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If the first World War is known as the chemist’s war, the second World War was definitely won by the physicists. For US scientists that worked at the Rad Lab, “the nuclear bomb ended the war, but the radar won it”. Two laboratories are behind these technological advancements. The Rad Lab, at MIT that focused on microwave and radar research. The Tizard mission lead to the development of the cavity magnetron and microwave-based radar. At Los Alamos, the Manhattan project lead to the development of the first nuclear bomb that would be dropped on Hiroshima and Nagasaki the 6th and 9th of august 1945, leading to the unconditional surrender of Japan the 2nd of September 1945.

This technological prowess came from a country that profoundly transformed its scientific capabilities in the first half of the 20th century leading up to World War II. The US got from following the Europeans for scientific lead to being the leaders in the 30s and 40s. One of the major change, known as ‘Big Science’, in the 1930s lead to the large scale projects of Los Alamos and the Rad Lab. The goal of this paper is to study how the US developed ‘Big science’ in the 30s and how it gave them the technological edge in the second World War with the example of the Manhattan project.

One of the initiator of ‘Big Science’ is Ernest Lawrence, the 1939 Physics Nobel Prize winner for the invention of the cyclotron. This invention is fundamental for two reasons, the size and scale of these machines but also because these tools later lead to the development of calutron which will be of paramount importance in the development of the nuclear bomb. Lawrence is a US born physicist that studied solely in the US, after getting his PhD in physics at Yale in 1925, he went on to become a professor at the University of California in 1928.

After studying the work of Rolf Wideröe and his work on obtaining high-energy particle with the aid of a linear accelerator, Lawrence develops a circular and more compact version, the cyclotron. The idea is to organize circular chamber around the poles of electromagnet to accelerate a charged particle. The cyclotron is the first sign of ‘Big science’. At first, science experiments and demonstration were meant to stand on a presentation table. At the time of Benjamin Franklin or Joseph Henry, all electrical based demonstrations could be done in a room. Quickly, the cyclotron became something that needed buildings, not rooms.

The first cyclotron was 4 inches and cost around $25. After that, Lawrence never stopped improving and proposing bigger designs, 27 inches in 1932, 37 inches in 1937, 60 inches in 1939 and finally 184 inches with 4500 tons magnet with an estimated cost of $2.65 million dollars. Lawrence not only paved the way for big science, he also invented an entire branch of physics, ‘High energy’ physics. In a letter addressed to Lawrence, Wood, a physicist, wrote: “As you are laying the foundations for the cataclysmic explosion of uranium ... I'm sure old Nobel would approve."

The bigger the cyclotron, the higher the energy, the more information you can get out of it. However, building these expensive machines at the time of the Great Depression was not easy task, Lawrence had to find funding. Initially, he got money from the Research Corporation and the Chemical Foundation. Upon the advice of the Research Corporation, Lawrence filed a patent for his machine which ended up being approved in 1934. In 1931, Berkeley dedicated an entire building for his research, this building would later evolve into the Rad Lab. Between 1931 and 1940, his research had ‘consumed’ $550,000 dollars. He managed to keep finding new funding by diversifying the applications of his machine. By using it as medical tool to treat cancer, Lawrence got funding from the National Cancer Institute, the Macy and Rockefeller foundation. Lawrence himself said, to Niels Bohr in 1935:"I must confess that one reason we have undertaken this biological work is that we thereby have been able to get financial support for all of the work in the laboratory. As you know, it is much easier to get funds for medical research." This project was large due to its funding and size requirements but also due to its personnel, the staff grew from a team of 10 scientists in 1932 to 60 scientists in 1939.

‘Big science’ is really an American invention, Franz Simon said in 1932, while visiting the US:”Americans seem to work very well, only they obviously insist on making everything as big as possible”. We already discussed of the scale, we can also add the diversity of profiles to such a scientific endeavor. To get into biomedical application, Lawrence had to add physicians and biologists (one of them was his brother, a Doctor of Medicine. Even if the scale was important, some mistakes were made. The Rad Lab at Berkeley missed alpha particles that were discovered in 1932 by British scientists and artificial radioactivity discovered by Joliot and Curie. Still, McMillan discovered long-lived radioactive isotopes, Alvarey and Bloch measured the magnetic moment of the electron.

This pre-war era Rad Lab gave ideas to the scientists and physicists that would win World War II. Oppenheimer, for instance, was at Berkeley at the time and learned from Lawrence and his organization. The Rad Lab was a source of knowledge and enlightenment for many scientists that would visit or study the blueprints of the cyclotrons that Lawrence would send all over the US. This laboratory definitely sparked the interest of many physicist and the idea that building big is possible.

After the attack on Pearl Harbor in December 1941, the US is officially at war. Big science turned into the Rad Lab at MIT and the Project Manhattan. The new purpose of the cyclotron was now to help build the bomb. The idea of the bomb sparked in the mind of physicist after the discovery of nuclear fission by Otto Hahn and Fritz Strassmann. Since nuclear fission is possible, neutrons can be produced by it, a chain nuclear reaction is theoretically possible and could be used as a bomb. The first estimations, in 1938, for the critical mass was 10 kg, typically something that could be carried in a bomb.

The Y-12 National Security Complex build in Oak Ridge, Tennessee, was the plant designed to produce the material required for a nuclear bomb. From February to November 1943, the facilities were constructed. To produce Uranium 235 from Uranium 238, two techniques could be used at the time. The first one is gaseous diffusion, which was also researched and developed at the same time as the second method, the calutron. The Calutron (which is the combination of the University of California and Cyclotron) worked as a ‘sector mass spectrometer’. Since the two isotopes have the same charge but different mass, they would react differently to a magnetic field. Their deviation after being accelerated in a classical cyclotron would be different, thus the possible separation of the isotopes. This technique, known as ‘electromagnetic diffusion’ was first developed by Nier.

The calutron was first developed in 1941, by January 1942, the Lawrence’s team managed to produce 18 micrograms with 25% of uranium 235, by February 1942, it was 75 micrograms with 30% of uranium 235. After these first attempts, it was decided that the enrichment of uranium would have to happen in two stages, the alpha and beta. As we have seen before, ‘Big science’ requires funding, which was not a problem since the army was backing the project up, the real problem was getting the materials to follow up on the needs of scientists. The magnets were recycled from the cyclotrons from the Rad Lab at Berkeley and the additional electromagnetic coils were constructed out of 14,700 tons of silver taken out of US reserves. This enrichment process is the perfect continuation and embodiment of ‘Big science’, vast resources involved but also big size. At the Y-12 site, 200 structures were built, and 1,200 people worked at the Rad Lab of Berkeley. The calutron and electromagnetic diffusion method lead to the production of the critical mass required to construct the bomb dropped on Hiroshima.

If Lawrence is the father of the material, Julius Robert Oppenheimer is the father of the atom bomb. Oppenheimer, unlike Lawrence, studied in Europe where he met European physicists such as Heisenberg, Pauli, Dirac or Fermi. After coming back from Europe, Oppenheimer became an associate professor at Berkeley where he would meet Lawrence and work on quantum electrodynamics.

In October 1941, before the formal entrance of the US into World War II, the Manhattan project was approved. Oppenheimer was asked to join the project in 1942, his first task was to work on fast neutron calculation. When Grover, a military engineer, became the director of the Manhattan project, he put Oppenheimer as the head of the project’s secret weapon laboratory. His motivation to do so was based on the impression he had of Oppenheimer, he was able to grasp quickly the underlying problems and subtleties of a wide range of topics. The multidisciplinary aspect of this ‘Big science’ project required someone that could play out of his own field of expertise.

In 1942, the laboratory of Los Alamos started to come into shape. The entire lab, under military supervision worked under strict rules of secrecy. These rules later lead a young Richard Feynman to repeatedly go through holes in fences. Two major designs for the bomb were researched at Los Alamos, the first one, a gun type plutonium-based weapon and an implosion type uranium-based one. The basic mechanism of a nuclear weapon is to bring nuclear material to a concentration that will force a self-sustained nuclear fission reaction. The gun type involves smashing one radioactive material into another, forcing the chain reaction. The implosion type involves having a non-critical mass of uranium that would be put into such conditions of temperature of pression (due to an explosion) that the new conditions would make the uranium be in a critical state, thus triggering the explosion. As early as 1943, the preferred design was the gun type. It was later decided that the more complex design of the implosion type could bring better results in august of 1944. Oppenheimer then reorganized the entire Los Alamos lab to work on implosion and one section worked solely on the gun-type bomb. Both designs ended up being fruitful as little boy (gun type) and the ‘gadget’ reached the end of their development phase by July 1945.

The famous Trinity test took place in New Mexico on July 16th, 1945. “The Gadget”, which would be the design retained for Fat Man, the Nagasaki bomb, had an implosion architecture. The scientists of Los Alamos were convinced that the gun-type would work, the only one that needed testing was the gadget. After this success, the decision to actually drop the bomb was in Henry Truman’s hands. The main islands of Japan still had 2 million soldiers willing to rather die than surrender. A proposal of unconditional surrender was offered to the Japanese that rejected it. A demonstration of the newly created bomb was rejected as a successful demonstration would not work, according to the presidency, and a failed demonstration would have disastrous effect on the actual nuclear capability of the US. The bomb was then dropped on Hiroshima and later on Nagasaki, causing the death of 200,000-250,000 people (depending on the source and whether radiation is taken into account).

People around the world reacted differently to the news of this new weapon. Politicians and political opponents of Truman and the US said that dropping the bomb was a way of showing the USSR what the US was capable of. That the war could be won without having to rely on such weaponry. The defeated Germans fell in disarray as their own projects could not reach the scale of what the US had been capable of achieving. For some, focusing their ‘Big science’ military project on the V1 and V2 rockets meant that developing the bomb could have been done by them also. In 1947, the doomsday clock was created by worried physicist, the clock always indicating that a nuclear war could be triggered in the lapse of minutes. Oppenheimer, the father of the atomic bomb himself felt some sort of remorse. After the war, he tried to convince the US generals not to develop an even stronger weapon such as the H-bomb. Oppenheimer is also known for quoting the Bhagavad Gita: “Now I am become Death, the destroyer of worlds”. This new technological possibility of self-destruction also inspired or scared writers. In 1987, the writer and singer Yves Simon wrote about the 3 main events of humanity, when he stood straight, when he walked on the moon and when he dropped the bomb.

The nuclear bomb and its possible proliferation is still a vividly debated topic today. All 5 members of the UN security council have it and many more countries want to develop it as a way to ensure their protection just like the ‘big 5’ do. However, one might argue that the mere existence of such weapons stopped the two superpowers of the Cold War to clash each other into a third world war. Even today, no country that possesses nuclear weapons has ever been attacked by a foreign country. If nuclear deterrence and Mutually Assured Destruction is frightening, then it is working as intended.

For big science and high-energy physics, the trend only accentuated after the war. On the impulsion of Rabbi, the CERN saw the light of day and many more accelerators ended being developed in the US. The LIGO laboratory also comes to mind. The problem with these projects is that they are becoming bigger than what a sole state (even the US) can sustain. If the US brought science from table-sized demonstrations to giant cyclotrons spanning across several countries, the next step seems to be international cooperation. It worked for big projects like CERN and the International Space Station. If it is not obvious for the US, it is for the Europeans that cannot sustain big projects without cooperation. Airbus,