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Global Nuclear Energy Partnership Strategic Plan

U.S. Department of Energy

Office of Nuclear Energy

Office of Fuel Cycle Management

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1.0 Policy

1.1 Purpose

The United States "will build the Global Nuclear Energy Partnership to work with other nations to develop and deploy advanced nuclear recycling and reactor technologies. This initiative will help provide reliable, emission-free energy with less of the waste burden of older technologies and without making available separated plutonium that could be used by rogue states or terrorists for nuclear weapons. These new technologies will make possible a dramatic expansion of safe, clean nuclear energy to help meet the growing global energy demand."[1]

GNEP seeks to bring about a significant, wide-scale use of nuclear energy, and to take actions now that will allow that vision to be achieved while decreasing the risk of nuclear weapons proliferation and effectively addressing the challenge of nuclear waste disposal. GNEP will advance the nonproliferation and national security interests of the United States by reinforcing its nonproliferation policies and reducing the spread of enrichment and reprocessing technologies, and eventually eliminating excess civilian plutonium stocks that have accumulated.

1.2 Principles

To enable the expansion of nuclear energy for peaceful purposes and make a major contribution to global development into the 21st century, the United States seeks to pursue and accelerate cooperation to:

- Expand nuclear power to help meet growing energy demand in an environmentally sustainable manner.

- Develop, demonstrate, and deploy advanced technologies for recycling spent nuclear fuel that do not separate plutonium, with the goal over time of ceasing separation of plutonium and eventually eliminating excess stocks of civilian plutonium and drawing down existing stocks of civilian spent fuel. Such advanced fuel cycle technologies would substantially reduce nuclear waste, simplify its disposition, and help to ensure the need for only one geologic repository in the United States through the end of this century.

- Develop, demonstrate, and deploy advanced reactors that consume transuranic elements from recycled spent fuel.

- Establish supply arrangements among nations to provide reliable fuel services worldwide for generating nuclear energy, by providing nuclear fuel and taking back spent fuel for recycling, without spreading enrichment and reprocessing technologies.

[1] *The National Security Strategy of the United States of America* (March, 16, 2006): 29.

- Develop, demonstrate, and deploy advanced, proliferation resistant nuclear power reactors appropriate for the power grids of developing countries and regions.

- In cooperation with the IAEA, develop enhanced nuclear safeguards to effectively and efficiently monitor nuclear materials and facilities, to ensure commercial nuclear energy systems are used only for peaceful purposes.

2.0 Implementation

The need for nuclear energy to play a major role in meeting base load electrical energy requirements is now recognized by most of the world's industrialized nations. Similarly, in the United States there is growing recognition of the need to start building new nuclear power plants as soon as possible and to rebuild our national nuclear infrastructure -- needs supported by both the Energy Policy Act of 2005 and DOE's Nuclear Power 2010 program. This paper outlines an implementation strategy to enable a world-wide increase in the use of nuclear energy safely, without contributing to the spread of nuclear weapons capabilities, and in a manner that responsibly disposes of the waste products of nuclear power generation. First, some key evaluative criteria any GNEP fuel cycle must address are outlined. Second, the GNEP technology requirements for government and industry are discussed, with a focus on those facilities of GNEP to be built and proven in the U.S. Third, a two year GNEP Program Technology Action Plan is outlined.

2.1 Criteria

2.1.1 Proliferation/Safeguards Risk

Two parts of the nuclear fuel cycle that have the greatest potential of misuse for the purpose of developing nuclear weapons are the enrichment process and the spent fuel reprocessing/refabrication process. Enrichment facilities typically separate uranium with a U235 content of 2.5% to 5% for use in a nuclear power plant, which is not weapons- useable. However, the same enrichment technology could be used to produce highly enriched uranium that would be weapons useable. Similarly, a reprocessing plant using solvent extraction technology takes used fuel from a reactor and separates the remaining useable nuclear fuel (plutonium and uranium) from other waste products. As long as the fissile materials remain combined with sufficient quantities of non-fissile materials the product is not directly useable as a nuclear weapon. However, the same technology can separate plutonium and could be used for weapons purposes. Safeguarded nuclear power plants do not by themselves present a significant proliferation risk.

The risk of non-peaceful use of the civilian nuclear fuel cycle comes from two principal sources: (1) a nation wanting to advance toward the capability to build nuclear weapons in a shorter period of time and (2) a terrorist group wanting to divert nuclear materials to quickly fabricate and explode an improvised nuclear device or a dirty bomb. GNEP aims to address both of these issues by providing incentives to forego enrichment and reprocessing facilities, and by eliminating over time excess stockpiles of civil plutonium.

2.1.2 Proliferation Prevention

Preventing the spread of commercial nuclear technology does not by itself prevent the spread of weapons capability. Several countries that have no commercial nuclear reactors have either developed or sought to develop nuclear weapons; e.g., North Korea or Libya. The plutonium contained in spent fuel discharged from a Light Water Reactor is not considered "weapons grade." However, plutonium separated from spent nuclear fuel could be fashioned into a weapon and achieve a nuclear yield of some magnitude. Further, both centrifuge enrichment plants and chemical reprocessing plants can be readily adapted from commercial use to weapons use.

For the past 30 years the United States has conducted research to develop advanced methods of reprocessing spent commercial nuclear fuel that might make reprocessing easier to safeguard and more proliferation-resistant. While safeguarding bulk-handling facilities will continue to pose significant technical challenges, advances have been made in developing processes that are easier to safeguard, allow improved materials accountability, are more resistant to terrorist threat, and offer the possibility of placing a much reduced burden on our waste disposal facilities.

However, *there is no technology "silver bullet" that can be built into an enrichment plant or reprocessing plant that can prevent a country from diverting these commercial fuel cycle facilities to non-peaceful use.* From the standpoint of resistance to rogue-state proliferation there are limits to the nonproliferation benefits offered by any of the advanced chemical separations technologies, which generally can be modified to produce plutonium if a nation is willing to withdraw from its Non-Proliferation Treaty (NPT) or violate its NPT or safeguards obligations.

One challenge we face is that all nations that have signed the NPT retain the right to pursue enrichment and reprocessing for peaceful purposes in conformity with article I and II of the Treaty. GNEP seeks to develop advanced fuel cycle technology for civil purposes, centered in existing fuel cycle states that would allow them to provide fuel services more cheaply and reliably than other states could provide indigenously.

2.1.3 Terrorist Threat Reduction

In the most general terms, GNEP seeks to eliminate over time excess stocks of separated plutonium and reduce stocks of spent fuel worldwide, thereby strengthening nuclear security worldwide.

In more specific terms, a key objective with respect to any GNEP recycling facility is to deny access to fissile nuclear materials of critical mass that could be readily made into a nuclear device. Supportive policies can be implemented in this regard: (1) minimize transportation; keep fissile materials inside one integrated facility from the time used fuel enters until recycled material leaves; (2) maintain a mixture of fissile material with non-fissile material in a ratio that is not easily useable as a weapon; (3) use advanced safeguards and security techniques; and (4) maintain a goal of minimizing the buildup of, and eventually eliminating, stockpiles of separated civilian plutonium or its near equivalent.

2.1.4 Reduce Repository Burden

Commercial spent nuclear fuel can either be disposed of directly into a repository (e.g., Yucca Mountain in the U.S.) or reprocessed/recycled and the byproduct high level waste sent to a repository.

The PUREX reprocessing technology currently in use in France and the U.K., for example, has three basic product streams: uranium, plutonium, and vitrified high level waste that includes fission products and minor actinides. Other residues include the cladding hulls, process wastes and some noble gases. (Japan mixes some uranium with the plutonium at the end of their process so no pure plutonium exits in the final reprocessing stage. Both France and a U.S. company have proposed a variant of their process that does not result in a pure plutonium product stream.) The vitrified waste product can be uniform, well characterized and robust. Repository capacity would also be increased through this recycling method (because of the change in the waste form) and the amount of spent fuel to be disposed of would decrease, thus resulting in a double benefit to our waste disposal obligations. The actual volume of that benefit could vary substantially depending on factors such as the length of time the spent fuel is cooled prior to reprocessing. Reprocessing using this proven and currently available technology (light water reactor with a mixed oxide fuel) would offer some minor benefit to the repository but would not meet the GNEP objectives.

The full benefit envisioned for the separations process in GNEP anticipates substantial repository benefits (by separating out all the actinides) and a reduction in liquid process waste. The most significant repository benefits can be achieved by removing the very long-lived minor actinides and recycling them as part of the fuel for fast reactors. To obtain a repository capacity increase ranging from one to two orders of magnitude and allow Yucca Mountain to satisfy our repository needs for the remainder of the 21st century it will be necessary to remove and fission through recycle the very long-lived minor actinides. Further repository benefit can be achieved by removing the fission products cesium and strontium from the high level waste stream and allowing them to decay separately. These elements have a relatively short half life and after decay could be disposed of as low level waste. Additionally, removing the technetium and fixing it in a matrix with the cladding hulls could reduce the possibility of this fission product migrating away from the repository area. DOE has been conducting work on processes to achieve all of these additional advanced partitioning objectives as well as work on how to recycle and consume these materials in a fast spectrum reactor. To date these efforts have been carried out as part of the Advanced Fuel Cycle Initiative, and it is proposed to continue this work as part of the broader GNEP initiative. Similar work is being carried out in Japan, France and Russia with promising results.

2.1.5 Assured Fuel Supply

The U.S. seeks to encourage the world's leading nuclear exporters to create a safe, orderly system that spreads nuclear energy without proliferation. States that refrain from enrichment and reprocessing would have reliable access at reasonable cost to fuel for civil nuclear power reactors.

The implementation of a regime by which nations wanting to enjoy the benefits of nuclear energy without needing to develop the expensive indigenous capability to enrich or reprocess spent nuclear fuel was the subject of an IAEA Special Event on *Assurances of Nuclear Supply and Nonproliferation* on September 19-22, 2006. This event attracted 300 international participants from 61 countries and organizations. A number of proposals were put forward, all having in common that a country choosing to obtain enrichment and reprocessing on the international market should be able to have international assurance that its nuclear fuel cycle requirements will be met. The six-country concept for reliable access to nuclear fuel, the U.S. commitments to support an enriched uranium reserve, and President Putin's initiative on international nuclear fuel service centers are all paths to a common objective of assuring that all nations should be able to enjoy the benefits of nuclear energy without the burden of investing in expensive enrichment and reprocessing facilities.

The implication for the U. S. is that if we are going to participate in assuring access to nuclear fuel, and in the longer term, spent fuel services, to these countries as they enter the nuclear arena, the U.S. must have the capability to provide the needed fuel cycle services – capability that we do not currently possess. Our fuel cycle technology should also build our ability, and those of our partners, to establish and sustain "cradle to grave" fuel service or leasing arrangements over time and at a scale commensurate with the anticipated expansion of nuclear energy by helping in a major way to solve the nuclear waste challenge.

2.1.6 Capability & Leverage

The GNEP vision has been well received by the international nuclear community, particularly among the leading fuel cycle states. Sustaining and building on that enthusiasm depends upon the U.S. ability to get back in the commercial nuclear business and assume an active role. Participating fully in that business is essential in order to shape the rules that apply to it. The nuclear capability of the U.S. has atrophied over the past 30 years since the last nuclear plant construction permit was issued. We no longer have the capability to forge the ingots needed to fabricate major nuclear reactor components. Whereas, the U.S. was once the unquestioned leader in enrichment technology we currently meet only a portion of our domestic demand with outdated technology, and we depend on foreign sources for more than 80% of our enriched uranium requirements. We have no domestic commercial fuel recycling facilities, no operating fast- or gas-cooled reactors and no operating high level nuclear waste repository. Further, each year less and less of the nuclear material in international commerce is of U.S. origin and therefore subject to U.S. consent over its transfer and use.

However, we still have more operating nuclear reactors than any other nation; we have a vision of a future world that can universally enjoy the benefits of safe, economical, emission-free energy; and we have programs and plans to put the U.S. back in the nuclear energy game in a leadership role. Access to our market is itself a form of leverage. However, much international interest in GNEP and the resurgence of U.S. leadership is predicated on the assumption and belief that the United States will follow its words with concrete actions. Prospective partners await congressional action on the GNEP budget and will in part gauge the responsiveness of their actions by it.

Funding for GNEP is absolutely essential; how we spend those funds and how we leverage them to achieve the greatest effect is an equally important issue. In one sense, GNEP must be more than an R&D program. No matter how successful our laboratories and universities may be in solving the remaining fuel cycle technology issues, GNEP must build facilities that have true *commercial* value in order to succeed. If GNEP ends 15 or so years from now with nothing but test facilities in use at our national laboratories, then how do we make international "cradle to grave" fuel cycle services envisioned by the preceding section of this paper? In another sense, it is the responsibility of *government* to demonstrate for industry the feasibility of closing the fuel cycle in a time frame and manner that can achieve the GNEP vision. The challenge is to design the incentives and controls to implement our technology pathway that can reconcile these competing imperatives.

2.2 Nuclear Technology: Government & Industry Roles

2.2.1 Required Technology and Facilities

There are three facilities[2] required to implement and thus affirm our commitment to GNEP: (1) a nuclear fuel recycling center to separate the components of spent fuel required by GNEP; (2) an advanced recycling reactor to burn the actinide based fuel to transform the actinides in a way that makes them easier to store as waste and produces electricity; and (3) an advanced fuel cycle research facility to serve as an R&D center of excellence for developing transmutation fuels and improving fuel cycle technology.

The pursuit of these three facilities constitutes a pathway with two complementary components. The first component, the nuclear fuel recycling center and the advanced recycling reactor, would be led by industry with technology support from laboratories, international partners, and universities. The second component, research and development led by the national laboratories, would include the advanced fuel cycle research facility funded by the Department and located at a government site. The two components would work closely together to move GNEP forward by integrating the national laboratories' capabilities with the needs of industry.

Sodium-cooled fast reactors suitable for adaptation as advanced recycling reactors already exist and there are proven separations processes. But there is a great deal of new technology that is needed to fully implement GNEP, and much of that technology can and must be developed at our national laboratories and universities in cooperation with similar international institutions. However, to effectively bring GNEP into the commercial application we need to engage industry now. Through submittal of Expressions of Interest, industry has indicated not only its support for GNEP, but a potential willingness to invest very substantial sums of private money to build and operate GNEP fuel cycle facilities. At this early point, it should be recognized that potential industry participants have expressed interest, but certainly have made no commitments or fully explained what strings they might wish to attach to their participation. Nonetheless, *a GNEP goal is to develop and implement fuel cycle facilities in a way that will not require a large amount of government construction and operating funding to sustain it.* However, GNEP will

[2] These facilities are referred to in other project documentation as the Consolidated Fuel Treatment Center (CFTC), the Advanced Burner Reactor (ABR), and the Advanced Fuel Cycle Facility (AFCF), respectively.

also require a significant federal investment in supporting R&D and incentives to ensure that the long-term goals are sustainable

2.2.2 Risks/Benefits

GNEP will have lasting benefits at home and abroad and also presents both technological and political risks. However, there are greater risks without GNEP.

The magnitude of this effort is large and involves significant domestic political challenges, as well as a substantial international effort. In the United States, difficulties in effectively dealing with spent fuel will plague the government from a liability standpoint, and impede growth in both the nuclear-generated electricity industry and energy security. Abroad, the anticipated nuclear growth will likely be widespread and allow the continued accumulation of separated plutonium for decades that could be misused by rogue-states.

Technical challenges remain for the implementation of the closed-fuel cycle as envisioned under GNEP. Many of the technologies essential for the successful implementation of GNEP have been demonstrated at laboratory and bench scale. But uncertainties – such as scaling up the chemical separations for the recycle process, or fabricating and qualifying the transmutation fuel for the advanced burner reactor – exist and require consideration. These technical risks warrant continued R&D and technology development for GNEP.

A government-industry partnership is required to implement GNEP. The approach outlined here requires expanded involvement of industry in the design of facilities in preparation for expansion to commercial scale. The approach is to define a technology roadmap to resolve those uncertainties in conjunction with assets available to the government (i.e., National Laboratories, universities, and international partners), but does so in a way that obviates the need to build engineering scale facilities. The government would necessarily define its requirements through contractual means to ensure commercial operation sustains policy goals. The ability of industry to execute the requirements set forth by the government and to demonstrate progress will require careful monitoring and control. This would ensure additional risks are identified in a timely fashion.

Thus, if successful, the approach could reduce overall costs, and increase the speed of arriving at a commercially operated system of prototype GNEP facilities, without significantly increasing programmatic risk.

2.3 GNEP Program Technology Action Plan

The objective of this GNEP technology and facilities implementation plan is to harness and coordinate the strengths, capabilities and resources of industry, national laboratories, universities, and international partners with the clear objective of getting commercial scale facilities that accomplish our GNEP vision into use as quickly and economically as possible. At the core of this effort will be the development of a sound, achievable business plan. The task for the next two years is to assemble the requisite technology, economic and environmental information that can present a convincing case for a path forward to commercial scale facilities that can be approved by the Secretary of Energy in a Record of Decision. Specific programmatic actions planned (subject to funding, risk and project management processes specified in DOE Orders[3]) to reach this decision-point include:

- ***Obtain input from U.S. and international industries and governments on how best to bring the needed GNEP facilities into being, what technology and policy issues must be resolved, and what business obstacles must be overcome.*** (In the U.S., the line between government and industry is quite clear, but internationally there may be little or no distinction.) This process has already begun with the receipt of responses to DOE's request for Expressions of Interest in commercial scale fuel treatment and fast reactor facilities. These initial responses suggest that there is substantial industry interest in building and operating such facilities, and in doing so with private money and at their own risk under the proper circumstances. Separately, there appears to be genuine interest in an international fast reactor construction program.

- ***Develop a detailed GNEP technology roadmap for demonstrating solutions to the remaining technical issues in order to support commercial GNEP facilities. Inform and adjust this roadmap with input received from industry, international partners, and the policy community.*** Carry out the technology development work principally in existing U.S. national laboratory facilities, universities, in a advanced fuel cycle research facility and in the facilities of our international partners. Internationally, we will use existing Generation IV International Forum agreements, I-NERI agreements and new bilateral or multilateral agreements as appropriate.

- ***Pursue industry participation in the development of conceptual design and other engineering studies that support both a nuclear fuel recycling center and an advanced recycling reactor.*** For the nuclear fuel recycling center, the designs would be expected to show, for example, not only what can be built with proven technology (no pure plutonium) but also how the facility would be designed to operate, incorporate and expand using advanced separations modules as they are proven (i.e., minor actinide recycle, Cs and Sr separation, Tc stabilization, etc.). Further, the designs would be expected to meet proliferation resistance, security, waste management, and other important requirements.

    - A majority of the construction cost and schedule (site preparation, fuel receipt and storage, shearing, dissolution, waste treatment, effluent control, etc.) of the nuclear fuel recycling center is associated with known technology. The processes yet-to-be-proven involve small volumes of material but also define the components of programmatic risk. Further, in a chemical separations plant it is possible to make provision to insert new or modified separations modules.

- ***Prepare a programmatic GNEP Environmental Impact Statement.*** Fund several siting studies at locations that submit proposals to host nuclear fuel recycling center and/or advanced recycling reactor facilities and develop environmental data for these sites.

[3] e.g., DOE Order 413.3 on Program and Project Management for the Acquisition of Capital Assets.

- ***No later than June of 2008, prepare a decision package for the Secretary of Energy to proceed with a government-industry partnership to build a nuclear fuel recycling center and a prototype advanced recycling reactor***, assuming that:

    - A credible technology pathway has been developed and satisfactory progress has been made in its implementation;

    - a credible business plan exists;

    - there is reason to believe that a government-private partnership can be formed to build the GNEP facilities that is in the best interests of all parties;

    - relevant NEPA requirements are satisfied; and

    - nonproliferation criteria are defined and met.

In addition, an advanced fuel cycle research facility would be built on a government site to serve as a long-term center of excellence for developing transmutation fuels and improving fuel recycle technology. Further, in parallel with the design and construction of this facility, we should be well along in the development of a program of advanced simulation and modeling for the nuclear fuel cycle and reactor design that has the potential to revolutionize the way the next generation of facilities, beyond GNEP, are designed, built and regulated.

3.0 Conclusion

In sum, we propose to proceed in parallel to: (1) build and operate nuclear fuel recycling center and advanced recycling reactor facilities using the latest commercial technology available after final designs are validated (as soon as possible after the Secretary of Energy's decision in 2008), and (2) continue an aggressive R&D program to complete development of advanced spent fuel separations techniques and transmutation fuel fabrication and recycle technologies and develop validated simulation and computation techniques to advance the development and approval of fuel cycle technology. The parallel activities will have strong cross-connections with industry-requested technical information provided by R&D according to the technology roadmap.

A nuclear fuel recycling center would be designed to incorporate the advanced separations and fuel fabrication modules, with construction scale paced by success in the R&D validating these modules and the prospect for use of separated product as fuel in fast reactors. The output of a nuclear fuel recycling center would be fuel including transuranics for fast spectrum reactors. It would not produce MOX for Light Water Reactors. Once the nuclear fuel recycling center is approved to accept spent fuel, shipments of fuel could begin from utilities, which would be a significant step in providing confidence in our nation's ability to meet its nuclear waste management responsibilities.

A prototypical advanced recycling reactor would aim to reduce capital and operating costs in order to economically produce electricity while consuming plutonium and other transuranics. R&D would continue on technology for recycling used transmutation fuel for further burning in an advanced recycling reactor, with one goal being to minimize the risk that such facilities would be abused to produce pure plutonium.

It is reasonable to expect that in the decade or more that design, approval and construction of these “base technology” facilities would take place, we can successfully prove and incorporate the vital actinide separations steps and develop and qualify a minor actinide bearing fast reactor fuel. Even if the advanced R&D effort was not fully successful or is delayed, we will still have made proven advancements over facilities in operation elsewhere in the world and could make a policy judgment at that time how best to proceed. Our current focus is on making the integrated GNEP system work.

The advantage of the parallel approach is that the U.S. could save nearly a decade in time and a substantial amount of money, while still engaging and reinvigorating the nuclear community with new facilities and continued long-term R&D. Development by the U.S. of a credible program for construction of commercial fuel cycle facilities is a critical element of a strategy to convince any other nation considering beginning a nuclear energy program that they can rely on the U.S. for any of their fuel cycle needs. Making the U.S. a player in fuel cycle technology is vital to fulfilling the GNEP vision.