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Washington Internships for Students of Engineering

Addressing Proliferation Concerns for a New Generation

A Study of the Generation-IV Nuclear Energy Systems Initiative and its Relation to National Non-proliferation Goals

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TABLE OF CONTENTS

Background

Public Policy Issues

The Proliferation Resistance Argument

Generation-IV Proliferation Resistance Performance

Conclusions and Recommendations

ABOUT THE AUTHOR

Wayne Blaylock is currently a senior studying chemical engineering at Tennessee Technological University. His primary academic interests are nuclear studies, both scientific and historical, and compressible fluid dynamics. From May 2001 to May 2002 he was on a cooperative education assignment at Y-12 National Security Complex in Oak Ridge, Tennessee where he worked as a Chemical Process Design Engineer supporting Enriched Uranium Operations. This paper evaluates the Department of Energy's suggested Generation-IV advanced nuclear fuel cycles from a standpoint of nuclear non-proliferation policy and is the result of research conducted during the 2002 Washington Internships for Students of Engineering (WISE). His internship was co-sponsored by the American Institute of Chemical Engineers and the American Nuclear Society.

ABOUT WISE

The Washington Internships for Students of Engineering is a ten-week program that brings fourteen to sixteen outstanding engineering students to the nation's capitol to learn about the public policy-making process. During the internship, they learn how government officials make decisions on complex technological issues and how engineers contribute to the public policy process. Students are exposed to the policy-making process through frequent meetings with representatives of the legislative and executive branches, government agencies, industry leaders, and prominent non-government organizations. As a final product of the summer, each student is expected to submit a public policy paper evaluating a policy issue of professional relevance to the intern's sponsoring society. For more information about the WISE program, visit the WISE website at http://www.wise-intern.org.

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EXECUTIVE SUMMARY

The Generation-IV Nuclear Energy Systems Initiative is a Department of Energy effort to evaluate and design future nuclear energy systems and an advanced fuel cycle that will be ready for deployment by 2030. A primary area of concentration in the Generation-IV Nuclear Energy Systems Initiative and the focus of this paper is non-proliferation and how it relates to advanced nuclear energy systems and fuel cycles. Advanced fuel cycles that involve reprocessing used nuclear fuel can pose a greater proliferation risk than the traditional open fuel cycle; therefore, technologies and safeguards that will minimize this proliferation-risk should be explored.

Non-proliferation has long been a serious concern regarding reprocessing technology, and as a result, public policy with regard to commercial reprocessing has been highly dynamic. With the exception of George H. W. Bush, every president since Jimmy Carter has essentially reversed his predecessor's policy toward the commercial application of reprocessing technology. The current policy was put in place by President Clinton in 1993 and states that the United States does not participate in the reprocessing of used fuel. It appears that this policy may again undergo modification or rescission by the George W. Bush administration, which stated that it was in favor of commercial reprocessing in the 2001 National Energy Policy Report.

A key task of the Generation-IV Nuclear Energy Systems Initiative is to ensure that future energy systems and fuel cycles will be the least attractive route for obtaining weapons-usable material (i.e., proliferation-resistant). Proliferation resistance is increased by applying intrinsic technological barriers and extrinsic safeguards to protect the nuclear material from diversion. One of the largest difficulties associated with proliferation resistance, however, is defining a method through which to measure the degree of resistance exhibited by a particular system or fuel cycle. Most methodologies that are under consideration focus on qualitative discussion resulting in normalized rankings to measure the proliferation resistance of a system. Comparative metrics, which would allow several nuclear systems and fuel cycles to be compared and contrasted from both a qualitative and possibly even quantitative standpoint, would be a highly useful methodology for measuring proliferation resistance. Comparative metrics, however, will not be easy to develop. Such metrics have been researched since the 1960s,

including large domestic and international efforts such as the Non-proliferation Alternative Systems Assessment Program and the International Fuel Cycle Evaluation, respectively.

If it is the opinion of the Department of Energy that pursuing reprocessing technology is a viable option, it will be necessary for the current Bush administration to revise or rescind Clinton's policy toward reprocessing before deployment can proceed. In the interest of preserving national non-proliferation policy, however, it should be made clear that the process for the separation of plutonium from used fuel must include inherent resistance to the proliferation of nuclear material. A revision or rescission by the George W. Bush administration would not necessarily ensure the same policy would remain in place by 2030 when the Generation-IV reactors and fuel cycle would be ready for deployment. It is possible that a future administration would once again reverse U.S. policy toward reprocessing; however, the justification for all past U.S. policies against reprocessing was the threat of proliferation. If the Department of Energy makes headway in proliferation resistance through Generation-IV, the likelihood of a future administration enacting policies against reprocessing would be considerably less. To ensure that progress is being made, it is also necessary to develop a robust methodology to measure proliferation resistance. A significant amount of effort to examine the development of rigorous proliferation resistance performance metrics should be part of the Generation-IV Nuclear Energy Systems Initiative.

The United States has damaged its ability to stand at the forefront of proliferation-resistant technologies and advanced safeguards applications with regard to closed fuel cycles through its effective isolation from commercial reprocessing research and development. To have the level of influence on international non-proliferation issues that is necessary for ensuring national security, the United States must follow through with the National Energy Policy recommendations of the George W. Bush administration in at the very least the areas of research and development and possibly even deployment of advanced nuclear fuel cycles that employ proliferation-resistant reprocessing technology.

Addressing Proliferation Concerns for a New Generation

ISSUE DEFINITION

A new generation of nuclear reactor designs that will meet the energy requirements of the next century is being developed as part of the Department of Energy's Generation-IV Nuclear Energy Systems Initiative.[1] Questions have been raised about the sustainability of the current once-through, or open, fuel cycle and the ability of for the United States' nuclear power generation infrastructure to continue to meet the energy demands placed upon it. As a result, the Department of Energy is currently studying transitioning from the current once-through fuel cycle to a closed, or recycled, fuel cycle. By recycling used nuclear fuel, it is possible to prolong the life expectancy of current uranium stockpiles and reduce the amount of waste that must be placed in a repository.

Used nuclear fuel is both toxic and highly radioactive, primarily as a result of its content of fission products. While the used fuel would pose little risk to the general public if placed in a repository in specially designed casks, the used fuel would pose a high risk to any individuals who might wish to remove the material from the casks. This danger reduces the likelihood of the proliferation, or spread, of the nuclear material; however, if the used fuel is reprocessed, a proliferation threat could be introduced because the reprocessing of the fuel can involve removing potentially weapons-usable material from the used fuel, separating it from the fuel's highly radioactive fission products. The Department of Energy is sensitive to this concern and as a result has established the proliferation resistance of the chosen advanced fuel cycle as a primary area of concentration in the Generation-IV initiative.

Current United States policy, which was put in place by President Clinton through Presidential Decision Directive 13 (PDD-13), states that the "U.S. does not encourage the civil use of plutonium, and accordingly does not itself engage in plutonium reprocessing for … nuclear power … purposes." This policy was first promulgated by the Ford and Carter administrations when the perceived risk of proliferation from plutonium reprocessing led the federal government to ban commercial nuclear reprocessing. Although the policy was officially reversed by the Reagan administration, it was re-established by President Clinton. Even if it is again changed by the current Bush administration, non-proliferation remains a concern. As a result, it would stand to reason that any future reprocessing plans proposed by the Department of Energy must be aligned with the United States' national non-proliferation policies.

This report serves to evaluate the goals of the Generation-IV Nuclear Energy Systems Initiative and how they relate to the United States' non-proliferation goals and policies. The report will outline the history of the United States' fuel cycle, the goals of the Generation-IV Nuclear Energy Systems Initiative, public policy aspects associated with commercial reprocessing, the proliferation resistance of attractive advanced fuel cycles, and evaluate and offer recommendations concerning the key issues associated with proliferation resistance and advanced nuclear fuel cycles.

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[1] See the Generation-IV website for more information at http://gen-iv.ne.doe.gov

BACKGROUND

The Generation-IV Nuclear Energy Systems Initiative

There are four primary areas of concentration within the Generation-IV initiative:

- Sustainability
- Safety and reliability
- Economics
- Non-proliferation.

"Sustainability is the ability to meet the needs of present generations while enhancing and not jeopardizing the ability of future generations to meet society's needs indefinitely into the future."[2] The sustainability of nuclear energy is dependent upon its ability to minimize the impact on the environment while providing energy security in the long term. Sustainability will be addressed through two primary routes: increasing fuel utilization to stretch uranium reserves, thereby decreasing mining and milling activities, and minimizing the production of nuclear waste, thereby reducing the future stewardship burden.

Safety and reliability are key priorities in the development and operation of nuclear energy systems.[2] This is an area of concentration previously realized in existing generations of nuclear energy systems; however, the Generation-IV Nuclear Energy Systems Initiative sets as its goal the improvement of safety and reliability by further reducing the likelihood of significant damage to the nuclear reactor and the threat of off-site radioactive releases. Ultimately this goal seeks to increase public and investor confidence by (1) protecting the public through further decreasing the risk to public safety and health and the environment, and by (2) protecting capital investment through further decreasing the risk of reactor core damage in the event of an accident.

The third primary focus area of the initiative is economics. Economic competitiveness is a requirement of the marketplace and is therefore a key component of the Generation-IV nuclear energy systems.[2] The Department of Energy seeks to improve economics by reducing capital costs and exploring new uses of nuclear energy systems to gain a clear-cut life cycle cost advantage. Although Generation-IV nuclear energy systems will primarily produce electricity, their economics could be improved by aiding in the production of a wider range of products such as potable water, process heat, and hydrogen. The DOE also desires to decrease financial investment risk by decreasing cost and schedule risks associated with the start-up, operation, and decommissioning of nuclear facilities as well as through improvements in the areas of licensing and public concerns.

The fourth area of concentration of the Generation-IV Nuclear Energy Systems Initiative, and the focus of this paper, is non-proliferation. Linked with non-proliferation in this area of concentration is physical security. The non-proliferation portion of this goal was recently removed from the sustainability goal and elevated to a separate area of concentration.[3] It is the desire of the initiative to design "energy systems including fuel cycles [that] will increase the assurance that they are a very unattractive and least desirable route for diversion or theft of weapons-usable materials."[4] Civilian nuclear power programs have never been the *preferred* method of obtaining weapons-usable material, but they have been used for such purposes.[5] It is the intention of the initiative to continue the historical nature of civilian nuclear programs as unattractive sources of weapons-usable material and further increase the proliferation resistance of the overall fuel cycle. Current civilian nuclear activities in the United States are considered resistant to proliferation because of the high radiation levels found in used fuel after irradiation. If weapons-usable material (i.e., plutonium) is recycled back into the nuclear cycle through a closed fuel cycle, it is the intention of the Generation-IV Nuclear Energy Systems Initiative to design intrinsic technological barriers into the process and strengthen, if necessary, existing extrinsic barriers that will ensure the future fuel cycle continues to offer high resistance to proliferation.

Associated with the Generation-IV Nuclear Energy Systems Initiative is the Generation-IV International

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[2] Technology Goals for Generation-IV Nuclear Energy Systems, Pages 3-8

[3] Rob Versluis, personal interview

[4] Technology Goals for Generation-IV Nuclear Energy Systems, Page 4

[5] Foreign states have used civilian programs to produce weapons-usable material or shield similar covert activities (see Senate testimony of Dr. Tom Cochran, referenced in the Citations section of this paper)

Forum (GIF). The GIF promotes international participation[6] in developing advanced reactor and fuel cycle technologies to meet the need of future global power demand. The GIF is an ongoing effort to establish international cooperation in developing these future nuclear energy systems.

History of the closed nuclear fuel cycle in the U.S.

An advanced fuel cycle that employs reprocessing would not be a new concept in the United States. Reprocessing technology was developed during the 1940s and 1950s for defense-related purposes. Uranium-238 was used to make weapons-usable plutonium through a process that involved a reprocessing step for the removal of the plutonium. Although commercial nuclear power generation had originally been intended to employ a closed fuel cycle and reprocessing was encouraged in the Atomic Energy Act of 1954[7], little attention was given to employing closed fuel cycle technology for commercial applications until fears began to arise in the 1970s about the sustainable growth of the nuclear energy industry. The nuclear power generation industry was experiencing rapid growth and the need to recycle used nuclear fuel began to appear imminent. Rapid growth was expected to continue and the availability of economically recoverable uranium reserves was questionable at the time. Three commercial reprocessing facilities were built or were under construction in the United States during this period: the Nuclear Fuel Services' (NFS) pilot facility in West Valley, New York; General Electric's (GE) Midwest Fuel Recovery Plant in Morris, Illinois; and Allied General Nuclear Services' plant at Barnwell, South Carolina. Of the three facilities, only the NFS plant at West Valley, New York actually operated. The GE facility in Morris, Illinois was completed but declared inoperable in 1974 and the Barnwell, South Carolina facility was never completed because of the decision of the Ford administration to halt its construction over concerns about non-proliferation. The West Valley facility was built to explore the financial prospects and operational capabilities of the reprocessing industry in anticipation of the need for large-scale reprocessing. The West Valley facility operated from 1966 to 1972, when it shut down to increase its operating capacity in anticipation of the need for commercial-scale reprocessing; however, the facility faced increasing regulatory requirements and operational difficulties that would have required significant capital investment to address, resulting in the determination that it was not economically feasible to continue operation.

The process employed at West Valley was the Plutonium and Uranium Recovery by Extraction, or PUREX, process. In this process, aqueous extraction techniques[8] were combined with specific chemical reactions to separate out pure uranium and plutonium streams, leaving behind the fission products and the minor actinides in the used fuel raffinate.[9,10] It was the isolation of the pure plutonium stream that raised large concerns about the proliferation risks associated with commercial nuclear reprocessing.

The current U.S. fuel cycle

The closed fuel cycle that the United States had planned to implement was supplanted by the current, open fuel cycle following the close of West Valley. There are five primary components of the United States' present-day nuclear fuel cycle:

- Uranium mining and milling
- Uranium enrichment
- Fuel fabrication
- Energy production
- Spent nuclear fuel storage

Uranium mining and milling involve removing uranium ore from the earth and chemically concentrating the uranium portion of the ore into U_3O_8, or yellow cake. Uranium enrichment is the step of the fuel cycle where the yellow cake is chemically altered to an enrichment process-specific compound, which then undergoes physical separation to enrich a uranium

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[6] Members include Argentina, Brazil, Canada, France, Japan, the Republic of South Africa, the Republic of Korea, Switzerland, the United Kingdom, and the United States

[7] The Atomic Energy Act of 1954 is the fundamental U.S. law on both the civilian and the military uses of nuclear materials

[8] Aqueous extraction is the separation of specific material from an aqueous phase into an organic solvent phase

[9] The raffinate is the portion of an original liquid that remains after other components have been dissolved by a solvent

[10] Cochran and Tsoulfanidis. *The Nuclear Fuel Cycle: Analysis and Management*

stream in the fissile[11] uranium isotope U-235. The uranium mining, milling, and enrichment steps are being carried out today on a smaller scale than in the past because of surplus ore stockpiles from past overly-optimistic mining operations and growing stockpiles of highly enriched uranium from dismantled nuclear weapons. The fuel fabrication step involves transforming the enriched uranium into reactor-usable uranium dioxide, UO_2. If the uranium is highly enriched uranium derived from dismantled weapons, then fuel fabrication also involves down-blending the uranium by mixing the enriched uranium with the non-fissile uranium isotope U-238 to a U-235 enrichment of approximately three to five percent. The uranium oxide is then placed inside a nuclear reactor and undergoes fission for the production of energy until the fissile content is so low that a chain reaction is no longer sustainable. Current U.S. reactors are light water reactors, or reactors that use water for neutron moderation[12] and core cooling. The used fuel is then placed in interim storage, pending removal to a permanent nuclear repository, to allow its radioactivity and heat release rate to decrease.

This cycle, commonly referred to as an open or once-through cycle because it involves no recycling, bears an inherent proliferation resistance. Although weapons-usable material (i.e., plutonium) is produced during the energy production step of the cycle, the resulting used fuel is highly radioactive because of the presence of fission products (i.e., cesium, strontium, technetium, etc.) and minor actinides (i.e., americium, neptunium, etc.). The high degree of radioactivity is considered a form of resistance to proliferation because it would severely hinder if not prevent diverters from isolating the weapons-usable material. Also, at no point in this fuel cycle is the plutonium separated from the used fuel matrix, which increases the cycle's proliferation resistance.

Advanced nuclear fuel cycles

Because of the lack of reprocessing/recycling in the open fuel cycle, questions arise about its sustainability. Although current uranium stockpiles will decrease the need for additional uranium ore mining for several decades, if nuclear energy is a preferred energy source in the future, mining will eventually increase. A closed fuel cycle that incorporates reprocessing and recycling would decrease the need for uranium ore mining and milling, thus decreasing the negative environmental impacts of these activities. Reprocessing also decreases the amount of waste that must be placed in a permanent repository, resulting in additional environmental benefits and greater sustainability. Advanced nuclear fuel cycles could allow the proposed repository at Yucca Mountain to be used decades longer than possible now with the once-through fuel cycle.[13] Reprocessing activities would have their own associated negative environmental impacts and further research and evaluation is necessary before conclusions can be drawn, but it is possible that the net environmental impact of nuclear energy could be decreased. Both open and closed fuel cycles are under evaluation as part of the Generation-IV Nuclear Energy Systems Initiative, but closed fuel cycles are the most attractive from the standpoint of sustainability.

Advanced nuclear fuel cycles typically contain each of the primary steps of the current United States' nuclear fuel cycle with the addition of a reprocessing stage for the closed fuel cycles. Between the energy production and used fuel storage steps, some of the components of the used nuclear fuel can be removed and recycled. Each fuel cycle option would involve different amounts of recycled material. According to the March 18, 2002, Department of Energy's Generation-IV Report of the Fuel Cycle Crosscut Group:

> Depending upon the design of the fuel cycle and the reactor, the quantity of fissile material recovered may be large or small. With low conversion ratio[14] reactor designs, a continuing source of fissile material from virgin ore is required. With fissile self-sufficient reactor designs an outside source is still required if the deployment is growing. With breeder reactor fuel cycles, sufficient fuel may be recovered that fresh fissile material from uranium ore is not required even for a growing deployment; the depleted uranium[15] reserves would suffice for several centuries before mining would resume.

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[11] Fissionable material with the capability of undergoing slow neutron fission

[12] The reduction of the speed of neutrons

[13] Frank Goldner, personal interview

[14] Ratio of rate of production of fissile nuclei to the rate of consumption of fissile nuclei

[15] Uranium that has been depleted of U-235 isotope (i.e., the waste stream of enrichment)

Closed fuel cycles can generally be classified as one of three types: partial recycle, full fissile recycle, or full-actinide recycle. Each of the cycles involves some form of recycling actinides.[16] It is the recycling of the plutonium that is cause for concern regarding proliferation. While high radiation levels in used nuclear fuel shield these actinides, reprocessing of the fuel can remove the weapons-usable material from its protective radiation shield and render the material a proliferation risk.

In a partial recycle fuel cycle, a fraction of the used fuel is reprocessed and a fraction of the actinide material in the used fuel is recycled for new fuel fabrication. The recycled fuel is then returned to the reactor at least once and possibly several times for additional energy production. Uranium isotopes as well as plutonium isotopes may be removed from the fuel and placed in the nuclear reactor for energy production. If plutonium is removed, it would most likely be introduced into the reactor as plutonium oxide mixed with uranium oxide, a fuel commonly referred to as mixed oxide, or MOX, fuel. The French nuclear fuel-recycling program currently utilizes this fuel cycle.

In full fissile recycle, all of the used nuclear fuel is processed to remove the reactor-usable plutonium and/or uranium. The used nuclear fuel from each recycle is once again processed to continue the cycle. This process is continued through multiple reactor cycles until essentially all fissile material is completely consumed.[17] The minor actinides as well as the fission products are disposed of in the waste stream for each processing operation. This technology would be applied, for example, in a liquid metal fast breeder reactor fuel cycle. A liquid metal reactor would be used because liquid metals are effective coolants that do not moderate neutrons. Un-moderated neutrons are important to this fuel cycle because there is a wider range of isotopes present in the full fissile recycled fuel than partially recycled fuel. Fast neutrons induce more efficient fissions across a wide isotopic range than do slow neutrons.

The full actinide recycle also involves the processing of all the used nuclear fuel, but all actinides are recycled multiple times to consume the fissionable material (unlike the other two recycles where only a fraction of the actinides are recycled). This fuel cycle utilizes multiple reactor designs with varying efficiencies for the consumption of the recycled materials. For example, this fuel cycle might employ a series of light water reactors, liquid metal fast reactors, and molten salt reactors. The light water reactors would be used to produce power. The liquid metal fast reactors would be used to produce power and to manufacture excess fissile fuel from U-238 to fuel the light water reactors, and the molten salt reactor would be used to destroy the higher actinides that would have otherwise required placement in a repository.[18]

The partial recycle fuel cycle is an attractive fuel cycle because it would require little or no upgrade of the existing light water reactor fleet to use MOX fuel. The downside to this cycle is that the amount of material recycled is low compared to the other fuel cycles. The full fissile recycle involves the recycle of essentially all of the reactor-usable plutonium and/or uranium, but would require an upgrade to new fast reactor designs to promote economical energy production through multiple recycles. The full actinide recycle fuel cycle would also require upgrade to new reactor designs, but it introduces added benefits beyond plutonium/uranium recycle. The removal of the minor actinides from the waste stream in full actinide recycle reduces the necessary sequestration time in a repository, which could significantly reduce the future repository costs (i.e., monitoring, protection, etc.). A drawback of the full actinide recycle is that it would create challenges in reactor/fuel design since the minor actinides affect reactor physics, leading to extra cost for the development and implementation of the technology. The choice of which fuel cycle to convert to essentially depends on how these trade-offs are evaluated and judged.

As demonstrated by Figure 1, the current once-through fuel cycle requires more ore mining and generates more waste than the closed fuel cycles, both negative attributes with regard to sustainability. The diagrams

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[16] Actinides are any of a series of chemically similar, radioactive elements from atomic number 89 to 103 (including uranium, plutonium, americium, and neptunium). Uranium and plutonium are considered "fuel" actinides. The remaining actinides are considered "minor" actinides.

[17] The process would be carried out until it no longer economical because of low fissile content/quality

[18] Gen-IV Fuel Cycle Crosscut Group Report, Page 1-3

on the left represent the base of natural ore required to support each fuel cycle and the barrels on the right indicate a normalized view of waste products. The attractiveness of advanced, closed nuclear fuel cycles results, in part, from the decreased uranium ore needs and waste production; however, there are economic considerations that alter the overall effectiveness of a fuel cycle. With the abundance of nuclear fuel on the market today, it is notably less expensive to employ a once-through fuel cycle. Although the cost of waste disposal in repositories (i.e., repository construction costs, waste monitoring, etc.) is expected to be high, the current primary economic driver is the front-end of the cycle, not the back-end. The low cost and abundance of nuclear fuel is the primary impetus for the United States' current fuel cycle; however, as the space limitations of a permanent repository become more evident, the economic benefit of decreasing waste generation may become more important.

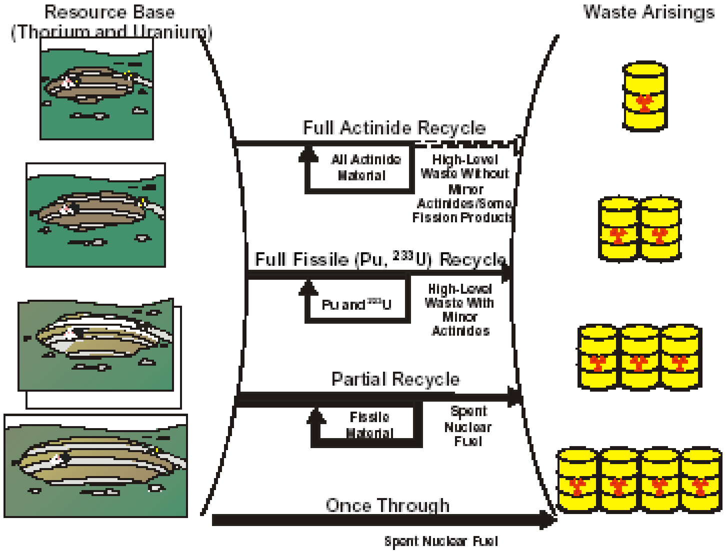

Figure 1: Advanced Fuel Cycles[19]

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[19] Oak Ridge National Laboratory Drawing 2001-125 (Generation-IV Fuel Cycle Crosscut Group Report, Page 1-7)

PUBLIC POLICY ISSUES

Public policy meets reprocessing technology

Proliferation has always been a concern with respect to commercial reprocessing, and by the early 1970s the nuclear industry had performed extensive research on safeguarding plutonium from diversion. Most industry specialists recognized that there was no foolproof method of safeguarding the separated plutonium, but there was a general confidence that reprocessing could be designed against the threat of proliferation. Furthermore, even if the material were diverted, there was a general consensus within the civilian nuclear industry that reactor-grade plutonium (i.e., plutonium generated from a civilian power reactor) could not be used to manufacture an atomic weapon. The weapons-grade plutonium that was bred at Hanford and the Savannah River sites for defense purposes was the result of only weeks of nuclear irradiation. The nature of nuclear power reactors required that the irradiation occur for a matter of years. With increased time in the reactor core, the concentration of the heavier plutonium isotopes, plutonium-240 and –242, increases. Not only are the heavier isotopes not ideal for nuclear blasts, the heavier isotopes also present a technical challenge in weapons design. The heavy plutonium isotopes undergo continuous neutron release, presenting the danger of criticality[20] and high radiation release before detonation.

The perspectives of weapons designers were in direct opposition to the industry perspectives on what constituted weapons-usable material; however, as a matter of national security, the nuclear industry was not necessarily privy to the perspectives of weapons designers at the United States' nuclear weapons laboratories. In 1962, the United States had actually exploded a device that was made from reactor-grade plutonium at the Nevada Test Site, which presented the theoretical possibility that reactor-grade plutonium could be used to make a bomb.[21] This possibility was enough to sway presidential candidate Jimmy Carter's advisors to lay the foundation during the 1976 presidential campaign for a platform against commercial nuclear reprocessing. Carter's advisors warned that reprocessing would isolate a pure plutonium stream and introduce the threat of proliferation. The Ford camp was also not immune to the proliferation jitters of the 1976 campaign. The Ford administration conducted a study and actually halted the startup of the Barnwell, South Carolina reprocessing plant just days before the election. President Ford stated that issues involving safeguards and nonproliferation would need to be resolved before startup could continue.[22]

In the mid-1970s, policy-makers were worried that international monitoring was not developed enough to prevent material diversion from civilian reprocessing plants for weapons purposes, but there was a constituency of industry representatives who pointed out the improvements in the accuracy of measurements for material accountability and suggested that between careful material accountability and adequate safeguards, proliferation resistance could be insured. This industrial wisdom was not necessarily a well-founded convention. Creating worry over civilian reprocessing were engineering calculations showing that even though advancements were being made in the accuracy of material control, the statistical uncertainties in the measurements made room for the diversion of multiple kilograms of fissile material per month. This much fissile material was enough for the production of several atomic weapons per year. The most disturbing aspect of this issue was that it could occur even under the watchful eye of an international monitoring agency.

Caution prevailed in the 1976 presidential election and led to the 1977 announcement by then President Jimmy Carter that the United States would cease *indefinitely* all commercial reprocessing activities. The president announced "he had reached the conclusion that this action was necessary to reduce the serious threat of nuclear weapons proliferation, and that by setting this example, the U.S. would encourage other nations to follow its lead."[22] This decision followed only three years after the "peaceful" nuclear explosion

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[20] Self-sustaining nuclear chain reaction

[21] Debate exists about whether or not the 1962 explosion was technically a nuclear bomb as the results were not entirely conclusive

[22] U.S. Policy on Spent Fuel Reprocessing: The Issues

conducted by India in 1974. The atomic explosion by India raised questions and concerns about the spread of nuclear technology. The Cirus research reactor, a civilian-acquired nuclear reactor from Canada, was used to produce the plutonium used in the 1974 explosion. At issue was the link between the explosion and India's civilian nuclear program. "India's civilian nuclear energy reactors and reprocessing facilities [had] provided India with the crucial plutonium for the development of atomic…bombs."[23]

President Carter initiated two studies to look into, among other things, commercial nuclear fuel cycles and weapons proliferation issues: one study was international, the International Fuel Cycle Evaluation (IFCE), and one was domestic, the Nonproliferation Alternative Systems Assessment Program (NASAP).

The following are some of the primary conclusions of the IFCE: [24]

1) The misuse of civilian nuclear facilities for the production of weapons-usable material is not a preferred method.

2) Plutonium recycling could lead to a uranium savings of 35 to 40%; however, it is not economically feasible to recycle plutonium under the current [1980] political and regulatory barriers.

3) In the long run, there is no real difference in the degree of proliferation resistance between the once-through cycle and closed cycles incorporating reprocessing.

4) International safeguards agreements can offer a substaincial reduction in proliferation and should therefore be an integral part of the global nuclear industry.

The following are some of the primary conclusions of the NASAP: [24]

1) There is no nuclear fuel cycle that is 100% proliferation-proof.

2) Improvements in technical aspects (safeguards technology) and institutional ones (ratification and commitment to international treaties) can increase proliferation resistance.

3) The once-through fuel cycle is the most proliferation-resistant because material directly usable for weapons is never produced anywhere during the cycle.

The primary difference between the IFCE and NASAP was that the IFCE found no real difference between the proliferation resistances offered by the closed and once-through nuclear fuel cycles. Neither study was able to develop a solid set of comparative metrics to be used for the evaluation and measurement of proliferation resistance. Unfortunately, the two studies did not serve to completely answer the questions concerning proliferation resistance and nuclear fuel cycles, but they did lead to opening international debate on what constituted proliferation resistance.

Congress followed suit with the Carter administration by including a ban on the reprocessing of U.S.-supplied nuclear fuel to foreign countries in the Nonproliferation Act of 1978. This angered many foreign nations and led to assertions that the United States, who had large hydrocarbon energy resources, was trying to gain energy superiority by limiting the expansion of nuclear energy in their countries. In 1982, Reagan lifted the restrictions imposed by Carter on commercial reprocessing and "allowed for programmatic (as opposed to case-by-case) approvals for reprocessing of U.S. origin fuel by the Euratom nations and Japan;"[25] however, this policy shift did not change the opinion of the nuclear industry in the United States. Much of the momentum for advanced fuel cycles was lost with the decisions of the Ford and Carter administrations. In addition, the economics were not suitable to begin commercial reprocessing.[26]

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[23] Jane's Sentinel Security Assessment – South Asia: Executive Summary, India

[24] Cochran and Tsoulfanidis. *The Nuclear Fuel Cycle: Analysis and Management*. Pages 211-212

[25] Presidential Actions: A Brief History

[26] This was because of excess uranium reserves and a decline in projected growth of nuclear power

The United States underwent yet another policy shift under President Clinton with the issuance of Presidential Decision Directive 13 (PDD-13). In this directive, Clinton stated that it is a matter of United States policy that the nation "does not encourage the civil use of plutonium, and accordingly does not itself engage in plutonium reprocessing for either nuclear power or nuclear explosives purposes." This was actually an incarnation of the original Carter order that took form in PDD-8. Clinton took a similar stance to Reagan with regard to foreign reprocessing activities by agreeing to "maintain [the] existing commitments regarding the use of civil nuclear programs in Western Europe and Japan."[27]

The George W. Bush administration generated a renewed interest in advanced fuel cycles with the 2001 National Energy Policy report. The following is an excerpt from the report:[28]

> The [National Energy Policy Development] Group recommends that, in the context of developing advanced nuclear fuel cycles and next generation technologies for nuclear energy, the United States should reexamine its policies to allow for research, development and deployment of fuel conditioning methods…that reduce waste streams and enhance proliferation resistance. In doing so, the United States will continue to discourage the accumulation of separated plutonium, worldwide.
>
> The United States should also consider technologies, in collaboration with international partners with highly developed fuel cycles and a record of close cooperation, to develop reprocessing and fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more proliferation-resistant.

The energy report makes specific references to advanced nuclear fuel cycles and reprocessing, which appears to be a significant policy shift. A key phrase in the above excerpt is the "deployment of fuel conditioning methods," which extends past administrations' support of fuel cycle *research* to a statement of support for actual *implementation*. This was the first time such an assertion had been made by a presidential administration since reprocessing was indefinitely halted during the Carter administration. It is important to note, however, that the energy policy report does not actually represent defined policy, but only policy recommendations.

Relevant acts of Congress

When discussing the production of a weapons usable material such as plutonium through the use of civil power generation facilities (i.e., reprocessing), the 1982 Hart-Simpson Amendment to the Atomic Energy Act is often brought up. The amendment specifically prohibits the use of special nuclear materials[29] from commercial reactors for nuclear arms. The advanced fuel cycles proposed by the Generation-IV Nuclear Energy Systems Initiative are designed to incorporate any separated special nuclear material back into the civilian cycle. As long as the material is not co-processed or stored with material reserved for defense-related purposes, the concern about violation of the Hart-Simpson Amendment would be alleviated.

The Non-proliferation Act of 1978 addressed reprocessing, speaking out against both domestic reprocessing and foreign reprocessing of U.S.-origin fuel. The Act directly addressed foreign reprocessing by stipulating that future nuclear cooperation agreements should contain consent rights over the U.S.-supplied fuel. The Act did not, however, directly place these requirements into law, only suggesting President Carter implement these policies. President Reagan essentially overturned Carter's policies in 1983; therefore, the Non-proliferation Act of 1978 no longer directly affects domestic commercial reprocessing or the foreign reprocessing of U.S.-origin fuel.

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[27] Non-Proliferation and Export Control Policy, White House Fact Sheet

[28] Reliable, Affordable, and Environmentally Sound Energy for America's Future (National Energy Policy), Page 5-17

[29] A special nuclear material is defined by Title I of the Atomic Energy Act of 1954 as plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235

TECHNOLOGICAL ADVANCEMENTS

Advanced fuel cycles are currently under evaluation that would incorporate reprocessing while increasing the proliferation resistance of the fuel cycle over that of the traditional PUREX process. These cycles are not necessarily more or less proliferation resistant than the current once-through fuel cycle, but through their design they display an increased resistance to proliferation over the PUREX process.

Pyrometallurgical reprocessing involves the use of electrodes to force precipitation of a solid mixture of plutonium, uranium, and the minor actinides from a solution containing the used fuel. Left behind in the used fuel solution are the fission products. The solid precipitate can then be manufactured into MOX fuel. The pyrometallurgical reprocessing technology is considered more proliferation resistant than the PUREX process because at no point in the process is a pure plutonium stream separated. In addition, because the minor actinides are precipitated out of the used fuel with the uranium-plutonium mixture, the mixture is highly radioactive and extremely hazardous to diverters[30]. There are also notable downsides to this process. First, it could be possible to alter this technology through the use of different materials for the collection electrodes to induce the precipitation of pure plutonium. The difficulty of doing this is unknown, but it does present the possibility of diversion. Second, this process could most likely only be applied economically to a nuclear fuel cycle that employed fast reactors[31] and the current fleet of U.S. reactors is composed of thermal, or slow, reactors.[32] Un-moderated neutrons (i.e., those found in a fast reactor) are important to this fuel cycle because there is a wide range of actinide isotopes present in the pyrometallurgically recycled fuel. Fast neutrons induce more efficient fissions across a wide isotopic range than do slow neutrons, making the application of pyrometallurgical reprocessing to fast reactors the most economical option. Also, the fuel would be in the metallic form following reprocessing, which is the form utilized in fast reactors.

Another advanced reprocessing technique is the Uranium Recovery by Extraction, or UREX process. This process is similar to the PUREX process in that it uses a solvent for aqueous extraction; however, only uranium is recovered in the UREX process. It is possible to modify the UREX process by later recovering a neptunium/plutonium mixture. This mixture could then be fabricated with uranium to make MOX fuel, much like the PUREX process. An added advantage of this process over PUREX is that the neptunium would decrease the purity of the plutonium and increase the level of radioactivity of the mixture, both of which would add resistance to proliferation of the material. This method has its downsides as well. It is not chemically difficult to separate neptunium from plutonium, so if the radioactivity can be shielded, it would be possible to isolate a pure plutonium stream. The process would be most proliferation resistant by leaving the plutonium behind with the fission products and other minor actinides in the used fuel; however, it would most likely be uneconomical to recover only the uranium from used fuel. Much of the recycle value of used fuel resides in the plutonium.

There are other advanced reprocessing techniques, but most employ the same basic principles. Through inherent technology built into the reprocessing method, a pure plutonium stream is never isolated at any point during the process. The plutonium may be mixed with uranium, minor actinides, or even fission products to create material barriers to proliferation.[33] In general, there are both positive and negative aspects of most advanced reprocessing techniques. No single process stands out at this time as the most proliferation-resistant technology.

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[30] Cochran and Tsoulfanidis. *The Nuclear Fuel Cycle: Analysis and Management*. Page 218.

[31] Reactors that employ little or no neutron moderation

[32] Reactors that do employ neutron moderation

[33] The material is too impure, hot, radioactive, etc. to easily use for the production of weapons

THE PROLIFERATION RESISTANCE ARGUMENT

Concern over non-proliferation

Two factors influence the United States' non-proliferation policies with regard to advanced fuel cycles: national security and politics. There are obvious threats to national security if a pure plutonium stream were separated from used nuclear fuel and then diverted by a sub-national or state threat. In 1997, the Department of Energy concluded that plutonium in a wide range of isotopic forms could be used to manufacture a nuclear weapon. The department concluded that reactor-grade plutonium is weapons-usable, whether by unsophisticated proliferators or by advanced nuclear weapons states, and that theft of separated plutonium would pose a grave security risk.[34]

The non-proliferation issue has also become a political one. The Ford and Carter stances against reprocessing were based on the separation of plutonium from the used fuel, not on the concept of recycling nuclear material. As more advanced fuel cycles are being postulated that do not involve the separation of pure plutonium, there is still much argument against reprocessing in the name of non-proliferation. These arguments come from two schools. First, and most legitimately, is the school that opposes all reprocessing because it deems a once-through fuel cycle as the least easily manipulated and therefore most proliferation resistant fuel cycle. This school is typically pro-nuclear power but anti-reprocessing. The second school views an advanced fuel cycle that incorporates reprocessing as fueling nuclear energy's "fire" by potentially increasing nuclear energy's viability and future sustainability. This school is typically anti-nuclear power and such a boost to nuclear power is counter-productive to its goals. Regardless of the school of thought, non-proliferation issues seem to be the largest barrier to reprocessing as far as public image is concerned, save perhaps safety issues. As a result, non-proliferation issues often take the forefront in arguments to stop commercial reprocessing development.

Civilian reprocessing has in many ways earned a fair share of the public's concern over its proliferation risk. The following is an excerpt of Senate testimony[35] by Dr. Tom Cochran, Senior Scientist and Nuclear Program Director of the Nuclear Resources Defense Council:[36]

> Civilian nuclear activities have directly and indirectly contributed to the spread of nuclear weapons. India's first nuclear weapons test in 1974, for example, used plutonium produced in a Canadian-supplied research reactor using U.S.-supplied heavy water as a moderator, and the plutonium was separated in a reprocessing plant built from blueprints supplied by an American firm, Vitro International. This plant was nominally part of India's civilian breeder reactor research and development program...Some nations have established nominally civilian nuclear programs as a pretext to acquire technologies for military programs or have acquired materials, equipment, technologies or technical personnel from the civilian sector for their nuclear weapons programs. Israel's plutonium production reactor and reprocessing plant at Dimona were provided by France ostensibly for civilian purposes, but were actually used for military purposes.

As demonstrated by this testimony, although commercial nuclear activities have never been the preferred route for obtaining weapons-usable material, civilian programs have in fact served in that capacity. For this reason, there is a fairly substantial public concern over non-proliferation issues related to civilian nuclear activities, in particular reprocessing. Commercial reprocessing can pose a proliferation risk, and it is the responsibility of the Generation-IV Nuclear Energy Systems Initiative to reduce this proliferation risk

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[34] Non-Proliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives

[35] Tom Cochran. Testimony before the Senate Energy and Natural Resources Committee, 18 July 2001

[36] Dr. Cochran is also a member of DOE's Nuclear Energy Research Advisory Committee; however, he was testifying on behalf of the NRDC

through advanced nuclear fuel cycles that possess inherent proliferation resistance.

Intellectual versus material proliferation

The two primary forms of proliferation are intellectual and material proliferation. Intellectual proliferation is essentially the spread of nuclear technologies that, either directly or through exploitation, can lead to the production of weapons-usable nuclear material. Intellectual proliferation can occur as a result of technology transfers or from the training of individuals in the technology, who then carry it away to a foreign state or sub-national group. Typically, the most dangerous intellectual proliferation involves individuals; export controls usually stop technology transfers of this nature from occurring (i.e., from within the United States). Material proliferation is the spread of weapons-usable material such as plutonium or highly enriched uranium. Although material proliferation is a more direct threat with respect to the production of nuclear weapons, intellectual proliferation can carry similarly heavy consequences. As a result, both types of proliferation should be afforded detailed attention.

The means of protection against these two types of proliferation have both similarities and dissimilarities. Export controls are used to stop dual-use technologies[37] from being proliferated to a large degree. The Non-Proliferation Act of 1978 deals extensively with strengthening United States export control policies to prevent intellectual proliferation. Intellectual proliferation involving trained individuals is much more difficult to protect against. The most effective prevention against this form of proliferation is actually the deployment of technology that requires significant alteration before it can lead to the production of weapons-usable material. In other words, it is virtually impossible to prevent technology from a civilian program from being carried away by trained workers and researchers. As a result, employing proliferation-resistant technology is the most effective way of dealing with the issue.

Employing proliferation-resistant technology also leads to the protection against material proliferation. There is no absolute protection against material proliferation. Material proliferation resistance is better measured in relative rather than absolute terms; in fact, it is difficult to measure proliferation resistance without comparison to the technological and economical difficulty of employing a technology that is commonly used for the production of weapons-usable material, such as laser or gaseous diffusion enrichment. Material proliferation is typically protected against in two basic forms: intrinsic and extrinsic barriers. Intrinsic barriers are inherent barriers that are built into the technology being employed or the facility being utilized that protect against material proliferation. Intrinsic barriers include material barriers (i.e., inherent qualities of materials that reduce the attractiveness of the material as weapons-usable),[38] such as isotopic composition and chemical form, as well as technical barriers (i.e., technical elements that make it difficult to gain access to materials and/or to misuse facilities to obtain weapons-usable materials),[38] such as facility accessibility and detectability of diversion. Extrinsic barriers are applied safeguards that are not inherent to the system or fuel cycle design, such as electronic surveillance and protective forces.

Performance metrics of proliferation resistance

The most commonly applied metric within non-proliferation analysis is that the difficulty to alter proliferation-resistant technology, such that weapons-usable material can be obtained, must be greater than the difficulty to employ currently existing and well-known methods of obtaining weapons usable material (i.e., laser enrichment, PUREX reprocessing, etc.). The downside of this metric is that it does not provide flexibility in comparing and contrasting the degree of proliferation resistance offered by various fuel cycles. The DOE Technological Opportunities to Increase the Proliferation Resistance of Global

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[37] Information that could be used for both civilian and military purposes

[38] Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS Report to DOE's Nuclear Energy Research Advisory Committee), Pages A2-3 – A2-4

Civilian Nuclear Power Systems (TOPS) Task Force for DOE's Nuclear Energy Research Advisory Committee concluded in the TOPS report released in early 2001 that it is necessary for the United States to "develop improved methods to evaluate the comparative proliferation resistance features of different nuclear systems [by improving and standardizing] the proliferation assessment of different reactors and fuel cycle approaches." The task force identified two forms of assessments that could potentially be used to build an improved assessment method upon.

The first assessment method is an integrated safeguards evaluation methodology (ISEM), which is being developed as part of the United States Support Program to the International Atomic Energy Agency (IAEA) safeguards program. This methodology is focused on the extrinsic barriers to proliferation and is aimed at optimizing the application of available safeguards measures such that the effectiveness of the safeguards is maximized within the available resources. This methodology was not developed for the evaluation of proliferation resistance in fuel cycles, but elements of ISEM can potentially be applied to analyze fuel cycles as well as advanced reactor designs, contributing to the overall analysis of Generation-IV nuclear energy systems. The following is a logic diagram of ISEM:

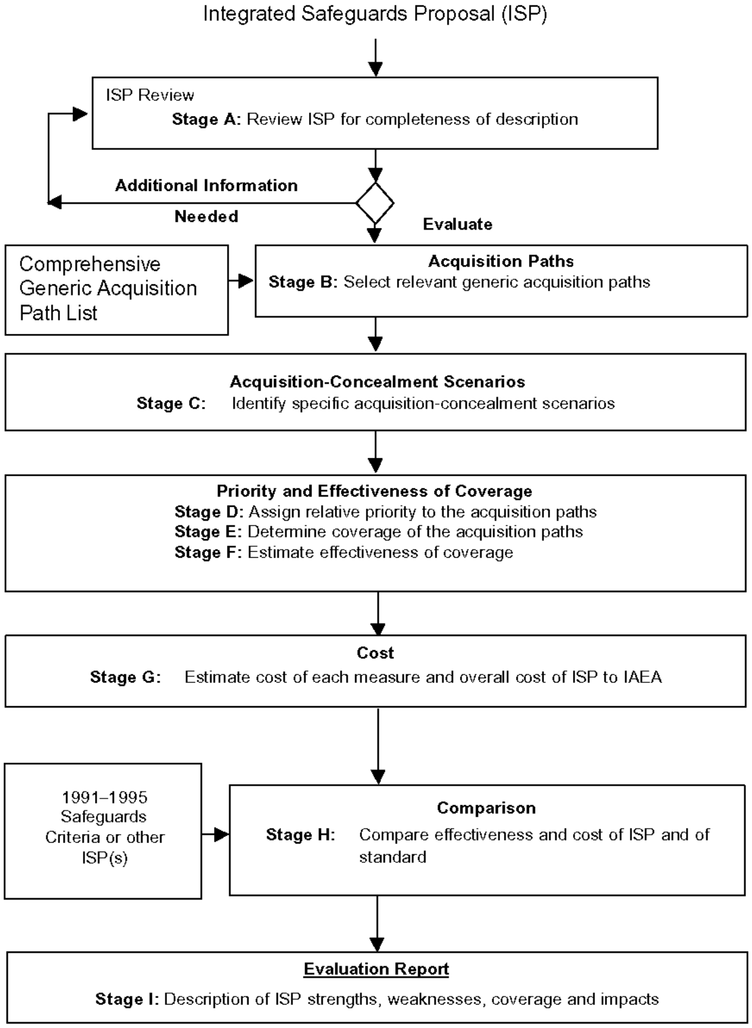

Figure 2: ISEM Flow Chart[39]

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[39] Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS Report to DOE's Nuclear Energy Research Advisory Committee), Page A2-2

The ISEM methodology consists essentially of identifying all possible covert acquisition paths,[40] applying priority to the proliferation risk posed by each path based on the time demands, cost, and technical difficulty of diverting the material, determining the applicability and effectiveness of the proposed safeguards in the Integrated Safeguards Proposal for protecting each identified acquisition path, performing a cost analysis, and finally comparing the cost and effectiveness of the proposed safeguards against a standard. This process may identify possible weaknesses in a safeguards proposal and may require several iterations, each involving several safeguards proposals, before a final evaluation report is generated.

To address intrinsic barriers to proliferation, the TOPS task force examined the applicability of a second assessment method, the "attributes methodology."[41] The process consists of identifying the intrinsic barriers of a particular nuclear system, evaluating the effectiveness of the barriers against the threats posed by various potential proliferators, and then identifying the extrinsic barriers needed to complement the intrinsic barriers, such that the combined proliferation resistance ensures that the applicable standard of protection[42] is met. This methodology would aid in providing an assessment of the overall resistance to proliferation offered by various reactor designs and fuel cycles. The attributes methodology was the primary focus of a working group at the TOPS International Workshop on Technology Opportunities for Increasing the Proliferation Resistance of Global Nuclear Power Systems, which concluded that additional focus on "improving and standardizing"[43] the methodology for performing comparative assessments of the proliferation resistance of various reactor designs and fuel cycles was necessary for the further incorporation of proliferation resistance into future nuclear reactors and fuel cycles. The attributes methodology was applied to various intrinsic barriers at a Technology Assessment Meeting sponsored by the TOPS Task Force in the summer of 2000 and Table 1, which provides a general indication of the importance of various intrinsic barriers to proliferation as they apply to various proliferators, was the result of that meeting.

As can be seen in the Table 1, the effectiveness of a barrier is dependent upon the degree of sophistication and motivations of a proliferator. The general concept behind the attributes methodology is to identify the strength of the intrinsic barriers to proliferation based on the perceived threat and then supplement the intrinsic protection with extrinsic safeguards against proliferation. The methodology embraces the philosophy that intrinsic barriers alone are not enough to prevent proliferation and that balanced extrinsic and intrinsic protection can lead to highly optimized proliferation resistance.

A combination of the ISEM approach, with its strong emphasis on adequate extrinsic barriers, and the attributes methodology, with its ability to match extrinsic barriers to the degree of protection offered by various intrinsic barriers, could possibly be the basis for a robust framework from which to build future assessment methodologies. This co-analysis of extrinsic and intrinsic barriers is key to the development of an effective assessment system. Even the best intrinsic barriers are not foolproof and the combined protection of intrinsic and extrinsic barriers is a key to adequate proliferation resistance.

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[40] Paths by which nuclear material could be diverted

[41] See the Attributes of Proliferation Resistance for Civilian Nuclear Power Systems, TOPS Task Force report

[42] These standards are subject to political decisions, international and domestic

[43] Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS Report to DOE's Nuclear Energy Research Advisory Committee), Page 9

Table 1: Relative Importance of Various Barriers to a Selected Type of Threat[44]

	Sophisticated State, Overt	Sophisticated State, Covert	Unsophisticated State, Covert	Sub-national Group
Material Barriers				
Isotopic	Moderate	Low	Moderate to High	High
Chemical	Very low	Very Low	Moderate to High	High
Radiological	Very low	Low	Moderate	High
Mass and Bulk	Very low	Low	Low	Moderate
Detectability	Not applicable	Moderate	Moderate	High
Technical Barriers				
Facility Unattractiveness	Moderate	Moderate	High	Very low
Facility Accessibility	Very low	Low	Low	Moderate
Available Mass	Moderate	Moderate	High	High
Diversion Detectability	Very low	Moderate	Moderate	Moderate
Skills, Expertise, and Knowledge	Low	Low	Moderate	Moderate
Time	Very low	Very low	Moderate	High

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[44] Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS Report to DOE's Nuclear Energy Research Advisory Committee), Page A2-4

GENERATION-IV PROLIFERATION RESISTANCE PERFORMANCE

Generation-IV Nuclear Energy Systems Initiative primary goals

The elevation of non-proliferation from a secondary sustainability goal and combining it with physical security in a separate primary area of concentration was a key step in recognizing United States non-proliferation policy while moving forward with advanced nuclear fuel cycles. Traditionally, most United States non-proliferation policy on reprocessing has been focused on the separation of a pure plutonium stream from used nuclear fuel. If an advanced closed fuel cycle can be found that meets the sustainability, safety and reliability, and economic goals of the Generation-IV initiative while preventing the separation of a pure plutonium stream during reprocessing, then the initiative will remain much more closely aligned with U.S. non-proliferation policy.

Incorporation of the non-proliferation goal

The DOE-TOPS report recommended that within the next five years, emphasis should be placed on the development of assessment methodologies. It is possible that ISEM and the attributes methodology can be merged to create a comparative-based metrics methodology for measuring proliferation resistance, but there are other alternatives as well. As part of the Generation-IV Nuclear Energy Systems Initiative, a DOE working group is currently being formed that will start work by late summer 2002 on an assessment methodology for measuring proliferation resistance.[45] It is important that this task force examine comparative-based metrics. In the near term, a focus on a qualitative metrics system would be beneficial. This would allow existing assessment systems to be built upon and provide the working group with a healthy base. Discussion about quantitative metrics would ultimately be valuable; however, development and implementation of such a system may prove difficult. It would be ideal for the group to explore the development of methodologies that include proliferation resistance barriers in the cost analysis of nuclear life cycles, which was a recommendation of the TOPS task force:[46]

> Improved analytical tools for economic evaluation of nuclear systems should be developed for life cycle cost and cost-benefit analyses so as to extend the traditional economic evaluation of nuclear facilities...to include an evaluation of the entire system that reflects the economic implications of proliferation features.

Incorporating proliferation resistance into the initial stages of reactor and fuel cycle design seems vital to ensuring that proliferation resistance is a primary focus of advanced nuclear systems.

Ultimately, it is the task of the Generation-IV Nuclear Energy Systems Initiative to ensure that civilian nuclear energy systems remain the least attractive route for nuclear material diversion for weapons purposes. There will be no foolproof method of proliferation resistance and no technologies or safeguards will eliminate altogether the risk of proliferation. The Generation-IV workgroups have embraced this concept and will set out to define technologies and optimization strategies[47] that will address this aspect of non-proliferation in advanced fuel cycles. To search for absolute proliferation resistance would be essentially futile; therefore, the Generation-IV Nuclear Energy Systems Initiative is correct in setting the goal to further reduce the attractiveness of the civilian cycle instead of setting the lofty and most likely unattainable goal of altogether eliminating the risk of proliferation in future energy systems and fuel cycles.

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[45] Rob Versluis, personal interview

[46] Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS Report to DOE's Nuclear Energy Research Advisory Committee), Page 12

[47] Strategies that optimize the use of intrinsic and extrinsic proliferation barriers

CONCLUSIONS AND RECOMMENDATIONS

U.S. policy perspective

Before an advanced fuel cycle that includes a reprocessing step can be moved forward to deployment and implementation, a shift in United States policy must occur. Although a reprocessing step could remove only uranium, leaving the plutonium behind with the minor actinides and fission products, economics would all but rule this fuel cycle out. For an advanced fuel cycle to meet the goals of economic feasibility of the Generation-IV Nuclear Energy Systems Initiative, it is virtually certain that both plutonium and uranium must be recycled from the used fuel. Current United States policy as spelled out by Presidential Decision Directive 13 would prevent such a fuel cycle. Indications are that the George W. Bush administration is currently revising PDD-13 to reflect the National Energy Policy proposed by the administration, which would indicate that the elements of the directive preventing the use of plutonium in commercial reactors would either be removed or revised. The exact wording of the revision is still uncertain.

Recommendation:

It is important that the George W. Bush administration revise Clinton's Presidential Decision Directive 13, making allowances for the civil use of plutonium in nuclear reactors; however, in the interest of preserving national non-proliferation policy, it should also be made clear that the process for the separation of plutonium from used fuel must possess inherent resistance to proliferation of nuclear material. This would also be a valuable opportunity to bolster support for the non-proliferation goals of the Generation-IV Nuclear Energy Systems Initiative and call for cooperation with other nuclear nations in advanced nuclear fuel cycle research, such as the recent U.S.-Russian working group.[48]

Feasibility of comparative metrics

Although systematic metrics for comparative proliferation measures are highly important to a streamlined and thorough analysis of the proliferation resistance of various reactor and fuel cycle designs, they will not be easy to achieve. Hal Bengelsdorf, a non-proliferation expert and member of the TOPS Task Force, said that although the TOPS Task Force recommended that the Department of Energy examine comparative metrics, he and others realized this was "much easier said than done."[49] Comparative metrics have been an elusive goal for some time. Efforts have been made since the 1960s and 1970s, including the NASAP and IFCE studies, which failed to come to a consensus on proliferation resistance metrics and measurement.

Ultimately, it is unlikely that we will move close to a sufficient comparative metrics methodology without an increased interest in implementing commercial reprocessing. Until further capital investment is made in reprocessing technology and deployment seems more likely, a focused and productive conversation on non-proliferation metrics will be difficult to achieve. It will require an organized and focused effort by the Generation-IV Nuclear Energy Systems Initiative, international cooperation, and increased domestic support for advanced nuclear fuel cycles to accomplish such a task.

Recommendation:

A significant amount of effort should be placed on the Generation-IV Nuclear Energy Systems Initiative working group that is being formed to examine proliferation resistance performance metrics. International participation through the Generation-IV International Forum would be ideal in finding the proper balance between intrinsic and extrinsic barriers from British, French, and Japanese experts who are currently involved in nuclear reprocessing activities. The ISEM and attributes methodology should be examined as a potential framework from which to build a set of comparative metrics. The difficulty of building a set of metrics should not be a stumbling block for further investment in research and design of advanced nuclear fuel cycles because such investment will most likely spur more intense and serious discussion of the issue.

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[48] A 60 day work group on advanced nuclear fuel cycles as a result of talks between Presidents George W. Bush and Vladimir Putin

[49] Hal Bengelsdorf, Personal Interview

The need for fuel cycle and non-proliferation research

A key motivation behind President Jimmy Carter's 1977 decision to ban commercial reprocessing was to set an example that other nations would follow[50]. This goal of the decision was never fully realized. Nations such as Great Britain, France, and Japan proceeded with the development of civilian fuel cycles that incorporated reprocessing technology. The United States' lack of commercial reprocessing actually left the U.S. without a voice in the global reprocessing community and severely hindered its ability to advocate for greater proliferation-resistance in the fuel cycles of the nations participating in reprocessing. The DOE-TOPS report concluded that "the exploration of advanced closed fuel cycle systems that would serve to reduce direct access to weapons-usable material…will advance the state of the art in proliferation-resistant technologies and will allow the United States to collaborate more constructively with other countries."[51]

Recommendation:

The United States has damaged its ability to stand at the forefront of proliferation-resistant technologies and advanced safeguards applications through its effective isolation from commercial reprocessing research and development. It is imperative that the United States government foster a renewed interest in advanced nuclear energy systems and fuel cycles and encourage research into proliferation-resistant technologies. If the United States does not do this now, it stands to lose the intellectual investment it has made in the past as researchers begin to retire from this nation's research laboratories. To have the level of influence on international non-proliferation issues that is necessary for ensuring national security, the Untied States must follow through with the National Energy Policy recommendations of the George W. Bush administration in at the very least the areas of research and development and possibly even deployment of advanced nuclear fuel cycles that employ proliferation-resistant reprocessing technology.

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[50] Carter, Jimmy. "Statement on Decisions Following a Review of U.S. Nuclear Power Policy." April 7, 1977

[51] Technological Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS Report to DOE's Nuclear Energy Research Advisory Committee), Page 11

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