Reactorphysical investigation of accelerator driven actinide transmutation systems

Summary of the Ph.D. Thesis

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Introduction

Finding solutions for the problem of long-lived radioactive isotopes originating from spent nuclear fuel of reactors is one of the recent challenges of nuclear energy. A deep geological repository proposed for final disposal of these isotopes must be sealed for millions of years, which makes safety of the repository uncertain and worsens the public acceptance of nuclear power. From the early 1990's, research projects started all over the world to solve this problem, i.e.: to transmute these long-lived isotopes to less dangerous short-lived ones to reduce the risk and the required storage time.

To implement these goals, long-lived isotopes have to be separated from spent nuclear fuel and irradiated by neutrons in dedicated devices. One type of these transmuter devices are the accelerator-driven subcritical systems (ADS). The ADS concept represents a new type of reactors: a subcritical reactor core is driven by a high energy particle accelerator. Most of recent ADS concepts [Kadi, 2001, Van Tuyle et al., 2001] are based on a proton accelerator, which produces neutrons by the spallation reaction. Such an ADS is capable to transmute spent fuel from several reactors. However, if a small-scale device is required to transmute spent fuel of one or a few reactors, an electron accelerator might be a better candidate than a proton one.

Objectives

My Ph.D. work covers the reactorphysical investigation of a small-scale electron accelerator driven molten salt subcritical transmuter dedicated to the transmutation of actinides. The device is proposed to transmute the spent nuclear fuel accumulated on the site of a nuclear power plant, eliminating the problems of transportation and accomplishing a proliferation safe nuclear waste management. The device, named MSENC (*e-n converter based molten salt subcritical device*), is fuelled by transuranium isotopes originating from pyrochemical separation of spent PWR fuel. The molten salt technology enables the linking of pyrochemical processing of spent fuel and on-line refuelling and purification of the fuel. The MSENC uses an electron accelerator driven lead neutron source to drive the subcritical reactor core.

My goal was to create a proper reactorphysical model describing the operation of MSENC (i.e.: production of neutrons in the target by high energy electrons; on-line refuelling; change of isotope composition of fuel) and to determine the transmutational potential of the device (i.e.: effect of irradiation in MSENC on the amount and composition, radiotoxicity and storage time of nuclear waste).

Summary of new scientific results

New scientific results of my work are summarized as follows.

1. I have worked out a proper reactorphysical model for a small-scale electron accelerator driven molten salt subcritical transmuter (*e-n converter based molten salt subcritical device*, MSENC). By modifying and linking widely used reactorphysical codes and developing algorithms for the on-line refuelling I have built a computer code system for modelling the device [6, 3].

2. I have investigated the electron-neutron converter properties of the lead target:

   - neutron yield relative to the beam energy increases but saturates at higher energies,
   - increasing beam energy does not effect spectral distribution of source neutrons,
   - neutron leakage from the target has no angular dependence,
   - neglecting proton transport in modelling decreases the neutron yield on the average 7%, but does not influence the neutron spectrum [5, 7, 4, 2].

3. I have determined the beam energy (150 MeV) with respect to the optimal electron-neutron conversion and determined the size of the target at which neutron leakage has a maximum. I have investigated the effect of position of the target on the neutron current flowing into the subcritical core and optimized the position of the target to obtain maximal inflow [7, 2].

4. I have examined the transmutational potential of MSENC for constant transuranium isotope (TRU) feed originating from spent WWER-440 fuel:

   - the initial mass of plutonium and americium is reduced to the half and the amount of curium is increased to eight times its original value in a 5-year long irradiation,
   - in the irradiated waste, as in the original spent WWER fuel, isotopes of plutonium have the highest abundance but that of ^{239}Pu is much smaller (17%),
   - in the irradiated waste, the composition of TRUs is shifted towards higher mass numbers,
   - the analysis of accumulation of TRUs for a unit of produced energy in a WWER-440 and in a WWER-MSENC coupled fuel cycle showed that the TRU accumulation is 40% lower in the coupled fuel cycle [8, 9, 10, 3].

5. I have showed that irradiation in MSENC reduces the required storage time of spent WWER fuel to 70% of the original one. On the basis of the amount and composition of the transuranium isotopes remaining after the irradiation

in MSENC I have stated that 5 years of irradiation in MSENC does not reduce significantly the risk and storage time of nuclear waste. This means that MSENC can not achieve the goals of transmutation [3].

List of publications related to the Ph.D. work

Publications

[1] Á. Brolly, M. Szieberth: The transmutation of long-lived, nuclear plant waste isotopes, Fizikai Szemle, Vol.50/2, p.44-49., February 2000. In Hungarian.

[2] Á. Brolly, P. Vértes: Concept of a small-scale accelerator driven system for nuclear waste transmutation, part 1. Target optimization, Annals of Nuclear Energy, Vol.31/6, p.585-600., April 2004.

[3] Á. Brolly, P. Vértes: Concept of a small-scale accelerator driven system for nuclear waste transmutation, Part 2. Investigation of burnup. Accepted for publication in Annals of Nuclear Energy.

Reports

[4] Á. Brolly, P. Vértes: Investigation of a small-scale, electron accelerator based ADS dedicated for transmutation, Report to the Hungarian Atomic Energy Authority, contract no.: OAH/NBI-ABA-08/02, October 2002. In Hungarian.

Proceedings

[5] P. Vértes, Á. Brolly: Evaluation of neutron sources for ADTW systems, Proceedings of the 10th International Conference on Emerging Nuclear Energy Systems (ICENES 2000), p.118-120., 24-28. September 2000., Petten, The Netherlands.

[6] Á. Brolly, P. Vértes: A code system for ADS transmutation studies, 9th International Conference On Nuclear Engineering (ICONE 9), CD-ROM, Paper No. 821., 8-12. April 2001., Nice, France.

[7] Á. Brolly, P. Vértes: Transmutation: towards solving problem of spent nuclear fuel, Wigner Centennial Conference, CD-ROM, Paper No. 19., 8-12. July 2002., Pécs, Hungary.

[8] P. Vértes, Á. Brolly: Study of an electron accelerator based transmutational system, Proceedings of the 12th Symposium of AER, p.493-499., 22-28. September 2002., Sunny Beach, Bulgaria.

[9] Á. Brolly, P. Vértes.: Electron accelerator driven subcritical reactor dedicated for transmutation, Nuclear Technology Symposium, CD-ROM, Paper No. 403., 3-4. October 2002., Budapest, Hungary. In Hungarian.

[10] Á. Brolly, P. Vértes: Concept of an Electron Accelerator-driven Molten Salt Sub-critical Reactor, 8th Information Exchange Meeting on Actinde and Fission Product Partitioning and Transmutation, `http://www.nea.fr/html/pt/iempt8/abstracts/Abstracts/Vertes_concabs.doc`, 9-11. November 2004., Las Vegas, Nevada, USA.

Additional publications

Reports

[11] Á. Brolly, P. Vértes: Spent nuclear fuel and environment protection, Report to the Hungarian Atomic Energy Authority, contract no.: OAH/NBI-ABA-17/01, October 2001. In Hungarian.

[12] Á. Brolly, Sz. Török: Final disposal of radioactive waste with respect to the spent nuclear fuel. Part of the report for the „Legal questions of modern technologies" National Research and Development Application, contract no.: 5/077, March 2003. In Hungarian.

Talks

[13] Á. Brolly, M. Szieberth: Partitioning and transmutation of the long-lived isotopes, 2nd Hungarian Nuclear Meeting, 25-28. May 1999., Balatonkenese, Hungary. In Hungarian.

[14] P. Vértes, Á. Brolly: About transmutation of spent nuclear fuel, 3rd Hungarian Nuclear Meeting, 1-2. June 2000., Balatonkenese, Hungary. In Hungarian.

[15] P. Vértes, Á. Brolly: Mitigation of the problem of spent fuel by transmutation of actinides and certain decay products, 5th International Nuclear Technology Symposium, 4-6. October 2000., Paks, Hungary.

[16] Á. Brolly: Transmutation of long-lived radioactive isotopes, „Spring Wind" Conference for Ph.D. Students, 20-22. April 2001., Gödöllő, Hungary. In Hungarian.

[17] Á. Brolly: Transmutation of long-lived isotopes, AERI's Autumn Reactorphysical School, 4-6. October 2004., Seregélyes, Hungary. In Hungarian.

References

Kadi, Y. 2001. ADS Design I, SMR/1326-4, Workshop on Hybrid Nuclear Systems for Energy Production, Utilization of Actinides & Transmutation of Long-Lived Radioactive Waste, Trieste, Italy, 3-7 September 2001.

Van Tuyle, G., et al. 2001. A roadmap for developing ATW technology: system scenarios & integration, Progress in Nuclear Energy, Special issue: Accelerator Transmutation of Waste, Vol.38., Number 1-2, p.3-23., 2001.