	12	13.7600	1.376	1 300	1 300	2 927.571	2 130
Carbon tetrachloride	1	1.800	0.180	58	41	40.300	229
Chlorine	36	120.970	12.097	100	66	4 859.703	402
Chlorine dioxide	2	0.300	0.030			3 090.830	10 300
Copper	1	2.200	0.220			14 011.619	63 700
Cyanides	7	2	0.200		0.24	65.481	327
Cyclohexane	1	0.113	0.0113	3 000	3 100	3 448.828	305 000
Diethanolamine	1	0.200	0.020	9.1	0.41	1 001.953	50 000
Ethanol	3	50.790	5.079	15	18		
Ethyl acrylate	3	1.130	0.113	1.3	4.8	5.330	47.2
Ethyl benzene	4	0.790	0.079	230	210	622.396	7 880
Ethylene	2	178.500	17.850	3 400	3 100	3 564.991	200
Ethylene glycol	31	593.830	59.383	870	570	3 825.509	64.4
Formaldehyde	10	41.050	4.105	240	220	478.677	117
Hydrazine	3	4.520	0.452			3.767	8.33
Hydrochloric acid	123	3 335.130	333.513	890	630	1 302.565	3.91
Maleic anhydride	1	2.800	0.280	0.027	0.55	0.726	2.59
Mercury	11	19.900	1.990			2.928	1.47
Methane	1	0.060	0.006	3 300	3 700		
Methanol	18	734.750	73.475	2 600	2 400	30 622.382	418
Methyl ethyl ketone	4	7.660	0.766	470	430	3 697.318	4 830
Methyl methacrylate	3	3.410	0.341	68	25	50.068	147
Naphthalene	3	6.400	0.640	38	65	146.125	228
Nitric acid	48	139.600	13.960	880	4	45.596	3.27
Nitrous oxide	1	0.600	0.060	33 000	29 000		
Phenol	10	14.200	1.420	24	32	211.729	149
Phosphoric acid	12	36.500	3.650	32	4.3	1 170.995	321
Phosphorus	16	45.520	4.552			0.006	0.0013
Phthalic anhydride	3	7.200	0.720	1.6	1.8	2.791	3.88
Propylene	1	9.100	0.910	860	760	1 278.33	1 400
Propylene oxide	2	22.020	2.202	260	61	60.941	27.7
Styrene	24	5 001.290	500.129	130	130	1 942.493	3.88
Sulphuric acid	155	13 362.470	1 336.250	120 000	82 000	71 221.121	53.3
Toluene	13	105.210	10.521	480	470	7 342.124	698
Toluene diisocyanate	7	1.980	0.198			0.596	3.01
Trichloroethylene	1	0.130	0.013	0.89	0.01	419.023	32 200
Vinyl acetate	8	7.410	0.741	69	69	153.82	208
Vinyl chloride	31	183.390	18.399	20	17	32.534	1.77
Xylenes	14	46.590	4.659	140	130	8 625.059	1 850

1.99 tonnes were spilled each year from 1974 to 1984. The volume from spills of vinyl chloride is similar to the total emission figures of vinyl chloride reported by CCPA and amounts to about 55% of the NPRI-reported emissions.

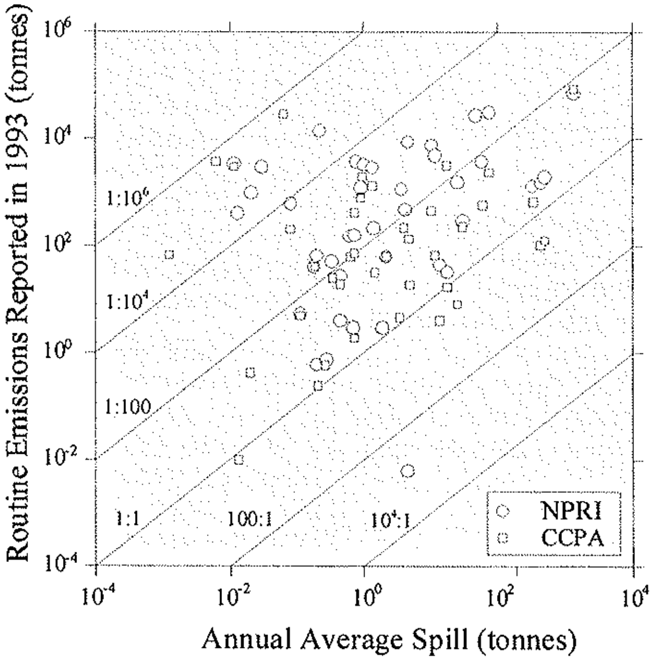

Figure 1 Routine Emissions vs Average Spill as Reported by the NPRI and CCPA *(See Table 1)*

Other chemicals for which spills account for an appreciable fraction of emissions, i.e., 10% or more, are ammonium nitrate, asbestos, hydrazine, hydrochloric acid, maleic anhydride, nitric acid, phosphorus, phthalic anhydride, styrene, and toluene diisocyanate.

Figure 1 is an attempt to display these data graphically. It is a plot of the CCPA and NPRI data, on a log scale, as the y axis versus the average spill data, and on a log scale on the x axis. The data comprises a cluster of points. The diagonal line labelled 1:1 corresponds to equal quantities on both axes, i.e., emissions equal spills. The 1:100 line, which is to the upper left, represents one tonne spilled for every 100 tonnes emitted. The 100:1 line, which lies to the lower right, represents 100 tonnes spilled for every 1 tonne emitted.

Clearly, points that lie to the lower right represent chemicals in which spills are important and must be considered as a significant contaminant source. Conversely, for points to the upper right, spills may be unimportant when compared with day-to-day emissions.

The following is an interpretation of Figure 1.

- For about 5% of the chemicals, spills exceed emissions, i.e., they lie to the lower right of the 1:1 line.
- For about 20%, spills represent 1/10 to 100% of emissions, i.e. they lie between 1:10 and 1:1.
- For about 20%, spills represent 1/100 to 1/10 of emissions.
- For the remaining 55%, spills are less than 1% of emissions, i.e., they lie to the upper left of the 1 to 100 line.

The median of the cluster corresponds to a line of about 1:120, which can be loosely interpreted to mean that, on average, spills represent slightly less than 1% of emissions.

The overall conclusion is, that for some 25% of the chemicals, releases during environmental emergencies can be significant, i.e., they are more than 10% of routine emissions and should be factored in to any system for evaluating releases to the environment. Releases from environmental emergencies are likely to be most significant for compressed gases and liquids, because it is virtually impossible to recover the spilled product. Solids are more readily recovered.

More Recent Data

As already mentioned, a potential flaw in this data analysis is that the time periods do not coincide. In an attempt to remedy this discrepancy, spill data were sought for the period from 1984 to 1995. Some problems immediately became apparent as can be seen by the numbers in Table 2.

Table 2 Average Annual Spills

	1975 to 1984 (tonnes /year)	1984 to 1995 (tonnes/year)
acrylonitrile	0.46	121
chlorine	12	588
ethylbenzene	0.08	35
phenol	1.4	142
sulphuric acid	1 336	2

There is undoubtedly a lot of variation from decade to decade, but investigation of these and other data suggest that a combination of factors contribute to poorer quality in the more recent data. It is suspected that units were occasionally reported incorrectly, e.g., pounds vs tonnes. In some cases, the spill may have been only 1% phenol but was nevertheless reported as phenol. The chemical may be misidentified, e.g., confusing phenol with phenolic resins or trichlorethane with trichlorethene. About once every 20 years, there are huge spills. Recently, reporting has not been as complete or accurate as in past years, due to cutbacks at both provincial and federal levels of government.

Perhaps the most significant problem, however, is that spill reporting is not mandated by legislation at the federal level. Most information is obtained on a voluntary basis from provinces. A province that reports diligently then appears to have more spills than a province that reports less diligently or only partially. With recent budget reductions, it is likely that the situation will continue to deteriorate and the Canadian public will be deprived of an accurate and comprehensive view of the true magnitude and impact of spills on their environment.

Discussion

The following aspects of these data deserve closer scrutiny.

Accuracy and Completeness of the Data - As estimating emissions and spill quantities is fraught with difficulties, the figures presented here should be viewed as approximations only. If an emission is less than a defined reporting level, it may not be reported at all. Many spills are not reported since Environment Canada relies on the provinces and even on municipalities and industry for much of the data.

The Potential for Catastrophe - Returning to the example of vinyl chloride monomer (VCM), the CCPA and NPRI data average some 25 tonnes/year. A typical single tank of VCM can contain 28 000 gallons or about 70 tonnes of VCM, more than twice the annual emission.

In 1980, there was a train derailment at MacGregor, Manitoba involving 31 tank cars, 12 of which contained VCM, and 2 of which leaked an estimated 70.6 m^3 (approximately 50 tonnes). At Oakville, Manitoba, a train with 24 cars of VCM was involved in an accident in which all but 2 of the VCM cars were derailed. If the worst had happened, 850 tonnes of VCM could have been released. Fortunately, there was only minor leakage. In 1988, in Parsgrunn, Norway, 90 tonnes of a mixture containing VCM were released from an industrial source.

In a similar vein, it is estimated that emissions of chlorinated "dioxins" and "furans" are 100 g/day (Environment Canada, 1985). Thomas and Spiro (1996) recently suggest that the emissions of dioxins expressed as "toxic equivalents" are about 3000 g/year in the U.S. The actual mass of all chemicals considered in this category is probably an order of magnitude greater, i.e., 30 kg/year. During the St. Basile le Grande fire near Montreal, an estimated 6.4 kg were released in one incident. At Sevesso, Italy, an area of 18 km^2 was contaminated with TCDD. The Sandoz incident in 1986 resulted in a release of 30 tonnes of pesticides into the Rhine. Meharg and Osborne (1994) have "estimated that 70% of PCB sources in the U.K. are due to accidents and that one fire at the PVC recycling plant produced up to 45% by weight of dioxins and furans of the total known, non-accidental sources in the U.K."

Meharg (1994a) has also estimated that 50 to 100 tonnes of chlorinated and non-chlorinated aromatic compounds were produced in three fires in the U.K., as well as quantities of cadmium, lead, antimony, and zinc. Meharg (1994b, 1994c) has also reviewed the ecological impacts of such events concluding that they can be very significant locally and even nationally.

It is widely recognized that spills can have devastating effects locally and the potential for local catastrophe is high. It has not been recognized, however, that the quantities spilled can be similar in magnitude to annual emissions, and in some cases, can actually exceed annual emissions.

Oil Spills - Spills of crude oil cause the most environmental degradation, at least on a local scale. Worldwide, there are about 30 spills per year exceeding 100 tonnes. From 1967 to 1989, there were 65 spills of over 8900 tonnes each. It is believed that the Kuwait Invasion and the Ixtoc I blowouts each resulted in over a million tonnes of oil being released. There have been at least 9 spills of 30 000 to 300 000 tonnes each (Paehlke, 1995). The potential thus exists for release of very large quantities of hydrocarbons which dwarf national annual emissions. Clearly there is a strong case for continued vigilance to prevent such spills.

Emissions of toluene from the chemical industry appear to be 400 to 500 tonnes/year. The EXXON VALDEZ released some 40,000 tonnes of oil. If, conservatively, 1% of this oil was toluene, then a year's supply of toluene was released during that one incident over a matter of days and in a relatively small area. The local exposure to toluene must have been orders of magnitude higher than the Canadian annual average.

Smaller releases also arise from spillage from road tankers and fugitive emissions from fuel storage and transfer facilities, including gas stations. There may also be releases of oil from road runoff and improperly disposed crankcase oil. These quantities can be substantial compared to emissions from industrial facilities.

Chemophobia

It is easy to use data such as these to promote chemophobia. That is not our intent. On the contrary, it is a tribute to those who manufacture, transport, store, and use chemicals, that there have been so few incidents and, to our knowledge, no loss of life. This happy situation has been reached by diligent application of loss prevention practices encouraged by regulatory efforts.

Apart from the inherent desirability of avoiding accidents for reasons of economics, safety, and health, there is a need to reassure a skeptical and often chemophobic public that chemicals are receiving appropriate "responsible care" and stewardship. What is needed is continuing vigilance and diligence, and not relaxation. This is certainly recognized by the chemical industry which stands to lose much in an atmosphere of chemophobia.

A Concluding Canadian Perspective

Canada is fortunate to have a relatively clean, high quality environment, free from the severe contamination that exists in regions of Eastern Europe or even parts of the United States. This is partly due to a limited industrial manufacturing base and a focus on resource industries, which are well distributed and "diluted" across the vast Canadian landscape. Canada's chemical industry is certainly a vital part of the economy, but is more limited than that of the United States or Germany. Canadians probably need as many hazardous chemicals on a per-capita basis as residents of any other industrially advanced country. Accordingly, and in contrast to the United States, the sources of chemicals to the Canadian environment tend to be less from manufacturing and more from transportation and distribution. We believe, but presently have no evidence to justify it, that if Figure 1 of this article was drawn for the United States, it would show a cluster of points moved to the upper left, i.e., emissions are more significant and spills less significant in their contribution to overall pollution.

Perhaps Canada can lead the way by demonstrating how a federal government can implement national policies to prevent and remediate spills, as well as include them in toxics release inventories. It is clear that significant quantities of chemicals can be released in local environmental emergencies, quantities comparable in some cases to entire annual national routine emissions. To neglect these sources is obviously unacceptable in any coordinated program to reduce chemical inputs and to assess their effects on humans and the environment.

A strong case can thus be made for integrating spill quantities into the NPRI system, continuing the process of preventing spills and mitigating their effects, as well as generally reducing the quantities of chemicals that enter our environment from all sources. These measures should not have to wait for the next big spill in order to be implemented.

Acknowledgements

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To broaden the scope of this newsletter, and to provide more information on industry and foreign activities in the field of spill control and prevention, readers are encouraged to submit articles on their work and views in this area.

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