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Prospect of nuclear battery as energy source in artificial organs

Abstract

In order to find an energy source with higher longevity than conventional sources, many scientists and researchers have proposed use of radioactive elements with sufficient half-lives. The most common approach for extracting energy is to utilize the decay heat of a radioactive element to produce electricity. This concept has paved the way to the development of nuclear battery, which is believed to be a prominent source of energy in future. This work focuses on the adequacy of the current designs in generating useful amount of energy that may be sufficient to be used to drive artificial organs. This paper also analyzes the potential human health hazards due implanting these radioactive elements inside the body and how they can be minimized. The study indicates that the available technologies to harvest nuclear energy from the source may not generate sufficient output to operate an artificial organ with high power requirements but may be suitable for devices with low power requirements.

Keywords: nuclear battery, ionizing radiation, decay heat, tissue weighting factor, dose limit

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Abbreviations: LET, linear energy transfer; HVL, half value layer; TVL, tenth value layer

Introduction

The world is composed of different materials, some of which have radioactive properties, also known as radioactive elements. These elements emit energy in two forms; kinetic energy of the radioactive emissions like alpha, beta and gamma rays and heat generated in the element during these emissions, also known as decay heat. These two forms of energy may be utilized in order to generate electricity, which is the basis of construction of nuclear battery. The use of nuclear battery may provide an energy source with long lifetime, which makes them attractive for the researchers. Nuclear batteries may, therefore, be used in artificial organs as energy sources. This study tries to find the suitable options for implementation of nuclear technology in generating electricity in smaller scale without compromising the safety of human health.

Discussion

A nuclear battery is a battery that uses a radioactive element as fuel in order to generate electricity with the help of the kinetic or heat energy of the radioactive emission. In order to generate electricity from decay heat, a common consideration may be the well known phenomena called the "Seebeck effect". This approach is acceptable if the temperature of the source is high enough to generate sufficient voltage difference. However, if we consider this approach for artificial organs or any other biomedical application, the maximum allowable temperature of the source may not exceed a few degrees from the body temperature in order to prevent any damage to the body itself. And since the output voltage is a dependant variable of the temperature difference between the two junctions, it may not generate a useful output voltage. As a result, this approach may not be of significant interest in the field of artificial organs. Another approach is to utilize the kinetic energy of the radioactive emissions. As the emitted rays have sufficiently high kinetic energies to cause ionization, it is possible to generate electricity through liberation of free electrons from the outer shells of the atoms. This ionization of a medium due to passage of radioactive rays through it is dependent on the energy of the ionizing ray as well as the charge of the emission. Alpha rays are heavier and have higher charge compared to beta rays; as a result they have higher ionization potential. Nonetheless, they have very low range due to very high LET. This high LET makes them suitable for nuclear batteries which utilize kinetic energy of the emitted rays. On the other hand, the beta particles have charge and mass equal to an electron, which results in much lower LET but higher range. Gamma rays have even lower LET compared to both the emissions as they are electromagnetic waves with no charge or mass. These results in even higher range.[1] This higher range tends the researchers to omit sources of gamma rays from consideration as they may cause much higher whole body exposure to radiation and thus higher dose. Alpha rays have higher equivalent dose coefficient which results in higher effective dose, but their lower range makes them easy to be blocked from reaching the body cells through use of shielding. The HVL and TVL thickness of alpha rays are very small; using an alpha source as battery fuel requires thin layer of shielding.[1] On the other hand, the higher LET of beta rays results in higher HVL and TVL thickness, thus higher shielding thickness for the source. The brighter side is that it has lower equivalent dose coefficient compared to alpha rays. This makes them less hazardous to the body.[1]

Both the alpha and beta sources have been studied by the researchers in order to find the suitable one between the two. It has been in a study that among hundreds of variations of radioactive elements, only a few possessed desirable properties like high half-life or easy shielding options etc. to be used as fuels of nuclear battery.[2] The two radioisotopes that were identified to be of special interest were ^{121}Te and ^{254}Es. However, the work could not establish a suitable methodology to get energy from these two elements. As a result, ^{242}Am and ^{210}Po have been used in alpha source fuelled batteries.[3,4] The maximum modeled efficiency is between 2-4% for the alphavoltaic batteries.[3] On the other hand, ^{63}Ni and ^{147}Pm are used in beta source fuelled batteries.[5,6] The ionized particles, in most cases, electrons are collected in a photosensitive layer such as ZnS or SiC in order to get photoelectrons. These electrons are collected as a form of output current or voltage. Studies have shown that the generated open circuit voltage from beta radionuclide fuelled battery is around 0.49V and short circuit current is around 29.44nA/cm^2 for an apparent activity of 4mCi/cm^2. The efficiency is limited to around 1.2%.[6] The output from alpha source fuelled batteries is rather high in case of reactor type design, which may not be suitable for most artificial organs. As a result, beta source is assumed to be of higher research interest. On the contrary, the generated voltage and current from beta radionuclide batteries is not high enough to drive any artificial limb like bionic arms as they have much higher power requirement in order to get useful working capability of the person using it.[7] The low power is suitable for devices with low power requirements, such as pacemaker. The pacemaker requires small amount of energy, in the form of electric pulses. Thus, they may easily be benefited by the use of beta radionuclide batteries as they have longer life than conventional batteries. Other devices may also utilize beta radionuclide batteries if they have low energy consumption without any significant damage to the nearby cells.[8] These points make the beta sources more attractive compared to alpha sources.

Conclusion

The above study tries to compare different types of nuclear batteries in order to identify the possibility of implementation of any of them as sources of energy in artificial organs. The outcome of the study is that the low power output of the conventional nuclear batteries limit their use to devices that have very low power requirements such as pacemaker. The artificial organs with higher power requirements like limbs may not be able to utilize current technologies due to their inadequacy. Further research is necessary in order to develop more efficient versions of nuclear battery so that nuclear energy can be utilized to its fullest.

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Conflict of interest

The author declares there is no conflict of interest.

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