Proliferation-Resistance Assessment of a CANDU Reactor Loaded with the DUPIC Fuel Using New User Requirement-1 Indicators of the INPRO Methodology

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1. Introduction

Since mid of 2000, the International Atomic Energy Agency (IAEA) continues to proceed an International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) for fulfilling the energy need of the 21st century along with its economics, sustainability, environment, safety of nuclear installations, waste management, and proliferation resistance [1]. After the results of the INPRO Phase 1B 1st part were produced for the 6 national and 8 individual case studies, the INPRO methodology was updated with 2 Basic Principles (BP) and 5 User Requirements (UR) in the proliferation resistance (PR) area [2].

From the beginning of 2005, the INPRO Phase 1B 2nd part was initiated, aiming at assessing the applicability of the updated INPRO methodology to the Closed Nuclear Fuel Cycle with Fast Reactor (CNFC-FR) analysis performed by an international joint study and the whole DUPIC fuel cycle [3] (from the uranium mining and milling to the permanent disposal of the spent DUPIC fuel) analysis performed by Korea [4].

In this study, the updated INPRO methodology in the INPRO Phase 1B report is reviewed and the new Indicators of User Requirements (UR) for Basic Principle (BP)-1 are modified to appropriately assess the Proliferation Resistance (PR) and to strengthen the Safeguardability of an Innovative Nuclear System (INS). Then the PR characteristics of a CANDU plant loaded with the DUPIC fuel are assessed by using the new Indicators.

2. Modification of Previous INPRO PR Indicators

Two BPs and five URs were suggested in the INPRO Phase 1B report to provide guidance to the government, sponsors, designers, regulators, investors and other users of a nuclear power and fuel cycle facilities, which incorporate the PR of the future nuclear energy system. Three URs under the BP-1 have one Indicator for each UR and two URs under the BP-2 have two Indicators for each UR. Under each Indicator, there are several variables such as extrinsic measures and intrinsic features. Each Indicator for each UR could be rearranged and broken down into the precise Indicators for an appropriate PR evaluation of the INS.

Regrouping and modifying the Indicators of the revised INPRO methodology, suggested in the INPRO Phase 1B report, the new Indicators of the UR under BP-1 are proposed as given in Fig. 1. But, the Indicators under the BP-2 are unchanged because they are already reasonably described to evaluate the PR of an INS.

The UR-1 under BP-1 is a requirement related to the attractiveness of the nuclear material. As shown in Fig. 1, it contains four Indicators: material quality, material quantity, material form, and nuclear technology. And each Indicator has several evaluation parameters. The UR-2 under BP-1 is a requirement related to the difficulty and detectability of diversion of the nuclear material. It contains five Indicators: accountability, application of C/S measures, detectability of nuclear material, difficulty to modify the process and difficulty to modify the facility design. And each Indicator also has several evaluation parameters.

The UR-3 under BP-1 is a requirement related to the extrinsic measures which are regrouped as two Indicators: States' commitments, obligations and policies regarding the non-proliferation to fulfill international standards and facility/enterprise undertakings to provide PR, which can be compared to five Indicators of the previous study [5].

3. PR Evaluation of a CANDU with DUPIC Fuel

In order to evaluate the PR characteristics of a CANDU reactor using the proposed Indicators of the INPRO methodology, it was assumed that the CANDU reactor was loaded with the DUPIC fuel. The material flow was calculated in consideration of a 10 GWe-year scale of the whole DUPIC fuel cycle. The results of plutonium content and radiation field calculations are summarized in Tables 1 and 2, respectively.

In this study, the PR characteristics of only the UR-1 Indicators were evaluated, because the evaluation scales of UR-2 were not fully settled down and the Indicators of UR-3 are decided by State's policies and not dependent on any INS.

Since the weight fractions of ^{239}Pu, ^{238}Pu and ^{240}Pu+^{242}Pu in the plutonium of a new DUPIC fuel are 40~ 60, 1.7~4.8 and 30~40 wt%, respectively, as given in Table 1, the scores of "Isotopic composition", "Spontaneous neutron generation rate" and "Heat generation" are "Very Strong", "Strong" and "Moderate", respectively, as given in Table 3. As the radiation field of the DUPIC fuel in a CANDU reactor ranges from 15 to 61 rem/hr as given in Table 2, the score of "Radiation field" is "Strong", considering the minimum value of the radiation field.

Regarding the 2nd Indicator "Material quantity", the total mass of one Significant Quantity (SQ) of plutonium is a key parameter and calculated to be 1026 kgHM which requires more than 40 DUPIC fuel bundles. It makes the scores of "Total mass" and "No. of items" be "Very Strong" and "Moderate", respectively.

On the other hands, the DUPIC fuel has an oxide fuel form processed from the PWR spent fuels and, therefore, the score of "Material form" is "Strong". Because there is no enrichment and extraction of fissile material during the irradiation of the DUPIC fuel in a CANDU reactor, the Indicator "Nuclear technology" is "Acceptable".

4. Conclusion

In the present study, the four Indicators of the UR-1 are proposed and newly classified to conveniently assess the PR by reviewing the previous study, while five new Indicators of the UR-2 are proposed to strengthen the Safeguardability of an INS. Then the PR characteristics of a CANDU reactor regarding the UR-1 were evaluated, assuming that the DUPIC fuels were loaded into a CANDU reactor based on a 10 GWe-year scale.

In the next phase, the evaluation scales for the UR-2 Indicators should be determined and refined. Also, the significance among the Indicators to evaluate each UR should be developed because the evaluation of an UR is required when integrating its Indicators.

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Table 1. Plutonium Isotopes of the DUPIC Fuel Cycle

Isotopes	PWR SF		Fresh DUPIC Fuel		DUPIC SF	
	g/M tHM	wt% of Pu	g/M tHM	wt% of Pu	g/M tHM	wt% of Pu
PU238	1.54E+02	1.7	1.54E+02	1.7	3.88E+02	4.9
PU239	5.33E+03	59.9	5.33E+03	59.9	3.16E+03	39.7
PU240	2.20E+03	24.8	2.20E+03	24.8	2.79E+03	35.1
PU241	7.52E+02	8.4	7.52E+02	8.4	5.24E+02	6.6
PU242	4.57E+02	5.1	4.57E+02	5.1	1.10E+03	13.8

Table 2. Radiation Field of the DUPIC Fuel Cycle

Items		Dose rate (rem/hr) for diversion of one assembly or one bundle	Total dose rate (rem/hr) for 1000kgHM diversion	Dose rate (rem/hr) for diversion of 1 SQ(8 kg Pu)
PWR SF	35GWD/MTU, 10yrs cooling	1,037	2,356	2,121
DUPIC SF	15GWD/MTU, 10yrs cooling	61	3,216	3,232
CANDU SF	7.5GWD/MTU, 10yrs cooling	22	1,151	2,284
Fresh DUPIC	PWR(35GWD/MTU, 10yrs cooling)	15	797	717

Table 3. PR Assessment Results of UR-1 of BP-1

Indicators	Evaluation Parameter		Evaluation scale				
			U			A	
			U	W	M	S	V
Material quality	Isotopic composition	239Pu/Pu (wt%)	> 93	80~93	70~80	60~70	< 60
		235U/U (wt%)	> 90	50~90	20~50	5~20	< 5
		232Ucontam. for 233U (ppm)	< 1	1~100	100~4000	4000~7000	> 7000
	Radiation field	Dose (rem/hr)	< 1	1~15	15~100	100~1000	> 1000
	Heat generation	238Pu/Pu (wt%)	< 0.1	0.1~1	1~10	10~80	> 80
	Spontaneous neutron generation rate	(240Pu+ 242Pu) /Pu (wt%)	< 1	1~10	10~20	20~50	> 50
Material quantity	Significant Quantity	Total mass (kg)	10	10~100	100~500	500~1000	> 1000
		No. of items	1	1~20	20~50	50~100	> 100
Material form	Chemical form	U	Metal	Oxide/ Solution	U compounds	Spent fuel	Waste
		Pu	Metal	Oxide/ Solution	Pu compounds	Spent fuel	Waste
		Thorium	Metal	Oxide/ Solution	Th compounds	Spent fuel	Waste
Nuclear technology	Enrichment		Yes			No	
	Extraction of fissile material		Yes			No	
	Irradiation capability of target		Yes			No	

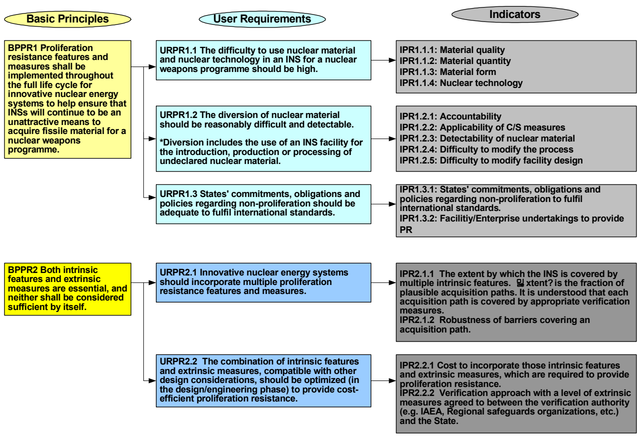

Figure 1. Proposed Indicators for UR-1, -2 and -3 of BP-1