THE ITEP CONCEPT OF THE ACCELERATOR TRANSMUTATION OF RADIOACTIVE WASTE

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ABSTRACT

Transmutation based on a high current accelerator of protons is considered at ITEP as most effective. A thermal neutron flux in the 10^{16}n/cm^{2}sec range is enabled by a 1.5GeV-100mA class proton accelerator. Besides not beeing safe, this flux level is at present difficult to achieve with the help of fission reactor, The high flux of thermal neutrons gives us an opportunity to incinerate all the essential actinides and fission products. The large thermal cross sections offer the advantages of both small actinide loading and high transmutation performance. A liquid mixture of incinerated waste circulates through the blanket and the heat exchanger which makes continuous processing possible, In this way two big demerits of the closed fuel cycle on solid elements can be avoided: a very complicated remote fabrication of fuel elements and secondary radioactive waste from construction materials. Besides, the hybrid system is always subcritical which ensures a high level of nuclear safety. The accelerator driven heavy water assembly allows to build up step by step the potential possibilities of the system and subsequently to solve the following problems: actinide transmutation without electric power production; actinide transmutation with electric power production; a ^{233}U production or a ^{239}Pu conversion to ^{233}U; transmutation of the fission products.

1. INTRODUCTION

Nuclear power is coming to a new stage of its development. The problem of a commercial closed fuel cycle is raised. The nuclear and radiative safety should be the deciding principle. Social acceptance will depend on the realized reliability and safety throughout the whole fuel cycle.

The purpose of transmutation is a safer and more effective use of the nuclear fission energy with the help of improvements in the end stage of the fuel cycle. Transmutation makes it possible to cut down the waste volume and to reduce the ill effects of radioactivity to the limits safe to handle.

It is expected that the purpose in hand can be achieved by transformation of the radioactive long-lived nuclides to the short-lived and stable ones. Using transmutation there is no tolerating an increase in (1) the low level waste, (2) the occupational dose, (3) the electricity cost, (4) the disposal and storage costs and (5) the research and development expenses.

2. THE BASIC PRINCIPLES OF A TRANSMUTATION DESIGN

Transmutation (the conversion under the particles irradiation] and partitioning require optimization with consideration of their interplay and description as a unit.

For the safety level to be high it is necessary to keep the distance between the areas where any processes (radiation treatment, heat transfer, chemical separation] run most intensively. To avoid losses and pollutions the above mentioned areas with their pipelines are boxed in.

A great deal depends on the working agent. It must provide (1) a high rate of nuclear reactions, (2) a simple removal of short-lived and stable reaction products, (3) an effective heat transfer, (4) a high conversion of thermal energy to electricity and (5) an unattended operation with a remote control.

The agent must possess many exceptional qualities including resistance to radiation, compatibility with transmutation products and construction materials. It is a liquid agent that could answer these requirements. Here we examine methods based on the idea that the transmuted substance could be made soluble.

3. COMPONENTS RAISING THE NUCLEAR REACTION RATES

High fluxes of thermal neutrons provide the most intensive running of the nuclear reaction. At present the best decision (the thermal neutron flux of about 10^{16} n/cm^{2}sec) is offered by a high current 1.6 GeV-proton accelerator, The accelerator generates spallation neutrons in the target being a flowing Pb-Bi eutectic. An unique flux of thermal neutrons is formed in the heavy water blanket after spallation neutron moderation [1]. Nuclear safe operation is provided by a subcritical regime.

The high neutron flux allows to apply the substantial dilution. It is for this reason that the irradiated material loading is very small. A low-inventory system especially when the transmuted material consists of actinides would be much safer.

Though schemes with a separate target and blanket have some advantages there exist homogeneous ones. From the facts already known a single fluid system is safer. The single fluid carries out not only the target function but the blanket function as well. In this case it is possible to minimize construction materials thus decreasing the secondary waste flow [2,3]. Systems of that kind are supposed to be realized for transmutation of the minor actinides by dissolving their fluorides in the fluorides of alkali metals.

A more sophisticated method is suggested in Los Alamos [1 1. It starts with a flowing Pb-Bi target for producing spallation neutrons and employs two loop types in the blanket. There co-exist loops with heavy water solutions and a molten salt loop for transmuting waste and generating electricity. The method is also based on the idea of dissolving the transmuted substance. We believe that the new class of combined assemblies present many of their own problems, connected with the construction materials and a risk of accidents. Before accelerator based systems find a wide application they may pass several consequent stages.

4. INCINERATION OF RADIOACTIVE WASTE DISSOLVED IN D_2O.

In the form of salts dissolved in heavy water the radioactive waste irradiated for transmutation flow through the blanket to the heat exchanger. Part of the solution is withdrawn for reprocessing. Chemical reprocessing of an irradiated solution is not a hard technical problem as there exist presently technologies of waste partitioning and extracting specific radionuclides, which have passed the stages of the laboratory, “hot” and pilot tests.

The heavy water solution is recovered by the extraction of the long-lived radionuclides and their subsequent return into the loop. The inherent. waste of that technology is a solution, carrying the stable and short-lived nuclides, which arrives at its vitrification,

To avoid spurious neutron capture by construction materials is necessary that the loop pressure be low, which makes it impossible that. the heat from minor actinids fissions be used in electricity production. The heavy water solution runs into heat removal difficulties those are overcome by essential dilution. Spallation neutrons are practically not multiplicated in the blanket. However a 1.5 GeV-100 mA class proton accelerator with a heavy water solution blanket would be able to transmute the discharge of 10 or more 1000 MWe power reactors.

5. WASTE TRANSMUTATION WITH ELECTRICITY PRODUCTION

The minor actinides are valuable fissile or fertile isotopes and should not be wasted but should be used as fuel. The flowing fuel allows to achieve reprocessing with less step numbers and to reduce losses. Molten fluorides are suitable for solving the problems of heat removal as well as the problems of chemical separating of actinides and transmutation products. A high heat-to-electricity ratio and a low fissile inventory identify a unique operating regime.

Though thermal fission cross sections for some primary constituents of the actinide waste, such as ^{237}Np and "'Am, are very small, in case of the 10^{16} n/cm^{2}sec - class thermal flux an efficient two-step fission is possible so that those react as good fuel. The system would operate well below criticality at high power owing to a substantial contribution of spallation neutrons.

Dissolved fluorides of minor actinides do not present any problems for flowing loop. It is an advantage of molten salts that the pressure in the loop can be low. Moreover in molten salt the cost of reprocessing is expected to be much lower than in aqueous solutions. The basic problem is that the removal of the fission products from the molten salt has not passed a demonstration stage yet.

6. ACCELERATOR BREEDER IN THORIUM-FUEL CYCLE

The thorium fuel cycle is characterized by recycling uranium instead of plutonium. In the Th-U-chain the build-up rates **for** long-lived **a-instable** transuranic isotopes are reduced. If comparable separation factors for the transuranium elements are assumed for both the U-PU and Th-U fuel cycles the risk of long--term waste storage resulting from reprocessing is remarkably reduced by one or two orders of magnitude.

Moreover the recycling of ^{233}U is easier than that of Pu. The processing of uranium into most diversified fuel elements is well known. It seems possible to bild a hybrid system consisting of different types of reactors including the mastered heavy water ones, The high intrinsic radioactivity of ^{233}U provides self-protection against unauthorized proliferation of fissile material. One can imagine a thorium fuel cycle where only denatured ^{233}U is permitted for the refabrication and recycling purposes. Therefore, the system may present an inherent protection against misuse for arms manufacture. It is also important to note that deposits of thorium are about twice to three times as abundant as those of uranium.

As ^{235}U resources are depleted, the fuel producted by breeders is expected to become more competitive [41. Electronuclear breeders present options for producing initial inventory of ^{233}U and supporting the systems that could operate on an advanced fuel cycle and be "near-breeder". Neutrons from spallation reactions are multiplied in a Th- containing blanket where fertile material Th is converted to fissile material ^{233}U. From the four most favoured blankets (a type of liquid-metal fast-breeder reactor, a CANDU-like assembly of fuel rods, an assembly with flowing heavy water solution and a type of the molten salt) each has its own advantages and disadvantages. We choose the latter two as those which provide for continuous reprocessing and radiowaste management application.

A very effective decision is suggested in the Los Alamos ATW project where ^{233}U is producted from Th dissolved as $Th(NO_3)_4$ in the water section of the blanket and after extraction it is burnt as $^{233}UF_4$ in the molten salt section of the same blanket.

Nuclear weapon reduction will raise one more transmutation problem, that is the use of the weapon plutonium. Being isotonically pure, the plutonium could be used at the first cycle of burning in the thermal reactors, After the processing of the fuel dirty plutonium could be fed to the fuel cycle of accelerator driven incinerator for generating ^{233}U. The essential advantages of the method are a high rate production of isotonically pure ^{233}U and high level of nuclear safety.

CONCLUSION

Transmutation makes it possible to cut down the waste volume and to reduce the radioactivity effects. Using transmutation two big demerits of the closed fuel cycle on solid elements must be avoided: a very complicated remote fabrication of fuel elements and secondary radioactive waste from construction materials. The accelerator driven heavy water assembly allows to build up step by step the potential possibilities of the system and subsequently to solve the following problems: actinide transmutation without electric power production; actinide transmutation with electric power production; a ^{233}U production or a ^{239}Pu conversion to ^{233}U; transmutation of the fission products. The resident actinides and long-lived fission products must circulate continually in the plant, Only the stable and short-lived radioactive waste would be discharged, which could be achieved by an in situ regeneration.

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