Analyzing Catastrophic Terrorist Events with Applications to the Food Industry

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Abstract

Using a dataset that we construct on terrorist activity involving the use of chemical, biological or radionuclear (CBRN) agents, we calculate the likelihood of a catastrophic event of this nature. *Assuming a continuation of recent trends in the use of CBRN agents*, an attack of the same magnitude as that on the Tokyo subway in 1995 is expected to occur by 2009. Consistent with pronounced non-stationary patterns in these data, the "reoccurrence period" for such an attack is decreasing every year. Similarly disturbing trends are evident in a broader dataset which is non-specific as to the methods or means of attack. Thus for instance an attack that leads to the deaths of 1000 people is expected to occur within the next ten years. However an attack of the same magnitude as the September 11 tragedy, when nearly 3000 people died, is not expected any time soon.

Key words: biological weapons, bioterrorism, chemical weapons, extreme value theory, food supply chain, nuclear materials, risk assessment, terrorism..

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1. Introduction

"Forget the past: it's a war unlike any other," read one headline in the days immediately following the worst terrorist event in recent history.[1] The subject of John Kifner's column in the New York Times was Afghanistan however it could have just as well referred to the wider war on terror for it is an apt description of how 9/11 marks a watershed in the way many of us view the terrorist threat. It is rarely a good idea to ignore lessons from past experience, though in the aftermath of great tragedy rationality recedes and emotion-laden themes pervade much of our thinking. But was it all emotion?

The attack on the World Trade Center was unique in its ferocity. In isolation this event redefined the boundaries separating the realm of the "possible" from the "unthinkable." To many, 9/11 broke from earlier forms of terrorism. It challenged old ways of thinking and called for fresher perspectives with new assumptions. Much of the discussion on the terrorist threat has embraced this approach. Thus attention has centered on what terrorists could do, rather than what they have done in the past, as a model for what they are likely to do in the future.[2]

Risk is therefore assessed on the basis of vulnerability. Accordingly the food sector has received considerable attention, since many concede that it is not only vulnerable to a chemical or biological attack, but that such an attack also offers the potential to inflict mass casualties. Yet, the fact remains that the food supply chain has not been a favorite target for terrorists and unless one believes that a new "strain" of terror has evolved from a fresh paradigm disjoint from its past, it is difficult to ignore the failure of terrorists, thus far, to systematically target the food supply chain. As such it may be premature to equate vulnerability with risk, and doing so may lead to surprise when the pattern of terrorist activities plays out:

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[1] John Kifner, "Forget the Past: It's a War Unlike Any Other." *New York Times*, September 21, 2001.

[2] It is important to stress that we are referring *specifically* to risk analysis. There is in fact a vast and impressive literature on terrorism and since at least Landes (1978) economists have been using both theoretical and empirical methods to examine various aspects of terrorism, from its implications for tourism (Enders and Sandler 1991), to its effects on capital flows (Enders and Sandler 1996, Blomberg and Mody 2005, Abadie and Gardeazabal 2005), and its consequences for economic growth (Abadie and Gardeazabal 2003). However, as far as we know, there has been very little work on developing a systematic framework for assessing the risk of terrorist activity.

> I, for the life of me, cannot understand why the terrorists have not, you know, attacked our food supply, because it is so easy to do.[3]

So if vulnerability does not necessarily correlate with the pattern of terrorist attacks, what is the threat to the supply chain? Is it real or is this all merely speculation? To our knowledge, this simple, yet important, question has yet to be answered. This paper takes a step toward this goal. We examine the risk of a catastrophic terrorist attack using chemical, biological, or radionuclear (CBRN) materials. This focus reflects the goal of this research, which is to provide insights into the terrorist-threat to the *food* sector. While the food supply chain can be attacked in a number of different ways, our focus on CBRN-materials is warranted since their deliberate introduction into the civilian population is biased toward targeting the food-sector's infrastructure, which provides reach over a wide region.

Assessing the risk of a major CBRN-event is complicated by our limited experience with such events as well as by the quality of the data; the largest open-source dataset on terrorist activities (maintained by Pinkerton Corporation's Global Intelligence Services) records only 41 incidents involving weapons of mass destruction (LaFree et. al. 2004). Clearly it is difficult to make any accurate statistical predictions from these data. Overcoming the paucity of these data however presents a significant challenge, as it becomes necessary to mine primary sources such as newspaper articles and internet postings, in addition to an earlier literature on terrorism. Nevertheless in doing so we were able to compile a new, more comprehensive, dataset on CBRN-incidents composed of over 300 observations. Although the number of data points is still small, the process of extending these data is ongoing, and we expect to add several hundred more incidents to these data over time.

In addition to these quite severe data problems, assessing catastrophic risks poses conceptual problems since it entails extrapolating from observed levels in the data to unobserved levels. Classical statistical models are not well-suited for this task; since emphasis falls on the modal-behavior of the underlying stochastic process, the tails of the distribution are estimated imprecisely. But within the current context, of extreme risks, it

[3] Speech by Tommy Thompson, former secretary of Health and Human Services on December 3, 2004.

is important to accurately estimate these tails. Fortunately, a statistical method known as Extreme Value Theory (EVT) provides a framework for doing precisely that. EVT is therefore well-suited for answering the types of questions that we are interested in.

Thus our contributions to this research are two fold. First, and most importantly, we develop a comprehensive dataset of CBRN-incidents. Second, we apply a *relatively* novel statistical method to estimate the probability of terrorist activities involving CBRN-weapons. Although extreme value analysis is well known to statisticians, to our knowledge this approach has not been utilized to assess the risk of catastrophic terrorist events.

The remainder of our paper is organized as follows. In section two, we describe our data in detail. In section three, we briefly discuss underlying patterns in terrorist activities, particularly those involving the use of CBRN-material. We stress in particular the pattern of attacks on the food supply chain. In section four, we outline our statistical methodology. In section five, we provide statistical evidence on the likelihood of a catastrophic event that involves the use of CBRN-material and compare these results to the underlying pattern in the severity of terrorist attacks in general. In section six we offer some conclusions. A separate data appendix, available from the authors, provides a case-by-case description of incidents in our dataset.

2. Data

There are several existing databases that describe the incidence of terrorist activity. Perhaps the most well-known of these is the *International Terrorism: Attributes of Terrorist Events* (ITERATE) database. These data were originally compiled by Mickolus (1982) and spanned a period from 1968 to 1977. They were later extended to 2002, by Mickolus et. al. (1989, 1993) and Mickolus and Fleming (2003). Included in these data are the date of attack, the type of event, the number of casualties (deaths or injuries), as well as various other characteristics of incidents, importantly however only transnational terrorist events are considered. ITERATE defines an event as transnational along several criteria. These include the nationalities of the perpetrators, the location of the attack, as well as the nature of the target (Mickolus et al. 1989).

A much more comprehensive database is maintained by Pinkerton Global Intelligence Services. These data are composed of roughly 74,000 terrorist events spanning a period from 1970 to 1997. While these data were compiled by Pinkerton Corporation's Global Intelligence Service (PGIS), they were coded through the efforts of Laura Dugan and Gary LaFree at the University of Maryland. The PGIS dataset is undoubtedly the most comprehensive source of terrorist-event data compiled from open sources. It includes political, religious, as well as economic acts of terrorism and unlike ITERATE, PGIS data record instances of both domestic and international terrorism. However to our knowledge these data are still not publicly available.

Recently the Center for Nonproliferation Studies (CNS) at the Monterey Institute for International Studies, has compiled a chronology of incidents involving the use of chemical, biological, radiological and nuclear agents dating back to 1900. Their *Weapons of Mass Destruction* database is perhaps one of the most comprehensive sources of data on such events. It is composed of approximately 1200 incidents relating to CBRN-material. However, much of these data are comprised of hundreds of hoaxes and pranks and other events that do not necessarily relate to possession with intent or actual use. In addition, the *Weapons of Mass Destruction* database is unfortunately not in public domain. Access is normally restricted to those with military or government IDs, except for a few years worth of data which are reviewed in various studies by CNS staff (Cameron et. al. 2000, Pate and Cameron 2001, Pate et. al. 2001, Turnbull and. Abhayaratne, 2003).[4]

Another impressive source of data is the *Terrorism Knowledge Base* which is maintained at the National Memorial Institute for the Prevention of Terrorism (MIPT). These data begin in 1968 and continue to the present. Moreover the MIPT database is updated regularly; thus it is inclusive of the very latest incidents. Unlike ITERATE data these data include incidents of domestic as well as transnational terrorism. However prior to 1998, the MIPT data are less complete in this respect. While the data are public domain, full or partial versions of the dataset are not released to the public. Instead each

[4] We are grateful to Major Adam Wickersham, US Army, for his help in acquiring some of these data. It is our hope that in later versions of this study, we will be able to update our own database on CBRN through Major Wickersham's help.

recorded incident is posted on a *separate* webpage. Thus we were able to compile a dataset by visiting each of these (*21,000 plus*) webpages and recording the main characteristics of each event. Our data span a 38-year period from January 1, 1968 to March 11, 2005. Over this period, the MIPT *Terrorism Knowledge Base* records 21,095 incidents of terrorism that resulted in 27,573 fatalities and 70,434 injuries.

Despite the very large number of recorded terrorist incidents, very few of these have involved the use of nuclear, biological, or chemical weapons. From the data we were able to compile from MIPT, 56 incidents involved the use of biological or chemical agents. LaFree et. al. (2004) conduct their analysis using the PGIS database. They record only 41 incidents that involved the use of nuclear, biological, or chemical agents, or sophisticated explosives intended to inflict mass casualties. Clearly, we have rather limited experience with such forms of terrorism. However, there is a perception that terrorism involving the use of chemical, biological, radioactive or nuclear materials often goes unreported, either because of ignorance on the part of authorities or because of their attempts to suppress evidence (Douglass and Livingstone 1987). Even when an incident is reported, depending on how we define "terrorism," it may not be coded as such, or an incident may simply be missed. Thus for instance, the large-scale poisoning in 1984 by the *Rajneeshee* cult is not recorded in the MIPT-database.

Given the scarcity of these data, we embarked on our own data collection effort. Our dataset is comprised of 314 incidents that have either involved the direct use of nuclear, biological and chemical agents, or that have implied a threat to their containment, by a group or individual. We compile these data by painstakingly gathering specific information about each event from various sources. These include databases such as the *Terrorism Knowledge Base* as well as reviews of recent terrorist incidents that were culled from the *Weapons of Mass Destruction* database (Cameron et. al. 2000, Pate et. al. 2001, Turnbull and. Abhayaratne, 2003) as well as the open literature, including fairly comprehensive sources of data on the use of chemical, biological, or radiological weapons such as Jenkins and Rubin (1978), Livingstone and Arnold (1986), Douglass and Livingstone 1987, Hirsch (1987), Mullen (1987), Thornton (1987), Kellen (1987), Leventhal and Alexander (1987), Kupperman and Woolsey (1988), Kupperman and Kamen (1989), Mullins (1992), Purver (1995), Tucker (2001), Miller et. al. (2001), Carus

(2002), Mize (2004). In addition, we consulted numerous newspapers and hundreds of websites. While our chronology currently includes 314 incidents, we expect this figure to increase significantly as more events that have yet to be cross-checked are added to these data.

Our chronology provides a general description of each incident, along with details on the type of agent employed and the number of casualties that resulted. The data cover a 45-year period from 1961 to 2005. Unlike the Monterey Institute's *Weapons of Mass Destruction* database, we focus only on those incidents that involved the use, or possession of, CBRN-materials; we exclude all hoaxes. In addition, we include a number of attacks that involved a threat to containment of CBRN-material. These include acts of sabotage, such as those at SL-1 US Army reactor in Idaho Falls in 1961 *Atomic Energy Insights* (Vol. 2, Issue 4) which led to three deaths. Also included are direct acts of violence committed on facilities containing nuclear, biological and or chemical material, such as the attack on the nuclear facility near Lyon, France, when five stolen French army rockets were fired at the reactor (*The West Australian*, January 20, 1982).

In our analysis of the use of CBRN-weapons, we do not make a distinction between terrorism and criminal activity. First, because the nature of these materials is such that whatever the underlying motivation behind their use, these weapons have the *potential* to do significant harm, or create an atmosphere of fear and panic. Thus for instance, on September 14, 2002, when Chen Zhengping tainted his competitor's water supply and pastry dough with rat poison, the underlying motive may have been purely financial, but the incident caused 41 deaths and over 400 cases of hospitalization.[5] Similarly the Tylenol murders in 1982, which though not linked to terrorist activity, nevertheless created an atmosphere of alarm and panic. The second and the critical reason why the distinction between criminal and terrorist activity may not be warranted is the fact that the use of biological, chemical or nuclear substances, even when they indicate acts of petty crimes such as the use of HIV-infected blood, betrays an increasing acceptance amongst the criminally inclined to resort to the use of previously exotic weaponry.

[5] "China Deaths Blamed On Rat Poison," *CNN*, September 16, 2002, "China Masks a Mass Poisoning," *The Guardian*, September 16, 2002.

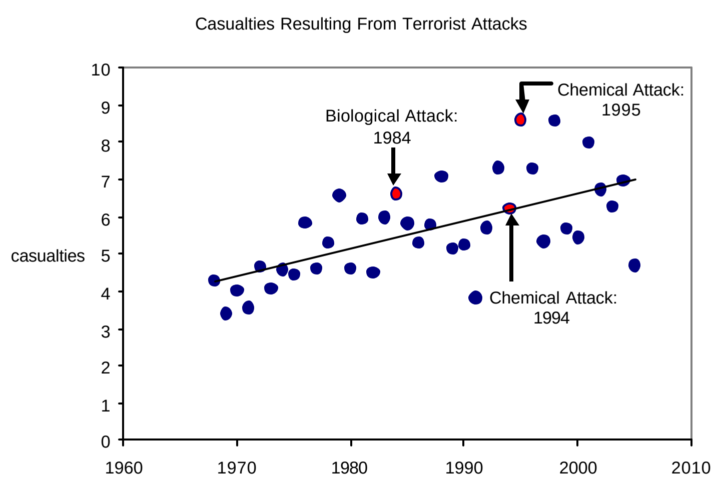
3. Trends in Terrorism

General Trends:

According to MIPT's *Terrorism Knowledge Base*, the frequency of terrorist attacks has steadily increased since 1968. Furthermore, there has been an increase in the severity of terrorist attacks over the past decade. Thus, as we see in table 1, almost all of the incidents where the number of people killed or injured exceeded one thousand occurred over the period from 1993 to 2004. This increasingly deadly pattern in the evolution of terrorism is clearly evident in Figure 1, which plots the logarithm of the maximum number of casualties (both fatalities and injuries) on any given day resulting from terrorist attacks. It is important to recognize that this trend is unlikely to be spurious. While the increasing frequency of terrorist incidents could merely reflect improved data collection efforts and better reporting in the media, this point cannot generally be made when we focus on a subset of data comprised of the *worst* terrorist events in a year. The argument here is that an attack of the same magnitude as that on the Tokyo subway system should generally not go unnoticed or unrecorded. Thus the inference that we are entering an increasingly deadly phase in the evolution of terrorism is not without merit.

Table 1 Goes Here

Figure 1. An Increasingly Deadly Trend in the Evolution of Terrorism

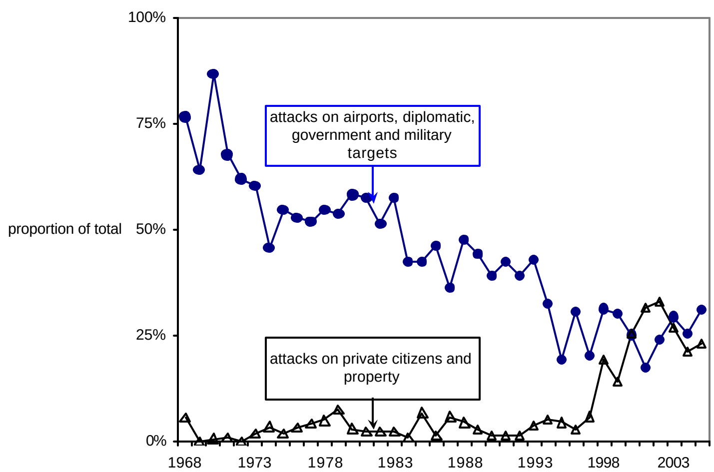


Notes: Casualties—the sum of fatalities and injuries—are measured in logs. Source: MIPT, Terrorism Knowledge Base, and sources cited by the authors.

Trends in the Food Chain:

Equally disconcerting are the trends that we observe with respect to the choice of weaponry, targets and tactics. In recent years terrorists have focused more of their efforts on "softer" targets. This switch simply reflects terrorisms' best response to increased efforts to police against well-established threats. The diversification of targets has been a gradual effort on the part of terrorist organizations. In 1968 approximately 3 out of 4 terrorist attacks were aimed either at the airlines, or at diplomatic, government and military targets. This concentration on "high profile" targets has diminished steadily. Now only one quarter of terrorist attacks are aimed at the airlines or government and military facilities. By contrast attacks on private citizens or private property have increased dramatically in the last few years (Figure 2).

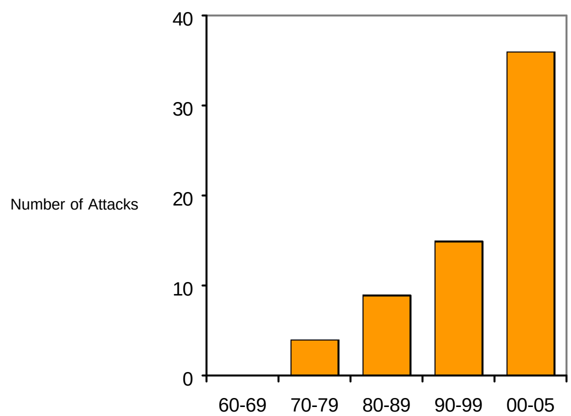
Figure 2 Terrorist Targets, 1968-2005



Source: MIPT, Terrorism Knowledge Base.

To the extent that the food supply chain constitutes such a softer target, the same trend is observed here as well. Thus, attacks on the food industry for instance have shown a dramatic rise since the 1960s, when there were no recorded attacks (Figure 3).

Figure 3. Frequency of Attacks on Food or Water Supply



Sources: Based on authors chronology of CBRN-events and the sources cited by the authors.

Most experts concede that the food chain, from production to processing and distribution, is highly exposed. In 1984 for instance, the *Rajneeshees*—an Oregon-based cult—contaminated food at ten restaurants with *Salmonella typhimurium* causing 751 cases of illness (Carus 2002). Court testimony suggests that cult members considered other more deadly pathogens including *Salmonella typhi* (which causes typhoid) and the AIDS virus (Carus 2002). Since then there have been several serious attacks on the food chain (Table 2), many occurring in China where disputes have been settled through the use of *Dushuqiang* a strong rat poison that has been banned since 1984. The most serious such attack occurred, as mentioned, in 2002 on a fast food restaurant that led to 41 deaths and over 400 illnesses. In the US, the most serious attack on the food chain since the *Rajneeshee* incident occurred at the Family Fare supermarket in which Randy Bertram poisoned about 250 pounds of ground beef causing at least 111 cases of illness.

Table 2 Goes Here

Yet importantly, while these cases of mass food-poisoning have led to large numbers of people becoming ill, in comparison to the September 11 attack, or any one of the major terrorist events in the last decade, the death toll has been relatively low. Thus the emphasis has often fallen on the potential economic costs of bio- or chemical terrorism, particularly the threat to agriculture. Pathogens affecting livestock such as foot-and-mouth disease (FMD) and Bovine Spongiform Encephalopathy (BSE) can cripple agricultural and cause widespread disruption to the food supply chain as recent events in the UK illustrate. Indeed an attack of this nature is not without president. In 1997, over eight million pigs had to be slaughtered in Taiwan after the presence of FMD was confirmed in pigs. It is *suspected* that the disease was introduced deliberately. In that same year, rabbit hemorrhagic disease (RHD) was introduced into the rabbit population in New Zealand (Carus 2002). As recently as May 10, of this year, a letter delivered to Prime Minister Helen Clark claimed that a vial of foot-and-mouth disease was released into the animal population in a farming community near Auckland, New Zealand.[6]

Chemical, Biological and Radionuclear Agents

While there have been attacks on our food and water supply that have involved the use of conventional weapons, there is no reason in particular why terrorists should favor the food supply chain over other potential targets when using such conventional means of attack. The real threat as far as the food chain is concerned is likely to come from chemical, biological or radionuclear contaminants, which can exploit an already present distribution network to maximize the potential for disruption. Of the 314 biological, chemical and radiological incidents that we recorded 64 involved either a direct attack or a plan to attack the food or water supply chains.[7] The majority of these attacks (50 altogether) involved the use of chemicals, eight attacks were carried out using biological

[6] "Foot-and-mouth scare hits New Zealand." *Associated Press*, May 10, 2005.

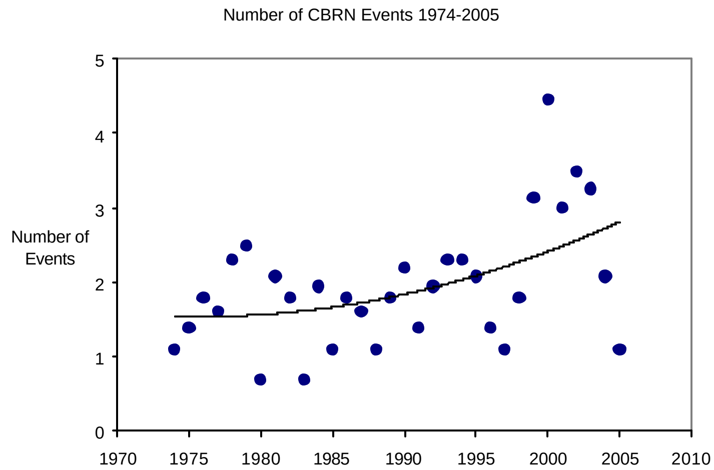
[7] We define attacks on the food or water supply as any attack that involves tampering with food and beverages with the potential to create large scale casualties. Thus for instance, simple targeted poisonings that are directed at one or perhaps a few specific individuals are not considered an attack on the food chain. However, the incident where contaminated water was handed to Filipino soldiers that led to 19 fatalities and 140 injuries is considered an attack on the food chain. We also regard attacks on livestock or the animal population in a separate category. Attacks on drugs and medication were also considered separately.

agents and one suspected incident involved the release of plutonium into the New York City's water reservoirs. In the remaining attacks the type of agent is unknown.

The use of biological weapons dates back to 700 BC, when the Assyrians employed rye ergot, an element of the fungus *Claviceps purpurea* to poison the wells of their enemies (Eitzen and Takafuji, 1997, Phillips 2005). Similarly ancient are the origins of chemical warfare, which date back to the fifth century BC during one of a series of wars between Athens and Sparta (Fries and West 1921). Since then their effectiveness as a weapon has significantly improved. Improvements in technology have made these weapons much more accessible leading to an increase in the frequency of their use in criminal and terrorist activity. Similar trends have also been observed in the use of radionuclear material (Figure 4).

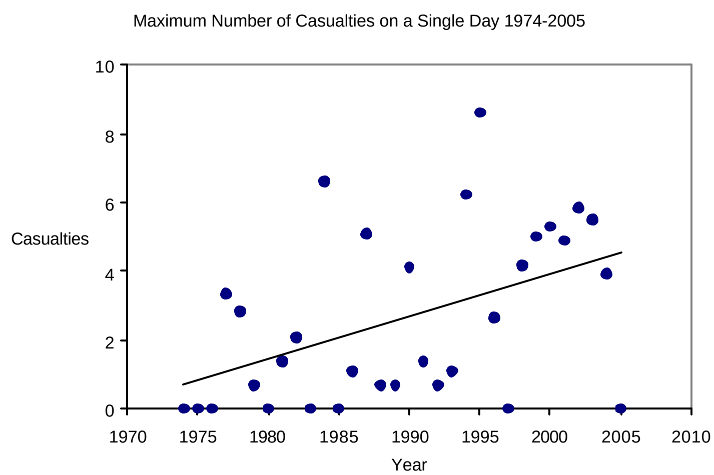
That said, the incorporation of such weapons into the terrorist arsenal has been slow. While many groups are believed to possess limited stockpiles of dangerous chemicals or pathogens, or even radionuclear materials, their ability to effectively deliver these agents is questionable. Thus for instance, the sarin attack on the Tokyo subway in 1995 was the culmination of several years of effort and trial and error by *Aum Shinrikyo* to perfect a weapon of mass destruction. During this time *Aum* experimented many times with the *botulinum* toxin and even considered the use of the *ebola* virus. Earlier attempts in 1990 and 1993 to release the aerosolized variant of the *botulinum* toxin failed. Evidently the transition from conventional weapons to chemical, biological, radiological or even nuclear agents is not without costs. This could explain some of the inertia of terrorist organizations. Nevertheless, gradually the terrorist-arsenal is expanding. Eventually the possibility exists that weaponized versions of these materials will be delivered against civilian populations. *Aum Shinrikyo's* attack on the Tokyo subway system is one example of this trend. Between 1960 and 2005 the number of casualties resulting from the deadliest attacks involving CBRN-agents has gradually increased (Figure 5).

Figure 4. Frequency of Attacks Using CBRN-Agents



Notes: The number of events is actually the logarithm of (1+number of events). Source: Based on authors' chronology of CBRN-events.

Figure 5. Increasing Number of Casualties Resulting from CBRN-Agents



Notes: "Casualties," which refer to both fatalities and injuries, are shown on a logarithmic scale. (The transformation log(1+casualties) was taken). Source: Based on authors chronology of CBRN-events.

It is difficult to predict whether a continuation of these trends is likely or not. This will depend largely on the validity of the assumptions we make about terrorists' inclinations toward these new technologies and their ability to invest in the transition to weaponized forms of hazardous agents. It will also depend on the success of future efforts to tighten up controls on the distribution of such material. Nevertheless the pattern over the last four decades is clear.

4. Methodology

As with all statistical analyses, extreme value analysis makes the axiomatic assumption that we are dealing with random events. Thus, before we embark on the description of our statistical methodology, we might ask whether or not terrorism is indeed a random event that would render itself to statistical analysis? There are at least three reasons why terrorism can be viewed as a stochastic or random event. First, even though some might view terrorism as an intentional, deterministic act to the individual terrorist, this view misunderstands the statistical concept of "randomness" from a macro perspective. This stems from an inherent asymmetry of information between a terrorist on the one hand and the citizens, security forces and the government on the other. Thus while Mohammed Sidique Khan, one of four London bombers, may have known for sure that he was going to explode a bomb on the London Underground on July 7, from the perspectives of governments and the citizens, this is stochastic event. The argument is analogous to the distinction between crime statistics and explaining criminal behavior.

Secondly, the effort to counter terrorism may succeed *X* fraction of time and fail 1-*X* fraction of time. In this way a successful terrorist attack is the manifestation of a random "system failure" in the sense of the operations risk literature. For example, the counter-terrorist activities in Europe over the past several years succeeded in disrupting numerous terrorist plots (PBS Frontline, July 05), but failed in the instances of Madrid and London. However, even from the perspective of the London terrorists, it still was not clear what the final outcome were to be. It could have happened for instance that the bomb would fail to explode. Indeed, two weeks after the first multiple bombing of London's transportation system, four more suicide bombers attempted to replicate the events of July 7 and failed.

Finally, even when a terrorist successfully carries out his attack, the severity of the attack is clearly random. Why is it that 27 people died on the train between Russell Square and Kings Cross, but far fewer, 7 people, died on the Edgware Road bombing?

Ultimately there may be little that separates a catastrophic terrorist event from a minor act of terrorism other than the final outcomes. The severity of terrorist incidents should therefore be viewed as random draws from some underlying stochastic data generating process. This is precisely the approach that we adopt here. The approach towards quantifying the risk of terrorism in this probabilistic way is indeed quite consistent with the new direction and of the Department of Homeland Security. [8]

Estimates of the probability of an event using traditional statistical methods strive for accuracy in the description of the modal-behavior of the underlying data generating process. Such methods are apt for making inferences over regions where the bulk of the data lie. However they are ill-suited for the estimation of extreme quantiles. While knowledge of the underlying cumulative distribution function would make this a non-issue, such happy circumstances are rarely encountered in practice. When the underlying distribution is unknown, as is more often the case, small discrepancies in its estimation over the main body of the distribution, can yield widely varying tail behavior.

Extreme value theory (EVT) is unusual in that it develops methods for accurately estimating the tails of distributions. At the heart of extreme value theory is the *extremal types theorem*, which states that if the maxima of sequences of observations converge to a non-degenerate law, then it must belong to one of three classes of distributions: (i) Gumbel distributions (light-tails); (ii) Fréchet distributions (heavy-tails); (iii) or Weibull distributions (bounded tails).[9] Through an appropriate re-parameterization of these three families of distributions, a unified representation, known as the generalized extreme value (GEV) distribution can be obtained.The GEV representation is particularly useful, since it bypasses the need to identify the type of distribution to which the extreme value limit law belongs. Instead standard statistical methodology from parametric estimation can be applied to identify the parameters of interest.

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[8] Thus, in his July 13, 2005 speech, Secretary Chertoff stated that, "Although we have substantial resources to provide security, these resources are not unlimited. Therefore, as a nation, we must make tough choices about how to invest finite human and financial capital to attain the optimal state of preparedness. To do this we will focus preparedness on objective measures of risk and performance."

[9] See for example Reiss and Thomas (2002)

5. Catastrophic Terrorist Events: How Often and How Bad?

In this section, we apply the above methods to estimate the likelihood of a catastrophic event that involves the use of CBRN-agents. These results are then compared with trends in more conventional forms of terrorism. The severity of an attack is measured in terms of the number of fatalities or injuries it causes.

CBRN Terrorism

The variation in our CBRN-dataset is rather limited. The overwhelming majority of attacks failed to cause death or injury. Nevertheless there is some structure in the tails of the distribution (Figures 6A and 6B). This coincides with the sarin attacks in Tokyo and Matsumoto, as well as a handful of other cases. To maximize the variation in our dataset, we model severity in terms of the total number of casualties, i.e. the sum of injuries and fatalities. Ideally we would like to consider fatalities and injuries separately. However the number of deaths resulting from CBRN-attacks is relatively low. This is clearly evident in Figure 6B; the tails of the distribution function underlying the severity of terrorist attacks shows much more structure along the axis measuring the number of injuries than fatalities. Thus it appears that chemical, biological and nuclear attacks have led to far more injury than death. The deadly sarin attack in Tokyo for instance claimed 12 lives, but injured over 5000. The largest number of fatalities resulting from the use of CBRN-agents (sulfuric acid) occurred in Uganda, when the cult, *Restoration of the Ten Commandments of God*, is suspected of poisoning its members. The total number of deaths in this poisoning attack is estimated at 200. However even this figure is relatively low when compared to the nearly 3000 people that died on September 11.

Figure 6A Frequency Distribution of Casualties from CBRN-Attacks

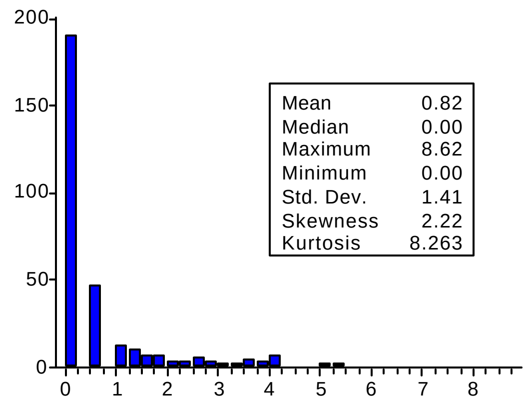
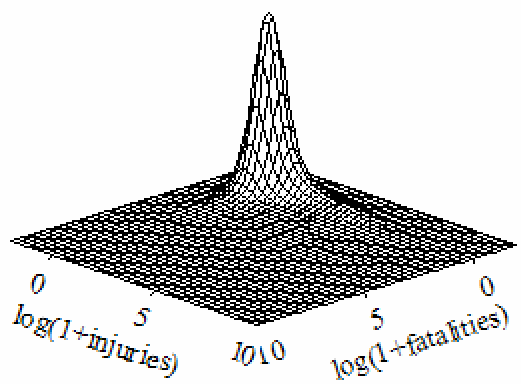


Figure 6B Frequency Distribution, Injuries, Fatalities, from CBRN-Attacks



Notes: Injuries, fatalities and the total number of casualties are shown on a logarithmic scale. (The transformation log(1+casualties) was taken). Source: Based on authors' chronology of CBRN-events.

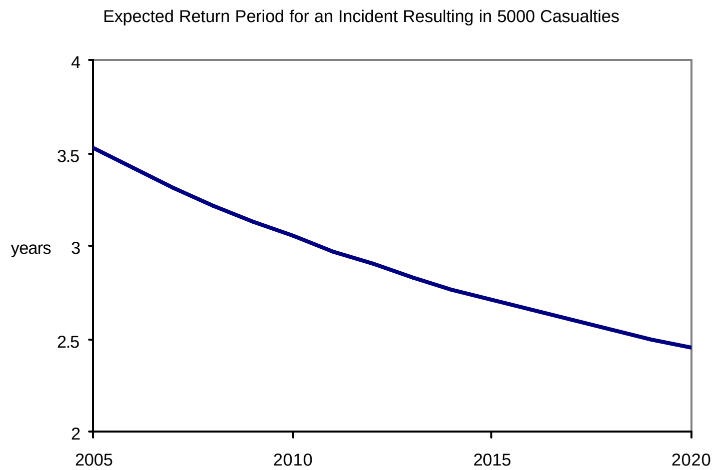
Clearly the limited variation in our sample is a concern. However, there nevertheless appears to be enough to derive an initial set of estimates of the incidence of extreme events. The application of extreme value theory typically involves "blocking" the data into disjoint sub-periods of equal length and fitting a GEV distribution to the block maxima. In setting the block size researchers face a tradeoff. "Blocking" too narrowly threatens the validity of the limiting argument made above leading to biases in estimation. Wider blocks however will generate fewer maxima, leading to greater variability in our estimates. The choice of blocks of length one year has proved particularly popular. In part this decision has sometimes been forced onto researchers—for example when only annual maxima of daily data are available. However, this decision also reflects technical difficulties that arise in the presence of short-run dependence within high frequency data: a one-year "blocking" window could bypass some of these difficulties. Given these considerations we choose a "blocking" length of one year.

Model Estimation

We restricted our sample from 1974 to 2005, since there were very few recorded CBRN-incidents prior to 1974. We fit a number of plausible model specifications to these data. Diagnostic checks of the various models, suggested the presence of non-stationary trend components in both the location and scale parameters characterizing the GEV-distribution, with some of the extreme variation in the data can be explained by the heavy-tailed nature of the underlying stochastic model. This finding is not altogether surprising given the strong visual evidence of an upward trend in the number of casualties inflicted from CBRN-attacks. We also considered more general specifications that allowed for quadratic trend components in either the location or scale parameters. However this usually led to "overfitting" in which the resulting models did not appear to explain the underlying structure of the data well.

Based on our estimated model, we can calculate the expected "reoccurrence period" for a catastrophic event that entails large loss-of-life or injury. For instance an event on the same scale as *Aum Shinrikyo's* attack on the Tokyo subway could be expected to occur by 2009. In that attack there were a little over 5000 casualties. The reoccurrence period for an attack of this size however is continually decreasing (Figure 7). By 2020 an attack of that magnitude would be expected to occur approximately every 2 ½ years. However these estimates assume a continuation of current trends, which may or may not be true.

Figure 7 Reoccurrence Period for a CBRN-Attack Resulting in 5000 Casualties



Notes: Based on the parameter estimates that indicate a linear trend in location and scale parameter of the distributions. Estimation was done in R using the ISMEV package. The ISMEV package is based on software written by Stewart Coles.

While our estimates of the probability of attacks of various magnitudes summarize recent trends in the use of CBRN-agents, there are a number of reasons why these figures should only serve as a rough guideline. First, the number of recorded incidents of CBRN-attacks is relatively low. This has implications for the precision with which parameters in the model can be estimated. But it also involves drawing inferences as to the future likelihood of events based on patterns of behavior that are not necessarily well-established. While the use of bio- and chemical weapons dates back many centuries, their effectiveness as a weapon in the terrorist arsenal is a recent phenomenon. Aside from *Aum Shinrikyo's* "mastery" over delivery mechanisms for chemical and biological toxins, few terrorist organizations have managed to successfully deploy these agents effectively. Even points of attack that have focused on fairly vulnerable sectors such as the food supply chain have usually failed. The injection of cyanide into grapes in 1978 failed because citric acid in the grapes broke down the cyanide. The Tylenol murders in 1982 by contrast caused seven fatalities, but even in this case damage was mitigated through preventative actions taken by the authorities. With some exceptions such as the *Rajneeshee* cult, which had access to their own medical facilities, terrorists have generally failed to introduce a bio-weapon that has been able to exploit the existing infrastructure in the food supply chain to cause catastrophic damage. While the sophistication of terrorists is likely to grow over time, it is apparent that the use of CBRN-agents as a terrorist device remains in its infancy. Thus future trends in their use are necessarily difficult to predict.

Second, our estimate of the likelihood of future attacks assumes a continuation of current trends. However, post-September 11, the war on terror has taken on new meaning in government politics all over the world, which has made it increasingly difficult for terrorists to operate in a clandestine fashion. Moreover, terrorists have learned that inflicting mass casualties entails mass retaliation, which may act as a deterrent for future attacks.[10] It is not clear at this point if September 11 marks a structural break in the evolution of terrorism.

Given our limited experience with CBRN-agents as a terrorist tool, an examination of the trends in terrorist activity more generally may help us shed more light on the future prospect of catastrophic terrorism. In the subsection below we examine these trends in more detail. Our analysis is based on the MIPT data, although these data have been expanded by including notable omissions in the dataset, such as the *Rajneeshee* food-poisoning case in 1984. Nevertheless by far, the bulk of these data relate to conventional forms of terrorism.

Conventional Terrorism: A Comparison

As with the use of chemical, biological, and or radionuclear agents, the use of conventional terrorist methods has also increased in frequency. Moreover, with the increased sophistication of bombs and explosives, the death toll resulting from the most severe attacks has steadily risen. These trends are evident in a plot of (the logarithm of) the number casualties resulting from major terrorist attacks (Figure 1).

We take a similar approach here as in the previous subsection and consider a variety of different models that include the most parsimonious specifications based on the

[10] For a game theoretic approach to understanding the action-reaction strategies of the governments and terrorists see for example Sandler and Enders (2004).

assumption of stationarity and allow for nonstationary trends in the parameters. Given the far wider variation within these data, we can measure severity as the number of fatalities, the number of injuries as well as the total number of casualties.

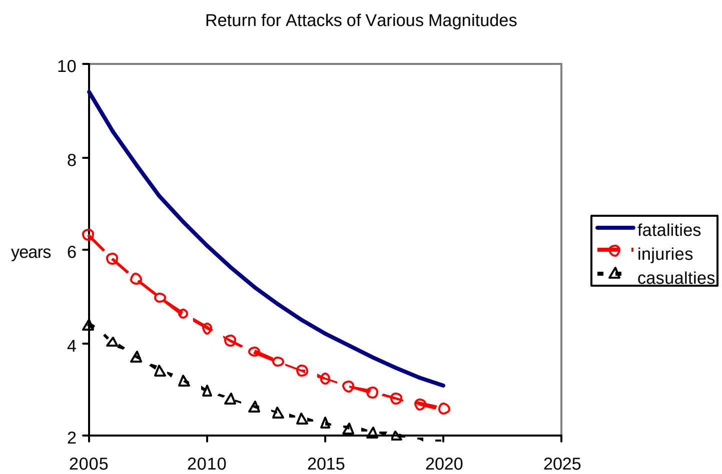
The tendency for the annual maxima in the number of injuries or fatalities caused by attacks to increase over time suggested nonstationary specifications. Our analysis confirmed this to be the case. The best-fitting models for the number of injuries and the total number of casualties (injuries and fatalities) are characterized by linear trend components in the location and scale parameters, with fairly light or bounded tailed behavior. Thus much of the increase in the severity of terrorist attacks can be described by deterministic linear trends in the underlying data generating process, rather than excessively heavy tailed-behavior.

Similarly the best-fitting distribution for the number of fatalities suggested a distribution with bounded-tails. However, importantly the number of fatalities from terrorist attacks did not show the same dramatic increase as the number of injuries. As a result a linear trend component in the location parameter alone sufficed to describe these data well. While we also considered quadratic trend components in both location and scale parameters, the strength of the evidence in favor of these more complex model structures was not particularly strong. As a result the more parsimonious specification was preferred.

Based on our estimated models, we calculated the expected number of years for observing an attack of various magnitudes. Consistent with increasingly violent trends in terrorism, the expected number of years until the next major terrorist event is declining through time (Figure 8). The expected reoccurrence period for an event leading to 5000 injuries and fatalities is a little over 4 years. This estimate is very similar to that based on the CBRN data. In fact the estimated reoccurrence period for such an event using the CBRN-data was slightly shorter. The explanation for this is fairly straightforward. While terrorism using conventional means has had a long history, the use of chemical, biological or radionuclear agents is still relatively new with limited consequences for public health. By far the majority of CBRN-incidents cause no injuries or fatalities. Thus recent exceptions, such as *Aum* (1994, 1995), the *Rajneeshees* (1984), the poisoning of

Filipino police officers in 1987 and Russian peace keepers in 1994, can only be explained within the confines of our statistical model by allowing the parameters of our extreme value distribution to be functions of time and by assuming heavy-tailed behavior. However when chemical, biological and radionuclear attacks are considered from a broader perspective that allows for various forms of terrorism, these nonstationary trends within the data become less prominent. Moreover, given the large numbers of fatalities and injuries arising from conventional forms of terrorism, catastrophic incidents such as the Tokyo gassing in 1995, can be easily described by statistical models characterized by fairly light-tails.

Figure 8 Reoccurrence Period for Attacks Resulting in 5000 Injuries or Overall Casualties or 1000 Fatalities



Notes: The reoccurrence period for injuries and total casualties that include fatalities are based on parameter estimates that indicate linear trends in location and scale parameters. The reoccurrence period for fatalities only was based on parameter estimates that indicate a linear trend in the location parameter only. Estimation was done in R using the ISMEV package and based on software written by Stewart Coles.

Based on our statistical model of the annual maxima in the number of fatalities we were also able to calculate the expected reoccurrence period for a catastrophic event that results in a large-scale loss of life. While an attack of the same magnitude of September 11, one that causes approximately 3000 fatalities, is not expected soon, an attack that leads to 1000 fatalities could occur within the next ten years. Moreover consistent with the nonstationary pattern in these data, the reoccurrence period for such an attack is decreasing steadily over time. By 2020 for instance an attack of this magnitude could be expected to occur roughly once every three years.

As noted above, at this moment there is not enough variation within the subset of incidents involving the use CBRN-agents to accurately estimate the risk of an attack of this (or any) magnitude. However, based on what has been observed to date, such an attack is unlikely to occur soon. Catastrophic terrorism that leads to a loss of life on a large scale is still more likely using conventional methods. As of yet, no terrorist group has demonstrated the potential to inflict a devastating attack using chemical, biological or radionuclear agents.[11]

6. Conclusion

This paper is the product of ongoing research into the assessment of the risk of bioterrorism in the food sector. Our contribution in this paper has been two-fold. First, we have developed a fresh new data set consisting at this time of 314 observations from 1961 to 2005. This dataset focuses on past terrorist attacks that have involved chemical, biological or radionuclear agents, agents that are especially likely to be associated with the food sector as the channel for their dissemination. Second, we have adopted a statistical technique known as extreme value theory to assess the probability of terrorist events and even forecast the "reoccurrence period" for events of certain magnitudes. We have also used another data set (MIPT) consisting of over 21,000 observations as a benchmark to compare the risk of terrorism in the food sector with that at large.

Our results are somewhat alarming: For example, we have found that the frequency of catastrophic terrorist events, i.e., those with large numbers of casualties, is

[11] This statement may need some qualification. In 1984, Bhopal, India, was the site of one of the worst chemical disasters in history leading to approximately 3800 deaths and over 250,000 injuries following a gas leak in the fertilizer plant of Union Carbide. It was claimed by the engineering firm Arthur D. Little that the disaster may have been the result of a deliberate act of sabotage where someone placed water in the gas storage tanks that caused the chemical reaction. However, no independent inquiry has ever endorsed the theory of sabotage. The Indian government has always claimed that the disaster could be linked to faulty plant design and the claim that sabotage was involved was an effort on the part of the company to escape liability (See for instance Mehta et. al. 1990 and "Bhopal disaster deliberate act of worker, Carbide claims," *Houston Chronicle*, August 11, 1986). At this moment we do not feel there is enough evidence to indicate that the Bhopal incident was a deliberate act of sabotage. Thus we do not include it in our chronology.

on the rise. Correspondingly, the average reoccurrence period for such scale attacks is declining, so that by the year 2020, an attack leading to 5000 casualties could be expected to occur every 2 ½ years. Similar trends underline our findings with respect to terrorist attacks more generally.

These finding have implications for calibrating the notion of risk assessment for private and public sector decisions involving risk avoidance and the costs and benefits of such decisions. These are some of the tasks ahead in this line of research that would be pursued in the coming year, but are outside of the scope of *this* paper.

Additional extensions of the present work might include relating the CBRN data to the larger dataset on more conventional forms of terrorism by developing a *conditional* probability measure in which the probability of a CBRN attack is estimated, given that a attack of a certain magnitude has occurred. Other extensions in this line of research may include considering other specific pathogens with a potential to be used for bioterrorism. But that effort will depend on finding useful data on such agents.

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Table 1 Major Terrorist Events Between 1968 and 2005

Date	Incident	Fatalities	Injuries
9/1/2004	On March 9, 2004 a group of 35 Chechen separatists seized a school in the Southern Russian town of Beslan taking children, parents, and teachers hostage in the school gym. In the aftermath of the attack, the official death toll reached 338 although unofficial figures were higher. At least 727 people remained hospitalized, some in grave condition. The total number of hostages is believed to have been around 1,200.	338	727
9/11/2001	Attack on the World Trade Center, the Pentagon and the hijacking of United Airlines Flight 93	2982	unknown
8/7/1998	On August 7, 1998, a car bomb exploded outside the U.S. Embassy in Nairobi, Kenya.	291	5000
1/31/1996	On January 31, 1996, the Tamil Tigers drove a massive truck bomb into the Central Bank building in Colombo. The vehicle exploded, killing 96 people and injuring over 1,400, amongst whom were 32 foreigners, including two US citizens, six Japanese and one Dutch national.	96	1400
3/20/1995	On March 20, 1995, the Japanese extreme sect Aum ShinriKyo (Sublime/Supreme Truth), released sarin gas on the Tokyo subway resulting in 12 fatalities and thousands of injuries.	12	5000
3/12/1993	In March 1993, 13 bombs exploded in Bombay within the space of three hours. At least 317 people died and 1200 were injured.	317	1200
2/26/1993	On 26 February, 1993, a bomb exploded in the parking garage of the World Trade Center in Manhattan, killing 6 and injuring 1042.	6	1042
4/10/1988	In April 1988, an attack on a weapons dump in Islamabad claimed the lives of over 100 people and caused over 1,100 injuries.	100	1100

Source: MIPT, Terrorism Knowledge Base.

Table 2 The Most Serious Attacks on Food Chain: 1961-2005

11/19/2003	0	50	About fifty people in more than 20 cities in Italy had to be treated for a variety of ailments including stomach pains, after they drank bottled water that had been injected with either bleach acetone or ammonia.
10/1/2003	0	64	Cao Qianjin threw 500 ml of a pesticide into the reservoir in Ruyang County, Henan. Province, China. Approximately 64 residents were poisoned.
9/23/2003	0	241	Several hundred (317) students and staff at an elementary school in Yueyang, Hunan Province, China, were sent to hospitals, after eating breakfast that had been laced with rat poison. Investigators stated that 241 students and staff showed some signs of poisoning.
12/31/2002	0	111	A supermarket employee in the US poisoned about 250 pounds of ground beef with an insecticide. At least 111 people who fell ill after eating the meat.
June, 2002	0	60	In June 60 students and teachers at a school in Volgograd, Russia, were hospitalized after being poisoned with the salmonella typhi toxin.
5/19/2002	7	47	Seven members of the Johanne Marange Apostolic Church, a Christian fundamentalist group, died and another 47 were taken ill after drinking a tea that had been poisoned.
1/30/2002	Unknown	92	In Linxiang city, in China's Hunan Province, 92 children at the Yucai Private (primary) School fell ill after eating their school lunch which had been laced with rat poison. Of the 92, 40 were in serious condition.
8/8/2001	0	120	At least 120 patrons in 16 restaurants were made ill after eating noodles that had been contaminated with rat poison in Ningxiang, Hunan Province, China.
3/8/2000	2	60	Poisoned food was served to hundreds of students at a religious school in Jalaludin, Afghanistan. Two students died and sixty others lost consciousness.
11/3/1999	Unknown	48	Approximately 48 people fell ill after eating meat rolls that had been laced with rat poison at a fast food restaurant in Deyang City, Sichuan Province, China.
3/8/1999	0	148	Five people were arrested in China, after putting nitric acid in a popular restaurant's specialty donkey meat soup, poisoning 148 people.
7/25/1998	4	60	Four people died and approximately 60 were hospitalized during a summer festival in Wakayama, Japan, in a case of mass food poisoning that possibly involved the use of cyanide.
1/1/1994	15	53	On New Year's day nine Russian soldiers and at least six civilians died after drinking champagne that had been laced with cyanide. The cyanide-laced champagne was being sold outside of the Russian compounds. Another 53 people, including 11 civilians, were hospitalized.
9/6/1987	19	140	Several fatalities resulted when members of the Philippine Constabulary were poisoned after accepting bags of ice water from an individual during a "fun run." As a result 19 people died and 140 fell ill.
Sep. 1984	0	751	Sometime early in September 1984, members of a religious cult known as the Rajneeshees contaminated salad dressing at ten restaurants in a small town in Oregon, USA. As a result 751 people became sick, there were no fatalities.

Sources: Based on authors chronology of CBRN-events and sources cited in the by the authors.