Accident Epidemiology and the U.S. Chemical Industry: Accident History and Worst-Case Data from RMP*Info

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This article reports on the data collected on one of the most ambitious government-sponsored environmental data acquisition projects of all time, the Risk Management Plan (RMP) data collected under section 112(r) of the Clean Air Act Amendments of 1990. This RMP Rule 112(r) was triggered by the Bhopal accident in 1984 and led to the requirement that each qualifying facility develop and file with the U.S. Environmental Protection Agency a Risk Management Plan (RMP) as well as accident history data for the five-year period preceding the filing of the RMP. These data were collected in 1999–2001 on more than 15,000 facilities in the United States that store or use listed toxic or flammable chemicals believed to be a hazard to the environment or to human health of facility employees or off-site residents of host communities. The resulting database, RMP*Info, has become a key resource for regulators and researchers concerned with the frequency and severity of accidents, and the underlying facility-specific factors that are statistically associated with accident and injury rates. This article analyzes which facilities actually filed under the Rule and presents results on accident frequencies and severities available from the RMP*Info database. This article also presents summaries of related results from RMP*Info on Offsite Consequence Analysis (OCA), an analytical estimate of the potential consequences of hypothetical worst-case and alternative accidental releases on the public and environment around the facility. The OCA data have become a key input in the evaluation of site security assessment and mitigation policies for both government planners as well as facility managers and their insurers. Following the survey of the RMP*Info data, we discuss the rich set of policy decisions that may be informed by research based on these data.

KEY WORDS: Accident epidemiology; chemical accident history; Clean Air Act; risk management

1. INTRODUCTION

The tragedy at Bhopal in December 1984, followed by a subsequent release of aldicarb oxime from a facility in Institute, West Virginia, resulted in great public concern in the United States about the potential danger posed by major chemical accidents. This public concern was translated into law in three different legislative programs. The first law intended specifically to address the problem of chemical accidents in the United States was the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA; Public Law 99-499), which required state and local governments to plan for emergencies and required

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chemical facilities to report information about chemical hazards to government and the public. The other two legislative programs addressing chemical accidents were enacted under sections 304 and 112(r), respectively, of the Clean Air Act Amendments of 1990 (Public Law 101-549). The first of these was the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) standard (29 CFR Part 1910), which required facilities having specified hazardous chemicals to implement accident prevention measures designed to protect workers. The most recent program, arising from section 112(r) of the Clean Air Act Amendments, was the Environmental Protection Agency's (EPA's) Risk Management Program (40 CFR Part 68). The EPA rule "Risk Management Programs for Chemical Accidental Release Prevention" (hereafter the Rule), sets forth a series of requirements aimed at preventing and minimizing the consequences associated with accidental chemical releases. The Rule applies to facilities (both public and private) that manufacture, process, use, store, or otherwise handle regulated substances at or above specified threshold quantities (which range from 500–20,000 pounds).[7]

The U.S. Environmental Protection Agency (EPA) estimated in its 1996 economic impact analysis justification study (USEPA/CEPPO, 1996) to the Office of Management and Budget (OMB) that about 66,000 facilities nationwide would be regulated under the Rule, including many facilities not covered under OSHA's PSM standard. With some exceptions, the Rule requires all regulated facilities to prepare and execute a Risk Management Program, which contains the following elements:

1. A Risk Management Plan (RMP), a report capturing certain details about the facility's accident prevention program, emergency response program, and hazard assessment along with administrative information about the facility.
2. A hazard assessment to determine the consequences of a specified worst-case scenario and other accidental release scenarios on public and environmental receptors and provide a summary of the facility's five-year history of accidental releases.
3. An accidental release prevention program designed to detect, prevent, and minimize accidental releases.
4. An emergency response program designed to protect human health and the environment in the event of an accidental release.

Beginning June 21, 1999, the Rule (section 68.42) also requires that regulated facilities submit their five-year history of accidental releases to the EPA as part of their Risk Management Plan and periodically update their submission every five years or when significant changes occur. The data reported here reflect the state of the RMP*Info database as of June 29, 2001, corrected for a few known errors (as described in the next section).

The purpose of this article is to describe the reporting facilities, the accidents that have occurred at these facilities in the first five years covered by the Rule, and the potential off-site consequences in the event that worst-case scenarios occurred at these facilities. The basic approach followed in this study has been the epidemiological methodology known as retrospective cohort study design. Epidemiology is the study of predictors and causes of illness in humans. Its use in studying industrial accidents has been proposed in a number of quarters (e.g., Saari, 1986; Rosenthal, 1997). The motivating idea is to study the demographic and organizational factors of those facilities whose accident histories are captured in RMP*Info to determine whether any of these factors have significant statistical associations with reported accident outcomes, positive or negative, just as one might use demographic or life-style data for human populations to determine factors that might be associated with the origin and spread of specific illnesses. This article provides the descriptive statistics on RMP*Info and serves as a foundation for analytical work (e.g., Elliott, Kleindorfer, and Lowe, 2003; Elliott, Wang, Lowe, and Kleindorfer, 2003) exploring the structure of statistical relationships between accident outcomes, facility characteristics, regulations in force, and the demographics of the communities in which facilities are located.

As several commentators have already noted, RMP*Info represents a significant step in understanding the scope of accidents in the chemical industry and in promoting more effective accident prevention and mitigation.[8] New business models have emphasized

[7] This is not meant to imply that any facility that does not meet threshold inventory requirements is completely exempt from the accidental release prevention provisions of 112(r) since a General Duty provision may still apply if the facility poses a potential hazard to the public.

[8] See, for example, Rosenthal (1997) and Mannan and O'Connor (1999) for discussions of the promise of using large-scale comparative data to determine robust predictors of accidents in the chemical industry.

the importance of learning across facilities, based on benchmarking and best practices. Using data in RMP*Info, together with other organizational and financial data on the facilities and companies involved, is taking this approach to another level. Indeed, looking across the entire U.S. chemical industry, as well as across specific segments, technologies, and chemicals therein, clearly holds the potential for detecting and validating factors predictive of severity and frequency of accidents. These models can then provide input for rational prioritization of risk management and regulatory policy initiatives designed to prevent future accidents.

The article proceeds as follows. In Section 2 we describe the nature of RMP*Info and the preliminary data screening undertaken to assure data quality for RMP*Info. Section 3 describes the nature of the facilities that filed, with the top 20 by chemical use and by the North American Industry Classification System (NAICS) Code listed explicitly. Section 4 presents results on accident frequency and severity, including details by chemical and NAICS Code. Section 5 presents some simple analyses on timing and location of accidents as well as on the size of plants (measured by the number of full-time equivalent (FTE) employees) involved in these accidents. Section 6 focuses on the Offsite Consequence Analysis (OCA) based on worst-case and alternative release scenarios in the RMP*Info database. Conclusions are offered in Section 7.

2. INTRODUCTION TO RMP*INFO AND PRELIMINARY DATA SCREENING

This section describes the information collected under the Rule. We also discuss data quality issues here as a necessary precursor to our analysis in the rest of the article. As promulgated in the Rule, the following are the data elements required to be reported in RMP*Info for each covered facility:

1. Executive Summary: This must cover the nature of the facility and its policies for prevention and emergency response, as well as a verbal summary of the facility's five-year accident history.
2. Section 1: Facility identification information and basic demographics on the facility, its parent company, and its covered processes, including a listing of regulated chemicals above threshold quantities at the facility and indications of whether the source is covered by various other regulatory processes (e.g., OSHA Process Safety Management (PSM) Standard, Emergency Planning and Community Right-to-Know Act (EPCRA) Section 302, Clean Air Act (CAA) Title V).
3. Sections 2 and 4: Description of worst-case release scenarios for regulated toxic (Section 2) and flammable (Section 4) substances above threshold quantities at the facility.
4. Sections 3 and 5: Description of alternative release scenarios for regulated toxic (Section 3) and flammable (Section 5) substances above threshold quantities at the facility.
5. Section 6: Five-year accident history for the facility, including a separate record for each accidental release from covered processes that occurred during the five-year reporting period for the facility.
6. Sections 7 and 8: Prevention Program descriptions for Program 3 processes (Section 7) and Program 2 processes (Section 8), including details on hazard analysis methods, operating procedures, training, and other related information, together with a list of the major hazards identified for these processes.
7. Section 9: Details on the emergency response plan at the facility, including indications of which of several federal and state regulations on emergency response apply to the facility.

As of June 29, 2001, 15,430 facilities had filed with the RMP*Info database. The vast majority (14,500 of 15,430) of facilities covered in this analysis filed their RMP data by the initial deadline of June 21, 1999, and some corrections were made on additions of new filers or exemptions of existing filers until June 29, 2001. Certain other facilities producing or utilizing flammable fuels such as propane sought legislative and judicial relief from the RMP requirements, and were granted a temporary judicial stay from RMP compliance and reporting requirements. Indeed, many of these facilities were eventually excluded from the Rule under the Chemical Safety Information, Site Security and Fuels Regulatory Relief Act (Public Law 106-40) passed in August 1999. In January 2000, the judicial stay was lifted and an additional 930 facilities, primarily propane-producing facilities and fuel wholesalers, filed risk management plans under the Rule.

The result of all of these developments in the implementation of the Rule is that the time window represented by RMP*Info is not uniform for all facilities. A facility, for example, that filed its RMP on May 10, 1999 could have interpreted the five-year history covered by the Rule to be May 11, 1994 through May 10, 1999. Other facility owners interpreted more precisely as given above, and anticipated filing updated RMPs if their facility had an accident between the time they filed and June 20, 1999. In addition, as will be discussed below, some facilities were initially exempt from filing, but eventually held to be covered by the Rule. These facilities then filed after the initial filing date of June 21, 1999, and their RMP reported accidents for the five-year period preceding their later filing date. Notwithstanding changes, the vast majority of the data represents accident histories for the period mid 1994 to mid 1999.

While, as noted above, the original estimate of the covered facilities expected to file under the Rule was 66,000, we will see in the data reported below that the number of facilities actually filing was, in fact, 15,430 (23.2% of the original estimate), with 1,205 of these facilities (7.8% of 15,430) reporting some 1,970 accidents over the five-year period of interest. A further restriction in information available to the public is that worst-case data, in the form of the required Offsite Consequence Analysis (OCA) noted under (1) above, have not been made available to other than "covered persons" in order to reduce the possibility that these data might be used by terrorists to target specific facilities. Members of the public can get limited access to OCA data for individual facilities by visiting any of 50 federal "reading rooms." The database itself has been named RMP*Info and has been available to the public after August 1999.[9]

Concerning accuracy and consistency, a first step in any epidemiologic study is the screening of data, and we therefore note some of the steps taken with respect to this critical issue in data quality assurance. In this regard, it is important to note that nearly all submissions under the Rule were electronic, with 97% of the final RMP submissions made using standardized software, entered on diskette, and mailed to the EPA. While manual submissions using a standard paper form were allowed, these accounted for only 3% of the total.[10] Electronic submission is critical to data quality since the data submission system, called RMP*Submit, used a standard data entry template and had a number of self-correcting and error-checking mechanisms built into it to assure that the data submitted were in a standard format and met other consistency checks (such as range checks).[11] Notwithstanding the significant effort undertaken by EPA to assure the overall quality of the data, the research team also undertook its own data-cleaning and screening checks. In particular, the following two steps were undertaken by the research team:

1. Extensive interviews with plant-level and corporate managers responsible for submitting the RMP data were undertaken during the period November 1998 through June 1999 to determine whether there were ambiguities in the minds of facility managers as to what data were required. The primary difficulties were with understanding the requirements for the OCA, both worst-case and alternative scenarios. The managers at both large and small facilities generally exhibited a clear understanding of the requirements of the Rule and they showed a positive and constructive attitude toward the RMP process, where smaller companies typically relied on trade associations and consultants to assist them in this process. The effort expended on complying with the Rule was considerable. Indeed, data on some 10 companies collected as part of this pre-screening process indicated that, including internal and external consultants' time, person-hours dedicated to putting the data together for RMP*Info ranged from 50 hours for some small companies to nearly 3,000 hours for some large facilities.
2. Standard approaches for quality assurance of data, commonly employed in epidemiologic studies, were employed to look for data errors. For all variables included in this report, frequency distributions were reviewed to look for unusual or unexpected values ("outliers"). Where appropriate, cross-tabulations were performed to look for internal inconsistencies in the data. Outliers were discussed with EPA staff, who reviewed these cases to determine their validity.[12]

[9] Since September 11, 2001, the RMP*Info data remain available to the public only on a more limited base through 50 EPA "reading rooms" set up for this purpose. For details on public access, refer to 40 CFR Chapter 4, and to the website http://www.epa.gov/ceppo/.

[10] Personal communication of 01/24/00 from Karen Schneider, who guided much of CEPPO's effort in data input and the quality assurance program surrounding RMP*Submit.

[11] It is not our purpose to review or comment on the extensive effort undertaken to assure data quality in the RMP process and the details of the software developed to assure data quality under the RMP*Submit system. The details of this can be found by consulting the extensive documentation provided by CEPPO at their website http://www.epa.gov/ceppo/.

[12] An example of this quality assurance process may be informative. A frequency distribution of the number of full-time equivalent

Because the number of reported deaths is such an important data element, further checking was done of each accident in which nonemployee deaths occurred. This led to the final result (reported in Tables VII and VIII below) that while there were 32 deaths among employees at reporting facilities, all of the originally reported 45 public responders' deaths and 11 public deaths were data errors.[13] We have incorporated these corrections on deaths to public responders and other nonemployees into our analysis. However, there may be corrections and revisions to RMP*Info at any time via the submission of a corrected RMP by any facility; other, less obvious changes to the database after June 29, 2001, will not be reflected in this report. In particular, in interpreting results from RMP*Info, it is critical to know the date of the last update incorporated in the analysis and any notable revisions, such as those above, undertaken to the data.

3. PLANT DEMOGRAPHICS FOR FACILITIES REPORTING IN RMP*INFO

This section reports the basic demographics of the facilities that filed under RMP*Info. There are 15,430 facilities in RMP*Info and there are 1,970 reported accidents in RMP*Info, with 1,205 facilities reporting at least one accident. However, the sample size for various analyses will not remain constant at 15,430 and 1,970, since some sites have multiple processes and some processes use multiple listed chemicals.

Tables I–III list various characteristics of filers under the Rule. Table I lists the 20 most commonly reported chemicals, along with the number of plants using each chemical and the number of FTE employees at these facilities. Also listed are the total numbers of facilities reporting use of at least one listed toxic or one flammable chemical. The average facility employees reported 158 FTE, ranging from facilities with less than 0.5 FTE (recorded as 0 FTE in RMP*Info) to 48,000 FTE. Half of the facilities have 11 FTEs or fewer. Of the top 20 chemicals in terms of reporting facilities, note that 11 are toxics and 9 are flammables.

Table II lists the 20 most commonly reported industrial sectors, along with the number of plants reporting each process and the number of FTE employees at these facilities. The industrial process is specified by the NAICS code of the facility reporting. The most common sector reported is farm supply wholesalers (4,357 or 29% of facilities), followed by water treatment and irrigation systems (2,000 or 13% of facilities) and sewage treatment (1,421 or 9% of facilities).

Table III lists the numbers and percentages of reporting facilities, which indicated that they were covered under various state and federal regulatory programs covering process safety, notification requirements, and emergency response regulations. Table III also lists the maximum Prevention Program Level of any process at reporting facilities (this was computed by considering all processes at each reporting facility and taking the maximum of the Prevention Program Levels across all processes at a given facility).[14] We note that 7,209 (or 47%) of the reporting facilities had at least one process at level 3, therefore requiring a full Process Hazards Analysis to be undertaken and reported in the facility's RMP.

As noted in the introduction, there is a substantial difference between the number of facilities that were

employees (FTEs) reported at each facility revealed a range from 0 to 48,000 FTEs. Eight hundred eighty-eight plants reported 0 FTEs and 14 plants reported over 15,000 FTEs. The authors of this report queried EPA staff about these outliers. EPA staff noted that all 14 of the facilities with over 15,000 FTEs were military bases and confirmed that these values were plausible. EPA staff hypothesized that the facilities with 0 FTEs might be related to specific industries. That led the authors to determine the NAICS codes of the facilities reporting 0 FTEs. The most common processes were Water Supply and Irrigation Systems (246 facilities), Farm Supplies Wholesalers (229), and Farm Product Warehousing and Storage Facilities (186). EPA investigated whether it is plausible for such facilities to report 0 FTEs. EPA staff responded, in part, to this question as follows: "Coops are usually large organizations, frequently covering several states, but certainly serving many communities with individual outlets. They reported having zero FTEs because they are reporting on a storage facility that is unmanned except for certain seasons. According to the way FTEs are calculated, if they have one person there for five months, they have less than 0.5 FTE and report zero employees." (Breeda Reilly, CEPPO, personal communication, December 14, 1999.) Further discussion with EPA staff addressed other categories of processes associated with 0 FTEs, until the research team and EPA staff were satisfied that the data were accurate.

[13] Breeda Reilly at EPA/CEPPO confirmed such errors. Four facilities reported total 45 public responders' fatalities but they were reporting errors. There was no public responders' death. In addition, two facilities reported a total of 11 on-site public fatalities and two facilities reported total 68 on-site public injuries. But they turned out to be errors. In fact, there were zero incidents for on-site public fatalities and injuries.

[14] EPA has defined three different Prevention Program Levels to reflect the potential for public impacts and the level of effort needed to prevent accidents. Only minimal requirements are imposed on Program Level 1 processes, while Program Level 3 processes are subject to much higher compliance requirements; Program Level 2 processes face intermediate requirements. Program Level 3 processes are those processes that are either subject to OSHA's PSM standard or belong to nine specific SIC codes placed in Program Level 3 by the EPA.

Table I. Twenty Most Commonly Reported Chemicals and Characteristics of the Facilities Reporting Them[15]

Chemical Name	Chem Type	Chem ID	Number of Filers	Avg FTEs of Filing Facilities	St. Dev. FTEs
Ammonia (anhydrous)	T	56	8207	120	345
Chlorine	T	62	4450	227	2088
Propane	F	98	1324	189	649
Flammable mixture	F	155	823	139	356
Sulfur dioxide (anhydrous)	T	49	762	180	1029
Ammonia (conc. 20% or greater)	T	57	513	138	346
Butane	F	118	323	225	436
Formaldehyde (solution)	T	1	279	280	1092
Hydrogen fluoride/hydrofluoric acid (conc. 50% or greater) [hydrofluoric acid]	T	55	269	310	699
Isobutane [propane, 2-methyl]	F	107	247	238	513
Pentane	F	125	171	241	348
Propylene [1-propene]	F	129	163	479	888
Toluene diisocyanate (unspecified isomer) [Benzene, 1,3-diisocyanatomethyl-]	T	77	161	268	779
Methane	F	93	160	394	749
Vinyl acetate monomer [acetic acid ethenyl ester]	T	29	154	241	449
Hydrogen	F	149	137	591	1085
Isopentane [butane, 2-methyl-]	F	115	116	272	381
Acrylonitrile [2-propenenitrile]	T	25	115	301	638
Ethylene oxide [oxirane]	T	9	107	359	721
Propylene oxide [oxirane, methyl-]	T	12	104	325	695
Total facilities reporting at least one toxic chemical	T		13714	158	1229
Total facilities reporting at least one flammable chemical	F		2648	207	669

originally projected to file under the Rule (66,000) and the number of actual filers (15,430). While a full study of this matter is beyond the scope of the present article, a few reasons should be noted. First, the original estimate was intended to be a conservative estimate to OMB to assure that the full costs of the regulatory burden imposed by the Rule would not be underestimated. Second, as noted, several large groups, including propane distributors, were excluded by P.L. 106-40. Third, a number of companies are likely to have responded to the Rule by reducing their inventories below the specified threshold limits required for reporting. Finally, noncompliance is always a possible explanation for the observed results. Which of these or other explanations are valid in various industrial sectors is clearly an important area for future research.

4. FACILITY ACCIDENT RATES AND SEVERITIES

Table IV provides data on the frequency of accidents at the facilities in RMP*Info. In particular, we note that 1,205 facilities (7.8% of 15,430 facilities) had at least one accident during the reporting period, and 355 facilities (2.3% of 15,430 facilities) had multiple accidents during the five-year reporting period. The cumulative incidence of accidents, expressed as a fraction of total reporting facilities, was 1,970/15,430 (or 12.8%).

Table V reports all accidents by listed chemical involved in the accident for the 25 chemicals most frequently involved in accidents. The three most frequently involved chemicals were ammonia (anhydrous), chlorine, and flammable mixtures. Chemical frequencies ranged from 696 accidents for anhydrous ammonia facilities to a single accident for 22 listed chemicals. Of the 140 chemicals listed under the Rule, 80 were involved in at least one accident during the reporting period. Table VI lists accidents by NAICS code of the process involved in the reported accident for the top 25 processes in terms of frequency of accidents.

[15] If the same chemical is used in more than one process at a facility, it is only listed once in Table I; however, the same facility may

Table II. Twenty Most Commonly Reported NAICS Codes and Characteristics of the Facilities Reporting Them[16]

NAICS Code	NAICS Description	Filers with the Specified NAICS Code	Avg. FTEs of Filing Facilities	Std. Dev. of FTEs of Filing Facilities
42291	Farm supplies wholesalers	4357	7	11
22131	Water supply and irrigation systems	2000	206	2337
22132	Sewage treatment facilities	1421	216	2153
49312	Refrigerated warehousing and storage facilities	576	196	303
211112	Natural gas liquid extraction	482	14	23
42269	Other chemical and allied products wholesalers	371	26	38
49313	Farm product warehousing and storage facilities	342	5	17
11511	Support activities for crop production	305	7	7
325211	Plastics material and resin manufacturing	255	263	519
325199	All other basic organic chemical manufacturing	252	248	500
454312	Liquefied petroleum gas (bottled gas) dealers	242	16	94
311615	Poultry processing	226	805	510
115112	Soil preparation, planting, and cultivating	194	10	10
325188	All other basic inorganic chemical manufacturing	193	243	577
32411	Petroleum refineries	168	370	396
221112	Fossil fuel electric power generation	140	86	113
32512	Industrial gas manufacturing	135	58	163
49311	General warehousing and storage facilities	131	600	4273
42271	Petroleum bulk stations and terminals	128	17	86
311612	Meat processed from carcasses	124	424	411

Tables VII and VIII report the number of injuries and deaths for employees/contractors and non-employees, respectively. There were a total of 1,987 injuries and 32 deaths among workers/employees, and there were 167 injuries and 0 deaths among non-employees, including public responders. There were 215 total hospitalizations and 6,057 individuals given other medical treatments.

Table IX notes the damage to property and the nonmedical off-site consequences resulting from accidents during the reporting period. Property damages alone were in excess of $1 billion, and they do not include business interruption costs, including losses in shareholder value and lost business associated with accidents.[17] In addition, large numbers of community residents were affected by accidents (over 200,000 involved in evacuations and shelter-in-place incidents). The ecological consequences of the accidents are also reported in Table IX. Four hundred and eight accidents (21%) resulted in on-site property damage; 51 (2.6%) resulted in off-site property damage; 174 (8.8%) resulted in evacuations; and 97 (5.0%) resulted in individuals being sheltered in place.

5. BASIC DESCRIPTIVE ANALYSIS OF ACCIDENT HISTORY

Analytic studies are concerned with establishing statistical associations between predictor variables such as facility characteristics and outcome variables such as frequency and severity of accidents of facilities having various characteristics. We will only pursue the simplest of such studies here, in the spirit of merely

appear more than once in this table if more than one of the top 20 chemicals are present at the facility. For the same reason, the number of facilities indicating the use of at least one toxic or flammable material will exceed the total number of filers since some facilities have both toxic and flammables on site.

16 In Table II, if a facility has multiple processes with the same NAICS code, it is reported only once. However, the same facility may appear more than once if it supports processes in more than one NAICS code.

17 These latter costs are likely to be larger, and perhaps much larger, than losses due to property damage. For a study of the full shareholder costs of environmental accidents, see Klassen and McLaughlin (1996).

Table III. Reporting Facilities Covered by Various Regulatory Programs

Name of Regulatory Program	Number of Facilities Covered (from a Total of 15,219 Reporting)	Percent of Total Facilities Reporting under the Rule Covered by Each Specific Program
Process safety and hazards permitting programs		
OSHA-PSM	7,600	49
CAA-Title V	2,267	15
EPCRA-302	12,689	82
Emergency response programs		
OSHA 1910.38	12,98	84
OSHA 1910.12	9,190	60
RCRA (40 CFR 264, 265, 279.52)	3,176	21
OPA 90 (40 CFR 112, 33 CFR 154, 49 CFR 194, 30 CFR 254)	1,424	9
State EPCRA rules/law	11,215	73
Prevention program level		
Level 1	647	4
Level 2	7,574	49
Level 3	7,209	47

describing the basic characteristics of RMP*Info in this article.[18]

Table X displays the incidence of reported accidents over the initial reporting period for RMP*Info.[19] Several artifacts of the data collection process confuse the results shown in Table X. The first artifact is that the lower numbers for 1994 and 2001 are because these years were only partly within the five-year reporting window for most companies. The second artifact is that RMP*Info lacks data on the age of the facilities reporting to it. We know that the reporting facilities existed as of their initial reporting date but we do not know for what part of the preceding five years they existed or conducted processes covered by the Rule. Without this information, it is not possible to compute the rate of accidents per plant per year to deduce anything about changes over time in the accident rate.[20] The third artifact is that plants that ceased operation before June 21, 1999 (or that ceased activities covered by the Rule) are not included in the RMP*Info database and any accidents occurring at these plants are not recorded. If plants with high accident rates were disproportionately likely to cease operation early in the reporting period, there could actually have been more accidents in the early years, in contrast to the apparent findings shown in Table X. Given these uncertainties, we cannot state whether

Table IV. Frequency of Accidents at Individual Facilities

Number of Accidents at Facility	Number of Facilities in RMP*Info with the Indicated Number of Accidents in the Reporting Period	Total Accidents Represented
1	850	850
2	197	394
3	69	207
4	31	124
5	25	125
6	12	72
7	7	49
8	4	32
9	1	9
10	3	30
11	2	22
13	1	13
14	2	28
15	1	15
Total	1,205	1,970

18 For a more detailed analysis of RMP*Info data relating facility characteristics and regulations to accident frequency and severity, see Elliott, Kleindorfer, and Lowe (2003).

19 Three accidents are omitted from this table because they were reported to occur in 1992 (2 cases) or 1993 (1 case). It is unclear if these represent data entry errors in the submissions, with the wrong date reported, or unnecessary reporting of accidents that occurred prior to requirements of the Rule. One accident was reported to occur in 1966 (1 case) but it was a data entry error. Breeda Reilly at EPA/CEPPO confirmed that the accident happened in 1996. We included the accident in our analysis.

20 Of course, this might be done for particular sectors or technologies if plant ages for these sectors or technologies can all be reliably determined.

Table V. Accidents Reported in RMP*Info by Chemical Involved in the Accident for the Entire Period 1994–2001 (25 Chemicals Most Frequently Involved)

Chemical Name	Chemical ID	Number of Accidents
Ammonia (anhydrous)	56	696
Chlorine	62	534
Flammable mixture	155	100
Hydrogen fluoride/hydrofluoric acid (conc. 50% or greater) [hydrofluoric acid]	55	98
Chlorine dioxide [chlorine oxide (ClO_2)]	71	59
Propane	98	51
Sulfur dioxide (anhydrous)	49	46
Ammonia (conc. 20% or greater)	57	46
Hydrogen chloride (anhydrous) [hydrochloric acid]	54	33
Hydrogen	149	31
Methane	93	27
Formaldehyde (solution)	1	21
Hydrogen sulfide	63	21
Butane	118	21
Ethylene oxide [oxirane]	9	19
Pentane	125	16
Titanium tetrachloride [titanium chloride (TiCl4) (T-4)-]	51	15
Ethylene [ethene]	95	14
Isobutane [propane, 2-methyl]	107	14
Ethane	94	13
Trichlorosilane [silane, trichloro-]	153	13
Nitric acid (conc. 80% or greater)	58	12
Oleum (fuming sulfuric acid) [sulfuric acid, mixture with sulfur trioxide]	69	12
Toluene diisocyanate (unspecified isomer) [Benzene, 1,3-diisocyanatomethyl-]	77	11
Vinyl chloride [ethene, chloro-]	101	11

Table VI. Accidents Reported in RMP*Info by NAICS Code of the Process Involved in the Accident for the Entire Period 1994–2001 (Top 25 Processes Most Frequently Involved)

NAICS Description	NAICS Code	Number of Accidents
Petroleum refineries	32411	182
Water supply and irrigation systems	22131	118
Sewage treatment facilities	22132	112
All other basic inorganic chemical manufacturing	325188	93
Farm supplies wholesalers	42291	93
Other chemical and allied products wholesalers	42269	89
All other basic organic chemical manufacturing	325199	81
Alkalies and chlorine manufacturing	325181	79
Poultry processing	311615	71
Nitrogenous fertilizer manufacturing	325311	70
Pulp mills	32211	55
Refrigerated warehousing and storage facilities	49312	55
Petrochemical manufacturing	32511	52
Animal (except poultry) slaughtering	311611	47
Plastics material and resin manufacturing	325211	37
Natural gas liquid extraction	211112	35
Frozen fruit, juice, and vegetable manufacturing	311411	31
Paper (except newsprint) mills	322121	30
Meat processed from carcasses	311612	29
Industrial gas manufacturing	32512	25
Other basic organic chemical manufacturing	32519	23
Pesticide and other agricultural chemical manufacturing	32532	21
Other basic inorganic chemical manufacturing	32518	20
Ice cream and frozen dessert manufacturing	31152	19
Frozen food manufacturing	31141	18

the incidence rate of accidents has increased or decreased over the last five years.

Table XI reports the day of the week on which accidents in RMP*Info took place. A small peak in accident rates is noticeable in mid-week. Again, one should not infer from this anything about "safe weekend operations" since we do not know how many of the facilities in RMP*Info operated as intensively on weekends as they did during weekdays. Similarly, we do not know whether the lower number of accidents on Mondays and Fridays is a result of shorter periods of operation on these days, different work attitudes on these days, or other factors. Additional data would be required in order to study this issue. A number of other factors should also be considered in analyzing the temporal pattern of accidents, including seasonal manufacturing facilities, continuous versus batch operations, and specific process characteristics.

Next, we report results related to the size of plant, as measured by FTEs at the plant, and accident rates during the reporting period. Several caveats must be kept in mind in reviewing these data. First, these data do not account for many possible confounders with plant size. For example, we do not control for the inherent hazards in the processes in question and this could be a significant confounding influence on the statistical association of plant size and accident frequency and severity. Generally, a much more detailed analysis controlling for such factors as process hazard,

Table VII. On-Site Injuries and Deaths Resulting from Accidents During Reporting Period

	Mean or Total	Std. Dev.	Min	Max	Number of Observations
On-site injuries to workers/contractors					
Total on-site injuries	1,987				1,969
Injuries per accident	1.0091	2.828	0	67	1,969
Injuries per FTE per accident	0.0207	0.0783	0	1	1,951
On-site deaths to workers/contractors					
Total on-site deaths	32				1,968
Deaths per accident	0.0163	0.218	0	6	1,968
Deaths per FTE per accident	0.0003	0.0070	0	0.25	1,950

OSHA PSM implementation, and so forth, would be required in order to understand the nature of the association of plant size with accident frequency and severity.

With these cautions in mind, Table XII shows the association of increasing plant size with a higher frequency of accidents. We separated the data into those facilities reporting less than 0.5 FTEs, between 0.5 and 10 FTEs, and more than 10 FTEs. As explained earlier (see footnote 13), the FTE category of less than 0.5 represents mostly seasonal or part-time farm operations that have less than 0.5 FTEs and, therefore, report 0 FTE. Plants with more employees were significantly more likely to have accidents ($p < 0.001$, chi-square for trend).[21]

6. OFFSITE CONSEQUENCE ANALYSIS: INFORMATION AND ANALYSIS

Perhaps the most interesting information in the RMP*Info database is the Offsite Consequence Analysis (OCA) information.[22] OCA information consists of data related to worst-case and alternative release scenarios. These scenarios represent hypothetical estimates of the potential consequences of accidental chemical releases occurring under specified atmospheric and topographic conditions. The OCA data reported in the RMP include the following:

1. Name, physical state, and percent weight (if a mixture) of chemical involved in the release
2. Analytical model used to perform the analysis (i.e., scientific technique used to estimate the distance to which a toxic vapor cloud, overpressure blast wave, or radiant heat effects will travel)
3. Type of scenario (e.g., gas release, explosion, fire, etc.)
4. Quantity released
5. Release rate and duration
6. Atmospheric conditions and topography
7. Distance to toxic or flammable endpoint
8. Residential population living within the endpoint distance.
9. Other public or environmental receptors within the endpoint distance (e.g., schools, hospitals, churches, state or national parks, etc.)
10. Mitigation measures accounted for in conducting the analysis

OCA information does not include any estimate of the probability of a scenario actually occurring. However, OCA scenarios are considered to be unlikely. Worst-case scenarios in particular are considered to be very unlikely. This is because they are based on the assumption of a very large accidental release (an unlikely event under any conditions) occurring under a combination of atmospheric conditions (low wind speed and stable atmosphere) that occurs rarely and does not persist for very long. Further, the regulatory requirements for conducting the worst-case scenario analysis prohibit facilities from accounting for any active release mitigation features such as water deluge systems and automatic shutoff valves that might significantly reduce the effects of an actual release. Facilities may, however, account for passive mitigation features such as containment dikes and building enclosures.

Note that each facility using at least one regulated toxic chemical was required to provide a toxic worst-case and alternative release scenario; similarly, each facility using at least one regulated flammable chemical was required to provide a flammable worst-case and alternative release scenario. The unit of analysis in the remainder of Section 6 is the scenario, not the facility.

[21] Note that the FTE number includes all reported employees at the facility, regardless of occupational class. Hence facilities with a large number of employees whose work does not involve regulated substances (e.g., military bases) will have a lower per-employee risk from chemical exposures than facilities where nearly all employees would be exposed to the consequences of accident releases (e.g., petroleum refineries).

[22] Because of security concerns, the OCA data are currently only available to members of the general public by appearing in person at one of the 50 reading rooms set up for access to these data. In accordance with these restrictions, the statistical analysis reported here was accomplished internal to EPA/CEPPO.

Table VIII. Nonemployee Injuries and Deaths Resulting from Accidents During Reporting Period

	Mean or Total	Std. Dev.	Min	Max	Number of Observations
Nonemployee injuries					
Total injuries to public responders for all accidents	63				1,968
Injuries to public responders per accident	0.032	.5537	0	21	1,968
Total on-site injuries to other members of the public for all accidents	104				1,968
On-site injuries to other members of the public per accident	0.0528	1.390	0	59	1,968
Total hospitalizations for all accidents	215				1,968
Hospitalizations per accident	0.109	1.931	0	80	1,968
Total other medical treatment for all accidents	6,057				1,968
Other medical treatment/accident	3.078	104.51	0	4,624	1,968
Nonemployee deaths					
Total public responder deaths	0				1,968
Total on-site deaths by other members of the public	0				1,968
Overall nonemployee deaths/accident	0				1,968

6.1. Worst-Case Scenarios

EPA defined the worst-case scenario as the release of the largest quantity of a regulated substance from a single vessel or process line failure that results in the greatest distance to an endpoint (for most facilities, this is the amount contained in the largest vessel or pipe in the process).[23] In broad terms, the distance to the endpoint is the distance, based on a release of the specified quantity of material, that a toxic vapor cloud, heat from a fire, or blast waves from an explosion will travel before dissipating to the point that serious injuries from short-term exposures will no longer occur. For toxic worst-case scenarios, EPA specified certain input parameters for conducting the analysis, such as wind speed and atmospheric stability. For flammable worst-case scenarios, EPA specified that the scenario consisted of a vapor cloud explosion.

EPA placed numerous specifications on worst-case scenarios in order to simplify the analysis and to ensure comparability among facilities. However, EPA did not specify that any particular analytical model be used to conduct the analysis. When comparing worst-case scenarios, this is a potentially confounding variable, since the same scenario analyzed using two different analytical models can sometimes produce significantly different results. However, most worst-case scenarios were conducted using EPA OCA modeling.[24]

6.1.1. *Endpoint Distances*

In general, toxic release scenarios result in greater endpoint distances than flammable worst-case scenarios. This is mainly due to the fact that for flammable substances, EPA specified the endpoint distance to be the distance from the source of a vapor cloud explosion to the point where the overpressure from the explosion falls to 1 psi. For most regulated flammable substances, this distance tends to be significantly shorter than the toxic endpoint distance resulting

23 Usually, each facility has a single worst-case scenario, but there are approximately 2,000 facilities that must report more than one worst-case scenario, for either of two reasons. First, facilities that have both toxic and flammable substances must report one worst-case scenario for each class of substance. Second, the Rule requires facilities to report more than one worst-case scenario when the facility has multiple processes that could affect significantly different off-site populations.

24 EPA published several guidance documents and one computer software program to assist facilities in conducting OCA modeling. Foremost among these is *Risk Management Program Guidance for Offsite Consequence Analysis*, which contains generic OCA lookup tables and modeling equations for all RMP-regulated chemicals. EPA also published several industry-specific guidance documents that contain lookup tables for regulated chemicals of particular concern to certain large industry sectors regulated under the RMP Rule. Additionally, EPA and the National Oceanic and Atmospheric Administration together produced a software program, called RMP*Comp, which conducts OCA modeling according to the same methodologies contained in the EPA guidance documents. OCA results achieved using any of these sources are derived from the same set of models.

Table IX. Property Damage and Nonmedical Off-Site Consequences Resulting from Accidents During Reporting Period

	Mean or Total	Std. Dev.	Min	Max	Number of Observations
On-site property damage ($ millions)					
Total on-site damage	$1,041				1,966
Damage per accident	$0.529	$6.641	$0	$219	1,966
Off-site property damage ($ millions)					
Total off-site damage	$11.7				1,967
Damage per accident	$0.006	$0.108	$0	$3.8	1,967
Off-site consequences					
Total number of evacuations	174				1,968
Total number of evacuees in all accidents	31,921				1,968
Number of evacuees per accident	16.22	140.97	0	3,000	1,968
Total number of accidents involving shelter in place	97				1,968
Total number of individuals confined to shelter in place in all accidents	184,839				1,968
Number of individuals confined to shelter in place per instance	93.9	1,913.4	0	55,000	1,968
Number of accidents with effects on the ecosystem					
Fish or animal kills	19				1,970
Minor defoliation	55				1,970
Water contamination	25				1,970
Soil contamination	29				1,970
Any environmental damage	104				1,970

from the release of a similar quantity of the most prevalent RMP toxic chemicals.

Figs. 1 and 2 are frequency histograms of endpoint distance for RMP toxic and flammable chemical process worst-case scenarios, respectively. Each bar represents scenarios having endpoint distances in a particular distance interval. Relatively few processes of either type result in extremely long endpoint distances. However, while the shapes of the two distributions are similar, flammable scenarios are differentiated from toxics by their shorter endpoint distances. The median endpoint distance for toxic worst-case scenarios is 1.6 miles, while the median endpoint distance for flammable worst-case scenarios is 0.4 miles. This reflects the differences in the physical nature of the two hazard classes and their worst-case scenarios, as described above.

6.1.2. Potentially Affected Population

Under the RMP Rule, the population potentially affected by a release is defined as the residential population inside a circle with radius equal to the

Table X. Pattern of Accidents over the Five-Year Period

Year	Number of Accidents in the Year	Percent of Total Accidents
1994	141	7.2
1995	319	16.1
1996	393	20
1997	436	22.1
1998	440	22.3
1999	204	10.4
2000	34	1.7
2001	3	0.2
Total	1970	100.0

Table XI. Day-of-the-Week Pattern of Accidents

Day of the Week	Number of Accidents	Percent of Total Accidents
Sunday	157	8.0
Monday	310	15.7
Tuesday	308	15.6
Wednesday	355	18.0
Thursday	351	17.8
Friday	281	14.3
Saturday	208	10.6
Total	1970	100.0

Table XII. Plant Size vs. Accident Frequency

FTEs at Facility	Proportion of Facilities with Accidents (%)	Number of Facilities
< 0.5	1.8	932
0.5–10	2.9	6,838
>10	12.9	7,654
Total	7.8	15,424

endpoint distance. Therefore, for a given population density, the population inside the "worst-case circle" will increase according to the area of the circle, or proportionally to the square of the endpoint distance. Naturally, population density is not constant, and other factors such as terrain, geography, zoning, etc., also affect this correlation. But, in general, one would expect to see population increase as the square of endpoint distance.

Figs. 3 and 4 are histograms of the potentially affected population for toxic and flammable worst-case scenarios. The distribution of the potentially affected population among the toxic worst-case scenarios is highly right-skewed: a mean of over 40,000 people would be affected per scenario, whereas the median scenario would affect 1,500. The distribution of the potentially affected population among the flammable worst-case scenarios is also highly right-skewed, although the estimated number affected is smaller: a mean of 668 per scenario, with the median scenario affecting 15. In evaluating these results, it is again important to consider the physical difference between toxic and flammable worst-case scenarios. Toxic chemical releases generally result in a plume that travels in the downwind direction.[25] Should an accidental release occur, only the portion of the population covered by the plume could feel its effects. This population usually represents only a minor fraction of the population inside the worst-case circle. Therefore, the OCA generally overestimates the impact of a toxic release.

Flammable worst-case scenarios, on the other hand, consist of an overpressure blast wave that generally travels in all directions from the source. While terrain and obstructions will affect the propagation of the blast wave to some degree, in general, everyone within the worst-case circle would feel the effects of a vapor cloud explosion resulting from a flammable substance release. So, while Figs. 3 and 4 indicate a very large disparity between potentially affected population for toxic and flammable worst-case scenarios, the disparity is, in fact, not as great as these figures indicate.

It is interesting to note that the distribution of residential population potentially affected by toxic worst-case scenarios appears to be log-normal in shape but that the flammable worst-case scenario distribution is clearly not log-normal.[26] It is unclear why the two distributions have such markedly different shapes, but the difference may be due partly because each distribution is actually a collection of underlying distributions, one for each different chemical represented in the database. It is also possible that facilities with toxic chemicals tend to be located in areas with different population densities than do facilities with flammable chemicals, thereby affecting the populations at risk. Further, while EPA modeling (i.e., EPA lookup tables and RMP*Comp software) was used to obtain the majority of OCA results in the database, the fact that several other analytical models were used to obtain the remaining results probably induces some artificial variations in these distributions.

6.2. Alternative Release Scenarios

The RMP regulation provides much greater flexibility in defining alternative release scenarios than worst-case scenarios. The only "hard" requirements for alternative release scenarios are that the scenario must be more likely to occur than the worst-case scenario and that it reaches an endpoint offsite, unless no such scenario exists. Facilities may account for both passive and active mitigation measures that may be in place when calculating the potential consequences from an alternative release scenario. Alternative scenarios are generally considered to be more representative of actual emergency scenarios that might occur.

Since there are no objective criteria for developing alternative scenarios, the results vary widely, even among similar facilities. Except for including the basic parameters of the data distribution in Table XIII, this study has not attempted any in-depth analysis of alternative scenario data.

Table XIII indicates basic descriptive statistics for endpoint distances and populations for toxic and

[25] Under certain conditions, the direction that a toxic gas plume travels may be dictated more by the elevation of surrounding terrain than by wind direction.

[26] Due to the extremely wide range of residential populations (0 to 12 million for toxic worst-case scenarios) both distributions are plotted on a logarithmic scale.

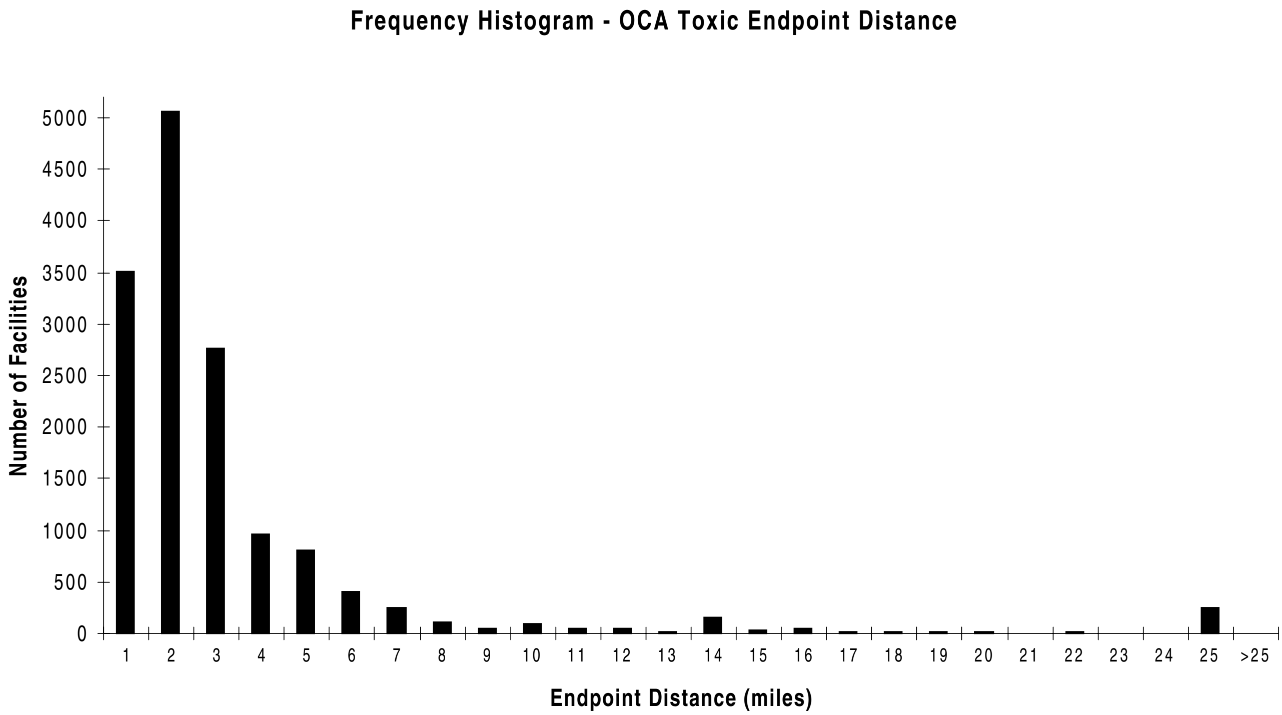

Fig. 1. Frequency histogram—endpoint distance for toxic worst-case scenario.

flammable worst-case and alternative release scenarios. As expected, alternative release scenarios for both toxic and flammable substances have, in general, shorter endpoint distances and smaller populations than do the worst-case scenarios for the same hazard class. Similarly, as flammable worst-case scenarios are generally less severe than toxic worst-case scenarios, so are flammable alternative scenarios less severe than toxic alternative scenarios. Table XIII also effectively highlights the much larger scale of toxic

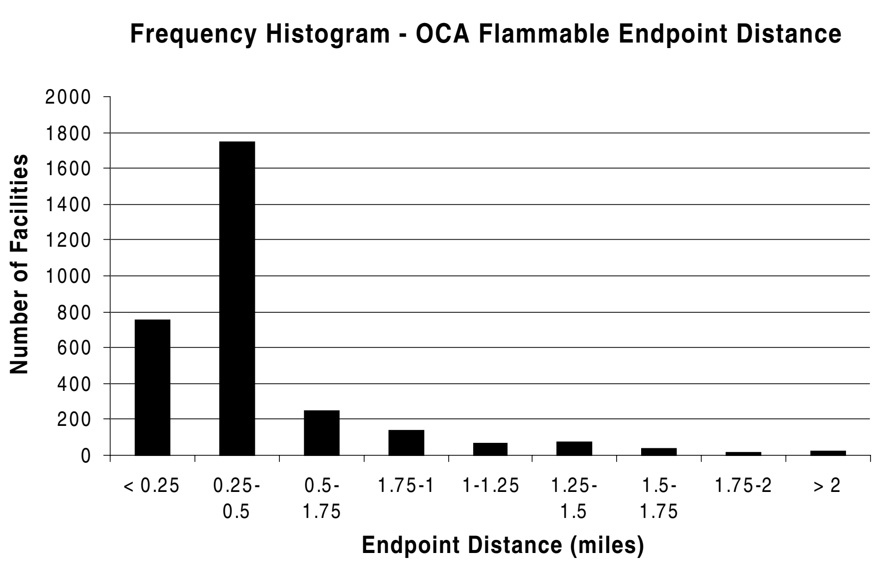

Fig. 2. Frequency histogram—endpoint distance for flammable worst-case scenarios.

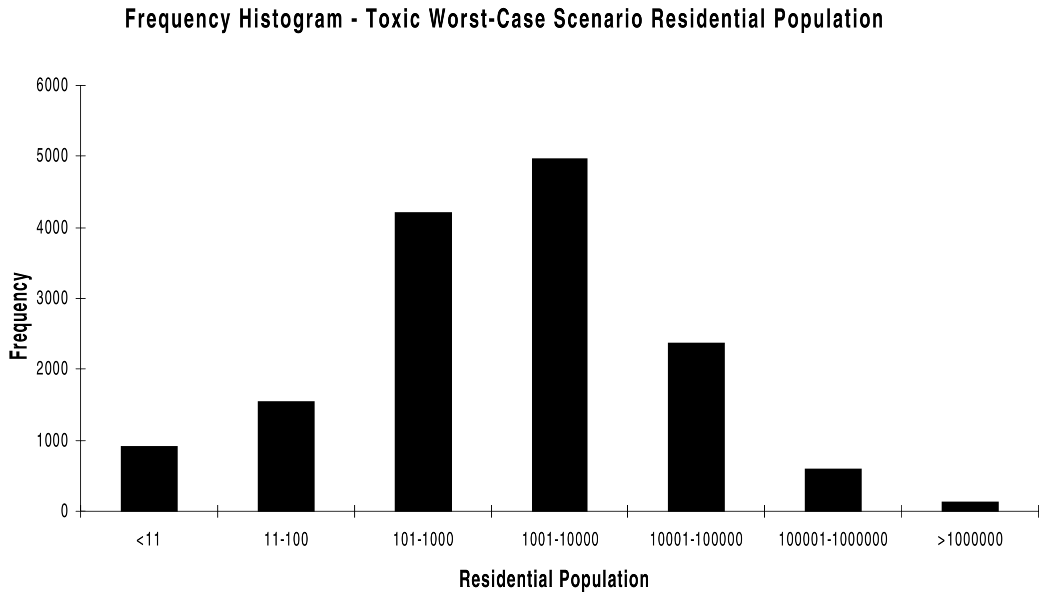

Fig. 3. Frequency histogram—toxic worst-case scenario residential population.

scenarios relative to flammable scenarios. All potential impacts from flammable scenarios are much lower than those for the distribution of toxic scenarios. In fact, flammable *worst-case* scenarios are, on average, even less severe than toxic *alternative* scenarios. Notably, most flammable alternative release scenarios would not even affect any members of the off-site public (i.e., the median population value for flammable alternative scenarios is zero).

7. CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

This article represents a start in harvesting the informational value of the data collected under the RMP Rule. Among the many open issues, an important area is continuing research on how complete RMP*Info is, i.e., to what extent does RMP*Info capture the entire population of plants covered by the

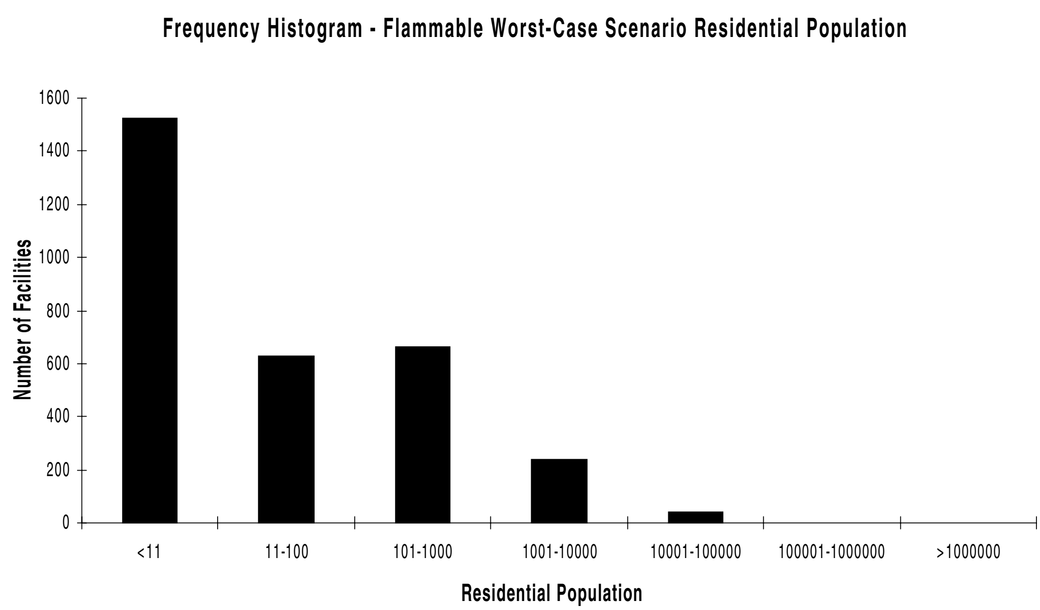

Fig. 4. Frequency histogram—flammable worst-case scenario residential population.

Table XIII. Descriptive Statistics for Worst-Case and Alternative Release Scenarios

	Type of Scenario			
Distance or Population	Toxic Worst Case	Toxic Alternative Release	Flammable Worst Case	Flammable Alternative Release
Endpoint distance (miles)				
Mean	2.9	0.45	0.44	0.13
Median	1.6	0.22	0.4	0.1
Mode	1.3	0.1	0.4	0.1
Std. Dev.	4	0.66	0.39	0.15
Range	40	18	6.4	4.4
Residential population				
Mean	38,161	937	713	66
Median	1,410	40	12	0
Mode	0	0	0	0
Std. Dev.	2.8×10^5	1.4×10^4	4.7×10^3	4.5×10^2
Range	1.2×10^7	1.6×10^6	1.5×10^5	1.1×10^4

Rule? Another important area, going forward, will be to evaluate desirable changes in RMP*Info for the next reporting of accident history data, scheduled to take place in 2004. Some questions for further study include:

1. Do the data reveal the need for any policy, practice, or regulatory changes with regard to particular chemicals, industrial sectors, processes, or equipment?
2. Do correlations exist between accident history data and other data elements (in RMP*Info or other databases, e.g., financial data, OSHA data on safety and health statistics, data on acute health effects as in the Hazardous Substances Emergency Events Surveillance (HSEES) database, TRI data, etc.) that might serve as predictors of accident-prone or accident-free performance?
3. Does the database constitute a large enough sample of chemical facilities to determine risk distributions with sufficient confidence to make decisions about low-frequency, high-consequence events at the tail end of the distribution?
4. Comparing the combined accident history data from the 1999 filing with the 2004 filing, what trends or patterns in accidents are evident?
5. What changes to the database or RMP regulation might be necessary to correct deficiencies in this important database to make the data more meaningful and useful for accident prevention?

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Center's work on accident prevention in the chemical industry should consult the Center's website at http://opim.wharton.upenn.edu/risk/.

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