A Study on the Nuclear Proliferation Resistance Assessment of Fuel Cycle in Korea

Yoon Hee Lee, Jongkuk Lee, Kunjai Lee

Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology

335 Gwahangno, Yuseong-gu, Daejeon 305-701, Republic of Korea

ABSTRACT

Spent fuel management has been a main problem to be solved for continuous utilization of NPP(nuclear Power Plant). Spent fuel management policy of Korea is "Wait and See". It is focused on Pyroprocess and SFR(Sodium-cooled Fast Reactor) for closed-fuel cycle research and development.

There are many factors for fuel cycle assessment such as environmental impacts, economics, proliferation resistance, etc... Proliferation resistance is one of key constraints in the deployment of advanced nuclear energy systems. It is also important for peaceful use of nuclear energy by impeding the diversion or undeclared production of weapon-usable material. Non-proliferation and safeguard issues have been strengthening internationally. However, there is not enough information and analysis on proliferation resistant of fuel cycle in Korea. It is needed that development of generally acceptable methodology or improved methodology for assessing proliferation resistance. It could be helpful for spent fuel management policy decision in the future. Case studies on proliferation resistance evaluation of several fuel cycles have been performed in this paper.

It is defined proliferation resistance as characteristics of nuclear energy system that impedes the diversion or undeclared production of nuclear material according to IAEA. Barriers to proliferation are that reduces desirability or attractiveness as an explosive and makes it difficult to gain access to the materials, or makes it difficult to misuse facilities and/or technologies for weapons applications. Barriers to proliferation are classified into intrinsic and extrinsic barriers. Extrinsic barriers(Institutional barriers) is an institutional or other external barrier that lowers the risk of proliferation of nuclear materials, such as physical security measures, monitoring techniques, and IAEA inspections. Intrinsic barrier is inherent quality of reactor materials or the fuel cycle that is built into the reactor design and operation such as material and technical barriers. There are many factors to describe each barrier.

Proliferation resistance in view of material barrier especially focus on the isotopic barrier has been evaluated for PWR(Pressurized Water Reactor) and CANDU(CANada Deuterium Uranium) spent fuel. FOM(Figure of Merit) was calculated to classify the attractiveness level which is suggested by U.S. DOE(Department of Energy). Attractiveness level is used for the non- proliferation measure which can represent the intrinsic barrier attributes in this paper. Heat generation and dose rate were calculated using ORIGEN and microshield. It will be performed with more specific data and more various back-end fuel cycle which is mainly considered as a future spent fuel management policy in Korea.

INTRODUCTION

Spent fuel management is the main problem to be solved for continuous utilization of nuclear power. Spent fuel management policy in Korea is "Wait and See". In general, factors for fuel cycle assessment are environmental impacts, economics, public acceptance and proliferation resistance. Especially proliferation resistance is important for peaceful use of nuclear energy by impeding the diversion or undeclared production of weapon-usable material. It is also one of key constraints in the deployment of advanced nuclear energy systems. However, there is not enough methodology for assessing proliferation resistance in quantitative manner. And it is difficult to develop a generally acceptable methodology for proliferation resistance assessment. Therefore it is focused on in this paper for evaluation of proliferation resistance quantitatively.

The objective of our study is development of improved parameter or method for assessing proliferation resistance. The assessment of various fuel cycles(back-end) in light of proliferation resistance and comparative assessment of the proliferation attributes and merits of different fuel cycles will be completed in the near future.

PROLIOFERATION RESISTANCE ANALYSIS METHOD

Fuel Cycle Assessment Process

Fuel cycle options have to be decided first for the assessment. As it is mentioned before, SF management policy in Korea is "wait and see". For once through cycle, the general PWR cycle is considered. Pyroprocessing and DUPIC cycles are considered for the recycling cycle.

Evaluation criteria also have to be selected which can estimate proliferation resistance. With those criteria each fuel cycle will be analyzed and the optimal back-end fuel cycle will be proposed.

Proliferation Resistance and Barriers

Proliferation resistance is defined as that characteristic of nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States intend on acquiring nuclear weapons or other nuclear explosive devices [1].

Barriers to proliferation can be described as that reduces desirability or attractiveness as an explosive, makes it difficult to misuse facilities and/or technologies for weapon applications. Barriers to proliferation resistance can be divided into intrinsic and extrinsic barriers. Intrinsic barriers are those inherent to technical and related elements of a fuel cycle, and its facilities and equipment [2]. Extrinsic barriers are an institutional or other external barrier that lowers the risk of proliferation of nuclear materials, such as physical security measures, monitoring techniques and IAEA inspections. Material and technical barriers are categorized as intrinsic barrier. Material barriers are depended

on the intrinsic physical qualities of the materials such as isotopic composition of the material, chemical property, radiation hazard, detectability etc.. Proliferation assessment focused on material barrier is performed in this paper.

Analysis Method

Figures of merit(FOM) that are intended to explain the attractiveness level [3] and it has been studying in many laboratory and institute [4]. The FOM is given by:

$$FOM = 1 - \log_{10}(x) \qquad \text{(Eq.1)}$$

$$x = M\left[\frac{1}{800} + \frac{h}{4500}\right] + \left[\frac{D}{500}\right]^{\frac{1}{\log_{10} 2}} \qquad \text{(Eq.2)}$$

where M is the bare critical mass of the metal in kg, h is the heat content in W/kg, and D is the dose rate of 0.2M evaluated at 1 m from the surface in rem/h. These factors(critical mass, heat generation rate, radiation) are seem to estimate isotopic barrier which is the main attribute of material barrier.

Table I. Attractiveness Level [3, 4]

	Attractiveness Level	FOM
WEAPONS Assembled weapons and test devices	A	
PURE PRODUCTS Pits, major components, button ingots, recastable metal, directly convertible materials	B	> 2
HIGH-GRADE MATERIALS Carbides, oxides, nitrates, solutions ($\geq$25 g/L) etc.; fuel elements and assemblies; alloys and mixtures; UF4 or UF6 ($\geq$ 50% enriched)	C	1-2
LOW-GRADE MATERIALS Solutions (1 to 25 g/L), process residues requiring extensive reprocessing; moderately irradiated material; Pu-238 (except waste); UF4 or UF6 ($\geq$20%<50% enriched)	D	0-1
ALL OTHER MATERIALS Highly irradiated forms, solutions (<1 g/L), uranium containing <20% U-235 or <10% U-233 (any form, any quantity)	E	< 0

RESULT AND DISCUSSION

Case Study

PWR and CANDU spent fuels are considered for the FOM calculation. The burnup of spent fuel is 35 GWD/MTU for PWR and 7.5 GWD/MTU for CANDU. The cooling time is assumed for 10 years and the decay heat value with those specifications is applied for each FOM calculation. Critical mass is assumed that the mass which can divert 1 SQ of Pu(8kg). Therefore, it is corresponded to 1000 kg for PWR and 3600 kg for CANDU.

Each FOM value for PWR and CANDU are calculated below the zero. Therefore both of spent fuels have attractiveness level 'E'.

Discussion and Further Study

PWR and CANDU spent fuels are considered in this paper. Various back-end fuel cycle options will be applied and evaluated. More specific data for critical mass, burnup and cooling time have to be studied. And also decay heat, isotopic composition and dose rate will be calculated more detail with computer code.

FOM value is a good attribute for isotopic barrier and material barrier which can explain proliferation resistance in quantitative manner. There are also many other attributes for intrinsic barriers. It will be integrated for proliferation resistance assessment using multiple attribute utility analysis(MAUA) or analytic hierarchy process(AHP) in the near future.

References

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