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Roles and effects of pyroprocessing for spent nuclear fuel management in South Korea

Joonhong Ahn

Department of Nuclear Engineering, University of California, Berkeley, Berkeley, CA 94720-1730, USA

A R T I C L E I N F O

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A B S T R A C T

Republic of Korea (ROK) changed its spent nuclear fuel policy from the once-through usage and direct disposal to a total system approach that includes pyroprocessing, sodium-cooled fast reactors, and a two-tier geological repository to achieve a breakthrough for domestic deadlock situation and thus enable sustainable utilization of nuclear power, but caused disagreement in the bilateral negotiation with the United States (US) for the Nuclear Cooperation Agreement.

Analysis has revealed that this shift is effective to make a breakthrough for domestic deadlock because it augments variety of technological options, with which more reversible decision-making process can be conducted to accommodate broad public needs. A trade-off has been explored first by deriving four engineering options from the ROK's system concept and then by comparing their performance from six viewpoints. The option including separation of high-heat emitting radionuclides by the electrolytic reduction process has been recommended.

This option should be modified as exogenous and endogenous situations change in future. It is imperative for ROK to integrate a public-participatory decision-making process that works in concert with technology development. US can verify that ROK's motivation is not deviating from successful spent fuel management by checking if a transparent process with public participation is conducted.

1. Introduction

Spent fuel management has been a challenge in any nuclear country. Even for countries with advanced technological capability and diverse geological and societal conditions, finding an actual site for a geological repository has proven very difficult politically and societally. Almost all countries that tried to advance from their feasibility study stage to siting stage had a major setback, such as the United States (Blue Ribbon Commission on, January 2012), Canada (Ramana, 2013), and Japan (Ahn and 2013 Oct).

In mid 1980s, Republic of Korea (ROK, South Korea) started its technology development and siting process for interim storage and geological disposal under the scheme of once-through usage and direct disposal (OTDD) because of a constraint imposed by the United States (US) for nonproliferation (see Section 2.3). In the past decade, as its nuclear capacity expanded rapidly, spent fuel accumulation drew public attention. Finding socially agreeable solutions for accumulating spent fuel has been commonly recognized to be crucial for sustainable utilization of nuclear power in ROK, but decision-making process for siting an interim storage facility for spent fuel has become deadlocked (Ko and Kwon, 2009). With the hope that technological options could make a breakthrough in social decision-making process, despite strong US concern for nonproliferation, in 2008, ROK changed its scheme from OTDD to a total system approach that includes pyroprocessing and sodium-cooled fast reactors (SFR) as core technologies (Long-term plan for promot and 2008 Dec. 22; Park et al., 2009).

Pyroprocessing (Hannum, 1997) proposed by Korea Atomic Energy Research Institute (KAERI) separates elements included in spent fuel into several groups as shown in Fig. 1 by utilizing difference in chemical potentials of constituent elements in high-temperature molten salt. Because of small difference in chemical potentials in such environment, transuranic (TRU) elements[1] tend to be recovered together. This is in principle the basis of ROK's claim that this separation technology is more proliferation-resistant than conventional PUREX process, which was designed for effectively recovering plutonium and uranium.

[1] Actinide includes all the elements of atomic number 89 (Actinium) and above, while transuranic elements (TRU) include Neptunium and above. In uranium-fuel-based reactors, major actinide elements of interest are U, Np, Pu, Am, and Cm. TRU means those without U. "Minor actinide" means TRU without Pu, i.e., Np, Am, and Cm, because of their small masses included in the fuel, compared with Pu mass.

E-mail address: joonhong.ahn@berkeley.edu.

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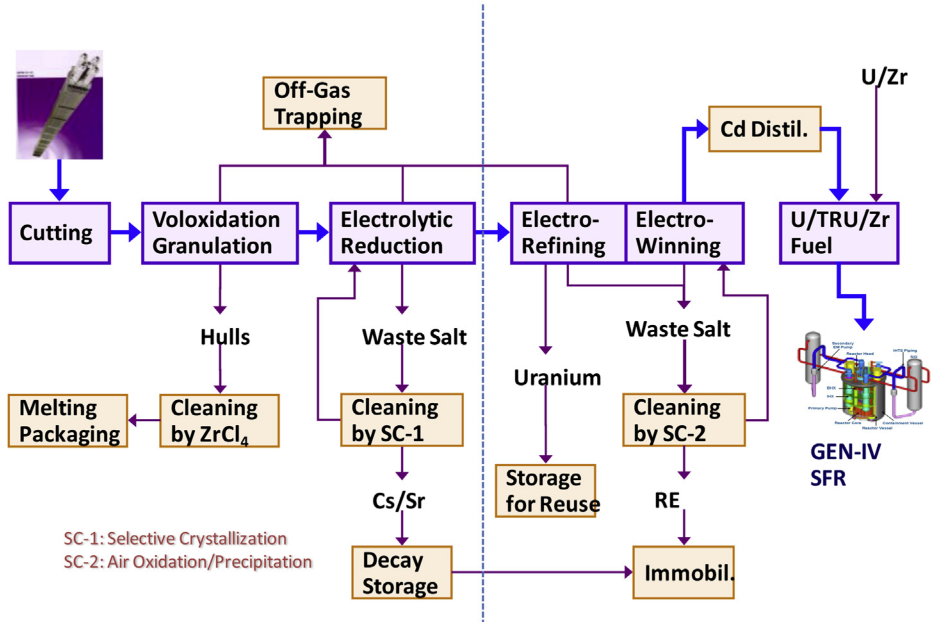

Fig. 1. Flow diagram of pyroprocessing (RE stands for rare earth elements; GEN-IV SFR stands for a sodium-cooled fast reactor considered in Generation IV reactor development).

Shifting from the OTDD scheme to the total system approach has added the US-ROK bilateral issue on top of all the domestic issues that ROK has to solve for spent fuel management. In addition, because the OTDD scheme is the simplest scheme for spent fuel management, the shift could make the spent fuel management technologically more complicated, uncertain, and costly. Depending on which near-term option is adopted, long-term risk and benefit can be significantly different. While long-term issues such as intergenerational equity and ethics are conceptual, they often become focal points in actual public discussion for siting a geological repository.

Thus, ROK seems to be stepping into a complex, uncertain future by this shift. Is it worthwhile for ROK to make the shift? This question is of universal interest beyond US-ROK bilateral and ROK domestic issues because emerging nuclear countries will eventually experience similar issues in spent fuel management that ROK currently faces, including its relation with US.

In this paper, we compare performance of various technical options derived from the ROK's total system concept for spent fuel management, and recommend a trade-off for ROK's future development and US-ROK negotiation. We first describe brief historical perspective that has resulted in the current deadlocked situation for the spent fuel management in ROK. This is followed by a brief summary on physical aspects of the spent fuel and on the ROK's total system concept. Four technological options are derived from the ROK's system concept, and are compared with respect to multiple viewpoints by using the *scorecard* method (Taebi and Kadak, 2010). Finally, a trade-off option is recommended, which may satisfy various stakeholders.

2. Histrocal perspective

2.1. Nuclear power utilization

ROK's national plan envisions nuclear power supplying 60% of its electricity needs by 2030 (The first national energy, 2008–2030). This heavy reliance on nuclear power has been motivated by its low self-sufficiency of energy. ROK's self sufficiency is as low as 3%, meaning 97% of primary energy sources, mostly coal, oil, natural gas, and nuclear, are imported from overseas. The combined share of the indigenous and nuclear power becomes 19%, which is comparable to Japan's 20%,[2] but far lower than Germany's 40% and France's 51% (Energy balance of OECD countries, 2011).

The reason why nuclear power is often considered together with indigenous sources is because it has characteristics remarkably different from fossil fuels; (1) because of its high energy density, much smaller mass, volume and footprint are required for fuel transportation and stockpiling than those of fossil fuels, (2) geopolitical situations for major suppliers of uranium including Canada and Australia differ from those for oil-exporting countries such as middle-eastern countries, and (3) carbon dioxide emission by nuclear power is remarkably smaller than that by fossil fuel.

By including principally-different energy sources in a portfolio, risks of common-mode failure in importing energy resources have been significantly reduced, and the bargaining power of consumer countries, such as ROK, in the international market of oil and natural gas has been enhanced (Toth and Rogner, 2006), as was observed in the "1980s oil glut" phenomenon (Petroleum Chronology of E and 2002 May). Nuclear power has been contributing to keep the ROK's industry and household electricity prices among the lowest in the world (theoildrum.com: Discussio and 2010 Dec 11). Thus, for its important contributions to stability of fuel price and supply, and diversity added to the energy portfolio, keeping nuclear power as one of major sources of primary energy has been the ROK's fundamental national energy policy, and is considered to be so in a foreseeable future.

2.2. Spent fuel management under OTDD scheme

With its planned nuclear capacity, ROK is anticipated to generate almost 100,000 metric tons[3] of spent fuel by 2100 (Park, 2009). About 1100 tons of spent fuel will be generated annually if and when all planned reactors are constructed. In the meantime, on-site storage at the existing nuclear power plants will reach saturation sometime soon both for CANDU and pressurized-water

[2] The data before the Fukushima Daiichi accident occurred on March 11, 2011.

[3] Same applies throughout this paper.