Injury Panoramas and Dimensioning Conceptualizations for the Swedish Healthcare System in the event of an Attack with a Weapon of Mass Destruction

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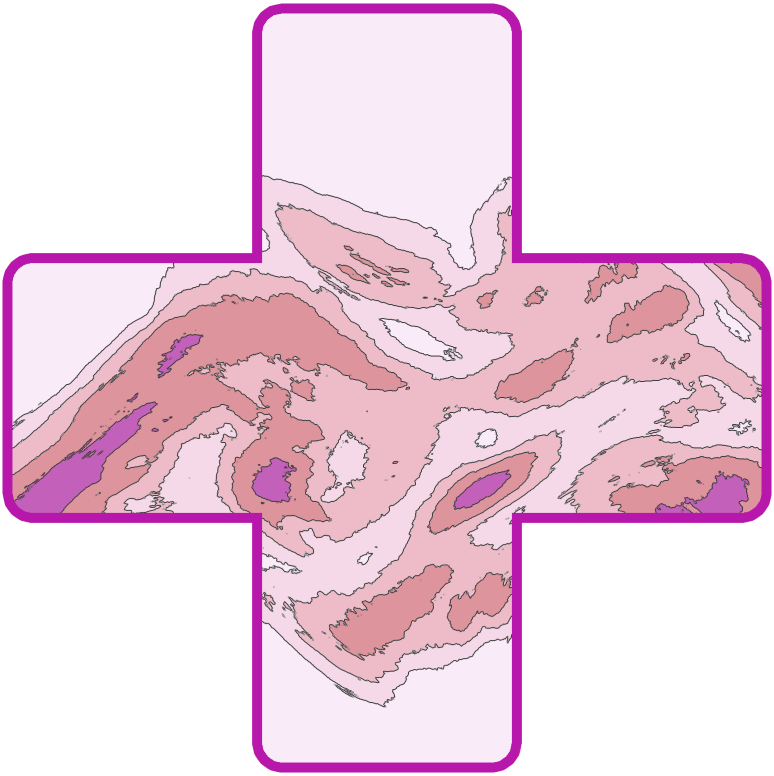

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Summary

As the threat landscape facing Swedish civil society continues to deteriorate, there is an increasing need to understand the relevant health risks associated with different types of attacks. This report presents dimensioning conceptualizations and representative scenarios for antagonistic CBRN events. The conceptual scenarios across the four domains include: artillery shells containing sarin, catastrophic release of liquefied sulfur dioxide from a tanker truck, airborne release of *Bacillus anthracis*, *Coxiella burnetii*, and *Yersinia pestis*, a nuclear reactor breakdown and finally a nuclear explosion targeting either a major city or a military installation and the associated effects of residual radiation. For each scenario, an injury panorama is identified, describing the typical symptoms and types of injuries. The scenarios are also used to estimate injury outcomes, that is, the number of individuals affected by the types of injuries that are specified in the injury panoramas. This is achieved through analyses of similar historical events, the use of previous reports, and new quantitative simulations. The objective is that this analysis will serve as a basis for the planning and capacity design of the Swedish healthcare system, enabling effective management of CBRN incidents and thereby minimizing overall harm.

Keywords: Swedish healthcare system, CBRN, scenarios, simulations, injury panoramas, injury outcomes

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1 Introduction

A government assignment with the Swedish title *Uppdrag att ta fram nyckeltalsberäkningar och dimensionerande målbilder för hälso- och sjukvården* was assigned in 2023 to the National Board of Health and Welfare in collaboration with the Swedish Defence Research Institute and the Swedish Armed Forces. The purpose of the assignment was to provide a knowledge basis and strengthening the capabilities of the Swedish healthcare in the event of war. The results of the assignment are presented, in Swedish, in the National Board of Health and Welfare's report *Nyckeltal och dimensionerande målbilder för hälso- och sjukvårdens planering för civilt försvar* [1]. In the main body of that report, overarching results and analyses are presented succinctly. Background information, methods, and reasonings for these results are provided in more detail in appendices. One of them, Appendix 3, addresses CBRN-attacks and is titled *Skadepanoraman och dimensionerande målbilder för hälso- och sjukvården vid anfall med massförstörelsevapen*. This document is a translation of Appendix 3 and should be considered within the intended context of the assignment.

2 CBRN

Weapons of mass destruction have been a continuous threat since World War I, when large-scale chemical weapons attacks were used on the battlefield for the first time. Back in 1925, the Geneva Protocol, prohibiting the use of chemical and biological weapons, was established. A further step to counter the use of chemical weapons was taken with the Chemical Weapons Convention (CWC), which entered into force in 1997. The Convention encompasses 193 countries, and the intergovernmental Organisation for the Prohibition of Chemical Weapons (OPCW) monitors compliance with it via a robust verification protocol. In 1975, the Biological Weapons Convention (BWC) entered into force and encompasses 185 state parties. However, unlike with the CWC, in practice there is no organisation that monitors compliance with the BWC. In the final stages of World War II, the first nuclear bombings were launched, leading to a large-scale arms race during the Cold War. Currently nine states have nuclear weapons, with the United States and Russia having by far the largest nuclear arsenals. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) entered into force in 1970 with the aim of requiring nuclear-weapon states (NWS) to disarm their nuclear weapons (although no date is specified), prevent nuclear proliferation to other states, and promote the civilian use of nuclear energy. There are currently 191 states who have joined the NPT, but despite this, it has been difficult to completely prevent nuclear proliferation.

It is worth noting that even after the entry into force of international conventions mandating the elimination of biological weapons and chemical and weapons, these weapons of mass destruction have been used in armed conflicts. Nevertheless, these international conventions, combined with normative political pressure against weapons of mass destruction, are regarded to have been successful in containing the use of these weapons of mass destruction during armed conflicts in the previous century. Unfortunately, recent years have witnessed an erosion of the importance of these conventions. Some countries show a lack of respect for the conventions, while security-political situation have deteriorated. The war in Ukraine has led to allegations and threats of the use of weapons of mass destruction (WMD), raising concerns that these weapons may be used in armed conflicts in the future.

Weapons of mass destruction fall into three different categories: Chemical (C), Biological (B) and Nuclear (N) weapons. In addition, the result of a nuclear bomb explosion or successful attack on a nuclear power plant would result in the release of Radiological agents (R). These four threats are abbreviated CBRN, and possess the common feature to potentially cause widespread harm and injuries. Each of the categories has different characteristics and pose threats in different ways. Even within each category, there is a wide variety of agents, applications, and outcomes. Taken together, this means that the consequences of a chemical, biological, radiological or nuclear material attack span a wide range in terms of both the injury panoramas and anticipated numbers of affected individuals.

The aim of this assignment is to formulate relevant dimensioning conceptualizations for the Swedish healthcare system. To achieve this, realistic and relevant scenarios have been used and summarised in this joint study. Scenarios are frequently used in the field of CBRN for risk analysis, training, and joint military exercises, as well as for further development of technology and methods. Concrete examples are a number of typical of CBRN cases that have recently been developed for the Swedish Armed Forces with different underlying purposes. Within NATO, *vignettes* are used which briefly describe different approaches but do not include descriptions of other facts and circumstances as thoroughly as scenarios often do. In this assignment, already existing scenarios have been taken into consideration in the selection and design of the scenarios used as a basis for developing dimensioning conceptualizations in this study and report. CBRN-attacks can be carried out in any of many different ways, and under a wide variety of situations and circumstances, which gives rise to a plethora of possible outcomes. The choice of scenarios is based on various factors, such as knowledge of the hostile powers' previous activities in the field of CBRN threats, the current security-political situation, the specific Swedish prerequisites and, above all, the purpose of the assignment. Emphasis has also been placed on capturing the diversified injury panoramas. The events and factual circumstances are chosen to give a good perception of the injury panoramas and possible and probable injury outcomes if CBRN weapons would be used on Swedish soil. Exposure of both the civilian population and military personnel is included, which includes differences in the situation and circumstances for these two groups. The design of the scenarios linked to military personnel was developed in consultation with the Swedish Armed Forces. For C and N (as well as for the fallout from radioactive material), Swedish Defence Research Agency (FOI) has performed its own calculations for selected scenarios, which are presented below. For B and R, existing external studies have been utilised.

This assignment and report concern antagonistic events with intentional and deliberate injury or harm. It may be assumed that such attacks are well planned in advance, have a clear objective, and are undertaken under circumstances of high tactical or strategic gain. In situations where mass injury or widespread harm is the goal, external factors, such as prevailing weather, become important parameters if the dispersal of agents occurs via atmospheric transport. It is important to emphasise that CBR incidents can and do occur even without military weapons or involvement, for example as a result of a traffic accident or industrial accident. When this occurs, the time and place are largely random and therefore the risk of injury is generally more limited. There is a significant overlap between the need for civilian emergency preparedness in the Swedish healthcare system for a medical response in the event of accidents, and the needs in the event that weapons of mass destruction would be used in a wartime context. This is most evident in the field of biology, where medical professionals in the healthcare system deals with situations similar to those that can occur after a biological weapons attack. The COVID-19 pandemic caused by the SARS-CoV-2 virus revealed how the healthcare system was initially not dimensioned for large-scale stresses and strains, and that a sudden and sharp increase in the number of patients proved very difficult to manage.

The studies that have been performed within the framework of this assignment are limited to the harmful impacts that would have an effect on the healthcare system in the immediate weeks following an attack. However, in many situations there would be delayed effects that are critical and relevant but that arise at a later stage. The delay means that these effects do not cause an equally sudden and unexpected surge of patients in the healthcare system, and thus the need for preparedness in this regard is lower. This assignment and report focus on the present threat landscape and anticipated threats and challenges for the near future. It should be noted that in a longer-term perspective, new situations may arise that will need to be studied and taken into account. This concerns both changes in the situation in regards to security policy as well as developments that affect the technical threat landscape. Examples of elements and factors that may give rise to new scenarios that are relevant, in a longer perspective, include the advancement of drone warfare and their use as weapon carriers along with advances in synthetic biology.

2.1 Methods for estimating injury outcomes

The dimensioning conceptualizations presented in this annex are based on scenarios where those related to biological incidents and nuclear reactor accidents or breakdowns are externally developed, while scenarios related to chemical and nuclear weapons and their radiological consequences are developed by FOI. The methods and assumptions that have been used in these scenarios are presented in detail in the FOI report *Beskrivning av metoder och antaganden som har använts till skadepanoraman och dimensionerande målbilder för hälso- och sjukvården vid anfall med massförstörelsevapen* (only available in Swedish) [2], while the overall descriptions and results are presented here.

CBRN incidents typically generate risks of adverse health consequences within limited spatial areas. By means of modelling and simulations, adverse health consequences probabilities can be projected and estimated, and the anticipated adverse health impact can be quantified when the population within the area is included. This means that injury outcomes for cities with different population densities vary even within the same scenario. In other words, it is impossible to calculate generalised injury outcomes for scenarios without also including population density in the assumptions. Since the scenarios should be applicable throughout Sweden, it is desirable not to specify and restrict the scenarios to any specific city. To keep the scenarios as general as possible but at the same time give a clear presentation of the injury outcomes, two population densities have been selected to be used in this study. The reasoning behind using these particular two population densities, referred to as Town and a Major City is given below.

2.1.1 Population density

Which particular population density that is relevant to apply depends upon the chosen location and local conditions. Thus, population density is the basis for regional and local injury estimates based on the risk areas presented here. The outcomes from the scenarios are however considered to be clearer and easier to understand if some form of relevant population density is included. The Swedish Association of Local Authorities and Regions (SALAR) has established and defined the grouping of Sweden's municipalities according to [3]:

A. Large cities and municipalities close to large cities
B. Large towns and municipalities close to large towns
C. Small towns/sparsely built-up area, and rural municipalities

The classification of a municipality is based on the size of the population of its largest city, where one with more than 200,000 inhabitants is regarded as a large city, with more than 40,000 inhabitants is regarded as a large town, and fewer inhabitants would be a small town/built-up area/village. This classification is however difficult to use for the calculations of injurie outcomes, as it is the size of the population (of the largest city) that has been used, which in fact is not directly linked to population density.

The Organisation for Economic Cooperation and Development (OECD) and the EC (European Commission) have attempted to construct a universal and global definition of cities [4]. Based on geographical data processing, areas are constructed and then classified according to:

- Densely populated area (cities/large urban area)
- Intermediate density area (towns and suburbs/small urban area)
- Thinly populated area (rural area)

The criteria used by the OECD-EC to define the three classification categories are based on geographical data processing and population density thresholds of 300 inhabitants per km^2 and 1,500 inhabitants per km^2. In this assignment, these population density thresholds have been used as a basis for defining two urban classifications. Considering that this assignment is primarily intended to be applicable to urban environments (and for civilian populations) and thus not as extensive a geographical area as the OECD-EC addresses, it is justified to adjust the population density thresholds upwards a bit. Therefore, the indicated thresholds regarding population density have been doubled and this study uses the following numbers as the criterion:

- Major City 3,000 inhabitants per km^2
- Town 600 inhabitants per km^2

Scenarios involving nuclear weapons may give rise to the dispersion of radioactive fallout that often results in risk of injury over a wider area than one city. In this case, the above urban classifications are not used, but instead a lower population density of 100 persons per km^2 is used.

Secondary infection caused by exposure to infectious biological agents and contaminated materials is an exception to the above reasoning on spatially limited risk areas. For these two effects, the health risk is extended from the primary risk area to a more difficult to estimate domain, and the injury outcome does not scale linearly with population density. Health effects caused by secondary infection are included in a scenario in this study where military personnel constitute a separate population that, after the initial risk of infection, can also transmit the infection internally within the group. No external transmission of infection to other military personnel or the civilian population is included in the considerations. Health risks from contaminated materials are not included in this study.

2.2 Consequences of chemical-related attacks

2.2.1 Background

Various events can lead to the exposure of civilian populations or military personnel to chemical agents. In particular, direct attacks with chemical warfare agents or discharges of toxic industrial chemicals pose risks of serious harm to a significant number of people. Chemical warfare agents are designed to maximise toxicity and are highly potent, meaning that only very small amounts are needed to cause serious harm. Industrial chemicals are generally less hazardous to human health but as the amount available in society is significantly higher, still pose a real threat. For example, chlorine gas is a highly toxic chemical that was previously used in large quantities as an industrial chemical in Sweden [5]. However not only has chlorine gas been used for industrial uses, it has been used in the intentional poisoning of a civilian population, such as in Syria [6]. Since 2010, the industrial use of chlorine gas has decreased significantly in Sweden, however other toxic gases such as sulphur dioxide, hydrogen sulphide, ammonia and ethylene oxide are still used and transported within the country in significant quantities [5]. For example, Swedish industry reports manufacturing or importing more than 65,000 tonnes of sulphur dioxide in 2016.

One alternative to the direct use of chemical warfare agents is to use conventional weapons to attack chemical transports or existing stocks of industrial chemicals in the vicinity of cities. Such an attack can cause significant casualties and still allow the attacker to assert that the target was unintentional and thus not a violation of the CWC.

There are a multitude of hazardous chemical agents that cause various injuries to exposed individuals when dispersed. In facilitating preparedness planning for Swedish health and medical care, analyses of injury panoramas and injury outcomes have been conducted for two different scenarios that are assessed to be prioritised and provide a good foundation for such estimations. The two scenarios incorporate various different agents, modes of attack, and magnitude of the discharges:

1. Antagonistic attack with the nerve agent sarin
2. Large-scale discharges of the industrial chemical sulphur dioxide

In the sarin scenario, both civilian and military exposures are accounted for, while the sulphur dioxide scenario focuses solely on civilian exposure.

2.2.2 Injury panoramas

The toxicological nomenclature in the field of CBRN-attacks often uses three levels of adverse health consequences: Minor injury, severe injury and fatal injury. Minor injuries involve temporary effects that may be troublesome, but will not lead to chronic consequences. Severe injuries involve the need for medical treatment along with health effects that can lead to chronic conditions as a consequence. These three levels are applied here, both in terms of injury panoramas and injury outcomes for the conceptual scenarios. The symptoms with minor and severe injuries have each also been divided into two sub-levels to further nuance the injury panoramas and to match the terminology used by the Swedish National Board of Health and Welfare [7]. This finer level of detail is used only in the description of the injury panoramas and is indicated in parentheses in Table 1 and Table 2.

2.2.2.1 Sarin

Sarin (military designation GB) belongs to the group of organophosphorus compounds, the most toxic variants of which are classified as chemical warfare agents of the nerve agent type. At room temperature, the substances are usually liquids with varying degrees of volatility. Nerve agents irreversibly inhibit the enzyme acetylcholineesterase, preventing degradation of the neurotransmitter acetylcholine which causes overstimulation of acetylcholine receptors in the central and peripheral nervous system. Nerve agents irreversibly inhibit the enzyme acetylcholineesterase, preventing degradation of the neurotransmitter acetylcholine which causes overstimulation of acetylcholine receptors in the central and peripheral nervous system. Initial symptoms of exposure to nerve gas poisoning include pinpoint pupils (miosis), resulting in impaired near vision and night vision, sweating, vomiting, diarrhoea, excessive saliva and lacrimation, and a general illness [8, 9]. The initial effects can quickly progress to severe breathing difficulties, seizures and muscle stiffness, which can lead to life-threatening respiratory paralysis without immediate medical treatment. After inhalation exposure to nerve gases the onset of symptoms is very rapid (severe symptoms within approximately 15 minutes of exposure), while dermal exposure results in a slower toxicity progression (symptoms may appear after 30 minutes, but it may even take up to several hours after exposure before they appear). Sarin is a relatively volatile nerve gas, which means that in the event of dispersion, inhalation of gaseous and aerosolized substances is likely to be the predominant route of exposure. At cold ambient temperatures, volatility decreases and thus the substance will be deposited on surfaces to a greater extent, leading to an increased risk of skin absorption via contact exposure. Sarin has previously been used in terrorist attacks, such as in Matsumoto (1994) and in Tokyo (1995) [10], and on several occasions during the civil war in Syria, including in Ghouta (2013) [11] and Khan Shaykhun (2017) [12]. Table 1 shows a compilation summary of the most common symptoms after exposure to sarin.

Table 1. Injury panorama for nerve gases in general, illustrated here by sarin. For the more serious levels of injury, symptoms have been indicated that are in addition to those that have already arisen for less serious levels of injury. The terms used by the Swedish National Board of Health and Welfare are given in parentheses [7].

Symptom	Minor injury (Minor injury)	Minor injury (Moderate injury)	Severe injury (Severe injury)	Severe injury (Very severe injury)
Headache	X			
Pinpoint pupils (miosis)	X			
Blurred vision	X			
Lacrimation	X			
Eye pain	X			
Rhinorrhoea	X			
Nausea		X		
Excessive salivation		X		
Profused sweating		X		
Muscle weakness		X		
Agitation/restlessness		X		
Chest tightness		X		
Dizziness			X	
Disorientation/confusion			X	
Sneezing/coughing			X	
Wheezing			X	
Excessive mucus production			X	
Vomiting/diarrhoea			X	
Muscle twitching			X	
Musculoskeletal weakness			X	
Breathing difficulties			X	
Shortness of breath (dyspnea)				X
Pulmonary edema				X
Seizures/convulsions				X
Arrhythmias				X
Urinary and bowel incontinence				X
Paralysis				X
Unconsciousness				X

2.2.2.2 Sulphur dioxide

Sulphur dioxide is an industrial chemical that is gaseous at normal ambient temperatures and pressures. This gaseous substance is water soluble and highly irritating immediately after exposure to the eyes and mucous membranes. Initial symptoms include upper respiratory tract pain or irritation, rhinorrhoea, and lacrimation and mucus [8]. Severe poisoning results in acute airway constriction, inflammatory reactions in the lungs, pulmonary haemorrhage and the development of pulmonary edema which, in particularly severe poisonings, can be life-threatening. During transportation and storage, the gas is carried in a liquefied condensed form under high pressure. In the event of a leak from a pressurized container, the chemical will quickly form a gas cloud that can pose a health hazard over a wide area, primarily downwind. Table 2 shows a compilation summary of the most common symptoms following exposure to sulphur dioxide.

Table 2. Injury panorama in the event of inhalation of the irritant gas sulphur dioxide. For the more serious levels of injury, symptoms have been indicated that are in addition to those that have already arisen for less serious levels of injury. The terms used by the Swedish National Board of Health and Welfare are given in parentheses [7].

Symptom	**Minor injury** (Minor injury)	**Minor injury** (Moderate injury)	**Severe injury** (Severe injury)	**Severe injury** (Very severe injury)
Irritation of the upper respiratory tract and eyes	X			
Coughing	X			
Lacrimation	X			
Exercise-induced airway obstruction	X			
Chest pain		X		
Airway constriction		X		
Airway inflammation		X		
Pulmonary edema			X	
Pulmonary haemorrhage			X	
Breathing difficulties			X	
Life-threatening dyspnea				X

2.2.2.3 Other injury panoramas following chemical exposures

Sarin and sulphur dioxide represent exposure through inhalation of nerve gases and irritant gases respectively. However, other chemical exposures can also generate a high level of stress on the healthcare system. In addition to respiratory symptoms, exposure to tissue-damaging agents can cause localised injuries to the eyes and skin, especially if the substances are in liquid form. Examples of corrosive substances are acids and bases, as well as blistering agents such as the chemical warfare agent sulphur mustard. After eye and/or skin exposure to corrosive agents, symptoms quickly appear, initially as irritation and burning, which can develop into severe corrosive and burn-like injuries, and which can lead to permanent damage if left untreated [13, 14]. After exposure to sulphur mustard, skin blistering and injury to the eyes may occur [15]. Symptoms occur earliest in the eyes, which become watery, swollen, and hypersensitive to light. The effect on the skin is delayed and may take several hours before blistering can be recognised (10-12 hours). Localised eye and skin injuries may be permanent if left untreated. Other systemic toxicants, in addition to nerve gases, that can cause major adverse health effects can be exemplified by synthetic opioids and cyanides [16, 17]. Severe symptoms usually appear very rapidly after exposure and are due to the agents' ability to cause acute respiratory distress, either by affecting the central nervous system or by inducing oxygen deficiency in the exposed person.

2.2.3 Dimensioning conceptualizations

The two selected scenarios are presented here in more detail individually. The results from these two scenarios together constitute relevant dimensioning conceptualizations for medical treatment in the Swedish healthcare system with regard to chemical agents. To quantify likely injury outcomes, dispersion simulations of the two defined event scenarios are used. Atmospheric dispersion and subsequent injury outcomes are strongly dependent on the prevailing weather conditions. It is reasonable to assume that the attacker has a good knowledge of the prevailing situation and circumstances, and that the attack will be designed to cause large-scale harm and a massive number of causalities. The selected event scenarios therefore include favourable meteorological conditions from the attacker's perspective. More details on the simulations and the assumptions in both the prevailing situation and circumstances, and the response of the population, are presented in a separate report [2].

2.2.3.1 Sarin

The sarin attack in Khan Shaykhun

Antagonistic incidents involving chemical weapons as a warfare agent have been a very rare occurrence since the World War I era. In the past decade, this type of WMD has been used primarily against civilian populations in the Syrian civil war. Information from this type of incident can be used to increase the understanding of the injury panoramas and injury outcomes. An attack with bombs containing sarin gas is deemed to constitute a relevant conceptual scenario for Sweden in the domain of chemical warfare agents. This is closely similar to certain events that took place during the Syrian civil war and therefore one of these chemical attacks has been analysed and used as a baseline reference.

On the morning of 4 April 2017, the Syrian town of Khan Shaykhun in the Idlib region was attacked with aerial bombs. At least one of the bombs was armed with sarin. The investigative journalism group Bellingcat conducted a detailed analysis of the remnants of the bomb and compared it with marker chemicals and available data on different types of bombs. They concluded that it was most likely an M4000 aerial bomb modified to carry 133 litres of sarin [18]. The United Nations commissioned the OPCW to conduct a Fact Finding Mission (FFM) to investigate and document the incident [12, 19]. The report from the OPCW-UN Joint Investigative Mechanism stated that there were no comprehensive and detailed records of the number of casualties, which may be due to the armed conflict. Based on the records available and a large number of interviews conducted, the OPCW estimates that some 100 residents were killed and an additional 200 residents suffered injuries as a consequence of the sarin attack. The symptoms highlighted as most common were pinpoint pupils (miosis), shortness of breath (dyspnea), excessive salivation, dizziness, unconsciousness, convulsions, nausea, and vomiting. Based on interviews, it was estimated that most of these injuries occurred within 400 metres of the impact site. Further details are provided by Alsaleh et al., which presents information regarding injury outcomes [20]. Experiences learned from the sarin attack on Khan Shaykhun are important for assessing the impact of this type of incident. The injury panorama fits well with what is expected for nerve gases.

Conceptual scenario

FOI assesses that an attack with artillery shells constitutes a relevant conceptual scenario for the use of sarin. The scenario is based on an attack by the Russian rocket artillery system, 9M542 Smerch MLRS. Such an attack is assumed to consist of 12 shells, each with a payload of 120 kg. Grenades might contain conventional explosives, but they might also contain sarin. In the latter case, a smaller explosive yield is also included as a dispersal mechanism for the warfare gas in the warhead. The grenades are distributed within an area of approximately 800 x 850 metres. The explosion occurs close to the ground, creating an airborne mixture of gas and aerosols and a ground covering of scattered droplets. The number of shells containing sarin remains speculative; in this scenario it is assumed that two shells contain sarin while the other ten shells are of conventional type. This scenario has similarities with the NATO vignette C03 [21].

The scenario is applied to both the civilian population and military personnel. For the military application, it is assumed that 90% of the personnel in the area have protection in the form of staying indoors or in vehicles. A company of 150 soldiers scattered over 1 km^2 is shelled and risks exposure to sarin. The soldiers are homogeneously distributed within the area shelled. The military has classified, based on intelligence, the current situation as an elevated CBRN threat level in terms of C-attacks and dress state ONE[1] applies accordingly. This means that personnel have respiratory protection close at hand. Under these

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[1] The Swedish Armed Forces uses a threat assessment level for the assessed risk of an attack with Chemical, Biological, Radiological or Nuclear material and predefined equipment rules based on the threat landscape.

circumstances, the personnel are assumed to be exposed to the primary cloud without protection, but will apply the respiratory protection in time for the secondary cloud and thereby eliminating exposure.

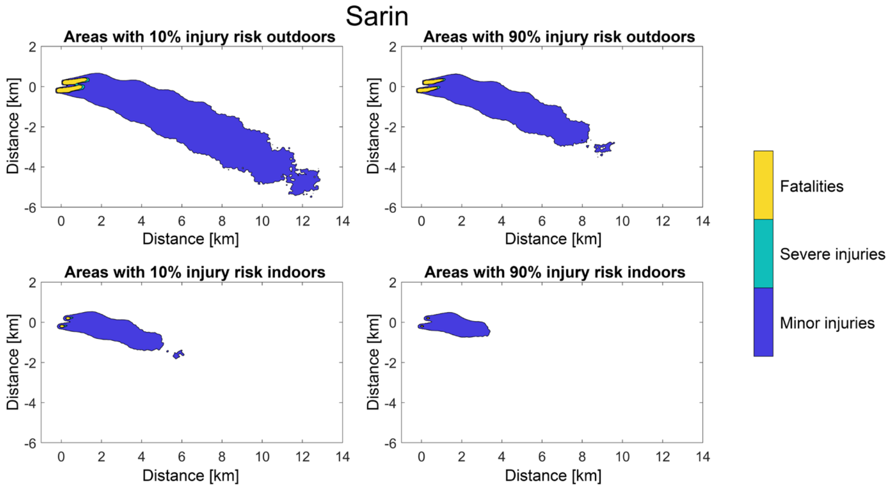

Figure 1. Probability fields for minor injuries, severe injuries, and fatal injuries for the example of a sarin attack on a civilian population.

Results from dispersion simulations for this event are presented in the form of a casualty likelihood field in Figure 1. To obtain a quantitative injury outcome, a population in the area is required. The number of casualties scales linearly with population density and examples of injury outcomes are presented in Table 3 for Town and Major City, with the behavioural patterns described in [2]. The military application with a company in the field is also included. For sarin, exposure leading to severe injury also implies a significant risk of death. In accordance with this reasoning, the results here show a large number of people with minor injuries and most of the other victims die.

Table 3. Injury outcomes for the sarin scenario applied to both the civilian population and military personnel.

Application	**Pop. density** (individuals/km^2)	**Corresponds to**	**Minor injuries** (individuals)	**Severe injuries** (individuals)	**Fatalities** (individuals)
Civilian	600	Town	3,200	15	40
Civilian	3,000	Major City	16,000	73	200
Military	150	Company	43	6	21

It should be noted that the same simulation procedure has been applied, as a validation procedure, to the circumstances of the Khan Shaykhun event. The meteorological situation during that attack varied over time, making a direct comparison difficult, but the results of the simulation are in reasonably similar agreement with the number of reported casualties and the size of the casualty area [12]. The same type of simulations was used to estimate impact and injury outcomes based on the selected scenarios in this study. This strengthens the credibility of the simulation results that form the basis of the dimensioning conceptualizations for chemical agents.

2.2.3.2 Sulphur dioxide

Sulphur dioxide is a common industrial chemical, which is produced in large quantities in Sweden. There is extensive transport between production sites and manufacturing facilities, which is achieved by first pressurising the gas into liquid form. Sulphur dioxide has a boiling point of -10°C at normal atmospheric pressure. During transport, the liquid has almost the same temperature as the ambient environment, which in Sweden usually exceeds the boiling point. This means that the pressure increases in the tank, which now contains a mixture of liquid with a higher temperature than its ordinary boiling point and pressurised gas. Under these conditions, the liquid quickly evaporates into the gas form upon discharge and a powerful jet spray is generated. One significant characteristic of this type of discharge is that the plume becomes cold and heavy, and stays close to the ground for a long distance. This increases the risk of exposure to high concentrations in the immediate vicinity of the release. Unlike the scenario with sarin, there is the possibility for an antagonist to attack existing infrastructure in the country, which could cause discharges of sulphur dioxide of a serious magnitude. This scenario concerns only the civilian population, as it is considered less likely that such type of attack would target military personnel.

Conceptual scenario

With regard to exposure to sulphur dioxide, an attack on a fully loaded tanker truck is a suitable example of an incident scenario that can be considered for our purposes. Sulphur dioxide is transported by railway wagons and tankers of various sizes. In the RIB Spridning Luft programme, which is used for risk assessment, the fire and rescue services use transport volumes of 64 tonnes as representative sizes for sulphur dioxide when transported by railway wagons and 24 tonnes when transported by tankers [22]. The conceptual scenario used here is a tanker of the same size, i.e. 24 tonnes of pressure-condensed sulphur dioxide. The tanker is shot at, which causes a relatively large hole through which the sulphur dioxide is expelled. A jet spray is formed with a mixture of liquid and gas that spreads with the wind. In addition, a pool of liquid form of sulphur dioxide is generated which evaporates and produces a more prolonged and elongated plume. Figure 2 shows the estimation of the risk of fatalities, based on the simulation results. Risk of fatal injury is present within 1 km, while minor injuries can occur as far as a distance of 10 km from the tanker. For people who are particularly vulnerable due to underlying health problems, the risk area will be even larger. The Figure clearly shows staying indoors provides distinct protection, as staying indoors greatly reduces the risk of injury.

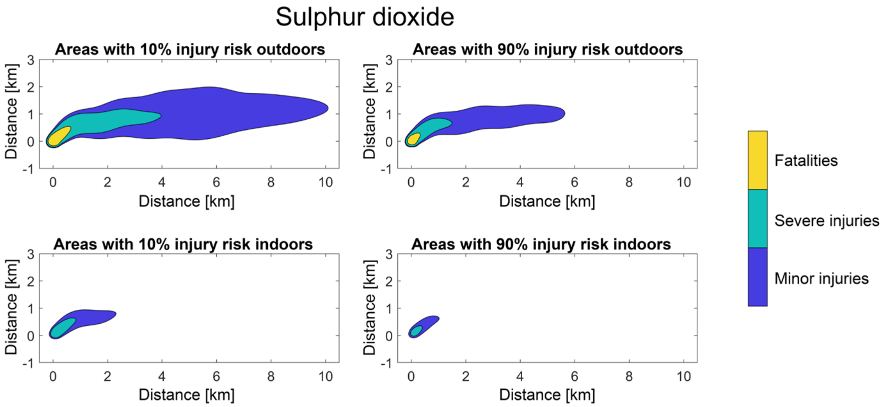

Figure 2. Probability fields for minor injuries, severe injuries and fatal injuries for the selected scenario of sulphur dioxide to the civilian population.

By applying population densities for Town and Major City and a behavioural pattern discussed in report [2], the injury outcomes are obtained as presented in Table 4. Only the civilian application is applied to this scenario. The injury outcome is estimated to be extensive. Even though most of the victims are only slightly injured, the results show a large number of severely injured persons and even fatalities.

Table 4. Injury outcomes for the sulphur dioxide scenario applied to the civilian population.

Application	Pop. density (individuals/km^2)	Corresponds to	Minor injuries (individuals)	Severe injuries (individuals)	Fatalities (individuals)
Civilian	600	Town	540	160	7
Civilian	3,000	Major City	2,700	790	35

2.3 Consequences of biological-related attacks

2.3.1 Background

In the past, several countries have had large-scale B-weapons programmes, with developed weapons for different purposes. Biological weapons have the potential to provide strategic or tactical advantage in any phase of an armed conflict. Whether used in a grey zone situation (hybrid warfare) in, during a period of mobilisation, or in an open armed conflict, biological weapons are a powerful tool in the hands of a competent combatant and the use of even small amounts of biological agents could have a major impact on the civilian population and/or military personnel. Animals and crops can also be targeted, with major impacts on food and water supplies.

Biological warfare agents can be selected according to their different characteristics, e.g. with regard to incubation time, severity of symptoms, incapacitating ability, and lethality (see Table 5). Some infectious diseases can also be transmitted from animals and humans, known as zoonosis. Stability, meaning the survival of the B-agent in the environment after dispersal, also varies and some B-agents can survive in water or the soil for an extended period of time. For this reason, an attack with biological weapons can not only have a relatively immediate impact, but if it becomes established in the environment it can also cause disease long after an attack. In addition, biological vectors such as ticks and mosquitoes can carry biological agents (pathogens causing infectious diseases).

To facilitate preparedness planning for Swedish health and medical care, injury panoramas and injury outcomes for three different B warfare agents have been selected with individual scenarios. The selected agents are characterised by the fact that they were present in known B-weapons programmes before the programmes were officially discontinued. These three infectious agents share the common features: they are zoonotic diseases, naturally occurring, and capable of causing disease outbreaks, sometimes even leading to epidemics.

2.3.2 Injury panoramas

2.3.2.1 *Bacillus anthracis*, Anthrax:

Anthrax is a serious infectious disease caused by the *Bacillus anthracis* bacterium. The bacterium is a spore-forming agent and these can be spread to the surrounding environment by an infected individual. The characteristics of the spores mean that they are very hardy and can survive in the environment for a very long period of time, while retaining the ability to re-emerge and infect a new host, making them a potential threat for antagonistic use. During the past 15 years in Sweden no anthrax cases in humans have been reported, however there have been natural outbreaks of anthrax, mainly in cattle herds. One explanation for this is that the dose required to become infected is higher in humans than in cattle. Anthrax can occur in different forms depending on the route of infection, and it is the pulmonary form that is the most serious and poses the greatest risk of severe illness with rapid progression and subsequent fatal outcome.

The incubation period for anthrax ranges from 1 - 70 days, however most commonly the symptoms begin to appear after 1 - 7 days after exposure. After the end of the incubation period, an initial illness disease phase (prodromal phase) begins where the initial signs and symptoms include:

- Fever
- Shivering
- Weakness
- Chest discomfort
- Shortness of breath
- Cough
- Headache
- Nausea, vomiting, or stomach pains
- Abdominal and chest pain

Therefore, the symptoms can be easily confused with influenza, COVID-19, or common pneumonia. The infection then progresses very quickly, and in a few days a severe pneumonia develops, followed by sepsis, i.e. a condition requiring intensive care.

2.3.2.2 *Coxiella burnetii*, Q fever:

Q fever is a disease caused by the bacterium *Coxiella burnetii. The disease* occurs globally and is a zoonotic disease. In the early 2000s, several human outbreaks occurred in the EU, mainly in the Netherlands (in 2009, 2,300 cases were reported), and in Denmark. Only a few cases of Q fever in humans are reported annually in Sweden, and most commonly, they are contracted abroad.

Many animal species, including domestic animals such as cattle, sheep, goats, cats, various small rodents, and also wild animals and birds, can be infected and in turn constitute a source of infection for humans. Even though many infected animals do not show any symptoms nevertheless fertility disorders such as miscarriages and a situation with weak or stillborn foetuses may arise. *C. burnetii* often reproduces in large numbers in the placenta and the infection is therefore usually transmitted during calving and lambing when large amounts of bacteria can be released into the air via aerosols from amniotic fluid and placenta. The risk of infection is therefore increased for farmers and veterinarians. However, infection can also occur through direct contact with contaminated animal products such as wool, hay and manure.

The symptoms in humans can vary greatly. The disease is usually divided into two forms, acute and chronic, where the acute variant, which is usually self-healing, can either be completely asymptomatic (50 - 60% of cases) or give rise to flu-like symptoms and appearance that may include the following symptoms:

- Fever
- Chills
- Nausea, vomiting, or diarrhoea
- Fatigue
- Intense headaches
- Muscle pain and chest pain
- Stomach pain
- Weight loss

Atypical pneumonia can sometimes be seen with cough, chest pain, and respiratory problems. The duration of illness can vary, usually between 1 and 3 weeks. Sometimes there are medical complications affecting the lungs (pneumonia) or liver (liver enlargement and hepatitis). The chronic form of Q fever affects about 1% to 5% of the cases and often takes months or years to develop, and the infection then attacks the heart valves causing an endocarditis with night sweats, fatigue, shortness of breath, weight loss and swollen limbs.

The risk of mortality from Q fever is generally low, and when it does occur it is usually because the patient has developed the chronic form. The chronic form can flare up months or even years after the onset of the disease, which is why antibiotic treatment extending over three years at least is recommended. Untreated, the chronic form of the disease can have a mortality rate of up to 60%. Individuals with a history of heart disease, compromised immune systems (immunosuppressed) and foetuses of pregnant women are at greater risk.

2.3.2.3 *Yersinia pestis*, Pneumonic plague:

Pneumonic plague is caused by the *Yersinia pestis* bacterium. The plague bacterium is usually spread through flea bites. This pathway for infection causes classic bubonic plague, which usually progresses to sepsis. The infection can also spread to the lungs or be transmitted directly to the respiratory tract by aerosols, which is known as pneumonic plague. In the case of pneumonic plague, there may also be person to person transmission, which is referred to as secondary transmission. The pulmonary form of plague is the most serious form. The risk of mortality with untreated plague is usually very high, about 50% for bubonic plague and approaching 100% for pneumonic plague. *Yersinia pestis* is now rarely seen but is still found in parts of Asia, Africa, North America and South America. In Madagascar there are annual outbreaks of the disease.

The incubation period for pneumonic plague is usually 2 - 3 days, after which the following symptoms appear:

- Fever
- Headache
- General weakness
- Chest pain
- Cough
- Shortness of breath

There is also gastrointestinal distress, nausea, vomiting and diarrhoea. The patients then develops pneumonia, which can rapidly progress to respiratory failure and shock. During the illness there is a risk of secondary infection, meaning person-to-person transmission. This means that an emerging infection can lead to an epidemic of unpredictable proportions.

Table 5. Characteristics of the three selected bacteria that all cause disease via inhalation.

	Bacillus anthracis	***Coxiella burnetii***	***Yersinia pestis***
Disease	Anthrax	Q fever	Pneumonic plague
Risk of mortality if untreated[2]	80% - 90%	Acute inf. 1% - 2% Chronic inf. 30% - 60%	50% - 100%
Incubation period[3]	1 - 70 (1 - 7) days	3 - 41 days	1 - 8 (2 - 3) days
Contagious between people[4]	No	No	Yes

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[2] Medical treatment reduces the risk of mortality, but is highly dependent on obtaining the proper treatment in time.

[3] The incubation period depends upon, among other things, the dose received and general state of health. The most common incubation period is indicated in parentheses.

[4] Secondary infection, isolation may be required.

2.3.3 Dimensioning conceptualizations

The selected B-agents, *Bacillus anthracis*, *Coxiella burnetii*, and *Yersinia pestis*, have been included in several countries' previous B weapons programmes and are, for a resourceful actor with the necessary knowledge, relatively uncomplicated to produce in the limited quantities referred to in these scenarios. The ability to formulate these B-agents so that they can be dispersed in the quantities and in the ways specified is also deemed to exist. The selected B-agents are all bacteria, but they still reflect fundamental differences in specific properties. What the selected bacteria have in common is that there are several possible routes of transmission, but the scenarios focus on transmission via air and inhalation, and ignore the others. In one of the example scenarios, *Yersinia pestis*, the important problem of secondary infection is highlighted.

The injury outcome obtained after an aerosol spread is often strongly influenced by the time of day and the weather conditions under which the spread occurs. Table 6 shows some agent characteristics that are important for their ability to infect people through atmospheric dispersion.

Table 6. The characteristics of the agent that affect the likelihood of being infected by atmospheric dispersion.

		Bacillus anthracis	*Coxiella burnetii*	*Yersinia pestis*
Dose of infection (number of organisms)		8,000 - 50,000	1 - 10	10 - 3,000
Stability in the environment		Spores can remain viable for decades	Months to years in soil and contaminated buildings	1 - 4 hours in air, weeks in water, months in cellular tissue, and years in soil
Degradation rate in the air (% / min.)	daytime	0	4	7.5
Degradation rate in the air (% / min.)	night time	0	2.5	4

Conceptual scenarios

As with the C-related incidents, it is reasonable to assume that the attacker has a good knowledge of the prevailing prerequisites, and that the attack will be designed to cause large-scale harm and a massive number of injuries. Consequently, the injury outcomes are calculated with this assumption, i.e. that favourable conditions for dispersal of the discharge are present. A study from the Institute for Defense Analyses (IDA) in the United States has been used and the injury figures in it take such favourable weather conditions into account [23]. The study describes injury outcomes based on different military units, different weapon types and attack methods, and different sizes of dispersal areas. In addition to optimal weather conditions, an optimal dispersion point is also used to maximise the injury outcome, which means that the stated injury outcomes represent a worst-case scenario and that a realistic outcome from an actual event will most likely result in lower injury figures. The stated injury outcomes (see Table 7) only highlight the infection rates that could affect military personnel in the event of an antagonistic attack in the outdoors.

The three scenarios for biological agents in this study are all based on the IDA report [23]. All scenarios are based on the same dispersal mechanism but the different types of agents result in a large variation in the injury panoramas and injury outcomes. The dispersal of 2.4 kg of either anthrax spores, coxiella bacteria or pneumonic plague bacteria is achieved by means of a ground-based dispersal device which results in an initial aerosolization of the spores/bacteria which then continues to spread with the wind giving rise to health risks primarily via inhalation over a relatively large area.

Table 7. Injury outcomes for different B agents dispersed using a ground-based dispersal device for a military battalion (4,042 individuals) over an area of 20 x 40 km. Note that this is the calculated maximum injury outcome if all worst-case exposure conditions apply.

B-agent	**Infection type**	**Infected (%)**	**Fatalities (%)**
Bacillus anthracis	Primary infection	79	68
Coxiella burnetii	Primary infection	8.3	0
Yersinia pestis	Primary infection	7.6	7.6
Yersinia pestis	Secondary infection	75	75

Pneumonic plague is contagious and therefore results in secondary transmission and infections, i.e. it is transmitted from person to person, and the primary injury outcome indicated in Table 7 can be significantly worse if the outbreak is not properly managed in the acute emergency phase. The injury outcome is therefore more fatal if an entire battalion is infected via a secondary infection event than after a primary infection. Coxiella bacteria can survive for a few days in the open air/environment and residual bacteria absorbed by, for example, flocks of sheep that can generate new aerosol clouds during lambing can generate the risk of extended infection later on.

2.4 Consequences of radiological-related attacks

2.4.1 Background

Incidents of a radiological nature include the effects of the dispersion of radioactive materials into the environment. The contribution of radioactive fallout to the population from a nuclear bomb largely depends on whether the explosion occurs close to the ground, in which case an updraft lifts soil material into the air where it becomes mixed with the bomb fragments. If this occurs, the radioactive fallout can result in significant hazards to human health, as discussed in the section on N. Other events that can release radioactive material into our environment consist primarily of an accident or a deliberate attack on a nuclear power plant or similar facility containing fissile material.

2.4.2 Injury panorama

Ionising radiation can cause direct adverse health effects. High doses of radiation over a short period of time cause harm primarily to the bone marrow and the gastrointestinal system. At increasingly higher doses, the central nervous system is also affected. These lesions are referred to as deterministic and have the following symptoms:

- Vomiting
- Feeling ill/nauseous
- Diarrhoea
- Headache
- Dizziness
- Unconsciousness
- Fatigue
- Disorientation
- Slurred speech

People who have been exposed to high doses of radiation normally go through three stages:

1. Initial symptoms: headache, nausea, vomiting and diarrhoea. Such symptoms usually subside within 24 hours, depending on the level of exposure.
2. Symptom-free period. An apparent recovery may occur after the first symptoms. If this period lasts less than one week, the result is often fatal.
3. Delayed symptoms. These include hair loss and lack of appetite, sore throat, fever, bleeding, prolonged weakness, inability to work, and death.

Depending on the amount of radiation dose received, medical treatment also affects the severity of the symptoms. Deterministic harm may also occur in the long term, such as injury to the eyes or skin, and increased risk of cardiovascular disease later in life.

Low doses of radiation can cause late harm in the form of cancer and hereditary diseases. The risk of these injuries starts immediately from the first radiation dose and then increases linearly with increasing radiation doses. These injuries are commonly referred to as stochastic radiation injuries.

2.4.3 Dimensioning conceptualizations

Radiological consequences, in terms of injury outcomes, are greatest after a nuclear explosion. Nuclear power plant accidents can also have major consequences, albeit with low injury outcomes. The consequences are primarily social and economic, and possibly later appearing impacts on the general population, such as increased risk of cancer in risk groups. So-called dirty bombs, i.e. conventional explosives used to disperse radioactive material, will likely result in radiation doses with relatively limited medical impact, as the ionising radiation in the acute phase is of low intensity. In cases where radiological agents have been used antagonistically and have had negative health effects, the attack has been directed at a particular individual. The consequences of radioactive fallout following an attack with nuclear weapons are described in section *Consequences of nuclear weapon attacks*, while a nuclear reactor accident or breakdown is the dimensioning conceptualization for radioactive incidents in general.

2.4.3.1 Nuclear reactor failure

In the event of an accident or a deliberate attack on a nuclear power plant, radioactive substances may be released into our environment. However, modern nuclear power plants have mitigation systems that limit the release. In the event of an attack however, there is a risk that these mitigation systems could be neutralised. The principal instances where accidents have occurred with an impact on the environment are the ones in Chernobyl and Fukushima.

The effects of an accident in a nuclear power plant in Sweden are described by the Swedish Radiation Safety Authority (SSM) [24]. In summary, even for an accident in a Swedish nuclear power plant where the mitigation systems do not function as planned, serious deterministic effects are unlikely if the protective measures proposed by SSM are implemented. The doses to the affected population are at most up to 500 mSv, and in most cases at most 100 mSv, which is below the doses that would be required to produce acute effects requiring hospitalisation. As the situation that would give the highest doses to the population does not give any initial health effects, it is not relevant to give a scenario description.

The largest nuclear accident in the world is the accident at the Chernobyl nuclear power plant in 1986. In that accident, substantial amounts of radioactive material were released high into the atmosphere. Large parts of the neighbouring region, as well as Sweden and other parts of Europe, received significant fallout of radioactive substances, primarily because rain and snow carried radioactive material from the atmosphere to the ground and into the ecological system. The impact on and in Sweden was initially significant, with restrictions on agricultural products and foodstuffs from the forest and reindeer husbandry. The health consequences for humans have however been so small that only a theoretical calculation of the number of cancer cases caused by the elevated level of radioactive substances has been possible [25]. Nevertheless, the social and economic impacts have been significant.

The most recent incident at a nuclear power plant that can be related to a discharge of radioactive material of a serious magnitude is the nuclear accident on 11 March 2011 at the Fukushima Daiichi nuclear power plant. Despite the accident having released large amounts of radioactive material, it has been established that no acute effects can be found among workers at the nuclear power plant or the general public [26]. The effects of the Fukushima Daiichi accident resulted in an increased radiation dose to a large number of people in the area surrounding the facility. No direct health effects on the general population caused by the ionising radiation have been found, however, the fallout caused major mental and social effects. Another related side effect was the death of a number of people during the relocation of hospitalised patients. Here too, the long-term health effects are not expected to be of such a magnitude that they can be detected. Moreover, measurements of radioactivity intake in the population to estimate future impacts of ionising radiation have caused considerable demands on resources for whole-body measurements and measurements of radioactive iodine in the thyroid. However, late start of measurements increased uncertainty in thyroid dose estimates. At the time of writing the UNSCEAR report, in 2013, a total of 149,000 whole-body measurements of Cs-137/134 had been performed [26]. The effects that may occur over the long term are primarily increased cases of cancer, but the frequency is most likely so low that the increase in frequency is undetectable [27].

Based on the calculations and estimations of expected radiation doses and the experience from previous discharges as described in the injury panorama, acute impacts on personnel and the wider community are unlikely in the event of an accident at a nuclear power plant. In the event of an attack on a nuclear power plant, however, the mitigation measures could be disrupted and thus cause a discharge of a sizeable magnitude, a situation that has not been analysed in this study. A nuclear reactor accident or incident will entail mental and social effects and will place demands on the ability to measure internal radioactive contamination in humans, both measurement of radioactive iodine in the thyroid in the short term and of radioactive caesium in the long term.

2.5 Consequences of nuclear weapon attacks

2.5.1 Background

A nuclear explosion releases an enormous amount of energy, generating several different weapon effects, which are briefly described below. The energy released in a nuclear explosion is usually expressed in kilotons (kt), where 1 kt corresponds approximately to the energy released in an explosion of 1,000 tons of TNT. For comparison, the explosive yield of the atomic bombs dropped on Hiroshima and Nagasaki was 15 kt and 21 kt respectively. Today's nuclear bombs can have explosive yields ranging from a fraction to many hundreds of kilotons. As nuclear weapons are included in the arsenals of several countries, their use in war cannot be excluded and must be taken into consideration when planning for mass casualty situations.

2.5.2 Injury panorama

The powerful energy release from a nuclear explosion will produce a shock wave similar to that of conventional explosions, but much more intensely powerful and with a longer duration. The temperature when a nuclear bomb explodes can reach several tens of millions of degrees, causing a pulse of thermal radiation that results in thermal radiation burns, and fires. The energy of the explosion is generated by nuclear reactions, which also emit various forms of ionising radiation. In the immediate aftermath of the explosion, it is mostly neutrons and gamma radiation that needs to be considered. Immediate weapon effects also include an electromagnetic pulse (EMP), a brief burst of electromagnetic energy, which can cause damage to critical electronic systems and networks. As electromagnetic pulses do not cause direct harm to humans, they are not discussed further here, but their effects can nevertheless have very significant implications for the Swedish healthcare system.

The principal types of injuries resulting from the immediate effects of a nuclear explosion include [28, 29]:

- Shockwave-induced injuries, which consist of
    - Overpressure injuries, which are mostly pressure effects on air-filled organs.
    - Splinter injuries, which occur when objects are thrown by the shock wave and hit people. Glass splinters are an important cause of this type of injury in the urban environment.
    - Physical trauma injuries due to people being thrown by the shock wave.
- Acute radiation injury due to the initial ionising radiation, mostly neutrons and gamma photons. The resulting radiation injuries are the

same as those described in the chapter on radiological incidents, but with a shift towards high radiation doses causing a higher degree of acute radiation injuries.

- Burn injuries.

Residual radiation in the immediate area resulting from a nuclear explosion may also cause harm:

- Acute radiation injuries resulting from the radioactive fallout, as described in the chapter on radiological incidents.

Affected individuals can often be exposed to more than one single type of injury, and it is important to note that a radiation injury that would not cause any symptoms on its own can nevertheless complicate the healing of other injuries. In situations where the explosion occurs close to the ground, there is additional harm from exposure to residual radiation, for example from the fallout of radioactive material.

Another likely effect of the employment of a nuclear weapon is its psychological impact with many traumatised people in a state of shock. Similarly, there may be a large number of people with minor injuries that burden the healthcare system. These impacts are not addressed in any detail here.

2.5.3 Dimensioning conceptualizations

The situation and circumstances under which a state with nuclear weapons will use them are determined by its nuclear doctrine and how this has been operationalised in its armed forces. As this is largely unknown, it is difficult to say what constitutes a “likely” scenario for nuclear weapon use, and it will also vary between different nuclear weapon states. Notwithstanding this, two nuclear events including nuclear weapons are specified here that are both conceivable and serve as illustrations of the consequences of a nuclear attack. The purpose of the attack, i.e. the intended target, is not specified. The first application is an attack on a target in a major city, which means that civilians will be directly affected. The second application involves an attack on a military installation located away from urban centres, an attack which does not have the same impact on civilian population.

Determining the number of fatalities and injuries resulting from a nuclear weapon explosion is a difficult task, as it depends on numerous parameters, some of which remain speculative. For example, the type of buildings and whether the population has had time to take shelter are relevant factors. With regard to skin burns, the time of year is important, partly because temperature and humidity have a major impact on the occurrence of fires, and partly because the clothing worn in winter would mean that less skin is exposed to thermal radiation. The explosion height also has an impact, in part on the size of the radioactive fallout and in part on the impact of the shock wave. For the two nuclear weapons scenarios used here, the explosions are assumed to occur at ground level, which will result in the presence of radioactive fallout around the explosion point and downwind. However, the immediate effects would be less than those of an atmospheric explosion with the same explosive yield.

Since the injury outcome for an arbitrary explosion point is considered, constant population densities are used. The previously described definition of a Major City is used here for the first application, while military personnel evenly distributed in an area around the explosion point on a field are used for the second application. Explosive yields within a wide range have been used to illustrate how the consequences vary accordingly.

The harm including causalities caused by radioactive fallout is dealt with separately and is presented in section *Effects of residual radiation*. The impact of radioactive fallout depends on several parameters, including explosive yield and the type of nuclear device (e.g. fission fraction), explosion height, precipitation, etc. In the calculations made for radioactive fallout, a ground explosion and no precipitation has been assumed. The radioactive fallout is therefore dispersed according to a model based on an idealised deposition field [30-32].

2.5.3.1 Application 1: Attack on a civilian population in a Major City

In this application, it is assumed that the nuclear attack is a sudden ground explosion, which means that no one has had time to take shelter. It is also assumed that all people are indoors and that 45% are in detached houses made of wood, 45% in a concrete building built from concrete elements, and the remaining 10% in solid concrete buildings, which corresponds roughly to the distribution of how people live in Sweden [33]. Regarding injuries from the shock wave, the Swedish National Defence Research Institute (FOA) has previously made calculations of the probability of fatalities, along with calculations of severe and minor injuries to people in a variety of building types depending on the explosive yield, the distance, and the height of the explosion [30]. However, injuries from glass splinters are not included in these probability distributions. Those who are outdoors are also impacted by the shock wave, but this is more challenging to calculate due to that the main source of injury from the shock wave in the outdoors is being hit by airborne material or being thrown into things, therefore everyone is assumed to be indoors.

The radiation dose from initial ionising radiation as a function of distance, explosive yield and type of explosive charge, is relatively well described [30]. The protection provided against the initial ionising radiation by being indoors is limited, unless one is in a shelter or possibly in a basement. The initial ionising radiation decreases rapidly with distance, which means that shielding has little effect on the distances at which health effects from ionising radiation occur. Due to that shielding effects from buildings have little protective effect where the initial radiation is greatest, they have not been included in this study.

The extent of injuries from burns is the most difficult to ascertain among the immediate effects. Not only is it challenging to determine how many people can be expected to be directly affected by the thermal radiation pulse, but above all, it is also difficult to calculate the occurrence of fires. Thermal radiation sets fire to thin objects, such as paper and drapery, even indoors through glass windows, as well as to vegetation outdoors. Whether or not all these small fires develop into large-scale fires depends on a variety of factors, ranging from the design and construction of buildings and the prevailing weather, to the choice of materials in furniture and the level of clutter in people's homes. Therefore, for burn injuries, the injury outcomes in Hiroshima and Nagasaki were used and then adapted to other explosive yields[5]. Among the survivors of Hiroshima and Nagasaki, about the same number of people had burns as shock wave injuries, 70% and 65% respectively, according to Table 12.18 in reference [31]. Even for a more modern major metropolis, the estimate is 70% shockwave injuries and 65-75% burns, according to page 39 of reference [31].

There is information from Hiroshima that shockwave impact injuries and burn injuries decreased in severity with distance from the explosion point in much the same way; refer to page 43 [34]. This indicates that the distribution of shock wave injuries also represents the distribution of burns for the explosive yield that Hiroshima experienced, i.e. 15 kt. As the explosive yield increases, here labelled W, the radius for a given shockwave injury outcome increases approximately as $W^{1/3}$. For burns, the corresponding exponent is instead 0.41. The extent of the burn injuries thus increases more with increasing explosive yield than the extent of the shockwave injuries, which is compensated for here by extending the damage radii for shockwave injuries to a corresponding degree and thus obtaining the extent of burn injuries.

The results of the calculations are shown in Figure 3 and in Table 8. Only the fatalities and severely injured (those requiring hospitalisation or other immediate medical care) are included[6]. In addition, there are many victims with minor injuries who may also seek medical attention to some extent. For those who suffer fatal shock wave injuries, no distinction has been made as to whether the person dies immediately or at a later stage (the reason for this being a lack of relevant data). This differs from the category of acute radiation injuries where this distinction and categorisation has been made. After exposure to ionizing radiation, assessing health effects becomes challenging, as a person who initially

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[5] Note that the dimensioning conceptualizations in this study are based on ground explosions, whereas the atomic bombs used on Hiroshima and Nagasaki were atmospheric explosions.

[6] Severely injured refers to those in need of hospital care. Specialist care for burns and radiation injuries is not assumed in the calculation of the probability of survival.

feels relatively well may have still received a lethal dose of radiation. The symptoms may be relatively mild, with the person experiencing issues such as nausea, vomiting, diarrhoea. These symptoms may also be induced by the shock of being close to a nuclear attack. It may take several days after the exposure before symptoms that indicate that a lethal dose has been received appear. To capture this group of people in the results, radiation injury deaths are divided into those who die immediately and total fatalities, which include those who die at a later stage (often after several weeks). The same applies to the total number of severely injured.

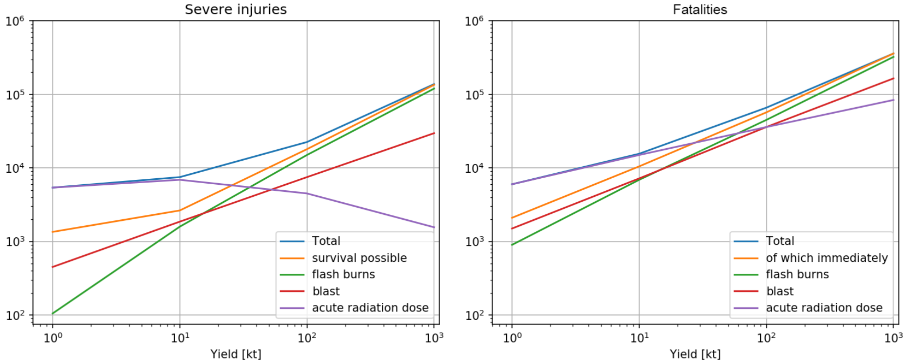

Figure 3. The number of severely injured and fatalities as a function of explosive yield for a constant population density of 3,000 persons/km^2. Green: burn injuries, red: shock wave injuries, purple: initial ionising radiation, blue: total number of severely injured or deaths. As it often takes a period of time for radiation harm to appear, the blue and purple curves in both panels include those people who are initially alive but who have received a fatal radiation dose. The orange line for severely injured indicates the total number excluding those who can be expected to die from acute radiation injury within a few weeks. The orange line for fatalities indicates those who die more or less immediately.

Figure 3 shows that the number of radiation injuries declines with explosive yield. The explanation for this is that other immediate effects increase to a greater extent with explosive yield and most of the radiation casualties for the higher explosive yields will die of other causes and thus not be included in the category of radiation casualties, as they are no longer alive. The figure shows that for lower explosive yield there are more radiation casualties than casualties from shockwave injuries for example. This differs from the descriptions coming from Hiroshima and Nagasaki. This may be due partly to the fact that a large number of people who are classified here as radiation injured will not survive in the long term, and additionally because the injured here do not include some categories, for example minor shock wave injuries.

Table 8. Injury outcomes for explosive yields of 10 kt and 1,000 kt for application 1: Attack on a civilian population in a Major City.

	10 kt	1,000 kt
Total fatalities*	16,000	360,000
Immediate fatalities	11,000	360,000
Fatalities from burns	6,900	320,000
Fatalities from shock wave injury	7,200	170,000
Fatalities from acute radiation injuries*	15,000	84,000
Total with a severe injury*	7,500	140,000
Severely injured, but expected to survive	2,600	140,000
Severely burned	1,600	120,000
Suffering severe mechanical trauma	1,900	30,000
Suffering severe radiation injury*	6,900	1,600
* *Including victims that die at a later stage from radiation injuries sustained*		

The category “severe injury” does not include those who die from any of the other causes. However, those who are expected to die from radiation injury at a later date are also included as severely injured, considering as they will require medical resources. The exception to this rule is the row “Severely injured, but expected to survive” which, in addition to the burn and shock wave injured, only includes the radiation injured who are expected to survive their radiation injuries. Similar to the fatality category, the same person can be severely injured by more than one type of impact. Note that the same individual can suffer a fatal injury in several categories, which means that the total number of fatalities is lower than the combined total of the subgroups.

2.5.3.2 Application 2: Attack on a military installation

For the application of an *Attack on a military installation*, approximately 200 military personnel are within 2 km of the explosion, while another 700 are within 10 km. Most of these will be unprotected, and to simplify the analysis it is assumed that all are unprotected. Since the number of personnel is relatively small in relation to application 1, the number of fatalities and severe injuries are reported together (this corresponds to the military concept of “*unfit for duty*”) in

Table 9. For a given explosive yield, the extent of injuries is often relatively clearly dominated by one cause (type of impact): for 1 kt it is acute radiation injury, while for 100 and 1,000 kt it is burns.

Table 9. Injury outcomes for explosive yields of 1 kt, 10 kt, 100 kt and 1,000 kt for application 2: Attack on a military installation. The table presents the total number of fatalities and severely injured, and the numbers are rounded to the nearest ten.

	1 kt	10 kt	100 kt	1,000 kt
Total number of fatalities and severely injured[*]	20	100	240	600
Fatalities and severely injured from burns	10	80	220	600
Fatalities and severely injured by shock wave injury	0	20	130	260
Total number of fatalities and severely injured from acute radiation injuries	20	60	140	200
[*] *Including those who die at a later stage from radiation injuries sustained*				

2.5.3.3 Effects of residual radiation

In the event of a nuclear weapon explosion near the ground, the radiological agents formed will mix with the ground material and generate extensive radioactive fallout. The calculation of the dose from the radioactive fallout has been made using the idealised particle deposition fields stated in the Nuclear Weapons Effects Manual [30]. These fields are expressed as the dose received during 48 hours after the fallout in the form of downwind ellipses with a circular part around the explosion point.

2.5.3.3.1 Injury panorama

A nuclear explosion near the ground can produce significant amounts of radioactive fallout. The effects of the ionising radiation are exactly the same as for the scenario with a nuclear plant failure, but in the nuclear explosion scenario there are no disaster mitigation systems in place and instead all radioactivity will be dispersed by the wind. Radiation doses will be high hundreds of kilometres away from the site of the nuclear explosion. At the same time, the dose rate decreases fairly quickly in a fallout from a nuclear bomb explosion, therefor substantial reductions in dose rate can be made by staying indoors for the initial period.

2.5.3.3.2 Dimensioning conceptualizations

By calculating the proportion of the total area affected by fallout, a relative proportion of injuries and fatalities has been calculated. When calculating the obtained radiation doses, three different premises have been used: staying outdoors 10% of the time and staying indoors in a detached house (protection factor[7] 0.4) 90% of the time, staying outdoors 10% of the time, and staying in an air raid shelter (protection factor 0.025) 90% of the time, and finally staying 100% of the time in an air raid shelter. The area most affected by the fallout is between 30 kilometres and 120 kilometres from the point of explosion and involves areas of between 50 and 1,800 km^2 depending on the explosive yield.

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[7] The dose received with mitigation by sheltering is calculated as the dose that would have been received without protection from sheltering multiplied by the sheltering/protection factor.

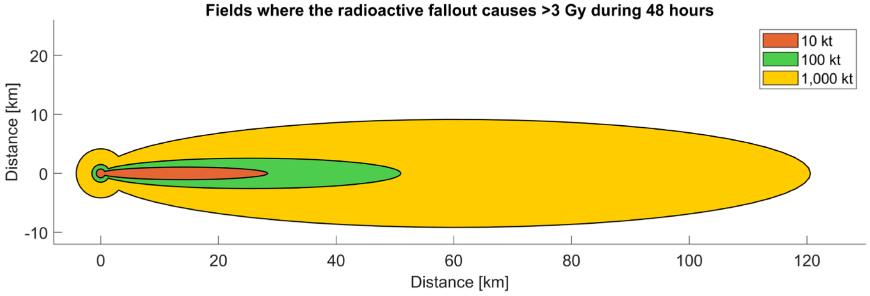

Figure 4. Idealised particle deposition field calculated according to [30] for the dose of 3 Gy during 48 hours if one is outdoors after an explosion with a yield of 10 kt, 100 kt and 1,000 kt respectively. The wind speed is assumed to be 6.7 m/s (24 km/h) and the explosions are 100% fission for the lowest explosive yield and 50% fission for the two higher explosive yields. The deposition field is stated as a downwind ellipse with a circular area closest to the explosion point. The length of the ellipse for explosive yields of 10 kt, 100 kt and 1,000 kt is 28 km, 51 km and 121 km respectively. For the same explosive yields, the width of the ellipse is 2.1 km, 5.2 km and 18.3 km respectively. The diameter of the circle is correspondingly 1.5 km, 3.0 km and 8.3 km in diameter.

In these calculations, explosive yields of 10 kt, 100 kt and 1,000 kt and an average wind speed of 6.7 m/s (24 km/h) have been used. For the two higher explosive yields, it has been assumed that half of the explosive yield comes from fusion and the other half from fission, while only fission is used for the 10 kt explosive yield. Under these conditions, the relative proportion of fatalities in the affected area will be about 45% of the population and the relative proportion of injuries 28% if the population spends 10% of the time outdoors and the rest of the time indoors in a detached house. If the time spent indoors can be replaced by a shelter (for 90% of the total time), the proportion of deaths and injuries drops to 7% and 16% respectively. If the population can enter a shelter before the fallout arrives and stay there for the first few days after the fallout, the effects will be limited to milder cases of headache, nausea and vomiting. Calculations of the fatality rate have been made using data from NUREG [35] and the injury rate from STANAG [36]. Higher explosive yields do not affect the relative proportion of fatalities and injuries as much, but the areas and number of people affected are significantly larger, see Table 10.

Since there are large areas involved and Sweden has hardly any large areas with high population densities, it has been assumed that there are 100 individuals per square kilometre. However, the numbers of casualties are scalable for other population densities using the specified fractions of fatalities and injuries.

Table 10. Injury outcomes for various explosive yields assuming a population density of 100 individuals per square kilometre for three different circumstances of staying indoors or outdoors. The size of the idealised deposition field is given for an isoline within which the population outdoors receives 3 Gy or more during the first 48 hours.

		10% of the time outdoors and 90% indoors in wooden houses		**10% of the time outdoors and 90% indoors in air raid shelter**		**100% of the time indoors in air raid shelter**	
Explosive yield (kt)	**Pop.** (number)	**Fatalities** (number / %)	**Injuries** (number / %)	**Fatalities** (number / %)	**Injuries** (number / %)	**Fatalities** (number / %)	**Injuries** (number / %)
10	4,900	2,000 / 45	1,400 / 28	300 / 6	800 / 16	0 / 0	<100 / 1
100	21,000	10,000 / 45	6,000 / 29	1,500 / 7	3,400 / 16	<10 / <1	200 / 1
1,000	179,000	86,000 / 48	49,000 / 27	17,000 / 9	29,000 / 16	10 / <1	2,500 / 1

3 Discussion

The use of weapons of mass destruction is a complex area where the outcome of incidents depends on many components not only those such as the attacker's choice of agent, quantities, dispersal methods and circumstances such as weather conditions, but also how the affected individuals deal with the situation that has arisen. The ambition of the assignment was to provide general understanding, within the framework of this assignment, of what the Swedish healthcare system may have to deal with in the event of a weapons of mass destruction attack. The results serve as a knowledge base and provide dimensioning conceptualizations that can be used in training programmes and for procurement of equipment, thereby contributing to increased preparedness in Sweden for possible CBRN attacks.

To limit the scope of the CBRN area to a manageable subset, a small number of agents and modes of attack were selected according to a number of criteria. With this objective in mind, the timeframe was also limited to the impact on the healthcare system in an acute phase (within the immediate weeks). It should be noted that, in many cases, there are delayed effects that are extremely serious and relevant, but that emerge at a later stage. This delay means that the healthcare system is not impacted with an equally emergency surge of patients, and the need for preparedness is therefore somewhat lessened. Examples of delayed types of harm include cancer caused by radiation, infectious diseases giving rise to epidemics or pandemics, ecological damage caused by contamination (something which affects the entire community and gives rise to increased health risks), and disruptions in water delivery systems causing sanitary challenges.

Knowledge of injury panoramas following a CBRN event is based on past incidents supplemented by theoretical and experimental studies. With some exceptions, symptoms and types of injuries are well researched and known. However, the injuries outcomes scale with the extent of the attack and depends on, for example, the course of dispersion and the response to the exposure. It is only possible to speculate on the extent of the attack and the other factors are also subject to uncertainty. In this study we have estimated the injury outcomes of the chosen conceptual scenarios. It is important bear keep in mind that there are inevitably significant uncertainties that are not accounted for.

The aim of this study was for the selected scenarios to convey a clear and relevant dimensioning conceptualization to the Swedish healthcare system and to form a basis for further knowledge development within the domain of Swedish total defence.

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