Assessing chemical, biological, radiological and nuclear threats to the food supply chain

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ABSTRACT
The food supply chain may be intentionally compromised. Potential devastating effects of attacks with chemical, biological, radiological or nuclear (CBRN) agents are particularly emphasised and the ease with which such an attack may take place is described in numerous sources. Yet, using the food chain’s carrying capacity to spread a CBRN contamination across a wide geographic area is (extremely) complicated. Although episodes of intentional food contaminations can be serious, they rarely result in mass fatalities. Economic damage may quickly arise, but is often a result of (too) rigorous countermeasures. Past incidents demonstrate that a sole suspicion or even rumour of food being contaminated can already have severe consequences. This paper provides insight into the threat of intentional CBRN contamination of the food chain. It describes various parameters, including the type of agents capable of yielding damage, possible points of introduction and potential consequences of deliberate CBRN contamination of the food chain, in an effort to facilitate future risk assessment.

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Introduction
The food supply chain can be compromised by different factors, including intentionally. There are numerous examples of food sources being tempered with throughout history and even more (frustrated) plots. During the invasion of al-Qaeda sanctuaries in Afghanistan in the early 2000s, for example, (U.S.) agricultural documents, lists of livestock pathogens and manuals for targeting the food supply were discovered (Olson, 2012). More recently, in 2016, a group of Islamic State-aligned terrorists allegedly planned to contaminate Indonesian’s (police and army) food and water supplies with cyanide in an attempt to destabilise the state (Boyle, 2016). Numerous officers, researchers and policy makers consider the food chain to be particularly vulnerable to attacks with chemical, biological, radiological or nuclear (CBRN) agents (e.g. Mohtadi & Murshid, 2009). They fear the ease with which such an attack may take place and emphasise its potential to create mass casualties. However, using the food chain’s carrying capacity to spread a CBRN contamination across a wide geographic area can be extremely complicated and its effects are unpredictable.

The misuse of chemical and biological agents, i.e. to intentionally contaminate food and water supplies, dates back many centuries. Agents’ increased effectiveness as a weapon is a more recent phenomenon: they have become more deadly and their means of delivery more sophisticated, particularly those developed under state’s weapon programmes. Due to globalisation, open information access and technological advances among others, these weapons, their toxic agents and information on how to fabricate them are now within reach of an increasing number of (non-state) actors. Unsurprisingly, such agents have occurred as a means of attack in terrorist plots in the past decades, including in relation to food. The World Health Organization (WHO) explicitly combines CBRN agents with ‘food terrorism’, defining it as ‘an act or threat of deliberate contamination of food for human consumption with CBRN agents for the purpose of causing injury or death to civilian populations and/or disrupting social, economic or political stability’ (WHO, 2002).

This paper takes the WHO definition as a starting point, but also considers animal feed and water supplies as potential targets. Targeted poisonings, directed at specific individuals, are not part of the main focus of this paper because they generally do not have the potential to create mass casualties or widespread damage. For example, the Polonium-210 poisoning of Alexander Litvinenko in the U.K. in 2006 – although perhaps the only confirmed use of radiological material
strong enough to kill an individual with a food related item— is not considered an attack on the food chain: there was no intent or potential to make use of its carrying capacity. This paper provides insight in the threat posed by CBRN contaminations that do have this potential. In order to do so, it first describes relevant CBRN agents, thereafter likely points of introduction in the food chain, and, thirdly, possible consequences of such attacks before drawing some final conclusions.

**CBRN agents with potential to contaminate the food chain**

Many CBRN materials are used for food-related benefits, for example, to fertilise soil, for crop protection or to increase durability of food. Therefore, such materials are often present in products and available in close vicinity to foodstuffs in different phases of the food chain. However, when improperly used or misused, i.e. in a way that is harmful or morally wrong, such agents could cause harm. Not all agents have the potential to yield disastrous effects. This section describes those that can, including readily available toxic chemicals, a plethora of (naturally occurring) microbiological pathogens and certain radioactive materials.

**Chemical agents**

In the past, large-scale food-related misuse of chemicals occurred and led to numerous innocent victims as a direct or indirect result thereof. For example, between 1961 and 1971, U.S. and Vietnam forces used herbicides to defoliate forests and mangroves to clear perimeters for military installations, but also to destroy crops as a tactic for decreasing enemy food supplies (Mager Stellman, Stellman, Christian, Weber, & Tomasallo, 2003). Due to the coloured identification bands painted on their storage barrels, these herbicides are known as the rainbow agents (e.g. Agent Orange and Agent Green). Today, people are still battling the aftermath of their use and the full socioeconomic, environmental and health effects remain partially unknown (some indications are provided by Palmer, 2005).

There are no recorded examples of mass casualties as a result of intentional misuse of chemicals related to food in recent history, though incidents continue to occur, e.g. when pesticides are (deliberately) wrongly used. An interesting example in this regard is the illegal spraying of fipronil at farms in the Netherlands and Belgium, which most likely started in early 2016 but became public in August 2017. Fipronil was used to kill lice present in poultry farms, despite being banned in the EU for use on farm animals. It entered chickens and subsequently eggs and got further into the food chain. Fortunately, no acute health effects occurred, but this scandal had significant economic and political consequences.

Despite measures taken to limit use or availability of toxic chemicals, including pest-control products, banned chemicals are still relatively easy available, e.g. on the black market or as part of left-over stocks. Malicious people may be tempted to acquire and use such chemicals to harm people, and have done so in the past. For example, in 2002, seven members of the Johanne Marange Apostolic Church died and another 47 were taken ill after drinking tea laced with pesticides (Mohtadi & Murshid, 2009). Similarly, rodenticides have been used intentionally for numerous poisonings. The toxicity of rat poisons has been particularly recognised in China.

Metals and commonly available (household) chemicals have been used for tempering with food products as well. In 1978, for example, some Israeli-grown oranges injected with mercury turned up in Germany and the Netherlands. The fruit was accompanied by a letter bearing the name of an alleged Palestinian terrorist group that claimed they had contaminated the fruit to sabotage the Israeli economy (‘Poisoned Oranges’, 1978). In addition to a handful of Dutch children being temporarily hospitalised, the import of million tonnes of citrus products was halted (Bjarnason, 2012). Arguably, the group thus succeeded in achieving their goal. Commonly available chemicals have been used to create damage more recently as well. In 2003, for example, 50 people in more than 20 cities in Italy had to be treated for several ailments after drinking bottled water that had been injected with bleach and acetone (Mohtadi & Murshid, 2009). Although creating mass casualties with such chemicals may prove to be difficult, they still can be appealing to use for contaminating food because they generally do not require complicated weaponisation steps and they still can create major (economic) damage.

Toxins are poisons produced by living organisms and are categorised as biological agents. However, they are also considered to fall within the category of (possible) chemical weapons due their inclusion in the definition of chemical weapons and their exposure effects. Botulinum toxins are among the most deadly substances known. They are associated with consumption of (preserved) foods, especially if improperly processed (WHO, 2017), but also among compounds explored by terrorists for use...
as weapons (Occupational Safety and Health Administration, n.d.). Similarly, ricin has already been used as a weapon in the past and remains a serious threat, including for the food chain. Ricin can be derived from castor beans and is particularly dangerous if made into a purified material (Centers for Disease Control and Prevention (CDC) (a), n.d.). The arrest of a man in Germany in June 2018 exemplified again that people with malicious intent can be capable of producing the toxin (Böhning, 2018).

**Biological agents**

Biological agents may be attractive as a weapon because, unlike other dangerous substances, they are able to reproduce. Under favourable conditions, a small number of micro-organisms may multiply in a very short time. Biological agents referred to in this paper include pathogenic micro-organisms such as viruses, bacteria (and their toxins) and parasites. Increased presence of biological agents can be found in different activities related to the food chain, including agriculture, farming, food production plants or, more generally, activities where there is contact with animals or products of animal origin, and water management such as purification installations (European Agency for Safety and Health at Work, 2010).

The possibility of contaminating food with biological agents has been widely explored by terrorists, and also successfully applied in the past. Most notably in Oregon, U.S. in 1984, when the Bhagwan Shree Rajneesh cult poisoned salad bars with Salmonella typhimurium bacteria in an attempt to influence a local vote by limiting voter turnout. Using a particular strain ordered from a commercial laboratory company, they infected a large part of the community; no one was killed, but 751 people fell ill, 45 of which had to be temporarily hospitalised (Ryan & Glarum, 2008). Perhaps if the group had different motives or chosen a different point of entry in the food chain, effects could have been far worse. Salmonella-related safety incidents can exemplify this. For instance, in 1996, Salmonella enteritidis gastroenteritis developed in 224,000 persons in the U.S. after they ate ice cream made from premix that was transported in improperly washed out tank trailers (Hennessy et al., 1996). The bacterium continues to cause millions of foodborne illnesses each year.

Salmonella may be interesting for those with malicious intent because it is rather easy to come by, being present in the environment and in animals. However, if killing is an actor’s objective, another agent may be better suited. For example, one that is stable enough to survive different circumstances it may be exposed to throughout food processing, such as heating or exposure to (ultraviolet) light. There are not many agents that naturally possess such features. Anthrax may be the exception as it is rather stable and persistent, especially in spore form. Otherwise, considerable effort, knowledge and (financial and technical) means are needed to attain such qualities. This could explain why no large-scale food incidents involving an intentional contamination with biological agents have taken place in recent history. However, the possibility that the 2011 Enterohemorrhagic Escherichia coli (EHEC) outbreak in Germany was the result of a deliberate epidemic cannot be discarded (Radosavljevish, Finke, & Belojevic, 2014). It led to almost 4000 infections, including 53 deaths (Robert Koch Institut, 2011).

Incidentally, it is important to note the distinction between pathogens like smallpox, plague or Ebola, and non-contagious micro-organisms, such as salmonella and anthrax. The first category is capable of human-to-human transmission, the latter is not. Particular interesting are also zoonoses, which are infections or diseases that can be transmitted directly or indirectly between animals and humans, for instance, by consuming contaminated foodstuffs or through contact with infected animals (European Food Safety Authority, n.d.). Due to their potential to spread among humans outside the food chain, contagious micro-organisms may be more interesting agents for terrorist purposes. However, obtaining plant or animal pathogens is generally much easier than acquiring those agents dangerous to humans. Furthermore, from a tactical perspective, certain animal or plant pathogens do not require weaponisation and thus are immediately ready to use. Despite risks of most animal diseases being transmitted to humans via food is (extremely) low, sometimes even non-existent, such outbreaks often do cause the type of disruption terrorists may seek, especially when governments take radical, sometimes unnecessary, measures (WHO, n.d.). Whether or not an agent is contagious for humans may not be clear to policy makers or the public.

**Radiological and nuclear agents**

Radiological agents include all radiological substances. Nuclear agents can be seen as a specific subset of radiological agents. The differences relate to their origin. Radiological agents include radioactive material that occur naturally in the environment or are generated as by-products and waste from particular
(mineral) processing industries, produced for use in industrial applications and medical therapy. Nuclear agents are radioactive material used to generate nuclear energy via nuclear fission or fusion, such as in nuclear weapons, nuclear power plants or reactors and their waste. Nuclear agents do not naturally occur in the environment (Plutonium) or need to be (highly) enriched and processed (both Plutonium and Uranium) to be suitable for such applications. Such agents can create damage because they emit ionising radiation. Radioactivity can contaminate food in particular after it has been discharged into the environment (FAO & WHO, 2011).

In the event of releases of radioactivity following an incident at a nuclear power plant, land, rivers, sea and structures in the vicinity of the power plant can become contaminated with a mixture of radionuclides. The Chernobyl (1986) and Fukushima (2011) accidents, for example, led to contamination of farm-raised (animals and plants) and illustrate that radioactivity can harm the food chain (e.g. RIKEN, 2015; White, 2016; WHO, 2005). Of immediate concern in such cases is iodine (I-131) that can be spread over a wide area, found in water and on crops, and which rapidly transfers from contaminated feed into milk (Food and Agricultural Organization of the U.N. [FAO] and World Health Organization [WHO], 2011). It decays within a few weeks. In contrast, Caesium can remain in the environment for a long time as it has a half-life of about 30 years. Although an attack directed on nuclear facilities as well as detonation of a nuclear weapon could theoretically result in the release of such agents into the environment, using this modus operandi to contaminate the food chain seems highly unlikely and is therefore not further considered here.

Widespread radiological contamination of food or water sources involving nuclear materials is unlikely in general as well, though an unconfirmed case of plutonium being put into New York City’s water reservoir exists. On 1 April 1985, the mayor received an anonymous letter, threatening to contaminate the water supply with plutonium unless all criminal charges against a subway shooting suspect were dismissed by a certain date. Analysis of drinking water samples was requested and the concentration measured was a factor of 100 greater than previously observed results in databases in at least one sample (Bogen et al., 1988). Additional samples were collected at various distribution points in the water supply system. Plutonium concentrations were much lower and comparable to earlier data. Due to inability to confirm the elevated concentration value for the first sample, it was impossible to conclude whether the threat was actually carried out or whether the sample was contaminated prior to receipt at the laboratory. Either way, the plutonium concentrations always remained far below the permissible level for drinking water.

There are not many additional examples of intentional food-related contamination with radiological materials. Most other cases involved specifically targeted attacks that fall outside the scope of this paper. Two confirmed incidents that occurred in the U.S. in 1995 are worth mentioning though: both food and a water cooler were contaminated with Phosphorus-32, affecting more than 20 people (Mooare, 1995). Remarkably, in all cases (including the dismissed, specifically targeted attacks), the perpetrators either worked in scientific laboratories that used radiological materials or had direct access to it (Dalziel, 2009, p. 20). Luckily, their victims suffered from physical discomfort only, or at most gained an increased likelihood of developing health risks associated with radiation exposure in the future.

**Points of introduction in food chain**

For food to get from production site to the dining table, several steps need to be taken; production, processing, distribution and preparation (CDC (b), n.d.). Although protective mechanisms often have been installed, the complexity of food systems and the variety of ways in which food is produced and distributed continues to create defence difficulties, especially when people attempt to bypass safety and security measures (Benoliel, 2007). Figure 1 depicts that intentional contamination of food with CBRN agents can occur at any (vulnerable) point along the chain. This section describes the threats per phase.

**Production**

Some foods are caught or harvested from the wild, but most food comes from animals and plants. Their production usually occurs on farms or fisheries; places that are often open and unprotected and thus vulnerable to potential attacks. Targeting plants and animals may have advantages over direct attacks on humans as it may present fewer practical roadblocks and they can even be made to look like an act of nature. This type of attack is considered a subset of food terrorism called agroterrorism. Agroterrorism is defined as ‘the deliberate introduction of an animal or plant disease for the purpose of generating fear, causing economic losses, or undermining social stability’ (Monke, 2004, p.1).

Chemicals can cause large-scale damage to crops, but attempts to eradicate illegal drug crops exemplify the massive logistical efforts needed to make a
substantial dent in agricultural production (e.g. Jelsma, 2001). It may thus be difficult or even impossible for non-state actors to achieve significant effects using only chemicals. Crop diseases could create more damage as they can be introduced in limited amounts, but still infect large areas due to reproduction and rapid spread. Yet, it is extremely challenging to obtain, let alone create and effectively disperse a sufficient amount of agent that can bypass disease monitoring systems. Introducing crop-eating organisms could be easier and may have been used as a means of attack in the past. In 1989, for example, a group called ‘the Breeders’ claimed responsibility for releasing crop-eating fruit flies in California as retaliation for state-mandated pesticide spraying (Hirsch, 2013). The medfly infestation did not fit the natural pattern, but investigations found insufficient evidence to identify it as an intentional introduction (Monterey WMD-Terrorism Database Staff & Staff, 2011).

Livestock has been targeted by multiple actors as well, either directly or via introduction of a toxic additive to their food. During World War II, for example, the British prepared and tested anthrax-infected ‘cattle cakes’ that could be airdropped onto German livestock fields (Kosal & Anderson, 2004). In the 1950s, the Kenyan Mau Mau allegedly injected British-owned cattle with a plant toxin (e.g. O’Hara, 2006). Direct contamination of animals using biological agents has also been explored and used as a tactic. For example, a group of New Zealand rural farmers that was frustrated by official responses to rabbit control problems, introduced and spread Rabbit haemorrhagic disease virus in a clandestine operation in 1997 (Mohtadi & Murshid, 2009, p. 1324). Remarkably, since then, changes to the law have been made to legitimise the possession and spread of certain virus-infected material. In fact, the Ministry of Primary Industries approved a nation-wide release of a new Rabbit Haemorrhagic Virus Disease strain, which took place over March and April 2018 (Ministry for Primary Industries, 2018).

In the aftermath of natural Foot and Mouth Disease (FMD), mad cow disease (Bovine Spongiform Encephalopathy, BSE) and avian influenza outbreaks, stricter controls and tighter mechanisms have also been promulgated, but it is not a watertight system (Benoliel, 2007). Farms are seen as a particular weak link in the food chain. Some larger farms have taken security measures, such as electronic alarms or security gate check-ins, but many maintain an old-fashioned security: lock, key and a watchful eye (Hirsch, 2013). Since livestock in many countries is concentrated in confined spaces at isolated locations, they can be an easy target. Fast spread among animal population in such locations is more or less ensured. Farms may also share equipment, vehicles and veterinary instruments, potentially allowing animal pathogens to spread beyond the original target (Olson, 2012). On the other hand, as soon as a contamination is known, it may be relatively easy to contain.

Significant containment challenges may continue to exist for FMD, which has been said to present a major, if not the biggest, threat to agriculture.9 Infecting a single animal may be sufficient to ensure rapid dissemination, since the virus is extremely contagious (Wolf, 2016). Arguably, it can be spread by wiping saliva from an infected animal (e.g. on a handkerchief) and then transferring the virus to healthy animals by wiping their noses (Olson, 2012). In contrast to other biological agents, this implies that technical capabilities may be less or even irrelevant for FMD. Furthermore, since it occurs naturally in animals in parts of Africa, Asia, the Middle East and South America, with sporadic outbreaks elsewhere, the virus is readily accessible to people with malicious intent (Knowles et al., p 19).

Incidentally, an interesting issue to take into consideration in regard to livestock’s vulnerability to

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**Figure 1.** Simplified depiction of possible introduction points of CBRN agents in the food chain.
contamination relates to antibiotics. In addition to commercial reasons, antibiotics are added to animal feed or drinking water to keep them healthy. Due to consequent public health issues, farmers and the veterinary profession have been put under high pressure to reduce the use of antibiotics.\textsuperscript{10} Yet, this will make animals more vulnerable to diseases and rapid spread thereof, including as a result of intentional introductions.

**Processing**

Processing refers to changing crops or animals into what is sold as food, e.g. washing, pasteurising and cooking. CBRN agents that may have been introduced at the production stage may be affected during this step. Most likely, processing will make an agent less toxic, though the possibility of it getting more toxic cannot be ruled out. Processing facilities themselves also present opportunities for agent introduction. Fruit- and vegetable-packing plants are among the most vulnerable venues for attacks, due to their smaller scale and lack of effective barriers to prevent contamination and further spread thereof (Leikin, 2014). Such vulnerabilities may be exploited. For example, approximately 28 individuals in Australia and New Zealand contracted Hepatitis A from eating tampered with frozen berries originating from a Chinese facility (Winfield, 2016, p. 37). Other small-scale manufacturers that specialise in ready-to-eat meats or aggregated foodstuffs may also be vulnerable. In particular, facilities that deal in already-prepared products that do not require cooking provide a viable portal to introduce agents (Olson, 2012).

Most food-related companies are part of a larger food chain. Contamination of products in one company could therefore potentially have widespread consequences. For example, large players in the food industry may use contract manufacturing with smaller companies. Outsourcing presents a risk as it could mean loss of control of the production process while still being accountable for end products or brands. Most companies comply with the general obligation to ensure that their products are safe for consumption. Yet, cases of adulteration exist. In 2008, for example, Sanlu Foods was accused of adulterating powdered milk with melamine to show a higher protein level. It affected some 300,000 individuals, including six infants who died of kidney stones (Gossner et al., 2009). The Chinese powdered milk industry has yet to recover.

Major food processing companies are also vulnerable for blackmailing by outsiders threatening to contaminate their products. Besides major economic harm, this could lead to health damage when threats are actually executed, including during other food chain stages. For example, between 1999 and 2002, a Dutch man poisoned yogurts, puddings and other foodstuffs in an extortion scheme against a number of major Dutch food companies. It took tens of police officers and even FBI involvement to catch him (Wiegers, 2003). Recalls were carried out, products were immediately removed from the shelves and at least one person fell ill (Deutsch, 2003). Such extortion threats directed at specific (commercial) organisations are more common than is generally believed. Furthermore, there is a perception that such threats, including CBRN-related contaminations, are underreported.\textsuperscript{11}

Personnel play an essential role in ensuring safe and secure food processing. Yet, the ‘insider threat’ is a big concern related to actors compromising the food chain. In addition to a number of examples already described, in January 2014, a Japanese man was arrested on the suspicion of having poisoned frozen foods with a phosphorous-based insecticide (Malathion) at the factory where he was employed. More than 2800 people across the country ate frozen products produced at this plant and fell ill (‘Suspect arrested’, 2014). This man was able to move back and forth between production lines and stated that it was easy for him to put pesticides into products due to limited (safety and) security measures (‘Food poisoning easy’, 2014). It is thus crucial to stay sharp on who works in facilities and has access to food. Yet, many food processing and packaging plants employ large numbers of unscreened (seasonal) workers and commonly operate uneven standards of internal quality (Interpol, 2016).

**Distribution**

Distribution refers to getting food from production site or processing plant to consumers. It can involve transporting foods just once, such as trucking products from a farm to the local farmers’ market, but often involves many stages (CDC, n.d.). During all these steps, there is a possibility of contamination. For example, if food is left in a too warm environment (temperature could also deliberately be tempered with) or products are transported in improperly cleaned vehicles. Most processed food travels to distribution centres, where a lot of food products may be located. A single contamination could therefore have significant (latent) ongoing effects, particularly if the source is not immediately apparent and products are kept in storage for a longer period of time (Chalk, 2005).
Traceability is important during the distribution phase. Producers must be able to identify where and from whom they receive materials as well as to whom they distribute (Benoliel, 2007). For ready-to-eat products this may be easy, but it gets more complicated for goods that are sold in bulk. Such products are frequently traced by batches and products often mixed. What may start as a local contamination can have widespread and serious consequences. In 2008, for example, the Peanut Corporation of America’s (PCA) King Nut facility produced a batch of Salmonella-Typhimurium-contaminated peanut butter. It was distributed to food manufacturers in many U.S. states, which incorporated it into some 1500 separate brands and 2000 individual products. More than 700 persons in 46 U.S. states and one person in Canada were infected with salmonella (CDC, 2009). In 2015, PCA’s executive was handed a 28-year prison sentence for knowingly shipping out contaminated food (Basu, 2015). It was the toughest penalty yet for a corporate executive in a food poisoning outbreak.

**Preparation**

Food is most vulnerable to contamination just before consumption. Unsurprisingly, most cases of (both accidental and) deliberate contamination can be found within this phase. Products have already passed strict food safety rules at earlier levels; thus, contaminated food will not likely be detected until after it is eaten. Furthermore, CBRN agents that are introduced at this stage will not be exposed to additional processing steps or at least the perpetrator has control over such processes. This increases agents’ chances of survival and creating damage. On the other side, introducing CBRN agents to food at this stage is unlikely to create widespread contamination and mass casualties, as there is no chance of further using the food system’s distribution capacity.

Intentional contaminations of food or beverages in this phase often involve acquaintances attempting to do harm to specific individuals, and the bulk of such cases involve less than five or even no casualties (Dalziel, 2009, p. 17). However, examples of more large-scale poisonings exist as well. The Bhagwan cult’s salmonella attack remains the most infamous and successful act, but incidents have taken place more recently as well. For example, a person in Japan caused four people to die and 63 to be hospitalised after serving a curry with arsenic at a summer festival in 1998 (e.g. ‘Wakayama curry poisonings’, 2002). In 2003, a former grocery store worker laced about 250 pounds of ground beef with insecticide, sickening 92 people in the U.S. (‘Beef with poison’, 2003). And in May 2016, a man went into multiple Michigan grocery stores and sprayed a poisonous mixture on open food (Berlinger, 2016). Health effects appeared to be non-existent in this last incident.

Incidentally, people with malicious intentions have themselves also been victims of food poisoning actions. For example, Islamic State (IS) militants, who themselves encouraged attacks on food and water supply as possible means of attack, have been targeted by poisoned food on multiple occasions. In November 2014, for example, some men infiltrated an IS camp posed as cooks and slipped a deadly substance into their lunch (Gee, 2014). At least a dozen fighters were killed. In July 2015, 45 militants were reported dead (Akbar, 2015). And two years later, in July 2017, another couple of IS fighters died and tens were sickened as a result of (deliberate) food poisoning (‘Die of food poisoning’, 2017).

**Water supply**

An attack on the entire water supply system is not easy to accomplish. It requires inherent knowledge of its structure and workings. Most agents are vulnerable to treatment used to make water potable for human use. Brucellosis and tularaemia, for example, are considered to be water threats, but they may be quickly neutralised by chlorine, which is commonly used in water purification systems (Gleick et al., 2006). Most biological agents cannot survive in water, though anthrax in spore form may be of concern. Achieving a significant chemical contamination of the water supply generally requires very large volumes due to dilution. Yet, certain pesticides and inorganic chemicals may cause disruption. In 1980, for example, water was contaminated with a pesticide (chlordane) in three suburbs of Pittsburgh, U.S. It forced officials to shut down the water supply for two weeks and bring in water for 10,000 residents (Dalziel, 2009, p. 10). Roughly 150 people became ill, but this number could have been much higher if the strong odour had not prevented people from ingesting the water. Similarly, water contamination with radioactivity is also unlikely to create many victims due to dilution.

Water for irrigation and water used as an ingredient in food processing can facilitate food terrorism. Contamination of the water supply for agricultural purposes, for example, may hurt animals or damage crops (and humans indirectly as well if they eat contaminated products). In 1970, for instance, Ku Klux Klan members in Alabama killed and sickened cattle by contaminating black farm owners’ water supply with a
cyanide salt (Cameron & Pate, 2001). More recently, in 2010, irrigation water for tomatoes and vegetables seedlings stocks was contaminated with an herbicide in Queensland, Australia. In addition to seven million seedlings being killed, this incident led to economic losses at both the local and national level (50 million and 100 million Australian dollars, respectively) and put more than 3000 employees temporarily out of work (Kennedy, 2010). Two similar cases of intentional contamination occurred in 2002 and 2006.

Targeted attacks on water supplies at particular facilities are probably easier to conduct, especially if purification processes have already occurred. In addition to many plots to do so, such attacks have actually taken place in the past. For example, in 1992, PKK people put a lethal dose of potassium cyanide into water tanks of a Turkish airbase, but it was discovered before anyone was poisoned (Gleick, 2013, p. 22). The media reported that proposals to poison the water supplies of major cities in the West ‘as a possible response to Western offensives against Islamic organizations and states’ were made at a meeting of fundamentalist groups in Tehran, under the auspices of the Iranian Foreign Ministry (Gleick, 2013, p. 20). Another example includes water source poisoning as part of a harassment strategy against displaced populations in Darfur, Sudan in 2004 (Amnesty International, 2004, p. 20). Fortunately, no casualties were reported in relation to those events.

**Possible consequences and effects**

Consequences and effects of CBRN contaminations of the food chain can range from minor to disastrous. Particular effects that can be expected include health implications (casualties), economic damage and (socio-political) disruption. Adequately predicting possible consequences and effects is complicated by factors resulting from methods to produce, process, distribute and prepare food, which also vary depending on cultural and geographical differences. Actual risks posed thus have to be examined on a case-by-case basis. This paper provides some general observations.

**Health implications**

This section focuses on health implications resulting from a CBRN attack on food among the human populace only, for two reasons. First, consequences of attacks on animal populations are generally considered to be economic. Second, there are no examples of attacks directly targeting animals (or animal feeds or crops for that matter) that resulted in human fatalities further down the supply chain (Dalziel, 2009). The number of casualties that could result from a CBRN attack on the food chain depends both on the type and dosage of the agent used, its point of entry and the security, monitoring and control measures in place, but includes also individual resistance, the speed and scope of discovery by (local) authorities and the provision of medical treatment.

It is argued that the potential impact on human health of intentional food contamination can be estimated by extrapolation from examples of unintentional outbreaks of foodborne disease. Possibly the largest incident in history is an outbreak of hepatitis A. It was associated with consumption of clams in Shanghai, China, in 1988, affecting nearly 300,000 people (Tang et al., 1991). However, efforts to strengthen food safety systems have decreased possibilities of such large-scale outbreaks. Smaller scale incidents continue to occur. For example, in 2010, some 225 people in 44 U.S. states fell ill by salmonella in imported black pepper used in sausages (Layton, 2010). And in March 2015, more than 600 people, mostly children, fell ill after eating tainted sandwiches provided as part of a NGO event in Cambodia’s Siem Reap province (e.g. Dara, 2015). Fortunately, most cases of intentional contamination did not result in substantial casualties. On average, less than a hundred people fall ill and less than ten people die yearly from malicious (CBRN) food and water contamination. In comparison: every year an estimated 600 million people – almost 1 in 10 people in the world – fall ill after eating unintentionally contaminated food, 420,000 of whom ultimately die (WHO, 2017).

It should be noted that attacks that fail to kill or injure large numbers of people may still have health-related repercussions. Any type of major food chain contamination can create serious effects, but psychological symptoms are more likely to occur when CBRN agents are intentionally used (or their use is suspected). CBRN agents’ intangible nature, uncertainties about being contaminated or not and a general lack of public understanding of likely effects may evoke fear. Especially when (a claim of) a contamination concerns consumables that are widely eaten. When many people report to health facilities, it can be difficult to differentiate between the ‘worried-well’ and individuals with actual physical injuries or disease. This not only complicates assurance of rapid diagnosis and adequate treatment, but also presents a danger of medical systems being flooded.
**Economic damage**

Rather than health implications, the potential economic costs of CBRN attacks on the food chain could be emphasised, in particular if directed at agriculture (Mohtadi & Murshid, 2009, p. 1324). Attacks targeting livestock and plants can cause economic damage on three levels (Olson, 2012). First, direct losses due to containment measures, such as orders not to transport, quarantines of suspected stock and costs related to culling and destruction of (live)stock – even as a precautionary measure. Second, indirect effects would arise, such as compensation of losses suffered by industries. And, third, costs related to protective trade embargoes. For example, the estimated cost of the FMD outbreak in the United Kingdom in 2002 was in excess of 20 billion dollars (Grote & Fittipaldi, 2007). It included the culling costs of over four million sheep, cattle and pigs as well as impact on animal exports. Tourist trade effects continued to be felt over six years after the outbreak. The cause was accidental, but did stir up fears as it happened concurrently with 9/11 (Hirsch, 2013).

Even if an episode is relatively minor, deliberate CBRN contamination of food can have serious economic and trade repercussions. In addition to the case of mercury-contaminated citrus fruits from Israel in 1978, this was exemplified by a comparable incident with Chilean grapes that took place in 1989. Two punctured grapes containing cyanide were found after an anonymous call. The Food and Drug Administration (FDA) announced an embargo on all fruit from Chile, resulting in orders around the world being cancelled, shipments stopped and tonnes of fruit destroyed. Damage amounted to several hundred million dollars and many growers and shippers went bankrupt (World Health Organization, Food Safety Department, Zoonoses and Foodborne Diseases, 2002). Much later, it has been suggested that this entire incident may have been a hoax (Long, 1994). Similarly, a number of countries (temporarily) closed their borders to New Zealand’s meat after its Prime Minister received a letter claiming that a vial of FMD was released into the animal population near Auckland (‘FMD “hoax” aftermath’, 2005). Officials almost immediately dismissed it as a hoax, but did dispatch some teams to survey and investigate a number of farms as a precautionary and reassurance measure.

A rumour of food being contaminated or only the suspicion thereof can thus have overwhelming (economic) effects, especially if governments or the public overreact. For example, a more careful assessment by its authorities could possibly have prevented amplification of a mass hysteria outbreak and the withdrawal of 30 million cans and bottles of Coca-Cola from sale in Belgium in 1999. Similarly, misidentifying an infection vehicle in an actual outbreak can also cause unnecessary damage. During the 2011 EHEC outbreak in Germany, for instance, it took some time before the source was identified (sprouts). Initially, Spanish cucumbers were blamed and the entire Spanish fruit and vegetable sector suffered needless consequences (Tremlett & Pidd, 2011).

Economic disruption may be a primary motive for a deliberate act; targeting a manufacturer, industry or a country. Many countries enjoy a safe, plentiful and (relatively) inexpensive food supply, which helps drive their economic prosperity. Many jobs are linked to food industries and billions of dollars are involved in trading products (Olson, 2012). Terrorists may realise that economic vitality supports a country’s strength. One pillar of al-Qaida’s strategy against the U.S., for example, was focused on inflicting economic harm; it presented a way to destroy U.S.’s ability to protect its military power abroad (Hofman & Weimann, 2009). Furthermore, political impact after inflicting economic harm may be exacerbated. Sociopolitical consequences are difficult to measure, but include undermining of confidence in and support of governments and could ultimately result in destabilisation (World Health Organization, Food Safety Department, Zoonoses and Foodborne Diseases, 2002).

**Sociopolitical destabilisation**

Although the food system is primarily a commercial venture, it is highly likely that citizens will blame governments in case of major food incidents. For example, BSE was first identified in U.K. cattle in 1986. Originally, no link of possible consequences on human health was established. However, during the 1996 epidemic, the government announced that it seemed possible that victims had caught Creutzfeldt-Jakob Disease by eating meat from BSE-infected cattle (‘BSE and CJD’, n.d.). A special BSE Inquiry was set up in 1998 to investigate this ‘public health scandal’. It took major efforts to restore public confidence in beef products, but also in credibility of the government. By calling attention to the inability of governments to protect the food chain, actors could raise doubts about (controlling) authorities.

Loss of confidence in governments’ capabilities could particularly occur if response to a crisis is in-/over effective, or perceived as such. Although emergency systems to respond to catastrophic incidents that
threaten the health of the population are in place in most countries, these response systems do not always include consideration of food as a vehicle for delivering harmful agents (Interpol, 2016). Insufficient preparedness and/or means to counter a food threat could lead to incorrect investigations, misdiagnosis and failure to identify and detain affected food. This would weaken or even preclude an effective response to food sabotage incidents. It can also reinforce overreaction to an attack; taking (too) rigorous measures just to be on the safe side. An appropriate and measured response, based on careful risk assessments, is thus essential.

Furthermore, any significant or continuing interruption in supply may rather quickly drive food prices up and lead to shortages as supermarkets generally stock only a 7-day supply (Olson, 2012). In a country where regular food supply cannot be assured, an attack on the food chain can even have immediate and severe consequences if pre-existing food shortages are worsened by deliberate contamination (World Health Organization, Food Safety Department, Zoonoses and Foodborne Diseases, 2002). Food insecurity, i.e. insufficient food to avoid hunger in a country, or famine can have serious impact on social and political stability: it heightens the risk of protest, rioting, civil conflict and democratic breakdown, thereby threatening economic, national and, in extreme cases, even international security (Brinkman & Hendrix, 2011). At times, these links are obvious, such as when a spike in food prices leads to riots and unrest in countries. For example, Haiti in 2008, when protests turned deadly and the Prime Minister was ousted (Klarreich, 2008). Often, however, food shortage should be seen in a wider perspective of sociopolitical discontent, e.g. in Venezuela, where major food riots took place in June 2016 (e.g. Gupta & Ulmer, 2016).

Conclusions

This paper discussed CBRN threats to the food supply chain by describing various parameters, including the type of agents capable of yielding damage, possible points of introduction and potential consequences of intentional contamination. It was observed that the majority of food-related CBRN attacks included use of commonly available household, agricultural or industrial chemicals. In addition to their widespread availability, they are easy to handle, generally more stable than biological agents and therefore have a better chance of creating victims if added to food, including earlier in the food chain. However, a successful biological attack may have more devastating effects. Certain biological agents are also easy to come by as they may be present in the environment, for example, when a disease is endemic. Yet, such agents were used only in few food attack cases, not in the least since effective dispersion is extremely challenging. Similarly, only a few cases involved radiological contamination. They included targeted, small-scale poisonings rather than attempts to create mass casualties. Interestingly, all culprits worked in environments in which radiological materials were at their disposal.

CBRN agents can be introduced into the food system during production, processing, distribution and preparation phases. If actors are able to contaminate food early in the supply chain, it could potentially have widespread impact due to the system’s distribution capacity. Yet, the earlier in the food chain an agent is introduced, the more an actor is dependent on processes that are not (entirely) within his control. Such processing steps will likely make an agent less toxic, though the possibility of it getting more toxic cannot be dismissed. Either way, one would need inherent knowledge of the food chain’s working, but also have access to vulnerable parts to bypass quality and security checks. Introduction of CBRN agents at the food preparation or serving stage is thus easier. This is also the phase where most intentional food contamination cases can be found. Rather than large-scale damages though, such attacks are more likely to cause local impact.

Concerning possible consequences, it can be concluded that episodes of intentional food contamination can be serious, but they rarely result in mass fatalities. Economic damage is more likely to occur. Millions of dollars lost as a result of import restrictions and destruction of (suspected) contaminated food products are no exception, in particular if crops or livestock are involved. Even the sole suspicion or rumour of food being contaminated can have devastating economic effects, especially if response is ineffective. From a review of past incidents, it is apparent that governments and the public may overreact to (alleged) food contaminations. Economic impact of an intentional food contamination may thus be pursued by non-state actors. They may also believe that they can undermine confidence in and support of governments by exacerbating impact of food incidents and, ultimately, facilitate sociopolitical destabilisation.

In conclusion, the food supply chain has been contaminated with CBRN agents in the past and this modus operandi remains of interest to people with malicious intent. Concerns about its security are therefore reasonable. However, existing measures and food processing steps reduce chances that actors can take
The practice of adding antibiotics to animal feed and drinking water can cause bacteria to develop resistance, which can be passed on to people through eating meat from animals carrying such bacteria (and through the environment). Since illnesses caused by drug-resistant strains of bacteria are more likely to be fatal when medicines used to treat them are rendered less effective, governments around the world consider this a major public health threat (Food and Drug Administration [FDA], 2013).

Underreporting may be a result due to ignorance on the part of authorities or because of their attempts to suppress evidence. Even when an incident is reported, depending on how ‘terrorism’ is defined, it may not be coded as such. Fear of copycat incidents and to minimise damage to consumer confidence and business may also lead to underreporting as is the case of extortion incidents. Furthermore, incidents may simply be missed (Mohtadi & Murshid, 2009, p. 1319).

For example, they called to poison athletes during the 2016 Olympics in Brazil, by way of putting poison or medications in food and beverages (Newton & Summers, 2016).

Between 1950 and 2008, 391 fatalities and 4355 injuries occurred from malicious food contamination, leading to an average of almost seven deaths (and 75 injuries) per year (Dalziel, 2009, p. 23).

Within 48 h after the news reported a number of school children falling ill after drinking a can of Coca-Cola, other children, from the same and other schools, also reported unwell. The national health authorities stepped in and banned the sale of Coca-Cola, while hundreds more people phoned the National Poisons Centre to say they, too, had been poisoned, including people in the North of France. No one was found to be seriously ill. Finally, it turned out to be an outbreak of mass hysteria, which followed an unrelated alert over potentially cancer-causing dioxins in Belgian meat and poultry (Dillner, 1999).

### Notes

1. For the purpose of this paper, the term CBRN agent refers to any chemical, biological, radiological or nuclear agent that through its action on life processes can cause death or permanent harm to humans, animals or plants, regardless of their origin. The paper focuses on malicious use of such agents.

2. For a general overview of non-state actors’ motivation to use CBRN agents, the probability of them conducting CBRN attacks and possible consequences thereof, see: Meulenbelt & Nieuwenhuizen, 2015.

3. Some argue that Yasser Arafat has also been poisoned with Polonium-210, but this proposition can only be moderately supported (Froidevaux et al., 2016).

4. Pesticides are responsible for an estimated 200,000 acute poisoning deaths each year (Human Rights Council, 2017), 99% of which occur when health, safety and environmental regulations are weak. For example, the deaths of farmers due to pesticide poisoning in Maharashtra, India, around October 2017, have opened up a debate over the rationale of using all pesticides in India which are either banned or restricted elsewhere in the world due to their high toxicity (Mohan, 2017).

5. Direct economic damage is estimated at 65–75 million euros, including culling efforts, egg destruction and recalls of egg-based products in 15 EU countries, Switzerland and Hong Kong. Long-term consequences are still unknown (Gallagher, 2017; Van Horne, 2017).

6. E.g. in September 2002, 42 people were killed in a restaurant near Nanjing. The perpetrator was a jealous rival restaurant owner. There are also a number of incidents at schools, such as in April 2004, in Tongchuan City, when 74 people were intentionally poisoned through toxic pancakes (Dalziel, 2009).

7. In 2010, CBS News reported that the Department of Homeland Security had uncovered a credible threat of attacks using poisons, such as ricin, in salad bars and buffets (Keteyian, 2010).

8. For example, Hazard Analysis and Critical Control Points (HACCP) can be used as a means to monitor foodstuffs. Seven basic principles are employed in HACCP plans: hazard analysis, critical control points, establishing critical limits, monitoring procedures, corrective actions, verification procedures and record-keeping and documentation. If a deviation occurs, indicating that control has been lost, it is detected and appropriate steps are taken to assure that potentially hazardous products do not reach the consumer (e.g. FDA, n.d.). An interesting analysis on the effectiveness of such systems is made by Pederson et al. (2016), who investigated whether standard food safety analysis can detect adulteration with selected chemical agents.

9. U.S. agricultural experts are unanimous in their assessment that foot-and-mouth disease is the most lethal weapon when considering acts of agroterrorism (Knowles et al., 2005, p. 3).

10. The practice of adding antibiotics to animal feed and drinking water can cause bacteria to develop a resistance, which can be passed on to people through eating meat from animals carrying such bacteria (and through the environment). Since illnesses caused by drug-resistant strains of bacteria are more likely to be fatal when medicines used to treat them are rendered less effective, governments around the world consider this a major public health threat (Food and Drug Administration [FDA], 2013).

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### Disclosure statement

No potential conflict of interest was reported by the author.

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