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Title: Increased Proliferation Resistance for 21st Century Nuclear Power

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Increased Proliferation Resistance for 21st Century Nuclear Power

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Abstract

World energy demand and greenhouse gases are expected to significantly increase in the near future. Key developing countries have identified nuclear power as a major contributor to their future energy sources. Consequently, the United States and others are currently exploring the concept of a Global Nuclear Energy Partnership (GNEP) to address the concerns of nuclear proliferation. This effort is also being encouraged by the International Atomic Energy Agency (IAEA). While the IAEA currently provides the framework for monitoring of state sponsored nuclear proliferation by way of international treaties, a complimentary action is to promote more proliferation resistant fuel cycles and advanced safeguards technology. As such, it is the responsibility of current technology owners to increase their nuclear fuel cycle proliferation resistance. For those countries that have an active and well-developed fuel cycle, it will require future enhancements. For those countries with extensive nuclear energy experience, yet less active programs, it will require re-engagement for technology development and deployment. ~~The~~ following paper discusses potential fuel cycle and technology changes that affect proliferation resistance; and consequently, may form the basis of future technology development efforts.

Introduction

The predominant nuclear fuel cycle in the world for power production is based on thermal reactors in which uranium is the fuel, and plutonium along with other radionuclides are the byproducts. The uranium is often enriched in the fissionable isotope ^{235}U for thermal reactors, to an enrichment level referred to as low-enriched uranium (LEU). This same fuel cycle with modifications, has also been used for production of uranium and plutonium used in nuclear weapons. While production of plutonium for weapons yields a different mix of plutonium isotopes than power production, the plutonium byproduct from power production under specific circumstances can be used for nuclear weapons. Although LEU can not be used for weapons, the technology used to produce LEU can be modified to produce highly-enriched uranium (HEU) for weapons. These are the primary proliferation concerns for global nuclear power production.

While many types of fuel cycles have been researched during the past fifty years, Figure 1 shows the most common proposed and deployed. Of the more common for power production, there are two primary versions of the fuel cycle for thermal reactors (1) the open fuel based on uranium fuel and disposal of spent fuel intact in an underground repository, and (2) the closed fuel cycle where the spent fuel is reprocessed, the plutonium byproduct separated and recycled as fuel, and the remaining radionuclides stored in an underground repository.

The open fuel cycle based on uranium utilizes natural (non-enriched) or enriched uranium. The CANDU thermal reactor utilizes natural uranium which eliminates the need for uranium enrichment technology; however, it does generate plutonium as a byproduct. The thorium fuel cycle, which could be operated as an open or closed fuel cycle, has the advantage of generating ^{233}U rather than plutonium as the byproduct. The ^{233}U byproduct can then be diluted with natural uranium during the separation process to reduce its fissionsability, and recycled as fuel; however, thorium is much less common than uranium as a resource. Once ^{233}U or ^{235}U are diluted with natural uranium it requires isotopic separation to purify.

The common closed fuel cycle for thermal reactors is based on mixed oxide fuel (MOX), a combination of plutonium and uranium. The recycled plutonium can be completely separated, or separated with uranium present, prior to fuel fabrication. Separation of plutonium with uranium will reduce its fissionability. Of the more common for power production, two primary versions of the fuel cycle for fast reactors have been proposed, (1) the breeder reactor, and (2) the burner or transmutation reactor. In both cases plutonium is generated and recycled, and hence the fuel cycle is closed. While both the breeder and burner generate plutonium, the breeder produces considerably more than the burner. The burner however is used to burn, or transmutate, select species of the waste which would otherwise be sent to a repository. These species are either (1) high heat generators, (2) very long lived or (3) highly mobile in the environment.

Reactor Type	OPEN FUEL CYCLE		CLOSED FUEL CYCLE				
	U		Th	Simple Pu		Pu Breeder	Pu Actinide Burner (Transmutation)
	Non-Enriched	Enriched		Pure Pu	Mixed Pu		
Thermal							
Fast							

Deployed	
Proposed	

Figure 1. Common existing or proposed fuel cycles for power production

While plutonium is a byproduct in thermal and fast reactors, it is also a fissionable feedstock highly proliferable in the separated form. With the open fuel cycle the plutonium byproduct remains mixed with the highly radioactive waste as spent fuel; and consequently, has a relatively high proliferation resistance due to a significant tracking signature (high radiation), sophisticated handling requirements (high radiation), and little direct use for weaponization. However, the plutonium byproduct can reduce reliance on uranium, particularly for those countries without significant uranium resources. This plutonium byproduct, in a separated and non-separated state, is currently being used as feedstock in the mixed oxide (MOX) fuel cycle for thermal reactors. In the case of completely separated plutonium, the tracking signature is relatively small (little radiation), the handling requirements are not complex (little radiation), and direct use for weaponization is possible. In the case of separated plutonium with uranium (less than highly enriched), the tracking signature is not significantly greater than pure plutonium, the handling requirements are no more complex than pure plutonium, but the direct weaponization may not be possible depending on the ratio of urnaium to plutonium. It is within this context of proliferability of the existing closed fuel cycle that increased proliferation resistant fuel cycles and enhanced safeguards are being sought.

Discussion

State versus sub-national diversion

The defenses against proliferation differ depending on whether the proliferator is the State or sub-national (such as a terrorist). It is generally considered that a State has the capability to further process, by way of clandestine facilities, nuclear material if they are successful with diversion. On the contrary, it is less likely that a sub-national can further process nuclear material; and therefore, the diverted material must be relatively pure. Consequently, proliferation measures for the sub-national may not be adequate for the State. Figures 2 and 3 are used to show the differences between State and sub-nationals for simplified proliferation scenarios.

Traditionally, it has been the responsibility of the International Atomic Energy Agency to monitor the State, not sub-nationals. Whereas, international agreements with States are possible prior to sharing nuclear technology, similar agreements with sub-nationals do not make sense. Therefore, sub-national proliferation has been managed individually by the States possessing nuclear technology. This is typically done with domestic regulatory agencies such as the Nuclear Regulatory Commission (NRC) in the United States. Other programs for controlling proliferation include the current joint Materials Protection Control and Accounting (MPC&A) program between the United States and Russia. With this program, the United States and Russia share advanced safeguards technology for their nuclear weapons production facilities.

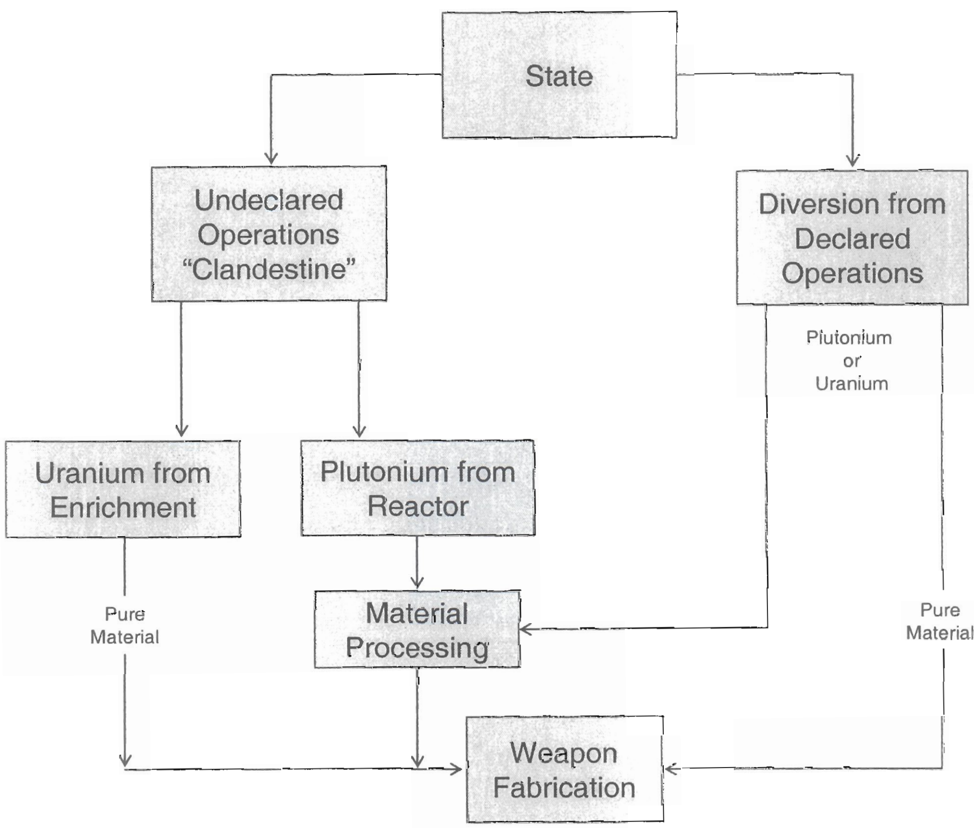

Figure 2. State sponsored nuclear proliferation through the fuel cycle

Fuel cycle enhancements

Two distinct categories of proliferation resistant measures are (1) proliferation resistance due to fuel cycle choices and (2) proliferation resistance due to facility safeguarding. Since there is no such thing as a completely proliferation resistant fuel cycle or nuclear facility, proliferation resistance should be thought of in relative rather than absolute terms.

Examples of fuel cycle choices that increase proliferation resistance include (1) not completely separating recycled Pu from uranium in the closed fuel cycle with thermal reactors (typical MOX fuel cycle), and (2) adding the higher actinide waste (Am, Cm, Np) to recycled Pu in the closed fuel cycle with fast reactors (i.e. transmutation). Avoiding the complete separation of plutonium from LEU decreases the material fissionability if directly used for weapon fabrication. Recycling the higher actinides with plutonium increases the radiation and hence increases the (1) signature for safeguarding, (2) material handling difficulty, and (3) weapon manufacturing difficulty.

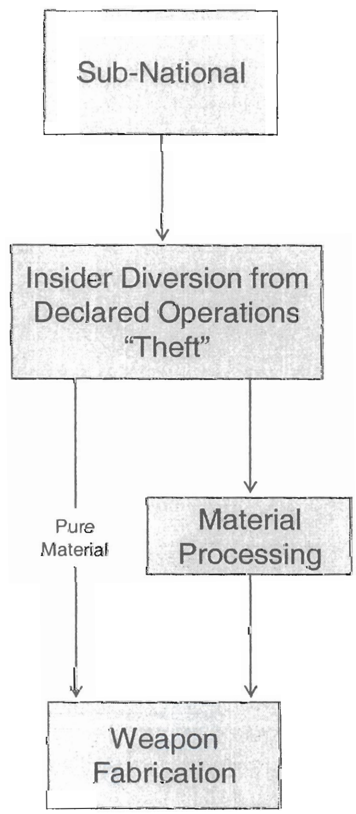

Figure 3. Sub-national sponsored nuclear proliferation through the fuel cycle

While a State, by way of a clandestine processing facility, may be able to overcome fuel cycle nonproliferation measures such as (1) a fuel cycle based on natural uranium (i.e. the absence of enrichment technology), (2) not separating plutonium entirely from uranium to decrease the fissionability of a weapon, or (3) adding the higher actinides to increase the handling difficulty, they may be thwarted by an increased signature that can be used for safeguarding. However, all of these measures should make proliferation more difficult for the sub-national.

Safeguards enhancements

Proliferation resistant measures related to facility safeguarding may include (1) advanced measurement techniques for improved nuclear material accountancy, and (2) advanced additional measures related to containment and surveillance. Figure 4 lists the basic components of nuclear safeguarding.

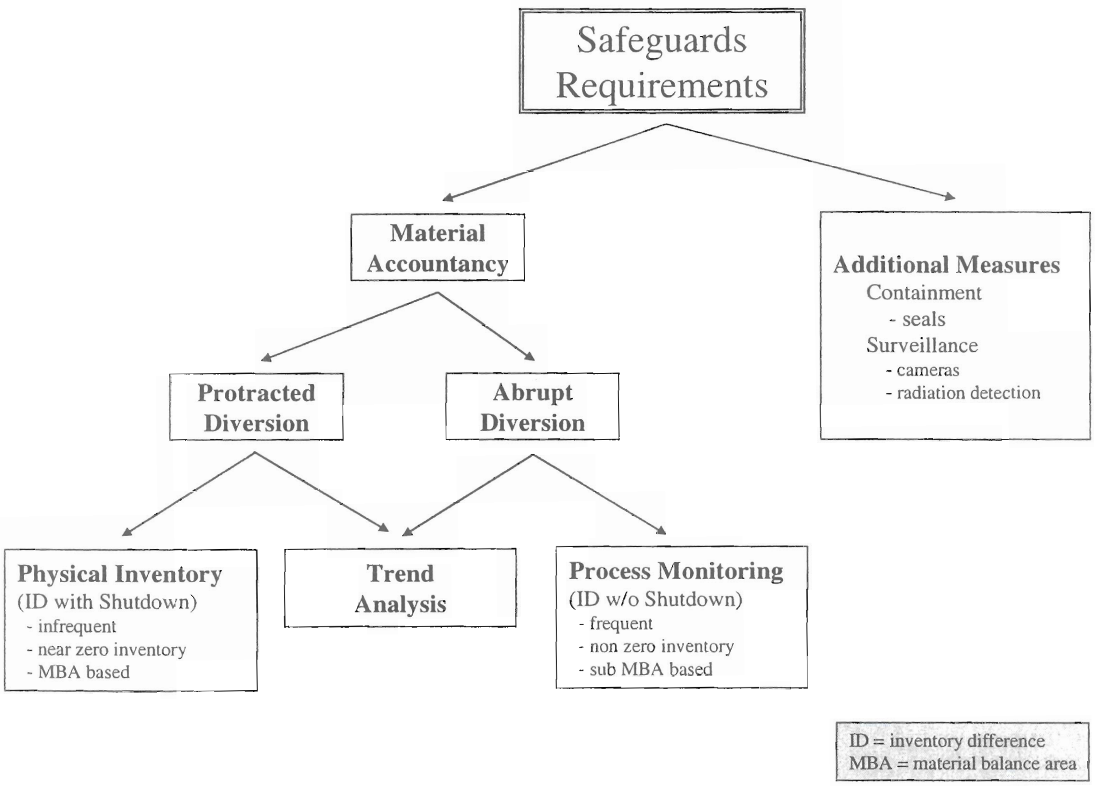

Figure 4. Basic components of nuclear safeguards

Advanced measurement techniques for improved nuclear material accountancy can include non-destructive assay (NDA) in the field and destructive assay (DA) in the laboratory. New fuel cycles will utilize different mixes of nuclear material to be monitored, and future requirements may place accountancy control on material not currently controlled such as the higher actinides. Advanced additional measures will include new technologies as well as enhanced data processing. The increased amount of safeguards data in future facilities will undoubtedly require advanced software interpretation to reduce inspector labor. See Tobin, et. al. for advanced safeguards technology development needs.

Safeguards by Design

As part of the GNEP effort, a "Safeguards by Design" methodology has been proposed for future nuclear facilities. In general terms, Safeguards by Design implies the consideration of safeguards requirements in parallel with the process and facility design, rather than after the fact as has often been done in the past. While the concept is simple enough, the practical implementation is not. Due to the limited use of this approach in the past, the specifics of the methodology are not well established or documented. The practical implementation of Safeguards by Design requires a safeguards design methodology that is integrated with the process and facility design activities.

As an example, if a nuclear facility design is executed in three phases such as (1) conceptual, (2) preliminary and (3) final, the relevant safeguards design activity will be somewhat different in each phase. During the conceptual phase the initial cost estimate is generated; therefore, facility layout and floor space are defined during this phase while the specific instrumentation may not. Additionally, during the conceptual design phase long lead-time technology development requirements need to be identified. The Safeguards by Design methodology attempts to sequence their design activities to best match those of the overall process and facility design effort.

Conclusions

It is likely that non-nuclear countries, that choose nuclear power for their future, will acquire available technology regardless of global proliferation concerns. For increased proliferation resistant fuel cycles and safeguards technology to be available, serious engagement in technology development and deployment by those countries with current nuclear capability is required. As discussed in this paper, there is no shortage of concepts for more proliferation resistant fuel cycles and enhanced safeguards. The issue then becomes not how to increase proliferation resistance for nuclear energy, but rather how to elevate this issue to a global imperative and then act.

References

S. Tobin, et al, Prioritization of Research and Development Needs/Technologies for Safeguards at the Advanced Fuel Cycle Facility, Los Alamos National Laboratory, LA-UR-06-8666, January 2007.