How Science and Engineering Changed the Face of Twentieth-Century War

Jordyana Edwards[1]; John Christy Johnson[1,2]; Peter Anto Johnson[1,2,]; and Austin Albert Mardon[1,2,3*]

[1]Antarctic Institute of Canada, Edmonton AB.
[2]Faculty of Medicine and Dentistry, University of Alberta, Edmonton AB.
[3]John Dossetor Health Ethics Centre, Edmonton AB.

E-mail: aamardon@yahoo.ca*

ABSTRACT

Conflicts have always benefited from the great minds of inventors, engineers, and scholars. The twentieth century saw the growth of scientific involvement with chemical warfare, communication and location technology, and nuclear energy, changing the definition and methods of war completely. With the introduction of greater scientific involvement, the roles and responsibilities of scientists and engineers in wars were forever changed. Over the course of both world wars, hundreds of thousands of scholars working in various scientific fields were involved in discovering and producing tools to aid in the war efforts. This essay serves as an insight into the scientific minds and inventions behind some of history's most influential discoveries, as well as their impacts in war and after it.

(Keywords: military history, military technology, STEM contributions to military science)

INTRODUCTION

The chemical warfare agent, chlorine gas, was first introduced by the Germans in April 1915 through gas canisters in trenches at Ypres, Belgium. This deployment of chlorine gas saw approximately one thousand soldiers killed, if not from the gas, by German artillery upon escape routes from the trenches. Despite its use being a war crime, more than 124,000 tons of poison gas weapons were released by the end of the First World War.

With the growth of the industrial revolution and global move towards militarism, traditional weaponry such as the rifle from the nineteenth century could no longer ensure the victory of any one country. Global powers such as Britain, Germany, and the Soviet Union began to focus more money and manpower on the militaristic advancement of their countries; a focus that would lead to the First World War.

Conflicts have always benefited from the great minds of inventors, engineers, and scholars. The twentieth century saw the growth of scientific involvement with chemical warfare, communication and location technology, and nuclear energy, changing the definition and methods of war completely. With the introduction of greater scientific involvement, the roles and responsibilities of scientists and engineers in wars were forever changed.

Over the course of both world wars, hundreds of thousands of scholars working in various scientific fields were involved in discovering and producing tools to aid in the war efforts. Unfortunately, some of the most well-known wartime scientists operated on the losing side of history. German scientist Josef Mengele nicknamed the "angel of death" for the inhumane experiments he conducted on Jewish citizens in concentration camps in Nazi Germany, is a good example of one of those scientists. There were, however, thousands of scientific scholars who focused not on the development of weapons but on defensive devices that saved many lives.

The invention of the gas mask and body armor, among other things, serve as examples. This essay serves as an insight into the scientific minds and inventions behind some of history's most influential discoveries, as well as their impacts in war and after it. From the introduction of chemical weapons in the First World War, the radar technology that gave the Allies their invaluable advantage over the air, and the atomic bombs which bore a new era in nuclear power research, the impacts of science in wartime reached far beyond just the battlefield.

Chemical Warfare Agents

German Jewish chemist Fritz Haber developed chlorine gas in 1915, not as a lethal weapon, but as a conventional one used to draw out enemy forces where they would then be fired upon by German soldiers. Haber, known as the "father of chemical warfare", led the German Chemical Warfare Program, consisting of many scientists, engineers, and physicists under the belief that technology could mean conclusive victory for Germany, that is until the allies developed defensive measures against them.

The Germans were able to weaponize chlorine after realizing that in gas form, it could be discharged in clouds when placed in a specialized cylinder. These cylinders were planted all along enemy trenches allowing chlorine to be dispersed easily across. Within minutes of its release at Ypres in 1915, chaos erupted, and French and Algerian soldiers could be seen leaving their trenches and running in all directions.

Chlorine gas, a lung irritant, caused soldiers to experience shortness of breath, nausea, and vomiting, although it was the soldiers' fear of the gas attacks which made them so powerful. These attacks were fast, unpredictable, and chaotic, and soldiers were unable to protect themselves from the effects of the gas.

For soldiers on the front lines, "gas shock was as frequent as shell shock". Another benefit of chlorine gas for the Germans was the length of time it left its victims incapacitated. With a sixty-day recovery period, chlorine gas required the most time of any of the other poison gases used in the World Wars developed after it. This meant that large numbers of troops were being removed at any time, weakening the Allies' defenses.

This new form of warfare led to the expansion of research in Britain, France, and America. Soon the British Army began enlisting the help of scientists from many universities across the United Kingdom. France, on the other hand, chose to militarize the chemistry, pathology, medicine, and biology programs from sixteen French medical schools and institutes. This created a much more obvious link between federal governments, science, and the military than had ever been established before. It was not long before chemical warfare became a sort of "technical chess", and both the Western Allies and Germany began mixing chlorine gas with a compound called phosgene resulting in more extensive casualties.

Phosgene gas was developed and weaponized at the same time as chlorine by Fritz Haber. Phosgene, much like chlorine is a lung irritator and a "lachrymatory" - a substance that irritates the corneal nerves and stimulates the production of tears - it is more deadly and effective than chlorine. It can cause fluid buildup in the lungs resulting in death. Both sides quickly began utilizing phosgene in place of chlorine due to its effectiveness and high casualty rate.

It was only a matter of time before Britain and France shifted their focus from offence to defense and began developing gas masks to protect their troops from attacks. The first successful mask to be developed was the Small Box Respirator (SBR) by Lieutenant Edmund Clegg Dockar of the Canadian Expeditionary Force and introduced to the front lines in 1916.

The SBR was a vast improvement from the first few prototypes, notably the "hypo helmet" which was incredibly fragile and obstructed the soldiers' view. The small box respirator was exceptionally useful to the Allied soldiers as it could be modified for protection against gases beyond chlorine and phosgene; a feature that came in handy in July 1917 when German troops introduced mustard gas, synthesized by British physicist Frederick Guthrie between 1822 and 1860. Mustard gas was completely unlike chlorine or phosgene gases in its effectiveness and caused more casualties than all other chemical agents combined.

Though chemical warfare only accounted for 30% of war casualties, mustard gas alone made up 80% of those casualties, earning it the title, "King of the Battle Gases". Chlorine and phosgene were lung irritants, but mustard gas was a "vesicant"; a type of blister agent which inflicted severe burns and blisters on the skin, lungs, and eyes, causing severe shortness of breath, blindness (temporary and permanent) and often death. Even treatment for victims of mustard gas exposure was more difficult to provide. The only way to treat someone contaminated with mustard gas was a hot bath, meaning portable shower units and trained medics needed to be available.

It was around this time that the United States officially joined World War I. Two months prior to their declaration of war on Germany, in February

1917, the United States began utilizing Director Van H. Manning's Bureau of Mines resources due to their experience researching noxious gases, detection technology, explosives, and breathing aids.

Within a year, major universities such as MIT, Johns Hopkins, and Harvard involved approximately 1,900 scientists and technicians - a number which grew to 5,500 by the war's end - to research both offensive and defensive chemical warfare. By August 1917, the Gas Defense Service was founded under the United States Army Medical Department with a focus on gas mask research and production.

In June 1918, Winford Lee Lewis synthesized an arsenic-based compound known as lewisite. It took little time for Lewisite to earn its nickname "dew of death" and would have greatly surpassed the death toll of mustard gas had World War I continued into the next year. Coming in contact with lewisite would cause painful pustules and boils as well as irreparable damage to the lungs. Luckily for troops on both sides, lewisite never saw action as its production came just before the signing of the armistice on November 11, 1918.

The development and implementation of poisonous gas in World War I led to the sustained involvement of scientists and engineers in chemical research. Though the 1925 Geneva Protocol maintained a prohibition of the use of poisons and chemical agents in warfare, their production was not prohibited. This freedom led the German scientist Gerhard Schrader to the synthesis of a nerve poison, Tabu (taboo), named after its potency. This Tabu gas would go on to be used in Nazi concentration camps in World War II to kill its Jewish prisoners. Developments in chemical warfare across the twentieth century represent just one of the ways in which scientific research has changed the modes of battle.

Radar Technology

A radar-focusing technique developed by Scottish physicist, Robert Watson-Watt in 1935, marked an enormous step into the future of defensive war technology. Watson-Watt informed the British defense committee of his realization that upon pulsing high-power overseas radios, aircraft echoes could be received. Radar focusing worked by sending out radio waves that would bounce off targeted objects at a distance revealing the object's location, granted the radio waves were powerful enough.

Radar technology gave Britain the ability to anticipate German air attacks early enough to prepare their defenses. Using this discovery, it took Britain no more than four years to set up radar warning stations, called Chain Home Stations, all across the South and East coasts of Britain. These stations were able to detect enemy aircraft at a range of approximately 140 kilometers. The first instance in which Britain's use of radar technology greatly assisted their army was at the Battle of Britain in the autumn of 1940 using the Dover radar station, Fighter Command received a warning of the German air force's, the Luftwaffe's, approach with enough time for British fighter jets to become airborne. This not only gave British pilots the time they needed to prepare their defense but gave them knowledge of the location of German jets which preserved fuel and time otherwise spent searching the air.

The people who operated radar towers and interpreted the signals recorded were called radar technicians. Allan E. Paull, a member of the Royal Canadian Air Force (RCAF), spent much of World War II in radio and radar operations. Paull's recount of his experiences working in radar stations in Britain was shrouded in secrecy much like anything else regarding British radar at that time. It is estimated that approximately 5,000 technicians worked through the air force to record and interpret the radar information that passed through Chain Home stations.

Radar technicians and operators used goniometers - devices that could determine the angles of incoming radio waves - and continuously turned the dial on these goniometers until a short "blip" was detected. The angles of these blips would then be recorded and transferred onto a location grid which would be communicated to air squadrons for investigation. These radars were invaluable to the British air-force and helped lead them to victory for the Allies over Nazi Germany. However, the radars of 1939 had one important problem, they were virtually useless in the dark and British military officials predicted that the German defeat at the Battle of Britain would soon lead them to night bombing. In 1940, engineers Henry Boot and John T. Randall were tasked with the development of the resonant-cavity magnetron which performed well in the dark and could be used in nearly all weather conditions.

The cavity magnetron worked by replacing the metal plates in the current radars with resonators that efficiently generated more (and much shorter) microwaves and produced 400 watts on its first trial - almost 100 times more power than its predecessor, the Chain Home system. After minor adjustments, the power output of the cavity magnetron grew to ten kilowatts. In September of that year, a prototype was secretly brought over to the United States with orders from Sir Henry Tizard, an English chemist and inventor, to request large-scale production of the magnetron. Then President of the United States, Franklin D. Roosevelt called the cavity magnetron “the most important cargo ever brought to American shores”.

The unsuccessful bombings targeting Luftwaffe in mid-1941 encouraged the scientific advisor of the British Air Ministry to request that their Bomber Command be paired with cavity magnetron radars to improve target location accuracy. This improvement was invaluable to the British bombers as they could now locate German jets deep within Germany. At this point, having discovered a much weaker radar system yet failing to employ it, the German air force was at an extreme tactical (and technological) disadvantage to the British. In their obsession with keeping cavity magnetron technology a secret from the Germans, British military officials decided against the implementation of the radar in their jets, warships, or land vehicles traversing into enemy territory lest they be captured by German forces and the technology replicated. Instead, British scientists opted to use the first onboard transmitters with the weaker and less accurate klystron.

Klystron, unlike cavity magnetrons which focused electron beams in a circular pattern using its strong magnetic field, used a linear electron beam to detect radio waves. After the war, many speculated that the extent to which Britain placed an emphasis on keeping cavity magnetrons a secret only resulted in missed opportunities to use the technology against Germany.

Watson-Watt, Boot, and Randall’s radar technologies have since been developed into countless warning systems and everyday appliances, most notably, the microwave. It was also the radar units surrounding the island that alerted the United States about the Pearl Harbor attack an hour before it happened. Radars are present aboard all modern aircraft to alert them of other aircraft sharing the airspace as well as airports to maintain air traffic control. It is the radar in speed guns that detects how fast a car travels by measuring the changes in the frequency of reflected radio waves, and the radar in a Doppler unit that predicts the weather and measures pollution in the air. The discovery inspired by Watson-Watt’s desire to protect Britain from the German Luftwaffe led to the technology that gave Britain its greatest advantage over its airspace and led to countless other inventions both related and unrelated to national security and conflict.

The Atomic Bomb

Founded in 1939, the Manhattan Project brought various foreign and American scientists and engineers together across the United States with the goal of researching and developing nuclear weapons to aid the United States in World War II. Though many research projects had been developed in the United States to study bombs and nuclear warfare, the Manhattan Project differed from them as it was the first project with the intention of building bombs to be deployed in war. Leo Szilard, a Hungarian-American physicist, was the first to encourage atomic bomb development in America after the discovery of nuclear fission in 1938 due to his fear that Nazi German scientists would soon be on the path to developing nuclear weapons of their own.

Szilard requested that Albert Einstein, a well-known German theoretical physicist, sign a letter sent to American President Harry S. Truman which recommended that the United States begin nuclear research and development. By 1939, the Manhattan Project had been founded under the U.S. Army Corps of Engineers consisting of - at first - hundreds of scientists, engineers, and technicians across the country. This number grew to no less than 130,000 people by the project’s end in August 1945.

Ironically, the majority of work in the Manhattan Project took place not in Manhattan but in many universities across the United States. Arthur H. Compton, a physicist, led a group of scientists in experimenting with plutonium isolation at the University of Chicago. Harold C. Urey, a physical chemist, led another group in extracting the 235-

isotope of natural uranium (which would appear in the “Little Boy” atomic bomb) at Colombia University. Ernest O. Lawrence, a nuclear scientist, did the same at the University of California, Berkeley for electromagnetic isotope separation. And finally, J. Robert Oppenheimer, a theoretical physicist, spearheaded the group of scientists who focused on designing the bomb, also at UC Berkeley. In understanding and experimenting in these areas, these scientists determined that the development of an atomic bomb could be made possible.

In late 1942, Brigadier General Leslie R. Groves, an army civil engineer, was appointed command of the Manhattan Project. Many of the scientists who worked under him disliked his methods of leadership as he cared very little about the actual scientific research but largely focused instead on army regulations. It is said he was also under immense pressure from the war and often took shortcuts to speed up the process with colleagues calling him an “unfeeling tyrant goaded by overweening ambition and excessive ego”. I reference this only to say that the scientists and engineers had very little say in anything other than the research they conducted. They were not used in creative or basic research - research meant for developing new ways of understanding and reconfiguring knowledge - but as tools to collect data by way of the scientific method.

Groves even implemented a system of “compartmentalization” which kept the different study groups isolated from each other for security reasons, but also to avoid scientific curiosity deemed irrelevant to the cause. Only in rare circumstances when Groves considered it beneficial to the project did they interact.

Not soon after his being appointed commander, Groves began his focus on securing production sites in Tennessee, New Mexico, and Washington and brought in the Corps of Engineers for the development of the actual bomb. The complexity of this project is demonstrated by the amount of collaboration that had to occur in order for the bombs to be built. For the electromagnetic plant designed by Lawrence’s team and Berkely, Groves enlisted the Stone and Webster Engineering Corporation to build it and the Tennessee Eastman Corporation to operate it. For the design of the gaseous-diffusion plant designed by Urey’s Colombia team, the J.A. Jones Construction Company would build it and the Carbide and Carbon Chemicals Company would operate it. Du Pont de Nemours and Company would build both the plutonium pilot plank and the full-scale production plant at Handford. By July 16th, 1945 the world’s first nuclear explosion occurred hundreds of miles from the New Mexico production site and was considered a success. Not one month later, the bombs would make history in Japan.

The majority of the scientists and engineers who worked in the Manhattan Project had worked under the impression that the development of the atomic bomb, initially designed out of fear of German nuclear development, would only be deployed if it became necessary in bringing the war to an end. Lilli Hornig, a Manhattan Project scientist expressed her belief that the United States military had made the decision long before that America would deploy the atomic bomb “no matter what”. After years of research and the understanding of what such nuclear power was capable of, Szilard, the physicist who initially encouraged nuclear research and the Manhattan Project, presented a memorandum in the spring of 1945 with petitions from many scientists, engineers, and technicians who worked in the project.

Along with many other scientists who opposed the “surprise attack” method that was planned for Japan, James Franck developed the Franck Report which proposed a peaceful demonstration of the atomic bomb as a sort of incentive for Japan’s surrender. Both memorandums and petitions were denied by the US military and Secretary of State James F. Byrnes. These ideas were also discouraged by Oppenheimer with the justification that “scientists have no business to meddle in political pressure of that kind” as they were not knowledgeable enough about military strategy. Oppenheimer went on to be one of many scientists who expressed deep regret about participating in the Manhattan Project following the bombings of Hiroshima and Nagasaki.

On August 6, 1945, at 8:15 am, the world’s first atomic bomb, “Little Boy” was dropped on Hiroshima, a small city in Japan. The initial explosion killed approximately 80,000 people instantly but totaled anywhere between 100,000 and 135,000 casualties from radiation exposure and other injuries. Anticipating an unconditional surrender from Japanese Emperor Hirohito, the United States waited three days before dropping another atomic bomb on August 9th at Nagasaki.

Though this bomb, “Fat Man”, was heavier at 10,000 pounds with a plutonium core which made it more powerful than the last, its effectiveness was limited by Nagasaki’s situation in a valley between mountains. Ultimately, this resulted in fewer casualties, estimated between 60,000 and 80,000 citizens in total.

Upon learning of the events at Hiroshima and Nagasaki, Albert Einstein declared in an interview with a Japanese magazine editor that “Had [he] known that the Germans would not succeed in developing an atomic bomb, [he] would have done nothing”. This referred to the letter sent by Szilard and signed by Einstein encouraging the former US president to begin nuclear weapons research.

J. Robert Oppenheimer, who previously expressed disagreement with the Franck Report - which opposed the deployment of the atomic bomb in Japan - became outspoken in his guilt about helping to advance nuclear weapons research. After having seen firsthand what the atomic bombs were capable of, Oppenheimer often challenged and tried to discourage the development of the hydrogen bomb because he believed thermonuclear weapons were “more destructive than mankind could control”. Though Oppenheimer still believed that the United States was justified in using the atomic bombs in Japan, he mourned the future he and thousands of other scientists and engineers had helped create in nuclear weaponry and referenced a Hindu proverb where “[Oppenheimer and his colleagues] [are] become Death, the destroyer of worlds”.

The Manhattan Project and development of the American atomic bomb led the Soviet Union to establish an atomic bomb project of their own and by 1949, the United States no longer held the upper hand in nuclear power. By 1998, seven countries had access to these weapons of mass destruction. Ironically, the atomic bomb’s power and the potential of “mutually assured destruction” - in which the use of nuclear weapons by two or more states would result in the complete destruction of all states involved - guarantee that they will never be deployed in a conflict situation.

CONCLUSION

It is evident that the contributions made by scientists and engineers have shifted the focus of war. Between chemicals that inflicted irreparable damage to a soldier’s body, technology to strengthen defenses, and weapons of mass destruction, it might be easy to speculate that much of the wars’ extensive death toll could be attributed to such inventions.

In addition to inventions and ideas, scientists and engineers contributed a whole new category of warfare; one where the victory of a nation did not rely solely upon foot soldiers and their ability to best an opponent in combat or on a general’s knowledge of terrain and military tactics. This new type of warfare relied upon constant innovation and the production of efficient technology to be placed in the hands of the soldier.

Throughout the twentieth century, the foot soldier gradually became the middleman, a translator of science and innovation to murder and destruction. It seems as though, for the scientists and engineers of twentieth-century war, the growing conflict created a global environment of academic competition in which ideas were constantly being adapted, improved, and weaponized. As the quote by Thomas Edison similarly states, competition breeds innovation and invention, some of which, employed in conflict, caused much more harm to humanity than good.

REFERENCES

1. AHF. 2016. “Leo Szilard's Fight to Stop the Bomb.” Atomic Heritage Foundation, National Museum of Nuclear Science & History. 15 July 2016, https://www.atomicheritage.org/history/leo-szilards-fight-stop-bomb.

2. AHF. 2020. “The Franck Report.” Atomic Heritage Foundation, Atomic Heritage Foundation, https://www.atomicheritage.org/key-documents/franck-report.

3. AMNH. 2022. “Einstein and the Manhattan Project: AMNH.” American Museum of Natural History, American Museum of Natural History, https://www.amnh.org/exhibitions/einstein/peace-and-war/the-manhattan-project.

4. Anderson, T. 2016. “Oppenheimer's Dilemma.” *Oppenheimer's Dilemma*. Stanford University: Stanford, CA. 19 Apr. 2016. http://large.stanford.edu/courses/2016/ph241/anderson1/.

5. BMJ. 1934. “Gas Warfare.” *The British Medical Journal*. 1(3828): 903–903, http://www.jstor.org/stable/25321060.

6. Dick, R. 1990. “Battle of Britain.” *Air Power History*. 37(2), Air Force Historical Foundation. 11–25, http://www.jstor.org/stable/26271113.

7. Dockar. E.C. 2022. “Small Box Respirator : Lieutenant E C Dockar, 43 Battalion, Canadian Expeditionary Force.” Australian War Memorial, https://www.awm.gov.au/collection/C158913.

8. Edison, T.A. 1928. “Thomas A. Edison Quote on Innovation”. https://www.azquotes.com/quote/1389495.

9. Encyclopedia Britanica. 2022. “Mutual Assured Destruction.” Encyclopædia Britannica, inc. https://www.britannica.com/topic/mutual-assured-destruction.

10. Fitzgerald, G.J. 2008. “Chemical Warfare and Medical Response during World War I.” *American Journal of Public Health, American Public Health Association*. Apr. 2008, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2376985/.

11. GSU. 2022. “The Magnetron.” Magnetron Operation, http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/magnetron.html.

12. Hewlett, R.G. 1976. “Beginnings of Development in Nuclear Technology.” *Technology and Culture*. 17(3): 465–78, https://doi.org/10.2307/3103525.

13. History.com. 2010. “Germans Introduce Poison Gas.” History.com, A&E Television Networks, 9 Feb. 2010, https://www.history.com/this-day-in-history/germans-introduce-poison-gas.

14. History.com. 2010. “Soviets Explode Atomic Bomb.” History.com. A&E Television Networks, February 9, 2010. https://www.history.com/this-day-in-history/soviets-explode-atomic-bomb.

15. Lorber, A. 2016. “Government of Canada.” *Technological Intelligence and the Radar War in World War II*. 5(1). National Defense, 18 Oct. 2016, http://www.rcaf-arc.forces.gc.ca/en/cf-aerospace-warfare-centre/elibrary/journal/2016-vol 5-iss1-07-technological-intelligence-and-the-radar-war-in-world-war-ii.page.

16. Lovell, B. 2004. “The Cavity Magnetron in World War II: Was the Secrecy Justified?”. *Notes and Records of the Royal Society of London*. 58(3): 283–94, http://www.jstor.org/stable/4142066.

17. Patton, J. “Gas in the Great War.” *Gas in The Great War*. KU Medical Center, https://www.kumc.edu/school-of-medicine/academics/departments/history-and-philosoph y-of-medicine/archives/wwi/essays/medicine/gas-in-the-great-war.html.

18. Paull, A.E. 1994. “Reminiscence of an RCAF Radar Officer Attached to the RAF”. *World War II RCAF Radar Personnel History Project*, University of Toronto, 11 May 1994, http://www-2.rotman.utoronto.ca/~paull/RADAR00.htm.

19. Robinson, D.M. 1983. “British Microwave Radar 1939-41.” *Proceedings of the American Philosophical Society*. 127(1): 26–31. http://www.jstor.org/stable/986362.

20. Shimshoni, J. 1990. “Technology, Military Advantage, and World War I: A Case for Military Entrepreneurship.” *International Security*. 15(3): 187–215, https://doi.org/10.2307/2538911.

21. SIPRI. 2020. “10. World Nuclear Forces.” SIPRI, n.d. https://www.sipri.org/yearbook/2020/10.

22. Stanley, W. “1940s: The Cavity Magnetron.” *Science Museum Blog*. 18 Mar. 2013, https://blog.sciencemuseum.org.uk/1940s-the-cavity-magnetron/.

SUGGESTED CITATION

Edwards, J., J.C. Johnson, P.A. Johnson, and A.A. Mardon. 2023. “How Science and Engineering Changed the Face of Twentieth-Century War”. *Pacific Journal of Science and Technology*. 24(2):59-65.

Pacific Journal of Science and Technology