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Optimal Beam for Accelerator Driven Systems

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Abstract : The concept of energy amplifier or accelerator driven system (ADS) involves the use of a particle accelerator coupled with a nuclear reactor. The accelerated particle beam generates a supplementary source of neutrons, which allows the subcritical functioning of the reactor, and consequently a safe exploitation. The harder neutron spectrum realized ensures a better incineration of the actinides. The almost generalized opinion is that the optimal beam for ADS is represented by protons with energy around 1 GeV (gigaelectronvolt). In the present work, a systematic analysis of the energy gain for proton beams with energy from 0.5 to 3 GeV and ion beams from deuteron to neon with energies between 0.25 and 2 AGeV is performed. The target is an assembly of metallic U-Pu-Zr fuel rods in a bath of lead-bismuth eutectic coolant. The rods length is 150 cm. A beryllium converter with length 110 cm is used in order to maximize the energy released in the target. The case of a linear accelerator is considered, with a beam intensity of 1.25×10^{16} p/s, and a total accelerator efficiency of 0.18 for proton beam. These values are planned to be achieved in the European Spallation Source project. The energy gain G is calculated as the ratio between the energy released in the target to the energy spent to accelerate the beam. The energy released is obtained through simulation with the code Geant4. The energy spent is calculating by scaling from the data about the accelerator efficiency for the reference particle (proton). The analysis concerns the G values, the net power produce, the accelerator length, and the period between refueling. The optimal energy for proton is 1.5 GeV. At this energy, G reaches a plateau around a value of 8 and a net power production of 120 MW (megawatt). Starting with alpha, ion beams have a higher G than 1.5 GeV protons. A beam of 0.25 AGeV(gigaelectronvolt per nucleon) ^{7}Li realizes the same net power production as 1.5 GeV protons, has a G of 15, and needs an accelerator length 2.6 times lower than for protons, representing the best solution for ADS. Beams of ^{16}O or ^{20}Ne with energy 0.75 AGeV, accelerated in an accelerator with the same length as 1.5 GeV protons produce approximately 900 MW net power, with a gain of 23-25. The study of the evolution of the isotopes composition during irradiation shows that the increase in power production diminishes the period between refueling. For a net power produced of 120 MW, the target can be irradiated approximately 5000 days without refueling, but only 600 days when the net power reaches 1 GW (gigawatt).

Keywords : accelerator driven system, ion beam, electrical power, energy gain
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