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Relative Proliferation Risks for Nuclear Fuel Leasing Arrangements

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INTRODUCTION

The present study demonstrates a probabilistic approach to quantify the prolifertion risks of fuel leasing and recycling. A Markov model approach is applied to evaluate the probability of proliferation success by diversion or theft. Proliferation risk is calculated as a product of the probability of success and the corresponding consequences.

MARKOV MODEL OF FUEL CYCLES

The Markov chain method has the capability to account for the dynamic features of proliferation [1, 2, 3]. In the Markov model approach, which follows the methodology developed by an international panel [4], the normal flows of nuclear material in the fuel cycle are accounted for and the abnormal flow due to proliferation activities or theft are modeled as a time dependent random process.

The evaluation of the proliferation success probability accounts for both intrinsic (technical difficulties, such as radiation) and extrinsic (safeguards) barriers to proliferation.

The consequence of proliferation is represented by a material type index (MTI with values between 0 and 1) and it is related to the type of material that has been diverted or stolen. A larger index implies the material has a higher potential for weapons use and thus the proliferation would pose more risk.

The characteristics of the fuel cycle scenarios are summarized in Table 1. Each scenario considers the fuel cycle in two types of states and the fuel leasing arrangement between states (countries). Type 1 states include weapon states (fuel suppliers). Other states with certain nuclear facilities belong to the Type 2 states (fuel recipients). These fuel cycles are similar to those studied previously by Reis et al. [5] who evaluated proliferation concerns by assessing the global inventory of weapons useable fissile material under different fuel cycle and leasing scenarios. In contrast, the current study applies a model that enables systematic evaluation of safeguards approaches and different design options with regard to proliferation resistance.

Scenario 1 represents the so-called business as usual scenario, namely open fuel cycle and no lease of fuel between the two types of state (OC-NL). Scenario 2 is a variation of the previous one and it considers fuel leasing in an open fuel cycle environment, (OC-L). Both fuel cycles in Scenarios 3 (closed cycle no lease, CC-NL) and 4 (closed cycle with lease, CC-L) are closed cycles where recycle facilities are present.

In this study, one of the Type 2 states is the proliferator and the target nuclear material can be obtained from both Type 1 states and Type 2 states (itself and/or other Type 2 states). The acquisition of material from a Type 2 host state is a diversion and the acquisition of material from Type 1 states or other Type 2 states is actually a theft, which should be more difficult to succeed than a diversion.

Table 1. Characteristics of Fuel Cycles Modeled by Markov Approach

Fuel Cycle Scenario	Fuel Leasing		Fuel Cycle Type (Recycle Facilities for Closed Cycles)		Reactor Type	
	Type 1 State	Type 2 State	Type 1 State	Type 2 State	Type 1 State	Type 2 State
Scenario 1 (OC-NL)	No	No	Open	Open	LWR#	LWR
Scenario 2 (OC-L)	Supplier	Recipient	Open	Open	LWR	LWR
Scenario 3 (CC-NL)	No	No	Closed (PYRO [6] & UREX+ [7])	Closed (PUREX)	LWR & ABR#	LWR
Scenario 4 (CC-L)	Supplier	Recipient	Closed (PYRO & UREX+)	Open	LWR & ABR	LWR

Light Water Reactor (LWR); Advanced Burner Reactor (ABR)

RESULTS

The goal of the proliferator is to acquire 1 SQ equivalent of either uranium or plutonium. The four scenarios identified in Table 1 are transformed to a Markov chain model, taking into account mass flows (both normal and diversion or theft) and intrinsic and extrinsic barriers to proliferation. The success probability and the corresponding proliferation risk are shown and compared in Figure 1 for plutonium proliferation. The trends for uranium proliferation are similar.

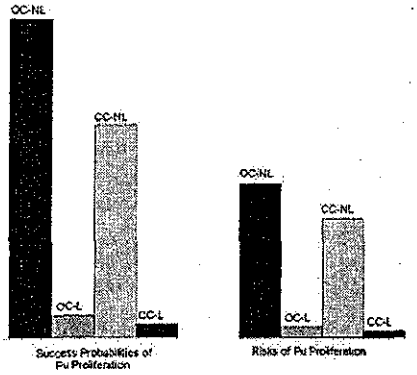

Fig. 1. Comparison of success probability and risk of Pu proliferation.

On a relative basis, proliferation concerns measured in terms of both proliferation success probability and proliferation risk suggest that (1) a fuel lease scheme is more proliferation resistant than without fuel lease; (2) generally a closed fuel cycle is more proliferation resistant than an open fuel cycle but this may change if Type 2 states have large inventories of plutonium from the PUREX recycling process.

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