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LA-UR-09-xxxxx

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Intended for: Global 2009 International Conference
Paris France
6-11 September 2009
(internal and external to LANL)

Los Alamos
NATIONAL LABORATORY
EST. 1943

Proliferation Resistance: Issues, Initiatives and Evaluations

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Abstract

The vision of a nuclear renaissance has highlighted the issue of proliferation resistance. The prospects for a dramatic growth in nuclear power may depend on the effectiveness of, and the resources devoted to, plans to develop and implement technologies and approaches that strengthen proliferation resistance. The GenIV International Forum (GIF) and others have devoted attention and resources to proliferation resistance. However, the hope of finding a way to make the peaceful uses of nuclear energy resistant to proliferation has reappeared again and again in the history of nuclear power with little practical consequence. The concept of proliferation resistance has usually focused on intrinsic (technological) as opposed to extrinsic (institutional) factors. However, if there are benefits that may yet be realized from reactors and other facilities designed to minimize proliferation risks, it is their coupling with effective safeguards and other nonproliferation measures that likely will be critical. Proliferation resistance has also traditionally been applied only to state threats. Although there are no technologies that can wholly eliminate the risk of proliferation by a determined state, technology can play a limited role in reducing state threats and perhaps in eliminating many non-state threats. These and other issues are not academic. They affect efforts to evaluate proliferation resistance, including the methodology developed by GIF's Proliferation Resistance and Physical Protection (PR&PP) Working Group as well as the proliferation resistance

[1] The views expressed are the author's own and not those of the Los Alamos National Laboratory, the National Nuclear Security Administration, the Department of Energy or any other agency.

initiatives that are being pursued or may be developed in the future. This paper will offer a new framework for thinking about proliferation resistance issues, including the ways the output of the methodology could be developed to inform the decisions that states, the International Atomic Energy (IAEA) and others will have to make in order to fully realize the promise of a nuclear renaissance.

Introduction

The vision of a nuclear renaissance has highlighted the issue of proliferation resistance. The prospects for a dramatic growth in nuclear power may depend on the effectiveness of, and the resources devoted to, plans to develop and implement technologies and approaches that strengthen proliferation resistance. The GenIV International Forum (GIF) and others have devoted attention and resources to proliferation resistance. However, the hope of finding a way to make the peaceful uses of nuclear energy resistant to proliferation has reappeared again and again in the history of nuclear power with little practical consequence. This highlights the need to understand fully the proliferation resistance initiatives that are being pursued or may be developed in the future, and the importance of efforts to evaluate proliferation resistance, including the methodology developed by GIF's Proliferation Resistance and Physical Protection (PR&PP) Working Group. This paper will offer a new framework for thinking about proliferation resistance issues, including the ways the output of the methodology could be developed to inform the decisions that states, the International Atomic Energy (IAEA) and others will have to make in order to fully realize the promise of a nuclear renaissance.

Enduring Interest in Proliferation Resistance

Since the beginning of the atomic age, it was recognized that the materials, facilities and skills comprising civilian nuclear fuel cycles could potentially be used in nuclear-weapon programs. These concerns led to sweeping international debates and extraordinary proposals for material control in the late 1940s and into the '50s. They also led to a hope that the link between the civil and the military atom could be mitigated if not eliminated. The idea of proliferation resistance, which reflects this hope, is as old as the Acheson-Lilienthal report. For the authors of the report, certain activities were seen as more proliferation resistant than others, and there was an effort to identify technological "fixes" or intrinsic fuel-cycle measures that could be used to reduce proliferation dangers. This was evident in the Acheson-Lilienthal report's discussion of "denaturing."[2]

The hope that even the sober authors of the Acheson-Lilienthal report could not shake of finding a way to make the peaceful uses of nuclear energy resistant to proliferation appears and reappears in the history of nuclear power. The assumptions (both right and wrong) and issues considered in Acheson-Lilienthal were largely reflected in the Atoms-

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[2] According to the report: "...U 235 and plutonium can be denatured; such denatured materials do not readily lend themselves to the making of atomic explosives, but they can still be used with no essential loss of effectiveness for the peaceful applications of atomic energy. They can be used in reactors for the generation of power or in reactors useful in research and in the production of radioactive tracers. It is important to understand the sense in which denaturing renders material safer. In the first place, it will make the material unusable by any methods we now know for effective atomic explosives unless steps are taken to remove the denaturants. In the second place, the development of more ingenious methods in the field of atomic explosives which make this material effectively useable is not only dubious, but is certainly not possible without a very major scientific and technical effort." (*A Report on the International Control of Atomic Energy*, pp. 26-27.) The report recognized that denaturing could be reversed, but held that "doing so calls for rather complex installations which, though not of the scale of those at Oak Ridge or Hanford, nevertheless will require a large effort and, above all, scientific and engineering skill of an appreciable order for their development." (Ibid., p. 27.)

for-Peace proposal and the nonproliferation regime based on its bargain, and remain with us today. The issue of proliferation resistance appear in the Nonproliferation Alternative System Assessment Program (NASAP) and in the International Nuclear Fuel Cycle Evaluation (INFCE) in the late 1970s and early 1980s. Later analyses, including the "TOPS" report of DOE's Nuclear Energy Research Advisory Committee have also reinforced the view that there is no simple technical fix or "silver bullet" to this problem, while nonetheless placing great hope in proliferation resistance.[3]

The Current Debate

The world has changed since 1946, when the Acheson-Lilienthal report was written. The environment today is also very different than those in which INFCE, NASAP and TOPS appeared. The current debate over proliferation resistant fuel cycles is beginning to be reengaged on a level not seen since the 1970s. There are, as in the past, expectations of dramatic growth in nuclear power; concerns about reprocessing and plutonium use; and perceptions of rising proliferation threats.

But there are major differences as well. Today proliferation dangers appear more real or concrete, with growing concerns about the international nuclear nonproliferation regime's ability to address them. Although reprocessing and closed fuel cycles have long been a concern, and have been highlighted in the last two years because of the Global Nuclear

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3 *Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems*, Report by the TOPS Task Force of NERAC (October 2000). See also, e.g., *Nuclear Power and Proliferation Resistance*, A report by the Nuclear Energy Study Group of the Panel on Public Affairs. American Physical Society, May 2005, at <www.aps.org/public_affairs/proliferation-resistance/>

Energy Partnership, the spread of uranium enrichment technology as a result of the A.Q. Khan network has highlighted the risks from highly enriched uranium (HEU). Given the difficulty of detecting clandestine gas centrifuge facilities, some have questioned the proliferation resistance of once-through fuel cycles that require increasing enrichment capability if nuclear power grows as expected, with an even wider spread of enrichment technology worldwide.

The risks today are also increasingly seen to be emerging from unanticipated sources, including non-state networks and terrorists. The prospect of nuclear terrorism is receiving unprecedented attention (although it was a factor in the debate during the 1970s). After 9/11, some concluded the danger of any use of nuclear power was too great to accept.[4]

There is a clear recognition that these threats must be dealt with if the promise of nuclear energy is to be realized. Moreover, the desire for energy independence has led to increased interest in nuclear energy. And global warming concerns have convinced many, including some staunch environmentalists, of the need to pursue nuclear power aggressively.[5] Moreover, to address rising concerns about proliferation and terrorism, strong efforts to reduce nuclear power's risks and vulnerabilities are being proposed and undertaken.

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[4] See, e.g., Ralph Nader, "Nuclear Power is not the Answer," 11 September 2007 at <http://www.commondreams.org/archive/2007/09/11/3761/>

[5] See, e.g., Patrick Moore, "Nuclear power: Massachusetts is facing up to Carbon Choices," *Patriot Ledger*, 12 April 2008 at http://www.patriotledger.com/opinions/x1403477302; and James Lovelock, "Nuclear Power is the only Green Solution," *The Independent*, 24 May 2004 at <http://www.ecolo.org/media/articles/articles.in.english/love-indep-24-05-04.htm>

In this new environment, proliferation resistance is becoming increasingly important. Although there has been some controversy and continued debate over the meaning of proliferation resistance, the International Atomic Energy Agency (IAEA) developed a widely accepted definition that remains interested in the technological elements of proliferation resistance that go back to the Acheson-Lilienthal report but also looks explicitly at institutional elements. According to the IAEA: "Proliferation resistance is that characteristic of the nuclear energy system that impedes the diversion or undeclared production of nuclear materials, or misuse of technology, by the host state in order to acquire nuclear weapons or other nuclear explosive devices."[6]: "Extrinsic proliferation resistance features," according to the IAEA, "are those features that result from the decisions and undertakings of states related to nuclear energy system."[7] As for intrinsic features, the IAEA states: "Intrinsic proliferation resistance features are those features that result from the technical design of nuclear energy systems, including those that facilitate the implementation of the extrinsic measures."[8]

In light of current notions of proliferation resistance, along with the technical realities underlying them, it is clear that both so-called "intrinsic" and "extrinsic" measures as defined by the IAEA have limitations. Neither alone is "foolproof." Together they may be more robust and both must be included in any efforts to reduce proliferation now or in the future. There are potential benefits that may yet be realized from reactors and other

[6] IAEA, STR-332, "Proliferation Resistance Fundamentals for Future Nuclear Energy Systems," Report on COMO meeting held in Como, Italy, October 28-31, 2002.
[7] Ibid.
[8] Ibid.

facilities designed to minimize risks coupled with effective safeguards and other nonproliferation measures. However, the technological and political feasibility of, and the prospects for, various measures need to be soberly assessed, with the costs, operational impacts, safeguards impacts and other factors fully taken into account.

Intrinsic Proliferation Resistance

Intrinsic factors have been seen as measures that would reduce the attractiveness or accessibility of nuclear materials or those that would increase the technical difficulty, cost and time required for diversion in, or misuse of, facilities for weapon purposes.[9] From this perspective, proliferation resistance approaches being pursued include efforts to avoid or to limit the use of weapon-useable material in power production and to design or retrofit reactors and other facilities to reduce their vulnerability to diversion or misuse. More specifically, among the new ideas for addressing underlying proliferation concerns using intrinsic measures, there is interest in developing advanced fuels that are more proliferation resistant. The idea of proliferation-resistant small reactors with long-lived cores to allow expanding nuclear power to the developing world without increased proliferation risks is also being pursued.

Material Quality

Material attractiveness or quality has also long been one key measure or metric for intrinsic proliferation resistance. It is recognized that radiological and thermal emissions can in

[9] For a discussion of proliferation resistance measures, including material quality and technical difficulty, see the *Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems*, Revision 5, 2006, PR&PP Expert Group, Generation IV International Forum, GIF/PRPPWG/2006/005..

some cases, as in spent fuel, provide intrinsic barriers to the material and make it to some degree "self-protecting" by limiting access and increasing the difficulty and dangers of handling. There have been proponents in the GNEP program and elsewhere of the proliferation resistance benefits of not separating plutonium from other actinides and perhaps other fission products. It has been argued that the resulting material would be less attractive for use in a nuclear weapon. Although not self-protecting or able to meet the so-called "spent fuel standard," this approach may make the theft of the resulting material by nonstate actors more difficult. As was the case with denaturing, however, this or other such approaches do not fully address the threat posed by states, which in most cases will have the capabilities and resources necessary to process the material in order to remove any barriers. This approach has other problems as well. The high radiation levels that can provide a barrier to material theft, and make the material somewhat less attractive for weapons, can interfere with materials accounting and make safeguards measurements far more difficult. Moreover, they would likely also have adverse operational impacts on nuclear facilities, including increasing costs. Other proposals that attempt to use material attractiveness to achieve proliferation resistance have similar issues. Accordingly, material quality should be considered not as an abstract value but in the context of the capabilities, motivations and strategies of states as well as nonstate adversaries.

Technical Difficulty

Technical difficulty has also been a key measure of proliferation resistance. No proliferation resistance measures—or indeed any other nonproliferation measures—can physically prevent a state from acquiring nuclear weapons if it decides that they are in its interests. In this context, proliferation resistance can only involve efforts to increase the technical difficulty, cost and time that is needed by the proliferators. This reflects the interest in technical difficulty as a nonproliferation measure. Increasing technical difficulty can be an important objective, but it is by no means purely intrinsic. Like material quality, it depends on the adversary. It must be recognized that it will in most cases be most effective if the state is not technologically advanced. The impact of technical impediments in proliferation resistance on non-state actors can be far more significant.

Non-State Actors

As suggested, both material quality and technical difficulty point to a basic reality—they depend on the capability of the actor. Although we have thought about measures primarily in terms of states, where as suggested they can have only a limited role, they may be more important for non-state actors and could complement current physical protection practices. Technology can play a role in reducing and perhaps in certain circumstances eliminating many non-state threats R&D in this arena may lead to new approaches in the future. However, even though the current approaches are directed against state threats, they arguably have some utility for non-state threats and need to be evaluated from that perspective.

Discrimination

There may be a problem of discrimination—of creating a new divide between states in perception if not in reality—hidden in the promotion of proliferation resistance. If proliferation resistance is limited for states, and especially for advanced industrial states, will these states argue that any measures are unnecessary for them and should be limited to less advanced states creating a new divide between states? Or should advanced states accept proliferation resistance even though the measures are largely irrelevant to them? In either case, there may be the perception of discrimination. Acceptance of proliferation resistance under these circumstances is by no means inevitable. There are three possibilities. Proliferation resistance measures will be acceptable to all, or they will be imposed on only those states that can least afford them or they will be ignored all together. Given this dilemma, it seems likely that relatively inexpensive measures with limited operational impacts will be most acceptable. Proliferation resistance measures may also be more acceptable if they are argued as necessary to address emerging non-state threats.

Safeguardability

The concept of proliferation resistance has usually focused on intrinsic as opposed to extrinsic factors. However, if there are benefits that may yet be realized from reactors and other facilities designed to minimize proliferation risks, it is their coupling with effective safeguards and other nonproliferation measures that likely will be critical. A novel approach that spans the intrinsic and extrinsic divide involves designing new technologies and facilities that embody cost-effective means to safeguard the material or, where possible, refitting old facilities and technologies to make them more "safeguardable." The objective is to improve the application of safeguards by, for example, reducing or eliminating diversion or misuse pathways or increasing the prospects for detection along pathways by facilitating verification, including development and use of more advanced safeguards technologies and approaches involving greater physical access as well as increased process and operating information, among other things. The ability of states to modify processes that are designed to be proliferation resistant highlights the need for both safeguards by design and continuous design information verification. Efforts to address problems in safeguards implementation should be a proliferation resistance priority. This can improve safeguards efficiencies as well as proliferation resistance. However attractive, the feasibility, costs, operational impacts and other possible effects of such approaches have not yet been demonstrated and will need to be analyzed further.

Extrinsic Proliferation Resistance

Even with enhancing safeguardability, the limits of intrinsic factors, particularly in the present day fuel cycle, means that there will be a significant role for extrinsic factors in any effort to promote proliferation resistance. A foundation for this are the various measures—from safeguards and physical protection to export controls—embodied in the international nuclear nonproliferation regime. There are also initiatives designed, in part, to further proliferation resistance through reliable supply, nuclear fuel leasing and other proposals.

Advanced Safeguards

Safeguards play a dramatically different role in the current proliferation resistance debate today than in the past. Far from adopting the view of the authors of the Acheson-Lilienthal report,[10] safeguards have been increasingly relied upon to address proliferation concerns across the nuclear fuel cycle. A key to proliferation resistance is the development of advanced safeguards in a defense-in-depth configuration fully responsive to emerging threats. Elements of a defense-in-depth safeguards approach include, inter alia:

- state-of-the-art instrumentation and methodologies for materials measurement, accounting and tracking, including sensor platform integration;
- enhanced containment and surveillance, including portal and area radiation monitoring, and measures to assure the absence of materials or radiation signals;
- integration of access denial and transparency elements of physical protection and safeguards; and
- integration of traditional process monitoring with non-traditional indicators, such as detection of radiation signals where they should not be, questionable movement of equipment and people, etc.

This approach should also utilize systems analysis to evaluate design tradeoffs between facility operations, safeguards effectiveness and cost, as well as to assess the effectiveness of an integrated safeguards system as a whole.

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[10] The report effectively rejected inspections. According to the report: "We have concluded unanimously that there is no prospect of security against atomic warfare in a system of international agreements to outlaw such weapons controlled only by a system which relies on inspection and similar police-like methods. The reasons supporting this conclusion are not merely technical, but primarily the inseparable political, social, and organizational problems involved in enforcing agreements between nations each free to develop atomic energy but only pledged not to use it for bombs." (*A Report on the International Control of Atomic Energy*, pp. 4-5.)

Next generation safeguards technologies will include:

- integrated facility design to enable advanced safeguards and eliminate/minimize proliferant facility designs;
- intrinsic transparency in facility operations; and
- more robust integration of physical protection and safeguardability.

International Control

International control has again emerged as a potential fix to the proliferation problem. The ADA proposal in the Acheson-Lilienthal report had as one of its objectives organizing fuel cycle activities to make the application of safeguards more "manageable."[5] Proposals by President Bush and those of International Atomic Energy Agency Director General Mohammed ElBaradei can be seen in the context of this long-standing desire. The Bush Administration's Global Nuclear Energy Partnership depended on slowing, if not halting, the spread of enrichment and reprocessing (ENR) technologies (and other sensitive nuclear technology); and creating a fully functioning, secure, effective and nondiscriminatory assured supply/takeback regime that would enable the political acceptance of ENR restrictions. Multinational or multilateral ownership and operation have been proposed by ElBaradei as a means to address this issue.[11] In both cases, the inherent difficulty of dealing with latent proliferation scenarios is recognized and addressed though the elimination of national facilities.

[11] See, Mohamed ElBaradei, "Toward a Safer World," *The Economist*, 18 October 2003. See also the report of experts that followed up the original ElBaradei proposal, *Multilateral approaches to the Fuel Cycle*, Expert Group Report submitted to the Director General of the International Atomic Energy Agency, issued as INFCIRC/640 at <www.iaea.org>

Evaluating Proliferation Resistance

If proliferation resistance is to be real, it will need to be pursued through an integrated strategy involving intrinsic (technological) and extrinsic (institutional) factors. As there are no simple technological fixes or "silver bullets," both features must be seen as important and both require extensive analyses and R&D, particularly on their effectiveness, cost and operational impacts. However, the complexity of the issues and the prospect of tradeoffs[12] all point to the need for a systematic evaluation methodology. The GIF realized that an evaluation methodology would be essential to meeting the proliferation and physical protection goals of the Generation IV roadmap, which were to increase assurances that any GenIV system would offer a "very unattractive" and, indeed, the "least desirable" path for the diversion or theft of weapon-usable.[13]

The Proliferation Resistance and Physical Protection (PR&PP) Working Group under GIF has been formulating a methodology for determining the proliferation resistance as well as physical protection characteristics of advanced nuclear energy systems under the auspices of the GIF. The evaluation methodology, which is described in Revision 5 of the PR&PP report, terms, involves identifying the threat space for a given nuclear fuel cycle, assessing the system's responses to the identified threats and projecting outcomes. More specifically, the methodology requires the development of detailed pathways by which

[12] Whether intrinsic or extrinsic, but especially for intrinsic measures, efforts to enhance proliferation resistance can be in conflict with other objectives. For example, the high radiation levels that can provide important barriers to material theft, and make material somewhat less attractive for weapons, can interfere with materials accounting. Another example involves recognized tradeoffs between security and safety.

[13] See *A Technology Roadmap for the Generation IV Nuclear Energy Systems*, issued by the US Department of Energy's Nuclear Energy Research Advisory Committee and the Generation IV International Forum, December 2002.

state or non-state actors could obtain weapon-usable materials from a given fuel cycle system; and the assessment of the performance of safeguards and other proliferation resistance and physical protection measures across those pathways. The comparative analysis of performance under a number of scenarios provides a gauge of the systems' levels of proliferation resistance and physical protection.

The evaluation methodology endeavors to take into account the system's intrinsic and extrinsic features. Separate measures for comparing the robustness of proliferation resistance and physical protection features relevant, respectively, to the host state and non-state threats were developed under the PR&PP approach. For proliferation resistance, the measures are:

- *Proliferation Technical Difficulty* (TD) – The inherent difficulty, arising from the need for technical sophistication and materials-handling capabilities, required to overcome the barriers to proliferation[14].

- *Proliferation Cost* (PC) – The economic and staffing investment required to overcome the technical barriers to proliferation, including using existing or new facilities.

- *Proliferation Time* (PT) – The minimum time required to overcome the barriers to proliferation (i.e., the total time assigned by the Host State to the project).

[14] Barriers refer to intrinsic barriers (e.g., technical difficulty) and extrinsic ones (e.g., safeguards) but do not include difficulties in weaponization.

- *Fissile Material Type* (MT) – A categorization of material based on the degree to which its characteristics affect its utility for use in nuclear explosives (e.g., bare sphere critical mass, neutron emissions, heat).

- *Detection Probability* (DP) – The cumulative probability of detecting a proliferation segment or pathway.

- *Detection Resource Efficiency* (DE) – The efficiency in employing staffing, equipment, and funding to apply international safeguards to the nuclear energy system.

In principle, if these measures are combined, they can provide information for policy makers and system designers to compare specific system design features and integral system characteristics and to allow informed choices among alternative options. In practice, there are challenges for PR&PP evaluations, including incomplete information, the need for assumptions and significant uncertainties. The choice of metrics and the ranges associated with the linguistic variables can affect how evaluations are performed and how the choices are influenced by uncertainties. Material quality and Technical Difficulty should be considered not as abstract values, but in the context of the capabilities, motivations and strategies of states as well as nonstate adversaries. The weighting of measures is also an issue. The importance of detection probability and possibly detection resource efficiency as proliferation resistance measures has been suggested by early analyses.[15]

These and other problems will have to be and are being addressed. An evaluation capability with broad international agreement is necessary for the progress of nuclear energy that is economic, safe and environmentally benign without increasing proliferation or terrorism risks.

Conclusions

The Acheson-Lilienthal report reflected the recognition that technical fixes to prevent proliferation were limited. But the hope that it could not shake of a technical fix that would make nuclear power resistant to proliferation appears and reappears in the history of nuclear power. Institutional solutions were also limited. Inspections by themselves were rejected in Acheson–Lilienthal. But the idea of international control envisaged in the report would be of primary importance in the nonproliferation endeavour and in thinking about future proliferation resistance.

As we look at nonproliferation efforts in the current threat environment, it is important to recognize that no proliferation resistant measures can prevent a state from acquiring nuclear weapons if it makes a decision to do so. As noted, proliferation resistance can in principle increase the cost and time needed by the proliferators. This can be an important

[15] See *Report of an Elicitation on an Example Sodium Fast Reactor (ESFR) System in Support of the Proliferation Resistance and Physical Protection (PR&PP) Working Group*, by Kory W. Budlong Sylvester, Charles D. Ferguson, Eduardo Garcia, Gordon D. Jarvinen, Joseph F. Pilat and James W. Tape, Los Alamos National Laboratory, October 1, 2008.

objective, but it must be recognized that it is far from "proliferation proof." Looking ahead, if proliferation resistance is to be real, it will need to be pursued through an integrated strategy involving intrinsic (technological) and extrinsic (institutional) factors. As there are no simple technological fixes or "silver bullets," both features must be seen as important and both require extensive analyses and R&D, particularly on their effectiveness, cost and operational impacts. This means that an internationally agreed evaluation methodology is absolutely necessary, as has been developed and is being improved by the PR&PP Working Group.