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# Review: Literature Study of Particle Accelerator Development and Its Applications In Material Physics Research

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**Abstract.** Particle accelerator is an invention which relates to the beginning of sophisticated revolution of technology especially in 20th and 21st century. The spacious range of particle accelerator application penetrates not only in particle physics research, but also in other scientific field which is like chemistry, biology, technology and industry. Generally, its application is supporting the medical diagnostic and therapy, product sterilization and preservation, and in optical or electrical component manufacture, etc. Based on the library research, accelerators that have been developed can be divided into conventional accelerators and modern particle accelerators. The conventional accelerator is an accelerator principle based on the early concept of electromagnetism which is applied directly and simply to help human work. Modern accelerator is the next generation of conventional accelerator which has been developing to reach the need in extremely high energy. Modern particle accelerators are built on the basis of physics concepts such as Maxwell's equations to the latest theory of particle physics. The varieties of particle accelerator include first generation of accelerator, Van de Graaff, linac, betatron, cyclotron, microtron, synchrotron, synchrocyclotron, electron linac, proton linac, SLAC, ring collider, tevatron, (LEP, LHC, RHIC), and SSC. Current and future accelerator research challenges are to develop accelerators that have high efficiency but are more eco-friendly by minimizing nuclear waste and radiation factors. As the example is muon collider. Muon Collider has great prospective but the character of its instability still has quite challenging puzzle to solve. The field of material physics is very possible to take a role in this research because in principle the development of particle accelerator both its science and technology are necessity for material research, especially in material characterization.
**Keywords:** linac, particle accelerator, material physics, muon collider, nuclear.

## INTRODUCTION

Discovery and research since the past along the timeline are an entity that influences one another. As the common example that the development of theoretical physics related to quantum fields is also supported by various results of particle physics experiments in magnetic field studies which are based on the Zeeman effect phenomenon (Jenczyk, 2020). The development of particle physics and nuclear physics is very dependent on science or accelerator technology (Barbalat, 1994; Leiss, 1979).

The particle accelerator is an important and versatile instrument in physical research. The needs and use of accelerators were increasingly widespread, starting from every field in physics, especially particle physics and solid matter physics, to other scientific fields such as chemistry and biology. The indirect impact is that the rapid growth of particle physics such as the discovery of antiproton particles, support the development of astrophysics, cosmology and various types of industry. (Barbalat, 1994; Virtanen, 2006).

The development of particle accelerators in several countries such as Japan, several countries in the USA & Europe and also Russia is significant (Natsir, 1998). However, the development of accelerator research has obstacles, it needs great financial and construction scheme considerations and the most considered factors are radiation and nuclear waste management which require careful handling (Steere, 2005). Therefore, it is still very possible for the evolution of accelerators in the future that are oriented towards safety and environmental sustainability and are able to answer existing challenges (Barbalat, 1994). It is why the literature study and research about accelerator are crucial.

Based on the required energy level, the accelerator can be divided into several types, including: 1) strong-current, high-energy accelerators 2) weak-current, very high-energy accelerators and 3) weak-current, medium-energy accelerators (Leiss, 1979). The application of the physical concept of accelerators has existed long before the 20th century in assisting human activities. Leiss (1979) called it a conventional accelerator. Some of the instrumentations included in the conventiona accelerator type were electrostatic accelerators, pulsed diodes, microwave linear accelerators (microwave linac), cyclotrons, and synchrotrons. The evolution of the accelerator occurs because of the emergence of a much greater energy requirement that conventional accelerators cannot yet provideAccelerators constructed out of the need for particle physics research. Particle physics is a branch of physics that studies elementary particles, radiation, and the interactions that may occur from these particles. At the end of the 20th century accelerators were developed significantly then the basic particles than were discovered as the latest findings. There are 3 groups of particles, each group consists of 2 quarks and 2 leptons. The existence of an accelerator can then explain the interaction forces that occur as well as the carrier particles, namely the W / gluon particles and the Z / boson particles. (Barbalat, 1994).

Barbalat (1994) also explained that other research, namely nuclear physics developed. The object of nuclear physics research is nucleus or nuclear which is related to the characteristics of electrons, protons and heavy ion beams. Therefore, a technology is needed to be able to penetrate into nuclear. In this case the accelerator plays an important role. As the particle velocity increases, the particle energy increases, allowing penetration. Finally, studies of nuclear structure and behaviour can be carried out which will lead to more specific research groups such as material physics.

## RESULTS AND DISCUSSION

Ernest Rutherford first used the principle of a particle accelerator when shooting α particles onto a thin sheet of gold. A decade later, in 1927, α particles with energy 5MeV were produced from the fission of the nitrogen radioisotope nucleus. It attracted the attention of scientists primarily in the field of particle physics to conduct research related to particle accelerators. (Steere, 2005).

### 1. Chronology of Accelerator Development

a. The first accelerator (1930)

For the first time, the particle accelerator constructed by John D. Cockroft and Walton at the Cavendish Laboratory in 1930 became known as the first accelerator. The emergence of the first generation of accelerators was based on the desire of scientists to probe deeper into the fundamental structure of matter by penetrating the atomic nucleus. Instead of α particles, this accelerator is projected to accelerate protons by considering their mass being lighter than α particles. The resulting potential is up to 800kV from 200kV input. (Steere, 2005).

The first accelerators were designed and operated on the principle of electrostatics. If there is a time-independent electric field, the energy-potential relationship can be written in the following equation:

$$E = -\nabla V \qquad (1)$$

The equation 1 shows that the increase in the energy of a particle is influenced by the presence of an electric field ($\boldsymbol{E}$) flowing from one point to another. This concept mathematically inspired Cockroft. Then his deduction about the amount of minimum energy required to penetrate the atomic nucleus was inspired by an article by George Gamow, an expert at Niehls Bohr's Institute of Theoretical Physics in Copenhagen. (Steere, 2005; Bryant 1984)

b. Van de Graaff (1931)

In 1928 Robert J. Van de Graaff conducted a study of the machines used to generate and maintain high voltages. In 1930 he became interested in the Cockroft-Walton accelerator until in 1931 he introduced his own model. The model designed consists of two hollow and spherical insulated conductors, 24 inches in diameter and made of aluminum. The two conductors are mounted on top of a glass rod with 7 feet height while the two belts made of insulated silk which are driven by a motor transport the opposite charged electricity to the two planes. The charge is transferred to the belt by the point of discharge from the point of the needle. One sphere is positively charged and the other is negatively charged. The charge spark formed between the spheres in which the charge is curve distributed there. This experiment was able to generate a potential of 1.5 MV with an input of 750 kV in each sphere.

The challenge that arises is to maintain the potential constant because if the potential can be kept constant, the concept will be 'the larger the spherical size, the smaller the electric field'. This research then inspired many scientists, in 1935 a group of researchers at the University of Wisconsin conducted an experiment using high pressure inert gas to increase the effect of insulation on the spheres. Van de Graaff's invention in 1933 operated to produce hydrogen ions with an energy of 0.6 MeV. Related research is still ongoing, some of which are able to produce 15 MV. The energy beam on Van de Graaff can be doubled by manipulating the Van de Graaff tandem configuration. (Steere, 2005).

c. Linac Betatron and Cyclotron (1931)

There are various difficulties in high potential maintaining in the gap or keeping the acceleration difference small mainly due to the tendency for sparks to occur. As a solution, scientists proposed the concept that particles are allowed to repeatedly pass through the gap or acceleration difference with low potential. (Steere, 2005; Bryant 1984).

In 1925 Rolf Wideroe proposed his first model, the electron beam transformer, which was the forerunner of the Betatron. In order to closely examine this accelerator, Wideroe was inspired by the publication of the 1924 work of Swedish scientist Gustav Ising, regarding the acceleration of large-mass ions in a linear path based on potential differences. (Steere, 2005; Bryant 1984).

Wideroe applies tension to tubes of different lengths. The concept is that with an ion source and a last ray catcher on the ground, the accelerated increase in particle voltage will be greater than the input voltage. In the experiment, used an alternating potential field of 25kV at a frequency of 1MHz to accelerate the potassium ion to a potential of 50kV. The accelerated ions will finally appear at the end of the tube connected to the ground and then hit the layer at a certain distance below the horizontal axis of the drift tube. This large distance is then used to extract information on the amount of energy by Wideroe. (Steere, 2005).

1. Linac (Linear accelerator) (1931)

Wideroe's research was published in a German journal of electrical engineering in 1929. The article then inspired an American scientist, David Sloan to be able to make a Linac model and another scientist, Ernest Orlando Lawrence who started research for the cyclotron model. (Steere, 2005).

Sloan designed a linac with ten or more tubular electrodes arranged in series and connected by alternating current at radio frequencies. In 1931, Sloan assembled it with 21 electrodes. In May 1931, it was concluded that from the acceleration of mercury (Hg) ions a potential of 1.25 MeV was generated. Related research continued to be developed until several years later, from the acceleration of positive ions Hg and Li, a potential of 2.8 MeV and 1.0 MeV was generated, respectively. (Steere, 2005).

The challenge that arose in the research at that time was that they were unable to accelerate lighter particles such as α particles because they required a vacuum tube that was long enough (several meters) to design the accelerator and could not design the radio frequency oscillator part. Likewise, obstacles also occur when trying to accelerate particles heavier in mass. Linac was thought to lack prospects so that it no longer received attention in the end and scientists' research turned to the cyclotron. (Steere, 2005).

2. The first generation of cyclotron

Based on the publication of Wideroe (1929), Lawrence assumed that it is possible to apply the working principle of the accelerator initiated by Wideroe to curved paths (curves) so that physical quantities and mathematical equations apply when particles are in circular orbits (Steere, 2005).

The cyclotron is known by another name, the magnetic-resonance accelerator, which is based on its working principle. In principle, the instantaneous radius of the orbit increases when the ion accelerates then gradually the ions will spin out due to the influence of the magnetic field so that energy is generated every time the gap is crossed. There are several provisions for this scheme to occur, including the oscillator being adjusted back and forth and conditioned to have a frequency equal to the frequency of the ions at the time of acceleration. The Cyclotron is designed using a 4-inch magnetic pole, a wax-sealed vacuum that fills the gaps between the poles. The electrode used is in the form of the letter D with a peak potential of 1000 V and a frequency of 10 MHz. The maximum energy gain recorded during this cyclotron experiment was 80,000 eV. In the end, this machine does not have enough capabilities in fission reactions (nuclear disintegration). So that later it was conceived and developed a cyclotron capable of accelerating light particles to obtain protons with an energy of 1.1 MeV in 1931 and 1.22 MeV in 1932 until the production of 10 MeV deuteron in 1940. In principle, cyclotrons have the ability to accelerate particles with relatively low potential but not to support the occurrence of nuclear fission reactions (Steere, 2005).

3. Betatron

Inspired by Wideroe's research in 1928, Betatron took the principle of the relationship between the fields as a function of the orbits of their trajectories and the mean field ($\bar{B}$). The mathematical equation is obtained from the derivation of Maxwell's equation (Leiss, 1979). The simple form can be written as follows:

$$B(\rho) = \frac{1}{2}\bar{B} \tag{2}$$

where the bending and acceleration of particles (generally in the form of electrons) is caused by an increase in magnetic field with time. The increase in the magnetic field is in line with the increase in particle energy so that the orbital radius is kept constant so that the induced electric field is able to cause this particle accelerates (Steere, 2005).

In 1940 D.W. Kerst succeeded in building a betatron at the University of Illinois which is capable of producing 2.3 MeV electrons and an X-ray output equivalent to 1 gram of radium. In 1942 successfully built a betatron capable of producing 20 MeV and 80 MeV of energy and in 1950 it reached 300 MeV. Furthermore, betatron was directed to research the high-energy beam collisions that inspired the collider, this idea earned Wideroe a patent for his name. (Steere, 2005; Bryant 1984).

d. Microtron (1945)

Schematically, the microtron is similar to a cyclotron, but it is designed in reverse to accelerate positive ions. Unlike the previous accelerator designs which had limits on the concept of maximum energy, such as Van de Graaff which was limited to the maximum electric field so as not to damage the insulator, then the cyclotron which was limited in relativistic mass for protons and deuterons, and the limited betatron because of loss big amount of energy and emitted radiation. Therefore, the microtron was conceived to produce much higher energy. In 1945 V. Veksler introduced his working principle is based on the synchronicity relationship of the orbiting particles with a radio-frequency time-dependent electric field. The microtron was developed until the MAMI was made, a microtron in Germany capable of producing 855 MeV of energy and another microtron in Moscow capable of producing 175 MeV of energy. (Steere, 2005)

e. Synchrotron (1947)

Synchrotron develops from microtron model so that it has an identical principle, namely synchronizing particles with magnetic fields using radio frequency electric fields. However, synchrotrons are better able to optimize the synchronization concept by synchronizing the magnetic field with the energy or momentum of the accelerated particles in order to maintain a constant orbit. V. Veksler put forward this stability principle in 1944. The orbital frequency tends to be constant when the electrons are fast approaching the speed of light. Synchrotron is made with various capacities according to application needs, for example, it is able to produce several energy quantities including 70 MeV, 140 MeV, 300 MeV, and 350 MeV. (Steere, 2005; Bryant 1984).

It can be concluded that some of the advantages of a synchrotron include having a better stability level than a microtron, being able to produce more energy than linac, betatron and van de graaff and can be designed more easily to produce a certain amount of energy desired.

f. Synchrocyclotron (1947), proton synchrotron (1952) and AG synchrotron (1953)

The design was developed after the discovery of the synchrotron and cyclotron (Steere, 2005). Synchrocyclotron was born from the application of the principle of synchrotron orbital stability which was applied to the cyclotron design. Synchrocyclotron was first conceived in 1947 with the aim of increasing the efficiency and capability of the accelerator engine (Steere, 2005). In order to maintain the stability of the resulting energy, orbital momentum stability is needed. Then this principle is applied to the cyclotron to obtain large energy.

The first design converted a 184-inch cyclotron into a synchrocyclotron capable of producing 190 MeV deuterons and He2 + 380 MeV ions. Since 1952 this research has been directed towards accelerating protons so that they are better known as synchrotron protons. In 1954 the proton synchrotron was able to produce 3 GeV of energy which was named cosmotron and in 1954 it was able to reach 6.2 GeV which was named bevatron.

After the discovery of the cosmotron and its use for 14 years, various accelerator devices with the same principle emerged because of the great demand. During this development, modifications were made to the beam focus system because it was associated with an increase in the efficiency of production costs, considering that the first cosmotron design cost a lot because it used very large magnet. The latest generation that uses this more efficient focusing principle is known as AGS (AG Synchrotron). Subsequently, AGS was developed to obtain more energy. In 1960 AGS operated and was capable of reaching 33 GeV. (Steere, 2005).

g. Electron and proton linac (1946-1952)

The development of the linac, after being considered prospectless for a long time, was then abandoned again, because it was inspired by the use of radar and radio technology during World War II. Berkeley concluded that it was possible to use the ultra high frequencies on the linac. (Leiss, 1979; Steere, 2005).

The proton linac was developed from the concepts of the Van de Graaff accelerator and the synchrotron proton. Ultimately, the proton linac holds an important role because it is used all over the world to accelerate protons and generate heavy ions. The first generation of the Proton linac was able to accelerate up to 32 MeV and was known as the Alvarez linac which later became the foundation for the development of the Proton linac to present days. (Leiss, 1979; Steere, 2005)

The greater energy needs have not been fulfilled maximally by utilizing the proton linac because theoretically it is limited to certain energies (Steere, 2005). As the use of the proton linac leads to more research needs, therefore, the first electron line was initiated by W.W. Hansen in the 1930s aimed at producing high energy or power (Steere, 2005). In previous research, circular path-based accelerators were impractical at energies above 10 GeV, so Hansen began his research to develop electron linacs. The design was first successful and operated in 1952. After 1952 the development of this type of accelerator became quite rapid because of the driving factors, especially the need for military technology.

h. SLAC (1966)

Stanford Linear Accelerator Center (SLAC) received permission in 1962 after 5 years from the submission of proposals and construction plans in 1957. SLAC is an accelerator built on a 2 mile long linac which is 25 feet underground. The design of this accelerator has been considered for radiation shielding purposes. SLAC entered service in 1966 and is capable of accelerating up to 18.4 GeV. (Steere, 2005)

i. Ring collider

The ring collider has the same principle as the betatron. The ideas put forward by Wideroe regarding colliders, among others, were that it was possible to collide protons with protons, protons with deutrons and electrons with protons. There was a long time gap until the ring collider was developed because Wideroe was more inclined towards the industrial world so that the development towards research was not accommodated until finally other scientists continued it in the late 1950s.

The development aims to produce high energy with a more efficient scheme than the previous accelerator. In principle, the total reaction energy that can be obtained from the shooting of an accelerated particle at a target particle is much less than the energy that can be generated by the collision of two beams at an interaction point (Steere, 2005; Bryant 1984).

j. Collider age

1) CERN (1969)

The first collider construction was in Europe. This European nuclear research center laboratory is known as CERN (Conseil Europeene pour la Recherche Nucleaire). In 1969, when it was first developed, an energy of 28 GeV was achieved. This laboratory is a ring magnet with a diameter of 300 m. There are two concentric ring magnets that act as synchrotron protons (CERN-PS). Both are not perfectly circular and are connected to each other by 8 contact areas where the beams will bump into each other in the contact and storage space known as intersecting storage rings (ISR). (Steere, 2005; Bryant, 1984)

ISR is the world's first collider protons. ISR officially operated in 1971-1983. Then for one year, in 1984, the ISR was targeted to produce gas jets by utilizing anti-proton injection with 3.5 GeV / c. (Bryant, The CERN ISR and Its Legacy, 2018)

2) DESY (1970)

Deutches Elektronen-Synchrotron (DESY) is a laboratory in Hamburg, Germany which in 1960 carried out experiments using the electron synchrotron principle until it reached an energy of 6 GeV. DESY is the forerunner to the rise of German participation in nuclear research. (Steere, 2005; Pancheri & Luisa 2018)

Combining the principle of the accelerator with the collider, DESY undergoes restoration. First, DESY was built into DORIS (Dopple Ring Speicher) which is a combination of the linac concept with a collider. In this first design, the beam instability occurred. After further research and improvement a new concept was designed, in 1978, PETRA (Positron Electron Tandem Ring Accelerator) was built, which was finally able to reach an energy of 22 GeV. PETRA is a ring with a circumference of 2,300 meters and divided by straight lines into 8 sectors. Two sectors are space for the RF (radio frequency) accelerator while the other 6 sectors are used for experimentation. PETRA grew to be able to reach 37 GeV of energy and operated until 1986. In 1988 PETRA II was built which became known as HERA (Hadron Electron Ring Accelerator). HERA has grown to be known as PETRA III, which functions as a synchrotron radiation facility. In 1999 HERA was completely completed and consists of two separate storage rings with a circumference of 6.3 km. The first ring is at a depth of 10 m below ground level and the other one at a depth of 25 m below ground level. HERA is built on 650 superconducting dipoles and quadropole magnets and a cooling system using a cryogenic helium cooling system that can cool down to temperatures of -269 ° C. Until the 21st century, HERA operates to accelerate protons up to 820 GeV and electrons up to 30 GeV. (Steere, 2005)

3) Proton-antiproton collider (1981)

The idea of a proton-antiproton collider design was first proposed by G.I. Budker who is a physicist from Russia. The method that stands out from this collider is the principle of beam cooling by the electron cooling process. The principle of this collider is that the electron beam is transmitted at a low speed both transversally and longitudinally, which is spread along with the proton beam which has a greater speed. (Steere, 2005; Pancheri & Luisa 2018).

This concept was implemented at CERN. Then, CERN developed into SPS (Super Proton Synchrotron) and FNAL (Fermilab's main ring). SPS is capable of generating energy up to 500 GeV (operated at 400 GeV) while FNAL works as a synchrotron proton capable of reaching 500 GeV (operated at 300 GeV).

From 1979 to 1981, a major renovation and expansion of CERN was carried out in order to increase energy production so that it can meet civilian needs. It was finally operational in 1983. CERN operates at hundreds of GeV (giga-electronvolts). Since 1983, CERN is known as the LEP (Large Electron-Positron Collider).

The LEP stopped operating in 2000. This is because it has been carried out by the latest concept from CERN, namely the LHC.

4) Tevatron (1983)

The LEP tunnel is the forerunner and former location for the construction of the LHC (Large Hadron Collider). The LHC is projected to produce energy up to TeV levels (tetra-electronvolts). The LEP principle that is injected into the LHC is the latest technology and is so sophisticated that CERN is known as the tevatron. (Steere, 2005)

In principle, the tevatron is identical to the synchrotron. Tevatron is a synchrotron equipped with a superconducting RF (radio frequency) chamber and a warm iron superconducting magnet (Steere, 2005).

Experiments in 1987 using a beam collision with 900 GeV produced a total energy of up to 1.8 TeV (Steere, 2005). It shows that the LHC has extraordinary prospects so that research continues and in the end the LEP operation was replaced by the LHC in the 2000s.

Along with the LHC research, RHIC (Relativistic Heavy Ion Collider) was developed which was also launched and operated in 2000. RHIC is designed to accelerate and crush heavy ions such as gold. The challenge that arose in developing RHIC was in the focusing part of accelerator.

5) SSC

Superconducting Super Collider (SSC) was built in 1985. SSC is as sophisticated as tevatron, but it has different projections and prospects. The purpose of establishing SSC is to observe particle physics phenomena. In essence, the SSC is geared towards research. Scientists hope to find evidence of the Higgs boson particle, supersymmetric standard particles, technicolor resonances, and more. However, the construction of this SSC is very costly and causes losses from a financial perspective. (Steere, 2005)

The SSC design is a proton-proton collider collaborating with the linac model. Beams accelerated to 0.6 GeV - 20 TeV. The SSC design consists of five dipoles and 1 quadropole superconducting magnet where the circumference is 500 m for SSC low energy booster (has a range of tens of GeV), 4 km for SSC medium energy booster (has a range of hundreds of GeV), and 11 km for SSC high energy booster (has TeV range). (Steere, 2005).

## 2. Accelerator application

a. Health and medicine

1) Medical diagnostic

Betatrons are developed to produce high-energy electrons, but some are used to produce protons. In 1930 this accelerator began to be developed and used for the benefit of hospitals / medicine, namely to produce X-rays. Its utilization is not long enough because it is immediately displaced by the synchrotron, therefore further research on betatrons is directed at high-energy beam collisions (Steere, 2005). In principle, accelerators are used as diagnostic instrument (Barbalat, 1994).

2) Radiotherapy

The use of nuclear technology for medicine that focuses on cancer therapy began in the 1980s (Steere, 2005).. In 1946 R.R. Wilson proposed that protons could be used for radiotherapy (Sudjatmoko, Triyono, & Supriyatni, 2000). However, it does not mean that the proposal can be realized immediately, but through a fairly long research process, especially accelerators research. Tumor radiotherapy was first introduced in Europe in 1984 by Harvard and Berkeley with the practice of radiotherapy in melanoma using low-energy protons, which is about 70 MeV (Sudjatmoko, Triyono, & Supriyatni, 2000). Soon after the success of this practice, research in radiotherapy and its application in medicine spread throughout the world. The several types of accelerators used include the synchrocyclotron, synchrotron, and cyclotron. In addition, the use of linac in Indonesia in the early 2000s was quite massive (Yunasti & et.al, 2003). This was emphasized again by Sudjatmoko, Triyono & Supriyatni (2000) that since 1980 the beam of hadronic particles, namely protons, neutrons and charged particles for cancer therapy, has been studied by several research centers in several countries. In principle, accelerators are used for therapy or treatment of a disease by being exposed to certain radiation, known as radiotherapy (Barbalat, 1994).

3) Production of radioisotopes

Some nuclear research centers have commercial purposes, for example to produce radioisotopes (Silakhuddin & Maman, 2002). As it is known, there are many requests from the medical sector for the detection of a disease which in the process requires radioisotopes (Yunasti & et.al, 2003).

b. Field of technology and military

After the discovery of the synchrotron, a decade later, the use of accelerators became more widespread. Its area of application extends to the interests of radar development, manufacture of electronic devices, nuclear physics research, as well as technology and military weapons aimed at war. The development of linac also contributed to military technology from the 1930s to 1950s, during World War II. (Steere, 2005) Radiation technology is an important issue that affects research related to satellites and space missions (Virtanen, 2006).

c. Research field

Accelerators are often part of a device that supports experiments from ancient times until now, for example the experiments conducted by Rutherford which involved shooting α particles or their current application to test the quality of a material. Prior to the development of accelerator, the research of nuclear physics included the study of nuclear structure, excited states and the spectroscopy of the association of each element, whereas after the development of accelerators, the study was about deformed nuclear conditions and which had very high angular momentum or in other words the nuclear was not stable. (Barbalat, 1994)

Another example, accelerators will trigger research in other fields mentioned by Zhang et.al (2016) that in the fields of material physics and nuclear physics, tungsten is being studied to be used as plasma facing materials (PFMs) in future fusion nuclear reactors due to its high melting point, Its high thermal conductivity, low sputtering results and can be manipulated in the synthesis of materials both in nanometers and micrometers.

d. Industrial sector

Several applications in the industrial

sector include: 1) ion implantation such as in the manufacture of semiconductor devices, 2) radiation processes to support chemical or physical reactions during the production process, 3) sterilization of products related to food or medical devices, 4) preservation of products, for example food preservation, 5) ion beam process for example used in the production process of thin films (thin film), 6) microlithography for IC (integrated ciruit) fabrication. (Barbalat, 1994; Natsir, 1998)

e. Energy field

Several applications in the energy sector related to nuclear power generation include heavy ion fusion reactions, plasma heating, acceleration and fission reactions, and radioactivity and combustion processes (Barbalat, 1994). The discovery of an accelerator becomes the foundation for nuclear energy technology, for example a nuclear reactor, is useful for transmutating nuclear waste and as an alternative means of producing high flux neutron beams (Silakhuddin & Maman, 2002).

## 3. Accelerator in Material Physics Research

As it is possible to penetrate a material. Finally, physical phenomena at the microscopic scale can be identified and support the development of particle physics. Various information and research that has been accumulated are very supportive and become a reference or basis in material physics research. It was then advanced material research was developed. (Barbalat 1994; Silakhuddin & Maman, 2002)

Research in materials science and technology requires the existence of accelerators because accelerators are an important component in material characterization tools. Material characterization is the final part of the experiment-based research method. The purpose of conducting material characterization is to find atomic or molecular information on a material. The information obtained is for example the structure and energetic and melting properties aimed at analyzing the stability of particles or elements even for detection up to the nanoscale (Zhang et.al 2016).

The ionic beam is used in the method of characterization and testing of a material. There are 4 grouping methods, namely:

a. Rutherford backscattering (RBS)

RBS is adapted for assessing heavy elements in light substrates such as semiconductor materials. (Barbalat, 1994)

b. Proton induced X-ray emission (PIXE)

PIXE is the basis for characterization methods related to imaging devices. (Barbalat, 1994)

c. Charged particle activation analysis (CPA) / nuclear reaction analysis (NRA)

The NRA was adapted to study the behavior of light elements on heavy / metal substrates. It has many applications in the metallurgical field. Meanwhile, CPA is applied in two areas, these are to analyze an element that is in a mixture, alloy or compound with a very small concentration and to provide data on the study of the use of a material. (Barbalat, 1994)

d. Accelerator mass spectroscopy (AMS)

AMS is a method based on the shooting of ions in the sample so that it can detect and assess an element based on whether or not it is ionized. AMS can be divided into two types, secondary ionization mass spectrometry (SIMS) and particle desorption mass spectrometry. (Barbalat, 1994; Gonsalves et.al, 2020)

The development of nuclear technology including accelerators also poses challenges for the field of material physics research, for example in the realm of protection and safety of an accelerator design (Ozturk, 2019)

4. Advanced Accelerators and Research Development Challenges

The development of accelerators generally is influenced by the development of science, especially physics, however based on the historicity of technological needs in various sectors such as health, electronic technology, technology for the military and so on, it is a driving factor for the emergence of ideas and the spirit of criticality of scientists in developing accelerators. Initially, accelerators were intended to support physics experiments and then developed into their use in a wide variety of technologies, so that challenges and obstacles emerged that pushed accelerator research to develop continuously. In the end, since the 1980s, the development of accelerators has been predominantly influenced by the development of particle physics, which then gave birth to the latest accelerator technology in the early 21st century in the form of the latest generations of tevatrons such as the LHC.

The accelerator that scientists have been waiting for now is an accelerator capable of hitting muon particles or known as muon colliders (Barbalat, 1994). Steere (2005) cites Shapero et.al (1990) mentions several related prospects, including: 1) muon colliders are able to produce, accelerate and crush muons at 0.5 to 4.0 TeV, 2) muon colliders can be developed from research related to electron colliders so that It is said that it already has many references for its development, 3) muon collider can be a technology that is more environmentally friendly than electron collider because considering the mass of muon is 200 times larger than an electron, its radiation effect is much smaller than that of an electron accelerator. It is confirmed by Bartosik (2020) that the muon collider is an ideal mechanism and instrument to achieve a very high mass center energy and luminosity. The negative aspects that appear along with these positive aspects include muons tend to be unstable and the decay time is fast, which is around several thousand seconds from the production of muons (Steere, 2005).

The concentration of scientists in the development of accelerators is now the muon collider. Some that are being researched, for example, are the cooling system in the reactor, the particle detector in the reactor, and designs to maintain its stability, for example in the focusing section. One of the proposed cooling systems is the design of the Muon Ionization Cooling Experiment (MICE). In MICE research, the conclusion is that reducing the momentum distribution and muon position will reduce emittance so that energy decreases and cooling occurs. (Hart et.al, 2020; Bartosik et.al, 2020)

In essence, the challenges that arise are how to maintain muon stability and / or how to design a scheme that allows the acceleration and collision processes to occur in a very short time. Based on the mapping made by M. Stanley Livingston cited by Steere (2005) on the timeline of accelerator development, it is possible to have accelerator evolution. In the early part of the timeline the development was quite slow but since the 1950's its development has been accelerating to point to an exponential graph, therefore, the development of an accelerator or even its evolution is a necessity.

## CONCLUSIONS

Accelerator studies develops continuously and evolving both theoretically and instrumentally and experimentally. Various types of accelerators in its evolution include the first generation of accelerators, Van de Graaff, linac, betatron, cyclotron, microtron, synchrotron, synchrocyclotron, linac electron, linac proton, SLAC, ring collider, tevatron (LEP, LHC, RHIC), and SSC.

The increasing of need for accelerators is as well as efforts to develop environmentally friendly technologies in the present global challenges in nuclear physics research, especially particle accelerators. In particle accelerator research, light electricity, light energy and light quality are variables that need attention. Muon collider is one of the ideas or design for the development of accelerators in present days and the future.

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