

GAME THEORETICAL MODELING OF THE USE OF RICIN AS A  
BIOTERRORISM AGENT

by

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Thesis directed by Professor Midge Cozzens

### ABSTRACT

Ricin is a toxin derived from the castor bean plant. Its toxicity has been known for years. There have been many cases of ricin toxification, mostly due to accidental ingestion of castor beans. It is possible that this agent will be used in bioterrorism, according to the Centers for Disease Control and Prevention (CDC). We look at this possibility from a game theory perspective in hopes of constructing ways to counteract bioterrorist attacks using ricin.

This abstract accurately represents the content of the candidate's thesis. I recommend its publication.

Signed \_\_\_\_\_  
Midge Cozzens

## **DEDICATION**

This thesis is dedicated to Althea who saw me through the best of times and the worst of times, and who has now passed on to better times.

## ACKNOWLEDGMENT

I would like to thank Midge Cozzens for her friendship and support as well as her brilliant idea to apply game theory to bioterrorism. I would also like to thank the rest of my committee, Mike Jacobson and Rich Lundgren, for their commitment to this topic.

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## **1. Introduction**

Since 9/11 the world has become more aware of the potential of a terrorist attack. On that fateful day, almost 3000 people lost their lives. As a nation and as a planet, we mourned.

This tragedy showed us that terrorism is a viable threat. One of the potential strategies for terrorists is bioterrorism. This growing concern has been addressed in small circles in the US government after known recent attacks on Capitol Hill. Both anthrax and ricin have been found in locations around the Capitol after 9/11. There is a vaccine for anthrax, but none exists for ricin yet. We focus this paper on the use of ricin as a bioterrorism agent.

### **1.1 The Basics of Ricin**

Ricin is a toxin derived from the beans of the castor plant. It was originally native to the Middle East and parts of Africa, but can now be found growing as a weed around the world. It is easy to obtain castor beans from either the roadside or a local greenhouse. Ricin can be extracted from these beans via a crude process that could be performed in any home environment.

Ricin is listed as a Category B bioterrorism agent by the Center for Disease Control and Prevention (CDC). An individual can be poisoned with this toxin through inhalation, injection, or ingestion. There is not a known treatment for ricin poisoning; only symptomatic care is available. Perhaps ricin has not received the attention that it warrants as a threat, since it is easy to make with little to no laboratory knowledge.

## 1.2 A Brief Introduction to Game Theory

The simplest form of a game is a two-person, two-strategy game. In light of the recent economy, we will use an example of a price war between two gas stations located next door to each other with the same possible customers and the same ease of access to the pumps. Thus, our two *players* [21] are I: gas station A and II: gas station B. Each player has the same two *strategies*: they can charge \$2 per gallon for gas or they can charge \$2.01 per gallon for gas. Let us suppose that most gas stations purchase their gas from a supplier who charges \$1.50 per gallon. It is easy to see that the profit for each gas station is \$0.50 if they charge \$2 per gallon and \$0.51 if they charge \$2.01 per gallon.

No customer wants to pay either of these obscene prices for gas, but cars do not run on water yet (except for the BMW Li series available in Germany). The customer remembers the good ole days when he used to buy gas for \$0.95 per gallon, so in this scenario the outraged customer will always choose to fill up their car at the cheaper station, even if they only save 1 cent per gallon. The game for this situation can be seen in Table 1.1. The payoffs for I are on the left-hand-side of the matrix and the payoffs for II are on the right-hand-side of the matrix [21]. All payoffs are given in dollars of profit per total 1000 gallons sold at each of the two gas stations.

Each player wants to maximize their profits [21]. If each player charges \$2 per gallon for gas then each player makes 50 cents per gallon or \$250 per total 1000 gallons sold between the two gas stations, the \$500 profit is split evenly between the two stations. So the *payoff* in this situation is \$250 for each [21]. Similarly, if each charges a penny more, then they each make 51 cents per gallon

		II	
		\$2.00	\$2.01
I	\$2.00	250 250	500 0
	\$2.01	0 500	255 255

**Table 1.1:** *Example of a Game*

or \$255 per total 1000 gallons sold between the two gas stations. If one gas station undersells the other gas station by a penny then the gas station with the discounted gas gets all of the market, \$500 per thousand gallons sold and the other gas station does not sell anything and has zero profit.

If gas station I knows that II is going to sell their gas at \$2.01 per gallon no matter what their competition decides to do, then I would be wise to sell their gas for \$2 per gallon so that they receive all of the profits. In this scenario, we would be in the top right-hand corner of the matrix in Table 1.1. Generally, this will not happen because no one goes into business not to make money. If I is selling their gas for \$2 then II will drop their price to match I's and gain back half of the market share.

The equilibrium point in the top left-hand corner, or *cell*, of the matrix is called a *Nash Equilibrium* [21]. To see that this is an equilibrium point one must look at each player's strategy individually. Both I and II are aware that they and their competition can choose to charge whatever they want for a gallon of gas. If I decides to charge \$2.00 per gallon then II's best strategy would be to charge \$2.00 per gallon because II would make a profit of \$250 instead of

zero. If I decides instead to charge \$2.01 per gallon of gas then once again II's best strategy is to charge \$2.00 per gallon because this will make them \$500 of profit instead of \$255. II wants to maximize his profit no matter what I does. This method of always choosing to pick on strategy on another is called a *pure strategy*. Similarly, no matter which strategy II chooses to play, I will get a bigger payoff if they choose the \$2.00 per gallon of gas strategy. Since no matter what the other gas station decides to do, it is more profitable for both gas stations to charge \$2.00 per gallon of gas. Since both gas stations are reasonable and in business to make money, they will both choose this strategy. Thus they will each make \$250 per every 1000 gallons sold. Since the game always ends up in the top left-hand corner we have a Nash Equilibrium there.

It is possible for a game to have either one, more than one, or no Nash Equilibriums. In the case of a *mixed strategy* game, one in which a player chooses one strategy a fraction, p, of the time and another strategy(s) 1-p of the time, the idea of a Nash Equilibrium disappears. If gas station II decides to play the \$2.00 strategy exactly half of the time and the \$2.01 strategy the other half of the time, then their payoff, when I charges \$2.00 per gallon, drops to

$$\$250 \bullet \frac{1}{2} + \$0 \bullet \frac{1}{2} = \$125 \tag{1.1}$$

whereas when I charges \$2.01 per gallon, II's payoff becomes

$$\$500 \bullet \frac{1}{2} + \$255 \bullet \frac{1}{2} = \$377.50. \tag{1.2}$$

When II is faced with the choice of playing a pure strategy or a mixed one, II will choose to play a pure strategy to maximize their profits. This is the essence of John von Neumann's Minimax Theorem, which states that each player wants

to maximize their profits while at the same time minimizing their competitors earnings [21].

This type of game can be applied to many other types of scenarios with varying numbers of players and strategies. The number of players in a game does not have to equal the number of strategies as it in this example.

This paper hopes to eliminate some of the naivete surrounding ricin and raise awareness to the threat using a game theory approach. First, we will establish the threat and finish by deriving a game theory matrix that will be used to help understand how to counteract a ricin attack. Thus, this paper is intended to mathematically establish a counteraction to ricin for anti-terrorists.

## **2. What is Ricin?**

Ricin is a highly toxic agent that is derived from the waste products left over from processing castor beans, *Ricinus Communis*, into castor oil. It is a very stable substance which is not greatly affected by extreme temperatures and does not deteriorate in air or water. It can be made into the form of a pellet, a powder, a mist, or it can be dissolved in food or water [8]. Due to its high toxicity and ease of creation, ricin has been listed by the Center for Disease control and Prevention (CDC) as a Category B bioterrorism agent. Category B agents are considered the second highest priority of the possible bioterrorism diseases and agents. These agents are moderately easy to disseminate and result in moderate morbidity rates [3].

### **2.1 The Castor Bean Plant**

*Ricinus Communis*, commonly known as the castor bean plant, can be grown almost anywhere from USDA Plant Hardiness Zones 2-11 [8]. This wide zone range rules out only Zone 1, where the minimum temperatures can go down to  $-50^{\circ}\text{F}$ . Zone 1 includes areas such as Fairbanks, Alaska, the Northwest Territories of Canada, and the northern most parts of Siberia. However, this does not rule out the possibility of growing castor bean plants indoors in even these areas of the world.

The castor bean plant was originally native to northeastern Africa and the Middle East. The plant was cultivated in ancient Egypt where castor oil was used for its lubricating and laxative effects. Egypt is still producing and exporting castor oil in the present day [8]. Today, approximately one million tons

of castor beans are processed annually worldwide. The resulting waste mash is approximately 3% to 5% ricin by weight [27].

The castor bean plant has escaped beyond the bounds of this cultivation and has become a naturalized weed in almost every part of the world that has a tropical or subtropical climate. The plant can be spotted growing on roadsides, rocky hillsides, and at the edges of cultivated fields [8].

The plant is very easy to grow. Anyone who has access to the Internet can readily learn how to raise these plants, indoors or out. These plants have a tendency to self sow and new seedlings will show up all summer long. It is one of the fastest growing plants in the world, reaching 8-15 feet in length in a single growing season in areas where it can be grown as an annual. The branches will develop later in the season and will produce large, stalked leaves consisting of 5-11 radiating, pointed leaflets with slightly serrated edges and prominent central veins, see Figure 2.1 [8]. Seeds or small plants can be purchased over the Internet or from a local greenhouse.

## **2.2 Waste from Production of Castor Oil**

Ricin is the toxin which remains in the castor waste after the oil has been extracted with either hexane or carbon tetrachloride. (Castor oil refinery machinery can be purchased on the Internet as well.) The ricin can then be easily extracted through a simple salting-out process [27]. This discovery was first published in 1889 by Entdeckt von Stillmark of the Pharmacologischen Institutes in Dorpat, Germany, [25] now known as Tartu, Estonia. Since these plants can be grown practically world-wide, it is feasible that ricin could be manufactured anywhere.



**Figure 2.1:** *Example of a Leaf from a Castor Bean plant*[8]

### **2.3 History of Use of Ricin**

There have been many cases of castor bean, more specifically ricin, poisoning throughout the 1900s. A majority of these cases have been the result of accidental ingestion of castor beans. The largest collective study to date on castor bean consumption and subsequent toxification was a joint project done by Emory University School of Medicine and the Georgia Poison Control Center in 1985. During this study 751 historical cases were documented showing only a 1.9% mortality rate for ricin toxification via ingestion [30]. This study is covered in more detail in Chapter 3 of this paper.

Medical studies have been implemented to investigate the potential healing properties of ricin, especially for tumor control. The first medical studies done

were to show that ricin can inhibit tumor growth, and were performed in 1951. The toxin was tested in patients with tumors by various routes: local application, intra-tumor, and intra-arterial [17]. In recent years, ricin has been studied as a factor of agents called immunotoxins. Chapter 3 describes this study in more detail.

Not all evidence of ricin toxification has been accidental or medically related. Ricin was first investigated by the United States as a weapon near the end of World War I. In the midst of WWII, the United States instilled the Biological Warfare Program. This program, worked in conjunction with the British, was designed to construct a bomb using ricin, code-named Compound W [27]. The weapon was tested, but reportedly never used in battle.

Ricin was first documented as being used as a weapon for assassination when Bulgarian defector Georgi Markov was shot in the leg by a ricin filled pellet, which was fired from a specially equipped umbrella in London in 1978. Reportedly, he felt pain almost immediately after the incident, but he did not seek medical treatment until thirty-six hours afterward. By this time he was very ill and died just over two days after the attack [27].

The Biological and Toxins Weapons Convention (BWC) was established in 1975, During this growth of biological weapons during the last century. It prohibits the development, production, stockpiling, or acquisition of biological agents or toxins and forbids weaponization of biological agents and toxins. It does allow defensive biological warfare research such as creating vaccines and protective equipment, thus the castor plant itself is not viewed as an illegal entity. As of 2004 there have been 167 signatories, 151 of which have ratified the

convention [20].

The United States implemented a similar law for internal use called The Biological Weapons Anti-Terrorism Act of 1989. The first arrests and subsequent convictions of this act occurred in 1994 and 1995. Four Minnesota men acquired 0.7 grams of ricin via a mail order ricin kit, which they proceeded to store in a coffee can at one of men's houses. The intent to distribute included an alleged plot to kill deputy sheriffs, US Marshals, and IRS agents. The men were part of a tax-protesting militia called the Minnesota Patriots Council. The sheriff's office was tipped off to this plot when the wife of one of the members had a dispute with her husband and, as retribution, brought the coffee can to the police station. Each of the men were sentenced to serve between 33 and 48 months of jail time [19].

Several other arrests were made in 1995. In August of that year, a 44 year old non-practicing oncologist was arrested for poisoning her husband's food with ricin. The husband had to undergo multiple heart and brain surgeries as a result of the poisoning. That same month a neurologist was apprehended for the assassination attempt of his former supervisor. At the neurologist's house the police discovered a small glass jar containing ricin. In December of 1995, a farmer from Arkansas was arrested for trying to smuggle 130 grams of ricin over the border from Canada to Alaska. Along with the large quantity of ricin, the Canadian custom agents found four guns and 20,000 rounds of ammunition [19].

During the following two years, 6 arrests were made in connection with ricin. In January of 1997, a Wisconsin man was found to have 0.67 grams of ricin after

the police responded to a 911 call regarding a domestic dispute. In April of the same year, IRS agents searched the home of a 39 year old electronics engineer and recovered a cache of chemicals as well as the home addresses of nearly 100 federal employees. Three members of a splinter group of the North American Militia in Michigan were arrested in March 1998. During the raid a cooking show format videotape was found which demonstrated how to extract ricin from castor beans. In August of the same year, a Michigan man was arrested for production of ricin with intent to use it on a housing official in his home town [19].

On November 5, 1999, James Gluck, a former Colorado resident, was arrested by the FBI in Tampa, Florida for threatening to kill court officials and “wage biological warfare” in Jefferson County, Colorado. Upon searching his Tampa home, agents found the ingredients necessary to produce ricin [19].

In June of 2002, police arrested a software engineer from Spokane, Washington, after being tipped off from fellow employees. Investigation of his cubicle at work produced a test tube which held approximately 1 gram of ricin. The engineer insisted that it was research for a Boy Scout project [19].

Perhaps the most famous incidents of domestic use of ricin took place during October of 2003 and February of 2004. Two letters containing ricin were found in October 2003, both signed “Fallen Angel.” One of these letters was discovered at a Greenville, South Carolina postal facility [12] and the other was found in an off-site processing facility for the White House. Both letters threatened to “turn DC into a ghost town” if changes in how truckers’ hours are regulated were not changed [18]. The FBI is still looking for the person(s) connected to

these letters. In February 2004, ricin was discovered in Senate Majority Leader Bill Frist's office [9]. This discovery prompted closure of three Senate office buildings. Law enforcement officials are unsure as to how the ricin got into the office [6].

Most recently, a 22 year old man from Ocala, Florida was arrested after authorities found a stash of ricin being stored in a cardboard box in his home. The sheriff's office was tipped off by an informant who saw the man carrying a vial of ricin in a local nightclub [4].

Recent ricin threats have not only occurred at home but have been prevalent abroad as well. In January of 2003, five men and one woman were arrested in their flat in London where traces of ricin were found [13]. In March of 2003, traces of ricin were found in two vials in a locker during a routine sweep at a Paris railway station, Gare de Lyon. This station serves southern France, Italy, and Switzerland, thus French officials are unsure if this weapon was intended for use only in France [7]. According to the Law Enforcement Agency Resource Network, instructions on how to make ricin have been found in Al Qaeda terrorist training manuals, see Figure 2.2 [2].

Given ricin's long recent history of use as a weapon, there exists a need to counteract both terrorist groups and individuals from using ricin. The game theory for this process can be found in chapter 4, and thoughts on what we, as a society, can do are found in chapter 5. We now investigate in more detail the different methods of toxification.

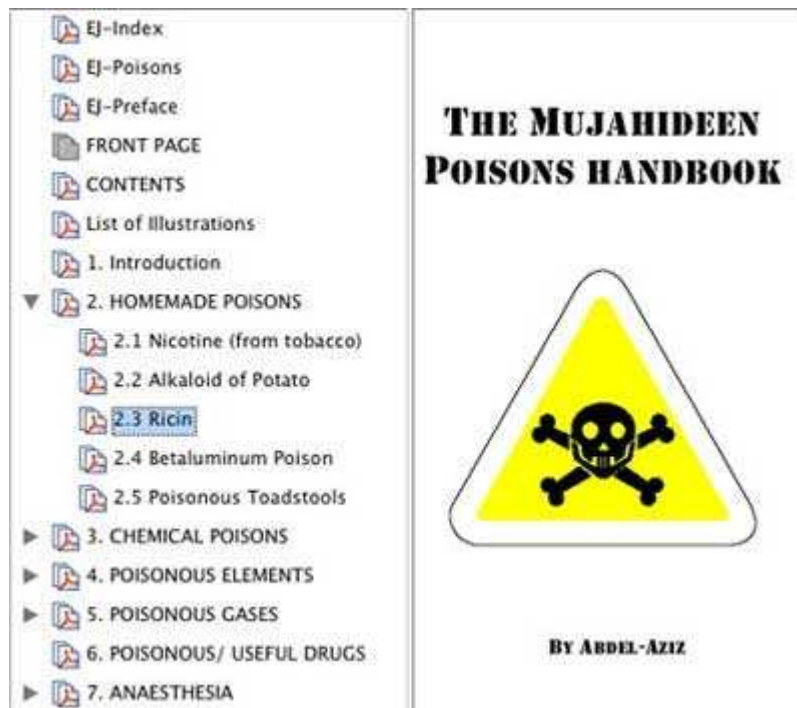


Figure 2.2: Copy of Al Qaeda Terrorist Handbook[2]

## 2.4 Toxicity

The toxicity of this agent is only rivaled by plutonium and abrin; abrin is a toxin derived from the rosemary pea plant [22]. The ( $LD_{50}$ ) of ricin, lethal dose to kill approximately 50% of those exposed, is  $3 \mu g/kg$  [27]. Keep in mind that  $1 \mu g$  is equivalent to one-millionth of a gram, so  $3 \mu g/kg$  is a minute amount.

### **3. Methods and Possibilities of Use of Ricin**

There are three methods of initiation for ricin toxification: ingestion, injection, and inhalation. The degree of morbidity increases with each of these methods in the order in which they are listed.

#### **3.1 Methods of Ricin Toxification**

##### **3.1.1 Ingestion**

In 1985, Emory University School of Medicine and the Georgia Poison Control Center collaborated on a landmark study of all reported cases of castor bean/ricin ingestion between 1900 and 1985. The resulting paper, published in the *Veterinary and Human Toxicology* journal, examined 751 cases of ricin toxification, and the results are summarized in Table 3.1. In this study there were only 14 total deaths which leads to a 1.9% fatality rate [30]. To understand the prevalence of mortality due to ingestion of castor beans we now look into those 14 cases in more depth.

One case, reported by Abdul-Kadir-Lufti, happened in Istanbul in 1934. In this situation a 24 year old man ate between 15 and 20 castor beans from plants that were growing near a railroad station in southern Turkey. Within two hours the man started feeling symptoms of toxification, including severe abdominal pain and tenderness, vomiting, diarrhea, and pain in the kidney region. He was admitted to a hospital where he was treated with caffeine, camphor (a medicinal herb), and 20% fructose intravenously. On the third day he was given strychnine. On the 12th day, he began having hallucinations and his blood pressure dropped

Study/ Location	Number of Cases	Results
Atlanta	12	
St Louis	2	
Italy	4	
Los Angeles	409	
Los Angeles	34	All hospitalized
Brooklyn	1	
Moschl	4	4 very ill
Abdul-Kadir-Lufti	1	1 dead
Liptak	3	3 dead
Kobert	150	9 dead
Fronne and Pfander	131	1 dead
Total	751	14 dead, 1.86% fatality

**Table 3.1:** *Cited Cases of Castor Bean Toxicity.*[30]

dramatically. He died during the night. At autopsy, there were holes found in his stomach; the kidneys were enlarged and congested; and there were microscopic tears in the heart's muscular wall [30].

In Vienna in 1938, Moschl reviewed what was then known about ricin agglutination which is the clumping of small particles in the blood. He found that human blood agglutinated by a 1:2 million dilution of ricin. Moschl also cited three unreferenced cases from literature in which 6, 5, and 3 castor beans were said to have led to death. Details on the ages and locations of the people who had consumed the beans and consequently died were not given. The reference was from a German journal published in 1938 and was unavailable to the author [30].

Kobert, Stillmark, and Beauvisage performed a similar case study of all 150 cases of human ricin poisoning up until 1906. In this study they found 9 deaths yielding a fatality rate of 6%. From these findings they calculated that 1mg of ricin was all that would be needed for a lethal human dose. One of the cases involved a 26 year old man in 1900. After consuming an unreported amount of castor beans and having had symptoms including vomiting for 3 days, this man sought medical services. He received unspecified treatment, but died on the 6th day. Another case involved a 15 year old boy in 1902. The boy became violently ill after eating 10 to 12 beans, and was admitted to the hospital upon the onset of symptoms. He was treated with calomel (Mercury Chloride) and cocaine. When this treatment did not bring about improvement, morphine was used. On the 10th day profuse diarrhea and fever set in. He died on the 12th day. The remaining seven cases were not detailed; the reference was from a German

journal published in 1906, thus, the article was unavailable to the author [30].

The most recent cases of death were reported in 1984 by Frohne and Pfander in which they cited a series of 131 cases collected since 1955. They reported only one death in which 10 children in Debrecen, Czechoslovakia ate castor beans, presented in class as “foreign nuts.” The other 9 children became very ill, but did not die [30].

The percentage of people who have died as a result of ricin poisoning has been small, 1.9%, and all deaths occurred before 1960. The use of camphor, strychnine, caffeine, and cocaine are now thought to be archaic [30]. In the age at the time these cases appeared, people were unlikely to seek medical attention until home remedies failed to work. By the time they did seek professional help, it may have been too late to treat the illness. Many cases may have been unreported due to this unhurried approach to medicine. It is reasonable to suppose that given modern technologies, proper fluid and electrolyte replacement in hospitals, and symptomatic care, we can reduce the possibility of mortality due to accidental ricin consumption to 0.4% according to Despott [22].

Recognition of ricin poisoning becomes important to reduce toxification due to ingestion. Initial symptoms generally occur within 8 hours of exposure. Symptoms may include: vomiting and diarrhea that may become bloody; severe dehydration; low blood pressure; hallucinations; seizures; and blood in the urine [3]. Left untreated the person’s liver, spleen, and kidneys may fail with fatality in the range of 6% [27]. The major symptomatic treatment for this method of toxification is to supply large amounts of fluid to the victim. Depending on the duration of time from consumption, induced vomiting may be prescribed as well

[24].

### 3.1.2 Injection

Studies on the effect of ricin toxification due to injection are cited in 3 different sources. The earliest of these three has been briefly detailed in chapter 2. The remaining two studies were performed in research labs, one was on the effects of ricin to aid tumorous, cancer patients, and the other study looked at the death rates and causes for rats injected with ricin. To understand the toxicity of ricin via injection, we shall look at each of these studies in more detail.

Case 1: The first case of death by injection of ricin occurred in 1978 in London. Georgi Markov was an anti-communist, Bulgarian broadcaster, who was assassinated while waiting for a bus. His assailant jabbed him in the back of the thigh with the tip of an umbrella that had been altered to administer a pellet 1.5 mm in diameter. The pellet, which was recovered at autopsy, had a cavity of  $0.28 \text{ mm}^3$  which was estimated to hold as much as  $500 \mu\text{g}$  of ricin. Mr. Markov reported feeling immediate pain, followed by a feeling of weakness within 5 hours. Between 15 and 24 hours later, he had a high fever and was vomiting. He was admitted to a hospital 36 hours after the incident. The hospital reported at the time of admission that Markov had a fever, swollen and sore lymph nodes in the groin region, and a 6 cm diameter area of inflammation at the injection site. Approximately, 2 days after the attack, Markov's pulse rate shot up, shock set in, and an electrocardiogram demonstrated a complete blockage in his heart. He died shortly thereafter [27].

Case 2: A Phase 1 medical study was held in 1984 in which 54 cancer patients with advanced disease volunteered to be subjected to ricin injections every two weeks to see if the ricin would effectively reduce their tumors. The doses ranged from 4.5 to 23 micrograms per square meter of estimated body surface. At levels ranging from 18 to 23 micrograms per square meter of estimated body surface, flu-like symptoms appeared, including fatigue, muscular pain, nausea, and vomiting. Only two of the patients died. Whether or not these deaths can be attributed to ricin or cancer is unknown [26].

Case 3: The third study involved injecting male Wistar rats with ricin. In this experiment, ricin was administered to the rats at doses of 7 or 40  $\mu\text{g}/\text{kg}$  body weight ( $\text{LD}_{50}$  being 3  $\mu\text{g}/\text{kg}$ ), via the penis dorsal vein which is a very fast route to the liver. These doses are approximately to 1 and 6  $\text{LD}_{100}$  respectively. Recall from chapter 2 that this represents a lethal dose to 100% exposed and six times the lethal dose to 100% exposed. Death occurred 24 hours after the 1  $\text{LD}_{100}$  dose and 13 hours after the 6  $\text{LD}_{100}$  dose. Only four hours after the 6  $\text{LD}_{100}$  dose all of the Kupffer cells were damaged. The Kupffer cells are the immune cells found in the linings of the liver, and these cells are capable of ingestion of foreign particles such as ricin. These cells were found to be the first target of the injected ricin. The ricin permeated the body via these Kupffer cells and caused death by coagulating in the arteries and veins of the body creating blockages [17].

Symptoms of poisoning by ricin using the method of injection seem to be very similar to the symptoms seen by ingestion. The crucial difference is that death is more imminent. The same symptomatic care as for ingestion should

help in these cases as long as medical care is sought immediately [27].

### **3.1.3 Inhalation**

Data on aerosol toxicity exposure in humans is not available. The only information documented on inhalation of ricin in humans is an allergic reaction reported in workers exposed to castor bean dust in and around castor oil manufacturing plants. These affected individuals respond to symptomatic care and removal from the source of exposure [27].

There has been one study done on the effects of ricin inhalation in primates. In this experiment five adult rhesus monkeys were exposed to an inhaled dose between 20.95 and 41.8  $\mu\text{g}/\text{kg}$  body weight of aerosolized ricin. All five monkeys either died or were euthanized due to severe respiratory distress between 36 and 48 hours after exposure. Upon autopsy all of the monkeys had gross lesions of the thoracic cavity, severe pneumonia, and acute inflammation of the airways which ultimately led to their rapid demise [32].

Without further research, it is impossible to say with certainty that symptomatic care will be life saving in the case of ricin inhalation. Within a few hours of ricin inhalation the likely symptoms are difficulty breathing, fever, cough, nausea, and tightness of the chest. There may be a build up of fluid in the lungs making breathing increasingly more difficult [3]. Finally, blood pressure drops and respiratory failure occurs, leading most certainly to death within 36 to 72 hours in the absence of symptomatic care [27]. The National Institute of Health recommends symptomatic care to include removal of victim to “clean air” and rescue breathing if necessary [24].

### 3.2 Use of Ricin in Bioterrorism

Now that we have explored the history and methods of toxification of ricin, how feasible would it be for a person or a group of people to use it as a bioterrorist weapon? Worldwide, approximately 1 million tons of castor beans are processed annually for the production of castor oil. The resulting waste mash contains between 30,000 to 50,000 tons of ricin [27].

At least 8 metric tons of ricin would be necessary to produce a mass casualty biological weapon (MCBW). A MCBW is a weapon that is used in open-air aerosol exposure under ideal meteorological conditions, over an area of 100 km<sup>2</sup> with a lethal dose for 50% of those exposed [27]. The laws of physics may prohibit 8 metric tons of ricin being used in a rocket, but a terrorist could fly 8 metric tonnes over a city approximately 100 km square, and drop its load, releasing a lethal dose to 50% of those exposed. A city of this size would be slightly smaller than Washington DC which is about 159 km<sup>2</sup>, or Boston (125 km<sup>2</sup>), but slightly bigger than Manhattan (87.5 km<sup>2</sup>).

It may be more plausible for ricin to be used as a weapon for terror than as a weapon of mass destruction. Based on the inhalation study discussed in the previous chapter, let us suppose that a terrorist were to target 42  $\mu\text{g}/\text{kg}$  body weight doses, keeping in mind that 1  $\mu\text{g}$  is equivalent to  $10^{-6}$  grams. The average male in the United States weighs approximately 87 kg (191 lbs) and the average female weighs about 75 kg (164 lbs). This means that the average male

would have to inhale 3.654 milligrams of ricin to have a lethal dose

$$87 \text{ kg} \bullet \frac{42 \mu\text{g}}{1 \text{ kg}} = 3.654 \text{ mg} \quad (3.1)$$

whereas the average woman would only need to inhale 3.15 mg

$$75 \text{ kg} \bullet \frac{42 \mu\text{g}}{1 \text{ kg}} = 3.15 \text{ mg}. \quad (3.2)$$

The Pepsi Center located in downtown Denver holds 20,000 people per event at maximum capacity [29]. If there were to be full attendance where half of the people were male and half were female, then a terrorist would only need to put about 68 grams

$$20,000 \bullet \frac{3.654 + 3.15}{2} = 68 \text{ g} \quad (3.3)$$

of ricin in the ventilation system in order to kill all 20,000 people in attendance. This is about 0.15 pounds of ricin, an amount that could easily be carried into the building through security in a person's pocket. Since the Pepsi Center is approximately 2,521,500 m<sup>3</sup> [29], it would take as little as 26  $\mu\text{g}/\text{m}^3$  (or .0000026 g/m<sup>3</sup>) to kill all in attendance at any given venue.

Terrorism through the use of ricin by means of injection is also possible. Certainly, one could imagine that if a person were stuck on the street by a needle in this day and age then the victim would seek immediate medical care. What if instead of using ricin as an assassination method, that a terrorist, or terrorist group, poisoned a batch of shots which people were willingly receiving such as a flu vaccine? Many of the symptoms of ricin poisoning mimic flu symptoms so people may not suspect that they had been poisoned. Even if a 40  $\mu\text{g}/\text{kg}$  body weight dose were used, which we recall from the previous chapter

is 6 times the lethal dose determined by the Wistar rat study [17], the average male (receiving 3.48 mg) would die approximately 13 hours after exposure and the average female (receiving 3 mg) would die in the same time frame. These trace amounts would easily fit inside a shot. These amounts are approximately 6 times larger than the amount that was estimated to have killed Georgi Markov. Access to large quantities of a flu vaccine may be difficult at a pharmaceutical company due to possible security clearance in laboratories, but vaccines may be accessed at hospitals or clinics. GlaxoSmithKline's flu vaccine, fluarix, has a shelf life of 1 year [5], thus a terrorist would have time to plan to pollute the vaccine at the source of distribution.

Ingestion has been shown in the previous chapter to be the most benign form of ricin toxification. It may be difficult for a terrorist to use this method to kill, but they could very effectively make people sick and raise fear. Tampering with a large food supply such as those found at a college dormitory or hospital cafeteria might be possible with large amounts of ricin and access to food before it is served. Certainly these situations would raise alarm for those in the near vicinity. Poisoning a city's water supply would be another means by which a large number of people could be subjected to ricin poisoning. Ricin has been shown to be resistant to free chlorine and coagulation/flocculation water treatment methods; however, both charcoal and reverse osmosis have been shown to be effective measures for counteracting the toxin if it is known to be present [23].

#### 4. The Game

We have just explored the possibility of using ricin as a bioterrorism agent. If we apply these possibilities to a two-person, multiple strategy game, then we will start to develop some ideas on how to counteract this potential problem. For a brief review of game theory, please refer back to chapter 1 of this text.

In our game, we will only consider two players: the “terrorist” and the “defender.” The Oxford Dictionary describes a terrorist as, “ a person who uses violence and intimidation in the pursuit of political aims.” Utilizing this concept of a “terrorist” includes the possibility of foreign agents and domestic threats alike. This also includes a one person terrorist against one other person like the assassination attempts described in chapters 2 and 3. The left-hand-side payoffs will represent the terrorist(s). The “defender” will be any agency, government, individual, or other group that wishes to defend against the possibility of attack in the form of bioterrorism, specially the use of ricin. The terms “defender” and “we” will be used interchangeably since the results of this game are intended to help counteract terrorism, thus we will take on the defender’s viewpoint. These payoffs will be displayed in the right-hand-side of the matrix.

The strategies available for the terrorist will be:

1. Put 1000  $\mu\text{g}$  (per person) of ricin in a food source (Food).
2. Poison a water supply with 1000  $\mu\text{g}$  (per person) of ricin (Water).
3. Inject a group of people with ricin from a tainted shot supply of 1000  $\mu\text{g}$  of ricin (Inject) which is twice the amount that killed Georgi Markov.

4. Distribute ricin into an Air Vent (AV) in a building of an amount two times the lethal dose, i.e. in the Pepsi Center example, 136g would be released.
5. Drop ricin via a Crop Duster (CD) over a city, 8 metric tonnes per 100 km<sup>2</sup>. This amount was chosen based on the work of the Surgeon Generals office [27].
6. No Action (NA).

Obviously, the defender will hope that the terrorist chooses the last strategy but this can not be counted on so the focus of this paper will be on the first 5 terrorist strategies. The amount of 1000  $\mu\text{g}$ /person for ingestion are based on the amount used for injection since the symptoms are very similar. The only research available on ricin ingestion involves consumption of castor beans, not pure ricin, so these ingestion amounts must be drawn from other methods of intoxication.

All conceivable strategies for the defender are listed below. We are assuming that these are all carried out with 100% efficiency:

1. Use of nasal swab combined with symptomatic care.
2. Some sort of detector to locate ricin in the air/water.
3. Intelligence: Knowing a priori where and how an attack will happen.
4. Reverse osmosis filtration in public water systems.
5. Tamper proof seals on foods.

6. Vaccinate the public.
7. Immediate Symptomatic Care.
8. Constant use of a gas mask.
9. No action for first 24 hours then provide adequate symptomatic care.
10. No action for first 48 hours then provide adequate symptomatic care.
11. No action at all.

The payoffs in our game theory matrices, Table 4.1 and Table 4.2, represent percentages that sum to 1. The payoff for the defender,  $p$ , is the percentage of people who survive which are exposed to ricin during an attack. Then, the payoff for the terrorist is  $1-p$ , the amount they “win” when they pull off a successful attack. The amount of each payoff was determined using information provided in the previous chapters of this text. For example, in the first column and third row of Table 4.1, the payoff for the terrorist is 1 and the payoff for the defender is 0. This means that if a terrorist injects a group of people with shots tainted with ricin, and the defender uses the strategy of diagnosis with nasal swabs then treat the symptoms, the terrorist will win 100% of the time because nasal swabs do not show toxification due to injection. For a second example, let us look at the third row and sixth column of the same table. Here we see that the terrorist who injects people who have been vaccinated with ricin will not succeed in killing anyone. If the terrorist(s) chooses non-action, then no matter what we choose as a strategy, no one will be harmed; thus, the payoff is 1 for the defender and zero for the terrorist in this case. A payoff of 1 for the defender

means that 100% of the population *exposed* survive whereas a payoff of .5 for a defender means that only 50% of the people *exposed* survive and so on.

#### 4.1 The Idealistic Game Theory Model

If we assume that all things are possible, such as everyone who is exposed to ricin inhalation will be treated with sufficient medical care, then the game theory matrix, Table 4.1, gives the payoffs for this model. All of the payoffs where the terrorist has a payoff of one and we have a payoff of zero indicates that the particular strategy we are using is not at all effective in thwarting the attack by the particular method the terrorist is using. For example, if we do not medically treat any people who are exposed to ricin intoxication because of 136 g of ricin in the air vents of Pepsi Center, then the terrorists win. Everyone who is at an event and is exposed to ricin will die (AV row, column 11). The payoff where we have one and the terrorists have zero means that our strategy is very effective in counteracting that particular form of terrorism. For example, no matter what strategy the terrorist uses, if we vaccinate the public, then everyone who is exposed will be safe (see column 6 of Table 4.1).

		Defender										
		1	2	3	4	5	6	7	8	9	10	11
Terrorist	Food	.06 .94	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	1 0	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	.01 .99	1 0	.01 .99	.02 .98	.06 .94
	Water	.06 .94	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	.01 .99	1 0	.01 .99	.02 .98	.06 .94	
	Inject	1 0	1 0	0 <input type="checkbox"/> 1	1 0	1 0	0 <input type="checkbox"/> 1	.01 .99	1 0	.5 .5	1 0	1 0
	AV	.01 .99	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	1 0	1 0	0 <input type="checkbox"/> 1	.01 .99	0 <input type="checkbox"/> 1	.5 .5	1 0	1 0
	CD	.01 .99	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	1 0	1 0	0 <input type="checkbox"/> 1	.01 .99	0 <input type="checkbox"/> 1	.5 .5	1 0	1 0
	NA	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1	0 <input type="checkbox"/> 1

**Table 4.1:** Idealistic Model: The left-hand side payoffs are for the terrorist(s) and the right-hand side payoffs are for the people trying to defend against the terrorist(s).

The payoffs for toxification due to ingestion, which are not simply one or zero, are calculated based on the works of Franz and Despott. According to medical experts, a person who is exposed to ricin toxification due to accidental consumption of castor beans has a 99% chance of living [22] if they get adequate medical care (intravenous replacement of fluids and inducing vomiting) [24]. Thus, the payoff for both symptomatic care and medical treatment of exposure after 24 hours is .99 for the defender and .01 for the terrorist. If we do not treat a person with ricin poisoning, from consumption by any means available, then medical experts predict that this patient still has a 94% chance of living. The payoff for both Food and Water rows combined with column 11, no action, is .94 for the defender and .06 for the terrorist. Only 2% of victims will die if symptomatic care begins 48 hours after toxification resulting in a payoff of .98 for us and .02 for the terrorist based on the numbers derived by medical experts for both immediate medical care and no treatment (column 10 and either row Food or Water).

The payoff values of toxification due to injection are a little simpler to compute than those by ingestion. If a person is injected with a minimum of 1000  $\mu\text{g}$  of ricin and does not get symptomatic care within the first 24 hours then that person is doomed. This result leads to a payoff of 0 for us and 1 for the terrorists when injection is combined with any of the following: treatment after 48 hours or no treatment at all. If immediate symptomatic care is sought then almost everyone can be saved. The payoffs for immediate care are .99 for us and .01 for the terrorist. These payoffs are based on the fact that the symptoms for injection are essentially the same as the symptoms found via the method of in-

gestion, thus the payoffs are the same for immediate care. If medical treatment is sought right after the first 24 hours then the chances for survival would drop to a 50/50 situation based on the Wistar rat study that 1 LD<sub>100</sub> injection results in death after 24 hours [17].

As stated in Section 3.1.3, data on aerosol toxicity exposure to humans is not available. Therefore, we have to extrapolate the payoffs for both AV and CD terrorist strategies based on animal studies. In one study, all of the subjects died within 36 to 72 hours. We computed in the previous chapter that an average sized man weighing 87 kg and an average sized woman weighing 75 kg would be killed by breathing in 3.654 mg and 3.15 mg of ricin, respectively, without treatment. Based on this it is safe to assume that without medical treatment within the first 48 hours a victim would surely die. This leads to a payoff of 1 for the terrorist and 0 for the defender in both the 10th and 11th columns of Table 4.1. There have been no studies to show how ricin poisoning would affect a person if they were able to receive immediate symptomatic care. In an ideal world, if we were able to take a nasal swab at the onset of symptoms, correctly diagnose ricin poisoning, alert the television and radio stations to advise all people who have been in that area of exposure to seek immediate medical care, and properly treat all of the victims with sufficient medical space and resources, then, hypothetically, we could save almost everyone who was exposed. There can be cases of people exposed who are either anaphylactic to weeds or who have a prior medical lung condition such as asthma, further complicating the situation. This leads to a payoff of .01 for the terrorist and .99 for the defender, which incorporates prior medical problem cases.

We have already stated above that the best situation for us is for the terrorist to use the no action strategy and this clearly shows up in the last row of Table 4.1. For the terrorist, choosing a no action strategy only gives them a payoff of 0, thus we must, under rationality assumption of players in game theory, assume that the terrorist will not choose “no action.” When we play the idealistic model of the game, we do not get a pure Nash equilibrium, discussed in chapter 1, because the payoffs never favor both players simultaneously.

Considering the remaining strategies that the terrorist may use, we see that strategies 3 (intelligence), and 6 (vaccinating the public) completely counter-act all attacks. These two are columns with the payoffs boxed in Table 4.1 to highlight the fact that we win with these strategies regardless of what the terrorist does. All of the cases where we win have been boxed in Table 4.1 Defender strategy 7, complete symptomatic care, comes very close to a perfectly effective strategy with at a minimum of 99% success. Strategy 2, use of a ricin detector for air and water, is the next best strategy which works for all terrorist strategies, except injection. Nasal swabs combined with symptomatic care (1) and wearing a gas mask (8) are both fairly effective in neutralizing a threat based on inhalation. Tamper proof seals are capable of guarding against ingestion based threats, and reverse osmosis filtration treatment centers in public water supplies will eliminate ricin poisoning through ingestion of that water source. The only strategy that does not help us across the board is “no action.” Therefore, regardless of how the terrorist decides to carry out their plan of a bioterrorism attack using ricin, in an ideal world, we should rely on intelligence and vaccinations.

		Defender						
		1	4	5	7	9	10	11
Terrorist	Food	.06 .94	1 0	0 <span style="border: 1px solid black; padding: 0 2px;">1</span>	.01 .99	.02 .98	.04 .96	.06 .94
	Water	.06 .94	0 <span style="border: 1px solid black; padding: 0 2px;">1</span>	0 <span style="border: 1px solid black; padding: 0 2px;">1</span>	.01 .99	.02 .98	.04 .96	.06 .94
	Inject	1 0	1 0	1 0	.85 <span style="border: 1px solid black; padding: 0 2px;">.15</span>	.92 .08	1 0	1 0
	AV	.85 <span style="border: 1px solid black; padding: 0 2px;">.15</span>	1 0	1 0	.85 <span style="border: 1px solid black; padding: 0 2px;">.15</span>	.92 .08	1 0	1 0
	CD	.99 <span style="border: 1px solid black; padding: 0 2px;">.01</span>	1 0	1 0	.99 <span style="border: 1px solid black; padding: 0 2px;">.01</span>	.99 .01	1 0	1 0
	NA	0 1	0 1	0 1	0 1	0 1	0 1	0 1

**Table 4.2:** Realistic Model: *The left-hand side payoffs are for the terrorist(s) and the right-hand side payoffs are for the people trying to defend against the terrorist(s).*

## 4.2 The Realistic Game Theory Model

In the real world some strategies are just not feasible or available; a more realistic game matrix is shown in Table 6.2. Here we have eliminated four of the defenders strategies, which appeared in the gray columns in Table 6.1: 2.A detector for ricin in the air or in water because it does not exist currently; 3.Humans are imperfect, so relying on intelligence, or a priori knowledge is not practical, even if such information is accurate; 6.Vaccinations are not currently available; and 8.It is not practical to have an entire population wear gas masks 24/7.

A realistic look at the situation not only limits some defender strategies, it changes some of the payoffs as well. In the case of ingestion, the payoffs for treatment sought after 24 or 48 hours become just slightly more favorable to the terrorist, but everything else remains essentially unchanged. This decrease in

defender payoff values is due to the reality of incorrect diagnosis and subsequent treatment.

The methods of toxification via injection and inhalation see a drastic decrease in payoffs for the defender in terms of immediate care as well as symptomatic care after a 24 hour period. The amount of hospital critical care space in this country may be better than most but it is still insufficient to handle a large medical crisis. For example, there are 5693 total hospital beds in the Denver metro area including Boulder, many fewer are critical care beds [14]. Even if every single hospital in metro Denver were vacant of other patients, which is highly improbable, there would still not be enough beds for the number of victims calculated in the previous chapter's Pepsi Center example. Let's say for the sake of argument that as many as half of the beds in Denver hospitals would be available to victims if an attack were to happen at the Pepsi Center. This estimate is probably on the high side, but we will assume it to be true. If 20,000 people were to be exposed to lethal amounts of ricin at the Pepsi Center, and there are only approximately 3000 beds available to treat victims, then only 15% of the victims could even access symptomatic care. This reduces payoffs for both nasal swabs and immediate symptomatic care from .99 to .15 and increases the terrorist payoff to .85. After 24 hours have passed we may be able to release some of the healthy victims and make room for more casualties, but we definitely can not treat everyone else. We could treat perhaps as many as 1500 more people leading to a payoff of about .08 for us and .92 for the terrorist. If we use the same figure for the number of hospital beds available in the case of 20,000 flu vaccines being tainted with ricin, then the payoffs for injection are

the same as those for inhalation.

If a terrorist attacks a city, say Washington DC, using a crop duster to drop an aerosolized version of ricin in the amount of 1 LD<sub>100</sub> per person over the city, then there would be a real crisis in our nation's capital. According to the US Census Bureau, there are 572,059 people living within the city limits of the District of Columbia [1]. There are approximately 3000 hospital beds in the DC area [15]. Once again, let us assume that half of these hospital beds are available. Even if half of the people who live in this area, 286,029 people, were exposed to a lethal dose of ricin, then there would only be enough room in hospitals there to treat slightly less than 1% of the victims. If the terrorist were to use the crop duster strategy then this reduces the payoffs for the defender to .01 and raise the payoff for the terrorist to .99 if the defender use either of the strategies of immediate symptomatic care and care after 24 hours.

The results of this reconstructed realistic game in Table 4.2 show a much bleaker outcome than the first game since our chance of success drops dramatically for virtually all scenarios. Our best case scenarios, given that a terrorist uses an action, are in boxes in Table 4.2 to highlight the realistic situation at a glance. Tamper proof seals on food products and reverse osmosis treatment systems are the best way to inhibit ricin poisoning from ingestion. The only means to neutralize the threat by means of either injection or inhalation is to treat symptomatically, and this is still not enough to save substantial number victims. In the realistic model, there is not one clear defender strategy to use against bioterrorism, as there was in the idealistic model.

		Defender	
		Vaccine	Medical Care
Terrorist	Water	0 1	.01 .99
	Inject	0 1	.7 .3
	AV	0 1	.7 .3

**Table 4.3:** Mixed Strategy Model: *The left-hand side payoffs are for the terrorist(s) and the right-hand side payoffs are for the people trying to defend against the terrorist(s).*

The result of comparing these two games, realistic versus ideal, is simple: We need a vaccine. A ricin detector could also be extremely beneficial. These topics will be addressed in the coming chapter.

### 4.3 A Mixed Strategy Game

A mixed strategy game is one in which more than one strategy can be used by a player simultaneously. Even if a vaccine does become available it may not be monetarily feasible to distribute the vaccine to an entire population. Let us reduce our game to include only vaccination or care for defenders and either water, injection, or air vent for the terrorist. The new payoff matrix can be found in Table 4.3.

The payoffs have changed again slightly from the idealistic and realistic models. All people who have been vaccinated will survive as seen in the first column of Table 4.3. Those who haven't been vaccinated against ricin have a 99% chance of living if poisoned via ingestion. Since there are people who are vaccinated in this case, there would be fewer patients needing medical care after exposure. If half the people who were exposed as in the previous section needed

to go the hospital then there would be a greater percentage of people getting treatment. This raises our payoff from .15 to .3 and lowers the terrorist payoff to .7.

Suppose that 60% of a population were willing and able to take an effective ricin vaccine assuming one is available. This means that in the event of a terrorist attack using ricin, 40% of the population has to rely on symptomatic care. In other words we would “play” vaccine  $3/5$  of the time and medical care  $2/5$  of the time. If the terrorist decided to use their strategy of putting ricin in a public drinking source, we get  $1(3/5) + .99(2/5) = .996$  or 99.6% of the defenders live. If the terrorist decides to taint a flu vaccine or disperse ricin in a large building’s air duct instead poisoning a water supply, then we get  $1(3/5) + .3(2/5) = .72$  or 72% of the defenders live. Thus, even if we can not vaccinate an entire population, vaccinating a percentage of the population will drastically increase the chances of survival.

## 5. What Can We Do to Protect Ourselves from a Ricin Attack?

Having raised the awareness of how unprepared we are in the event that a terrorist uses ricin, what can we do as a group to improve our security? Comparing Tables 4.1 and 4.2 helps us to understand that the only offense is a good defense.

First and foremost, an effective vaccine for ricin needs to become available to all soon. The United States Army Medical Research Institute of Infectious Diseases has developed an experimental vaccine that may protect humans against ricin. This vaccination has been proven effective in mice and will be tested on African green monkeys next, according to the Journal of the American Medical Association [28]. It is predicted that human testing is still at least a year away and an approved vaccine is at least 4 years away [16]. If and when the vaccine is finally approved by the Food and Drug Administration (FDA), it needs to be available at all hospitals, not just for military personal or in select regions of the country.

Further medical research needs to be funded to look at the effects of ricin inhalation, detection of ricin toxification, and discovery of therapeutic treatments. The only study on the effects of ricin inhalation found to date was performed on five rhesus monkeys in 1993 [32]. Five subjects, especially nonhuman subjects, is a very small test group. Medical studies with at least 20 subjects in each of several LD<sub>100</sub> groups, i.e. 1 LD<sub>100</sub> versus 5 LD<sub>100</sub>, should be tested to confirm or reject the current proposed effects of ricin inhalation. Tests have shown that

nasal swabs have been proved effective in diagnosing ricin aerosol exposure [10]. Identification of ricin in the blood and body fluids has proven to be difficult due to ricin's rapid protein binding and metabolism [11]. There need to be creative studies on other possible diagnostic tools. Currently, there are only resources to treat the symptoms of ricin poisoning, not the poisoning itself; effective treatments need to be established in case there is a terrorist attack. Over 150 agents have been tested in vitro for possible activity against ricin, to no avail [11]. These efforts need to be stepped up.

The hospital system in the United States is inadequate for caring for a large number of patients with intensive care needs. During the Determined Promise '03 exercise, NORTHCOM learned that, given a medical catastrophe, between 50 and 100 people in a small city could come into the hospital in an afternoon, all in acute respiratory distress. They would all need to be hospitalized with some going to intensive care with respirators. This amount could very easily fill up every hospital in the city with more space needed. In a large city this would be even more of a catastrophe. The problem is that we could not expand our medical surge capacity to provide lifesaving care [31]. Temporary care units would need to be established and be accessible within an hour of need, since symptomatic care has been shown to reduce risk of fatalities.

There are no detectors developed to warn communities of a ricin attack via water or air. These technologies need to be developed. The monetary incentive would be there if a manufacture were capable of producing detectors for mass market. Perhaps a wise CEO could offer a monetary reward and stipend for groups, academic or otherwise, to develop such a detector. The main problem

would be in the testing of the detector. This approach worked for the space program so why not apply it to bioterrorism.

Many possible techniques have yet to be developed to help us respond to a terrorist attack. Some of these suggestions may be initially costly but what is the cost of saving the lives of friends and family?

## 6. Conclusion

Ricin is a highly toxic poison derived from the castor bean plant. Originally native to northeastern Africa and the Middle East, the toxic effects of ricin have been known since ancient times. The castor bean plant has escaped beyond these regions and can be found worldwide in tropical and subtropical environments. Ricin is found in the waste mash of this plant after the lubricating castor oil has been extracted from it. Approximately, 300,000 to 500,000 metric tonnes of ricin could be produced annually just from the waste of castor oil manufacturing.

Over the years there have been hundreds of case of ricin poisoning documented around the world, most of these due to ingestion. There has been one case of ricin poisoning, involving a Bulgarian defector, via injection to a human. The rest of the cases of death by means of injection involve animal and medical research studies. The scariest means of toxification is inhalation. The only study on this method showed the death of all subjects. These deaths occurred within 36 to 48 hours. There has not been any human documentation so the effects of this method have been extrapolated in this paper to show that it would take less than 4 milligrams of aerosol ricin to kill a human being.

The use of ricin as a bioterrorist agent is definitely possible. The fact that castor beans are easy to obtain, ricin is easy to make in any setting, and that such a small amount can kill a person calls for more attention and funding for ricin research. With these facts in mind, perhaps ricin should be elevated from a Category B agent to a Category A agent, at least until a vaccine is available.

Creating a detector for ricin could be very profitable, but getting approval for a viable vaccine should be our first and most urgent priority.

The three different models of game theory with regards to ricin use, Table 6.1, Table 6.2, and Table 6.3, demonstrate the need for both an easily accessible ricin vaccine and a effective ricin detector for water and air. We will be in a grim state if one or both of these strategies does not become available before ricin is used as a bioterrorist agent against us.

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