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Complexities in Gauging Time-dependency of Proliferation Resistance

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Abstract
To a considerable extent, policy decisions on nuclear fuel cycle issues depend upon how decision makers recognize and weigh "long-term" and "short-term" nuclear proliferation risk factors. Priorities and structures of advanced fuel cycle and safeguards research and development programs are affected similarly. Unfortunately, there is a diversity of understanding of the precise meanings of these proliferation risk terms, leading to lack of precision in their usage. In addition, proliferation risk evaluation fundamentally involves value judgments on the relative importance of time-dependent risks. Poor communication and diverse conclusions often result. This paper explores some complexities in gauging "long-term" and "short-term" proliferation risk in the context of advanced nuclear fuel cycles. A convenient vehicle for this purpose is a commonly used notional plot of some proliferation resistance attribute of spent fuel or separated plutonium versus years from reactor discharge, often overlain with similar notional curves denoting multiple fuel irradiation and recycle. A common basis for misuse of such plots is failure to clearly define the range of proliferation threats being evaluated, as illustrated by several common examples of such omissions. Partial arguments of this type can be misleading and provide a disservice to policy makers who must have a clear picture of the tradeoffs being made. This paper concludes with a call for much greater care to avoid overly simplistic interpretations of notional proliferation-related concepts and greater precision in general in use of proliferation-related terminology.

Introduction

To a considerable extent, policy decisions on nuclear fuel cycle issues depend upon how decision makers recognize and weigh "long-term" and "short-term" nuclear proliferation risk factors. Priorities and structures of advanced fuel cycle and safeguards research and development programs are affected similarly. Unfortunately, there is a diversity of understanding of the precise meanings of these proliferation risk terms leading to lack of precision in their usage. Poor communication often is the result.

Evaluation of proliferation resistance of various nuclear fuel cycles is a particularly complex problem because both technical and institutional considerations are crucially important. Despite more than fifty years of effort, neither the technical (both fuel cycle and non-proliferation) nor the policy community has found consensus on how to compare the proliferation resistance of one fuel cycle to another. Much of the problem lies in the fact that value judgments are intrinsic to comparing factors even within one of these two categories, much less between the two. Indeed, as discussed below, some specific fuel cycle characteristics can be perceived as diametrically opposed with respect to proliferation resistance, depending upon the evaluator's value judgment on issues, including weighting of short-term and long-term proliferation scenarios.

This paper explores time-dependent complexities in gauging "long-term" and "short-term" proliferation risk in the context of advanced nuclear fuel cycles. A common deficiency in many arguments about proliferation resistance of particular fuel cycles is failure to consider the full range of proliferation threats. References 1-5 provide some backdrop of the technical dimensions of this problem. The arguments often fail to realize that value judgments invariably have to be made about the relative importance of short-term and long-term risks. As a result of initial assumptions, diametrically opposed conclusions can be reached. This paper illustrates this point by focusing on several characteristics of time-dependent plots that are used (implicitly or explicitly) to argue the relative merits of fuel cycles. The example characteristics used in this discussion are:

- the "notch" in the plots is not a notch;
- plutonium "tonnage" is an inappropriate proliferation-resistance metric for some important scenarios; and
- spent fuel characteristics (e.g., dose rate, plutonium isotopics degradation) that may have time dependencies likewise have negligible impact for some important scenarios.

This discussion is especially timely because of ongoing domestic and international technology development in the Generation IV advanced nuclear reactor program and the Advance Fuel Cycle Initiative.

Notch Plots

A convenient vehicle for discussing short-term and long-term proliferation resistance is afforded by the notional plot (example shown in Figure 1, hereinafter referred to as a "notch plot") of some proliferation resistance attribute of fuel assemblies (or some related parameter) as a function of years from reactor discharge. This type of plot, sometimes used by proponents of advanced fuel cycle programs, often is overlain with a similar notional plot with recycle. Figure 1 presents an example of such a plot.

The smoothly declining curve of Figure 1 for the once-through cycle intends to depict the decline in some proliferation resistance attribute (or collection of attributes) such as contact handling dose rate. The sawtooth curve for a fuel cycle involving reprocessing intends to portray an overall life-cycle increase in proliferation resistance (e.g., through reduction of global plutonium inventories, degradation of plutonium isotopics, or some other attribute). Usually it is argued that these perceived benefits outweigh the reduction in proliferation resistance during a presumed short period of time when plutonium exists in a state separated from the spent fuel.

Some of the ensuing discussion in this paper uses Figure 1 to highlight time-dependent complexities in evaluating proliferation resistance of advanced fuel cycles. Examples discussed below will show that plots of this type are easily misused or misinterpreted and can lead to dangerously erroneous conclusions if not used with high precision.

Imprecision in Proliferation Resistance

Many factors contribute to the lack of precision that plagues discussion of proliferation resistance. This lack of precision contributes strongly to widespread confusion in both technical and policy discussions. Indeed, it has been difficult for the technical community to agree on definitions of either "proliferation" or "resistance", much less the combination of terms (e.g., see Reference 1).

Thus, it should be no surprise that the many past efforts to quantify proliferation resistance have usually led to more frustration than clarity. Confusion and possible technical error also derives from failure of the technical community to clearly define the full scope of proliferation scenarios, and/or failure to acknowledge that judgment calls inevitably have to be made by policy makers in weighing the various scenarios.

The ordinate of Figure 1 sometimes is simply labeled "proliferation resistance", with insufficient definition of the parameter (or set of parameters) being evaluated. Often it is unclear what set of proliferation scenarios are being considered. As an example, if the proliferation resistance metric is global plutonium tonnage, the argument may have merit for limitation or rollback of vertical proliferation (major arsenal scenarios). However, global plutonium tonnage has relatively little to do with the very short-term lateral proliferation threats involving very small numbers of weapons that dominate today's news. Lack of clarity of whether lateral or vertical proliferation is the scenario being addressed pervades advanced fuel cycle technology development discussions.

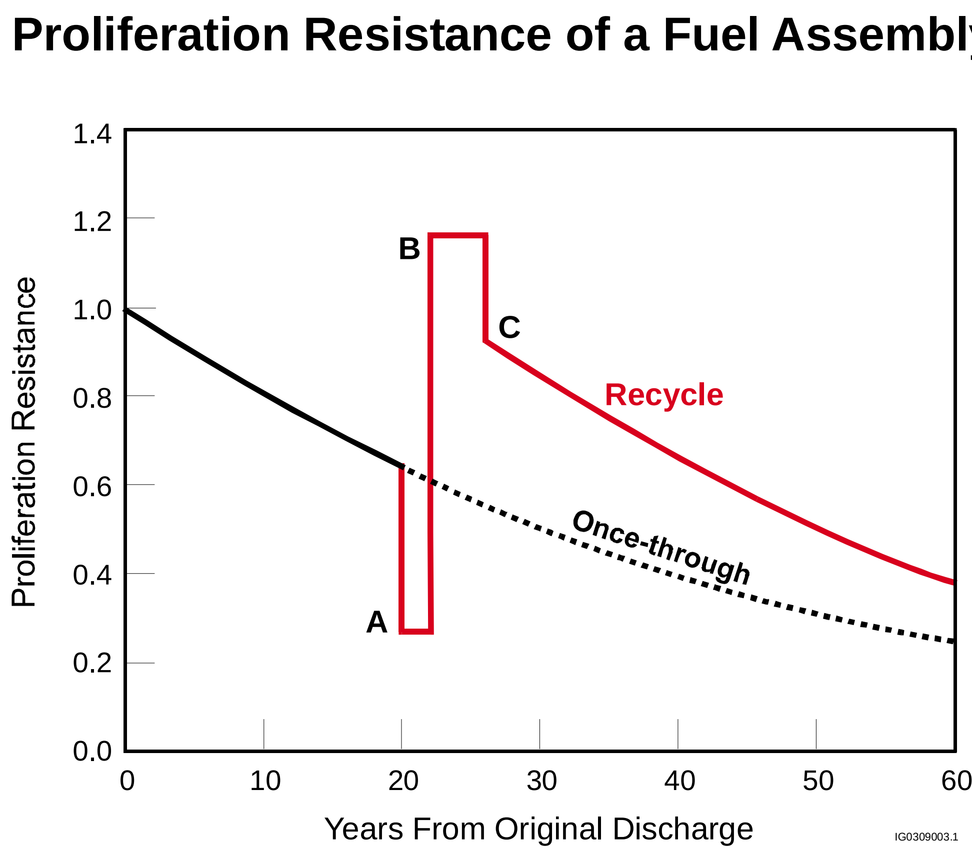

Figure 1. Notional Plot of Proliferation Resistance of Fissile Material in Spent Nuclear Fuel as a Function of Time and Fuel Cycle. This plot has been excerpted from the Blue Ribbon Non Proliferation Panel Committee Status Report (September 15, 2003).

Importance of Proliferation Resistance Time Frames and Scenarios

Table 1 summarizes time frames of interest for advanced nuclear fuel cycle research and development. In general, technology development programs such as AFCI cannot make major impact on short-term fuel cycle deployment (< 10 years). It follows that advanced fuel cycle development can have only minimal impact on proliferation resistance in the short term.

Table 1. Proliferation resistance time frames of interest for advanced nuclear fuel cycle research and development.

Time frame	Duration (years)	Comments
Near term	0-10	Too short to be impacted by current technology development
Intermediate term	10-30	Potentially impacted by current technology development
Long term	30-100 years	May be strongly impacted by advanced technology development
Very long term	100-10,000 years (or more)	Well beyond historic lifetimes of nation-state governances

Conversely, long-term time frames far exceed historic lifetimes of nation-state governances. For example, three of the five current nuclear weapons state have experienced multiple, dramatic changes in governance in the past 100 years. Thus, dramatic nation-state institutional changes are more the norm than the exception and can easily overwhelm any technical developments in proliferation resistance.

As a result, decision makers can reach diametrically opposed positions in their evaluations of advanced fuel cycles, depending upon how they weigh short-term and long-term proliferation scenarios (considering both technical and institutional factors). In this regard, it is also interesting to note strong divergences within the technical communities about how to weight short-term and long-term factors. In general, the non-proliferation community is far more concerned with near- and intermediate-term scenarios than with very long-term scenarios. In particular, some short-term scenarios involving even one weapon are tremendously worrisome. In contrast, many advanced fuel cycle advocates emphasize proliferation risk reduction in the very long-term (repositories) and scenarios involving many tons (potentially hundreds or thousands of weapons).

Figure 1 is useful for highlighting this dilemma. Many in the non-proliferation community would argue that the even a short-term spike in separated plutonium inventories resulting from a new separations facility would always outweigh any long-term concern they might have about unseparated buried materials centuries or millennia in the future. Discussions utilizing notch plots also tend to disregard breakout scenarios not involving nation-state regime changes and utilization of safeguarded facilities to develop indigenous nuclear technology bases.

There Is No Strong Consensus on Proliferation Resistance Metrics

As mentioned above, "proliferation resistance" has robust meaning only as a cumulative measure taking into account a broad range of technical and non-technical factors and a specific set of well defined scenarios. The relevant technical communities have yet to reach consensus on how to do this accounting. Unfortunately, notch plots sometimes are used to advocate a technical approach emphasizing the perceived advantage of one (or perhaps a few) non-proliferation attributes—and usually with a subset of assumed proliferation scenarios. Such an oversimplified approach can lead to unjustified conclusions and uninformed decision making.

The "Notch" Is Not Really a "Notch"

Notch plots as usually depicted really are more germane to a single batch of spent fuel making its way through a reprocessing cycle than to the way in which a plant will actually be operated. This is because reprocessing plants generally will operate in a nearly continuous mode involving many batches of spent fuel per year. Thus, a more or less steady stream of separated plutonium will exist in the operating plant and the total material flow for the plant will wash out the notch structure appearing in Figure 1. This steady state will involve non-trivial amounts of separated plutonium—probably tens of tons and perhaps hundreds of tons for a large separations facility. Thus, depicting material flow as in Figure 1 can be misleading. In addition, arguments that highly attractive separated plutonium is available only for "short" periods of time may be specious. Conceptually, sufficient plutonium can be diverted in a very short period of time to be of concern.

Plutonium Tonnage

The potential reduction of global plutonium tonnage via recycle sometimes is argued as an important non-proliferation characteristic of some advanced fuel cycles. This argument has validity principally for scenarios involving large numbers of new nuclear weapons (hundreds or thousands). It can be argued that such scenarios are exceedingly scenario-specific (state-specific), either for vertical proliferation among existing weapons states or horizontally to new weapons states. Indeed, current events can be used to argue that the most important near-term threat is the development by national or sub-national entities of very small numbers of nuclear weapons. The "tonnage" argument would appear to be relatively less important for the latter scenarios.

Spent Fuel Characteristics

It is often argued that a significant non-proliferation advantage accrues from the degradation of plutonium isotopic compositions, as a result of increased reactor exposure in recycle scenarios, from "weapons-grade" material used in high-performance nuclear weapons. This can be a contentious issue, but the fact is that plutonium isotopic composition is not recognized as an important safeguards factor by either the International Atomic Energy Agency or the U.S. government, except for materials where the Pu-238 isotopic fraction is greater than 80%. The nexus of the contention really is based on the presumed proliferation scenarios. Whereas weapons-grade material is indeed desirable for sophisticated weapons systems, other very credible threat scenarios involving devices of much lower reliability and yield can utilize much lower grade materials.

A similar situation pertains to arguments involving the higher dose rates of multiple-recycle materials. Dose rate decrease has little importance for some important proliferation scenarios.

Conclusions

Notch plots typically are used to argue that a recycle scenario can lead to an improved global non-proliferation posture. Essentially, this is a reincarnation of a debate that has existed for about sixty years—does spent fuel recycle involving plutonium separation help or hurt non-proliferation? The debate on this question is as important and intense today as it ever has been. It will not be settled by overly simplistic arguments. Indeed, the “answer” depends very strongly on complex assumptions that are deeply value-based and often depend upon weighting of time-dependent factors.

Based on the preceding discussion, we argue that much greater care is needed by both the non-proliferation and fuel cycle communities to avoid overly simplistic interpretations of notional proliferation-related concepts. In general, much greater precision is needed in use of proliferation-related terminology to avoid highly misleading advocacy and conclusions.

In the end, decisions about deployment of advanced nuclear fuel cycles will be made by policy makers who must weigh a variety of technical, economic and institutional factors. Most of these decision makers will not have deep technical backgrounds. It is imperative that both fuel cycle and non-proliferation communities communicate, in as unbiased, accurate and transparent fashion as possible, the technical dimensions of the problem.

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