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NUCLEAR FUEL REPROCESSING OPTIONS

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ABSTRACT

Different reprocessing techniques are being developed for the treatment of spent fuel in order to decrease the amount of nuclear waste that is being progressively added to the global cumulative inventory. All these processes aim to reduce the contribution to the final repository though more efficient disposal of nuclear waste. Therefore, some new reprocessing options with non-proliferation characteristics have been proposed and the goal is to compare the different techniques used to maximize the effectiveness of the spent fuel utilization and to reduce the volume and long-term radiotoxicity of high-level waste. The goal is to present the different techniques used for spent fuel reprocessing and a first approach of their composition. The work development might be employed in hybrids systems and generation IV reactors.

1. INTRODUCTION

Nuclear power generation is expected to play an important role to the world energy industry as annual projections by the IAEA predict substantial global developments of nuclear technologies during this century to ensure its safety and sustainability [1].

At the beginning of the nuclear era a “once through” fuel cycle policy was implemented, in which the uranium passes once through the power reactor and the irradiated fuel is disposed intact in a geologic repository. Currently the recycling of the irradiated fuel has been practiced in a number of countries, allowing the recovery of fissile uranium and plutonium back into the fuel cycle as mixed oxide (MOX) fuel [2]. Nevertheless, there is an extensive range of treatment options for spent fuel management which would follow interim storage of spent fuel. However, the continuous irradiation of the fuel increases the amount of long-lived transuranic elements, which pose a high radiotoxicity [3].

To reach a sustainable nuclear development it is necessary to enhance the effectiveness of natural resources utilization and reduce the volume and long-term radiotoxicity of transuranics, reinforcing the non-proliferation characteristics [4]. To achieve this goal it is necessary to identify viable technical options such as; a burn-up extension and recycling using different reprocessing techniques.

The main goal of this article is to describe the reprocessing technologies available and that can be reused in Generation IV Reactor and Hybrid reactors. It aims to reduce the amount of nuclear waste which goes to a final repository, have better management of natural resources and avoid proliferation of fissile materials. The reprocessing technologies were chosen considering the development stage in the lab scale, and the ones that offers a non-proliferation characteristics.

2. METHODOLOGY

The first step was to research the various reprocessing options and the development of new technologies of reactors [5]. The second step was to select the group of different techniques that will be used as nuclear fuel, which must fulfill non-proliferation characteristics. Those options aim to achieve one or all of the four objectives for waste management, such as, waste minimization, toxicity reduction, volume reduction and security (deterrence of proliferation). These objectives can be achieved through physical or chemical means.

3. DISCUSSIONS

Several categories of radioactive waste are produced in the nuclear industry, ranging from highly radioactive waste to low radiation level waste [4]. The selected processes are presented in Table 1. Different techniques using various types of solvents have been studied and tested in many countries to significantly reducing the amount of nuclear waste that goes to final repository. It is needed to achieve very high separation processes efficiency and the cost benefit of it, which will be a strong factor in deciding the suitable option to be utilized in the future.

Tab. 1. Spent fuel new reprocessing options with non-proliferation characteristics

Process name & country	Details
Co-extraction of actinides (COEX) - France	Aqueous separation methods using BTP extractant molecules (derived from PUREX process). MOX from FR. UO_2 from LWR.
New Extraction System for TRU (NEXT) – Japan	
Reprocessing-partitioning (REPA) - Russia	
Uranium extraction/heteregeneous (UREX+ 3a) - US	Innovative aqueous processes using new extractant molecules. UO_2 from LWR FR and ADS fuels
Uranium extraction/ homogeneous (UREX+1^{a}) - US	
Group actinide extraction (GANEX) - France	
Amide-based Radio-resources Treatment with Interim Storage of Transuranics (ARTIST) - Japan	
DDP (Dimitrov-grad DryProcess) - Russia	Non-aqueous technologies (dry route) - Pyrochemical processes
Pyro-chemical – (liq-liq) process - France	
Fluoride Extraction (FLUOREX) -Japan	Hybrid methods combining hydro and Pyrochemical processes.

3.1. Detalhes dos Processos

- COEX – The COEXTM or COEXtraction process has been developed by French workers, and is designed to bleed some of the U (and possibly Np) into the Pu product to eliminate the pure Pu stream [6]. Some of the process characteristics are: co-management of U and Pu for fuel fabrication; no pure Pu (enhanced proliferation resistance); Homogeneous MOX fuel fabrication; applicability to nitride and carbide fuels; possibility of integrated cycle (Online Reprocessing and Re-fabrication) and compatibility with Diamex-Sanex process for the separation of Minor Actinides [2].
- NEXT - Consists of high efficiency dissolution, crystallization, U/Pu/Np co-recovery and MA recovery with solvent extraction for trivalent f-elements intra-group separation. This high efficiency is obtained via separation and concentration of products, which are achieved by crystallization of bulk fission-product components [4]. This crystallization technology, which recovers approximately 70% of the uranium dominating the heavy metal mass in the solution of spent fuel beforehand, allows a drastic reduction of the throughput in the following processes, leading to a streamlining of installations. The purification process of uranium product and plutonium product is eliminated from this process [2].
- REPA – This process aim to reduce the volume and radiotoxicity of radioactive waste with no pure Pu separation. It is especially interesting for facilities far from sea, because of the separation of 3H in head operations. It is an optimized PUREX process with SNF thermochemical destruction, followed by oxidizing and re-crystallization, conversion of fuel to nitrates and production of concentrated solution, uranium separation by a crystallization method, and mother solution extraction reprocessing with simultaneous partitioning of (U + Pu), TRU and rare earths, and Cs/Sr [2].
- UREX+ 3 - Pu extracted with Np and then blended with U. Separation of U, Cs, Sr, Tc, I, noble gases. It is a cascade of five solvent separate extraction processes, referred to here as “process modules” and one ion exchange process [4].
- UREX+1 - Important as an extraction of the TRU elements as a group; there is no separation among the TRUs which are to be burned as fuel in fast spectrum reactors (FR). No pure Pu-separation (co-extraction of TRUs), separation of U, Cs, Sr (storage), Tc (storage or potential transmutation), Pu+TRU (recycling) and the FPs (waste) [4].
- GANEX – extraction of most of the uranium from the spent fuel, followed by group separation of plutonium and the minor actinides (neptunium, americium and curium). The process is important due to the co-management of actinides and no pure plutonium separation (Enhanced proliferation resistance) [7].
- ARTIST – Reduction of the volume and the radio-toxicity of waste. Expected high recovery factor for Am from SNF solution in a rather simple way, via extractants. The extractants called BAMA and TODGA are used for uranium separation and all TRU separation, respectively [2].
- DDP – It is an electro-winning process, where spent oxide fuel is de-clad and fragmented, resulting in the co-deposition of uranium, neptunium and plutonium oxides at the cell cathode and liberation of chlorine at the anode. The process results in a reduction of volumes of radioactive waste and the enhancement of proliferation resistance [2].
- Pyro-chemical – (liq-liq) process - Reprocess of a very high burnup fuels (radioactive solution with high content of fissile material). After de-cladding and crushing, the fuel powder is placed in an electrochemical cell in which the fuel and fission product oxides are reduced to the metallic

state by electrolysis in a LiCl bath. Salt resistant to radiolysis, low neutronic moderation ratio (criticality risk downsized) [4].

- FLUOREX – Is a hybrid system that combines fluoride volatility and solvent extraction methods; most of the uranium in spent fuel is separated efficiently by the fluoride volatility method and MOX is recovered by the well-established conventional PUREX process. Compactness of the equipment for the pyrochemical part of the process is important due to the reduction of LLW volumes and enhancement of proliferation resistance [2].

The nuclear fuel cycle management aims to eliminate minor actinides (MA) via partitioning and transmutation, in particular americium and curium [4]. After the separation process, they cannot be fully transmuted in a closed fuel cycle with thermal reactors and new reactor generations have been tested to be used for this purpose.

Considering the different treatment options for spent fuel, the best one to be employed relies on the context of overall nuclear deployment scenarios. This scenario may dictate different fuel cycle options depending on each country's nuclear policy, cost–benefit considerations, and public acceptance [3]. Currently, the once through fuel cycle with direct disposal of spent fuel and storage and postponed decision are the reference nuclear deployment scenarios in a very large majority of countries using nuclear energy due to its viability.

For future considerations, the different techniques with non-proliferation for spent fuel reprocessing and a first approach of their composition will be important for the selection of the best closed fuel cycle nuclear process.

Overall, the point now is to enhance the management of minor actinides given a particular envisioned future nuclear deployment scenario.

4. CONCLUSION

The development of fission-product reprocessing technologies will continue to progress in the future to meet the needs of nuclear waste management. The desirability of reducing the heat load on geologic repositories will likely keep interest for improved separations in the long term.

Due to the nuclear energy deployment scenarios, the direct disposal of spent fuel will not eliminate the possibility of introducing new techniques because of the energy demand and concerns about the environment

Expansion of applicable techniques beyond solvent extraction, ion exchange, and precipitation is occurring. Electrochemical methods, supercritical fluid extraction, and membrane technologies, for example, are expect to develop for application in advanced reactor concepts based on generation IV.

In summary, the need for advanced fission-product separation technologies will remain strong in the context of new fuel cycles, and it is expected to play an increasing role as a major option for optimizing the management of spent nuclear fuels.

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