

“Nuclear Energy and Nuclear Security in the Republic of Korea”

FINAL REPORT

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TABLE OF CONTENTS

<u>Executive Summary</u>	2
<u>Section I: Overview Perspectives</u>	3-9
<u>South Korea: East Asia Institute Perspective</u>	3-5
<u>United States: CISAC Perspective</u>	5-9
<u>Section II: Introduction</u>	10-11
<u>Section III: Domestic Nuclear Industry Issues and Export Potential</u>	12-23
<u>Section IV: Global Nuclear Governance</u>	24-25
<u>Section V: South Korea – U.S. Nuclear Cooperation</u>	26
<u>Section VI: South Korea – U.S. Nuclear Cooperation and the 123 Agreement</u>	27-29
<u>Section VII: Summary and Recommendations</u>	30-32
<u>Appendix I: CISAC and EAI Research Teams</u>	33
<u>Appendices II-V: Available upon request</u>	34

EXECUTIVE SUMMARY

This study employed diverse teams of scholars organized by the East Asia Institute (EAI) and the Stanford University Center for International Security and Cooperation (CISAC) to examine future opportunities for bilateral nuclear cooperation between South Korea and the United States and how to strengthen global nuclear governance. During the past 15 months, the teams exchanged ideas and perspectives of the nuclear industries in each country and their future trajectories, and analyzed future challenges and opportunities through multiple visits, workshops and conferences.

We found much common ground, especially once we better understood each other's objectives and views. For example, South Korea's dramatic emergence as a global industrial and nuclear powerhouse has changed the international nuclear landscape. Today, nuclear cooperation between South Korea and the United States offers as many benefits for the United States as it does for South Korea. With the U.S. share in the global nuclear power market declining and its influence on global nuclear safety, nuclear security and nonproliferation policies and practices endangered, teaming with South Korea can reinvigorate U.S. industrial participation and preserve U.S. influence on global nuclear governance. Bilateral ROK – U.S. nuclear cooperation is essential for both sides, both in technical and in policy matters.

The views of the two teams differ somewhat on future directions of South Korea's nuclear fuel-cycle choices – more in terms of how quickly these are required than in what choices may be best in the long term. The EAI team presents its case based on numerous ROK studies of these issues conducted over many years. The CISAC team conducted a TEP (technical, economic and political) analysis of fuel-cycle issues specifically for this study. Individual papers expressing the views of the EAI and CISAC teams on the issues of global nuclear governance and nuclear cooperation are presented in this report. We present the overview perspectives from both teams before presenting the findings in greater detail.

SECTION I: OVERVIEW PERSPECTIVES

SOUTH KOREA – EAST ASIA INSTITUTE PERSPECTIVE

The ROK-US comprehensive strategic alliance makes possible an expanded bilateral nuclear cooperation under the global nuclear partnership. The ROK-US global nuclear partnership aims to build a cooperative and mutually beneficial relationship aiming at the expanded nuclear energy and nonproliferation cooperation for a better world. In May 2013, President Park Geun-hye and President Barack Obama celebrated the 60th anniversary of the ROK-US alliance in their first summit in Washington D.C. Indeed, the ROK-US alliance today represents one of the most successful partnerships defending freedom and liberty and has done so since the Korean War. Despite the ups and downs in bilateral relations in the past decade, the alliance today has never been better with the two countries viewing it as a ‘comprehensive strategic alliance’ based on ‘shared values of liberty, democracy, and a market economy.’ In particular, changing geo-politics have elevated the role of the ROK-US alliance at both the global and regional level. Those factors include South Korea’s newfound global status, its growing military capacity, and changing strategic values with China’s rise and the relative decline of Japan’s role in regional politics.

The alliance is not without challenges however. As the two allies are engaged in restructuring the partnership to meet the challenges of 21st century global politics, they have to resolve outstanding bilateral issues in coming years. One of the impending issues is nuclear cooperation. The new partnership concerns many issues: building peace with strong nonproliferation, nuclear security and peaceful use regimes; building prosperity with job creation and nuclear exports in both states; strengthening energy security with sustainable use of nuclear energy, stable and secure supply of nuclear fuel and proliferation-resistant spent fuel management; enhancing nuclear safety; and protecting the environment with the use of low-carbon nuclear energy and sound waste management system.

The cornerstone of bilateral nuclear cooperation is South Korea’s unfailing commitment to non-proliferation in line with its general foreign policy. South Korea with its developed economy and democratization is moving from the paradigm of weak state’s foreign policy to that of “middlepowermanship.” There is growing consensus that South Korea can best achieve its national interests by contributing to enhancing universal values, both regionally and globally. By being a champion or at least facilitator of universal interests, South Korea can establish itself as a middle power. There is a growing concern as to whether the non-proliferation regime can prevent further proliferation under the current situation. In the area of nuclear energy and non-proliferation, South Korea needs to realign and consolidate the system of non-proliferation, which has been underdeveloped for many reasons. Also in dealing with North Korean nuclear problem, South Korea will broaden the scope of approaching the problem, simultaneously dealing with the issue for the future of the non-proliferation regime as well as inter-Korean peace and stability.

As the interest in nuclear power continues, the global nuclear industry faces a number of challenges in the future. These challenges are in the area of safety, nonproliferation, and fuel cycle management. At the same time, with the decline in the U.S. industrial leadership, the U.S.’ leadership on global nuclear governance is becoming fragile. This trend is certainly not conducive to enhancing global nuclear safety and security and nonproliferation. This work explores ways for

the ROK and US to collaborate to address these challenges in a mutually beneficial way. In particular, collaboration in nuclear fuel supply and/or spent fuel management is expected to help both countries to effectively address domestic challenges while enhancing the competitiveness in their nuclear export. Through careful coordination and planning, the U.S. and ROK nuclear cooperation could minimize uncertainty in global nuclear development that may adversely affect nuclear safety and nonproliferation. By taking advantage of each other's strengths and meeting each other's needs, the cooperation could present a new global collaboration model to promote Atoms for Peace Initiative as was originally envisioned by President Eisenhower.

Revising a 40-year-old nuclear energy partnership represents an immediate challenge for Seoul and Washington. South Korea's desire for more comprehensive nuclear capacity including enrichment and reprocessing put Seoul in direct opposite position of Washington which tries to enforce more strict nuclear non-proliferation regulation at global level.

Facing a tough negotiation with little room for compromise so far, the two allies have agreed to extend the negotiation for two more years from the original deadline of 2014. Barring technical difficulties and differences over the terms of agreement, the negotiation raises three challenges for alliance management. First, the two governments should not let it be politicized by local politics and become a litmus test for the alliance. Second, Seoul and Washington should make it clear that the nuclear negotiation would not drive any call for South Korea to have an independent nuclear deterrence capability. Third, the most serious challenge for both Washington and Seoul comes from a third party: North Korea and its nuclear program. The two governments must make it sure that the negotiation on bilateral cooperation for the peaceful use of nuclear energy has nothing to do with North Korea's nuclear weapons program. The two allies need to compromise in a way that Washington acknowledges South Korea's desire for full nuclear energy capacity at least symbolically, while Seoul needs to reassure Washington's concerns of nuclear proliferation in the region, as well as the world. As such, the two governments should engage in constructive negotiations in which they try to understand each other's position, identify common ground, and find a creative solution. Together, they should be able to turn this difficult bilateral issue into another opportunity to consolidate the ROK-US alliance in the Asia-Pacific century.

They need to respect each other's position. It is well recognized that the two governments have a different focus on the nuclear energy issue. Serious cooperation occurs when there are different interests. It is possible when countries recognize there is bigger benefit from cooperation than no cooperation. The two governments should develop ways to collaboratively strengthen their respective industrial leadership in global nuclear business and should actively seek opportunities for joint nuclear export.

Recommendations

1. ***They need to respect each other's position.*** It is well recognized that the two governments have a different focus on the nuclear energy issue. Serious cooperation occurs when there are different interests. It is possible when countries recognize there is bigger benefit from cooperation than no cooperation. The two governments should develop ways to collaboratively strengthen their respective industrial leadership in global nuclear business and should actively seek opportunities for joint nuclear export.

2. ***The two governments should not let the negotiation be distracted by other issues.*** The negotiation should focus on its original purpose. That is renewing the peaceful use of nuclear energy partnership and nothing else. It should not become a test case for the alliance. Both governments should not let the negotiation be hijacked by political interest groups or other agendas. Seoul should make it clear the negotiation has nothing to do with the North Korean nuclear issue. At the same time, it has to reassure the other parties that its fuel cycle agenda has nothing to do with a weapons program.
3. ***Within the framework of nuclear energy partnership, they need to broaden the agenda.*** The revision does not have to be only about enrichment and reprocessing. The two should discuss broadening their nuclear partnership in the global non-proliferation regime, the next generation of nuclear energy, the various stages and means of nuclear waste management, nuclear security and safety, and joint collaboration in the nuclear energy market. The two governments should use this opportunity to make their nuclear partnership more comprehensive and future-oriented. The two governments should work together to help newcomer countries develop and maintain infrastructure for nuclear safety, security, and nonproliferation.
4. ***In making a future-oriented partnership, they should come up with unique and creative method for ROK-US nuclear partnership.*** In other words, this partnership should not try to simply follow previous cases, such as the US-Japan, US-India, or US-UAE nuclear agreements. All those partnerships came at different times and in varied contexts and conditions. The ROK-US partnership should be negotiated on in its own terms and context. The two governments should accelerate the current collaboration in pyroprocessing technology development to effectively safeguards the technology and make it commercially viable. Also the two governments should explore ways to work together to secure nuclear fuel supply for the ROK by effectively utilizing uranium enrichment capacity of the U.S.
5. ***Do not hurry.*** The two understand that the negotiation will not be easy. If they find each other's position uncompromising and intractable, they should wait until things change and a new opportunity arrives.

UNITED STATES – CISAC PERSPECTIVE

Nuclear power is an essential element of South Korea's continued industrialization and economic development. South Korea has become a world leader in both the domestic utilization of nuclear energy and its export potential. South Korea plans to increase its domestic reactor fleet to supply 60 percent of its power by 2030 and build its nuclear industry into a global leader. The preliminary targets are 80 reactors for export by 2030 to capture 20 percent of the world market. In spite of its meteoric rise, South Korea faces serious challenges – it must demonstrate that nuclear power remains safe, that the government can convince the public to accept interim spent fuel storage and long-term geologic disposal, and that its choices of nuclear fuel cycle technologies do not compound global nuclear proliferation concerns. Because South Korea's ascendancy in nuclear power was built on close cooperation with American companies and was initially based on

American technologies, its nuclear fuel-cycle choices remain in large part dependent on U.S. concurrence.

The extent of U.S. control and influence of South Korea's nuclear choices is the crux of the current negotiations for the renewal of the 40-year old U.S.-ROK Agreement for Peaceful Nuclear Cooperation (the so-called 123 Agreement). The position of the U.S. government appears to have been forged primarily on the pillar of nonproliferation. South Korea, on the other hand, views energy security, competitiveness of the industry, and its national security as equally important. The politics and symbolism of the negotiations appear to have obscured a rational analysis of South Korea's nuclear future and its cooperation with the United States. This study was designed to conduct such an analysis by looking at these issues from both a South Korean and American point of view.

This study brought together scholars with background and experience in nuclear science and technology as well as in social and political science. These experts took a fresh look at future prospects for domestic nuclear power in South Korea and its export potential, and identified how cooperation on bilateral, regional or multilateral levels can help attain the desired outcome. In addition, the scholars explored how South Korea and the United States could cooperate to develop a better and more resilient form of global nuclear governance.

Three major events in the past decade, potential game changers, have dramatically reshaped the global nuclear landscape. First, the Fukushima accident has slowed the projected global growth of nuclear power. Germany immediately decided to phase out its substantial nuclear reactor fleet. Japan is still reeling from the effects of the accident and the future of its once prominent nuclear industry is in question. China slowed its ambitious plans, but appears to have resumed an aggressive growth plan. For South Korea the major impact will be a reminder that nuclear safety comes first. It can never be taken for granted and the industry and its safety regulators must have sufficient transparency to earn the trust of the government and the public.

The second major event is the revolution in technologies for the exploration and extraction of fossil fuels, primarily the extraction of natural gas through hydraulic cracking – or fracking. The effect in the United States has been to set back the attractiveness of new nuclear power substantially, unless the government imposes a carbon tax, which appears unlikely in the near term. Similar discoveries are being made in the rest of the world, but the impact on the energy landscape appears somewhat slower. Nevertheless, there appear to be huge new and competitive energy resources available on the African continent and countries like China, Kazakhstan and Mongolia. These changes may well slow down the expected nuclear export market and derail South Korea's planned expansion.

The third major event is the steady movement of the center of the global nuclear industry, both in nuclear power utilization and in industrial construction capacity to Asia, particularly to China and South Korea (Japan's leadership remains in question because of the events at Fukushima, but Japan still attempts to regain a foothold in the nuclear export market). Russia and France still remain major global nuclear exporters. The rise of Asia combined with the decline of the U.S. nuclear industry puts the United States at risk of losing its international influence on global nuclear governance. The United States has historically been the standard bearer for nuclear safety, security

and nonproliferation. Its efforts have helped to create a complex web of international treaties, agreements and organizations to promote best practices around the world, sometimes at the expense of its own industrial and business interests.

South Korea is poised to step in and play a greater role in all aspects of global nuclear governance. Some initiatives it can take independently, whereas others are best pursued jointly with the United States. The U.S. nuclear industry is no longer capable of providing much of the industrial nuclear supply chain for large power reactors, either for domestic construction or for export. South Korea, on the other hand, has become a global nuclear powerhouse, both in R&D and industrial capacity. Partnering with ROK nuclear industries and R&D organizations will enhance U.S. nuclear economics, increase U.S. nuclear exports potential, and slow the decline of U.S. leadership in global nuclear governance by keeping it in the global game. This reversal of nuclear capabilities must be reflected in the renewal for nuclear cooperation. The renewal must deal with South Korea the way it is today, not as it was 40 years ago.

Unfortunately, negotiations are polarized on the issue of U.S. consent for South Korean development of front end (enrichment) and back end (pyroprocessing) capabilities. U.S. opposition is based primarily on its desire to limit countries from developing their own enrichment and reprocessing (E&R) capacities because the spread of such technologies will exacerbate global nuclear proliferation concerns. South Korea bases its case on its desire to ensure sustainable nuclear power free from foreign constraints or market fluctuations and to provide a more attractive path to dealing effectively with its nuclear waste. Its nuclear industry also believes enrichment is important to its nuclear reactor export potential. Resolving these differences is important not only for the future of South Korea's nuclear industry, but also to prevent straining an alliance that is fundamentally strong. Regardless of the final resolution, it is important that the terms of renewal not become a litmus test for the alliance.

The CISAC team stepped back from the political stalemate and analyzed South Korea's nuclear future based primarily on technical and economic considerations, but informed by the political situation. It conducted a TEP (technical, economic and political) analysis of the entire fuel cycle, which includes the front end (uranium mining and conversion; enrichment), the middle (fuel fabrication; reactor fabrication and construction; spent fuel storage) and back end (fuel reprocessing; spent fuel disposal; high-level waste disposal).

The TEP analysis finds it inadvisable for South Korea to pursue domestic enrichment in the short term because of the low technical and economic benefits, the ready global availability of enrichment services, and the substantial political downsides of pursuing such an option. For the longer term and possibly to enhance South Korea's reactor and fuel-cycle facility export potential, developing domestic enrichment capabilities to provide a hedge against supply disruption or large price fluctuations may be advisable. However, because of proliferation concerns, such capabilities should be pursued only through international cooperative ventures, either bilaterally or multilaterally.

With the exception of spent-fuel storage, South Korea has world-class capabilities in the middle of the fuel cycle – in fuel fabrication and fabrication of virtually all reactor components and all balance of plant equipment. Its strategy of building a nuclear industry by focusing in the middle of

the cycle during the past several decades was brilliantly conceived and executed. South Korea's nuclear industry is now among the best in the world, as was demonstrated by South Korea being awarded the contract to build four light-water reactors (LWRs) for the UAE and its participation in the first AP1000 nuclear construction projects in China and in the U.S. However, domestically South Korea must take immediate actions to develop interim spent-fuel storage capacity since the capacity of reactor-site wet spent-fuel storage is almost exhausted. Although several temporary solutions are possible for the short term, South Korea must move to the construction of a centralized, away-from-reactors dry-cask storage, which will require a major effort to convince a skeptical public. Dry-cask storage will provide at least a 50-year time buffer to develop technical options for reprocessing and for permanent disposition of either spent fuel or high-level waste, as well as fast reactors technology which might burn recycled fissile materials. Dry-cask interim storage is technology neutral on the back end, that is, it does not depend on the ultimate spent-fuel management scheme.

The TEP analysis also indicates reprocessing spent fuel, either by the conventional PUREX process or pyroprocessing, is not critical to South Korea's short-term domestic program or its export market. Even if pyroprocessing can be shown to be technically and economically viable, its commercial development cannot be achieved sufficiently rapidly to deal with South Korea's near-term spent fuel accumulation problem. Moreover, the deployment of pyroprocessing faces considerable U.S. opposition. The best short-term option is to continue a robust pyroprocessing research program, preferably in cooperation with the United States as it is currently envisioned in the 10-year joint R&D program. In the longer term, the best prospects for the application of pyroprocessing are as a part of a fast reactor development program. Although the United States will move rather slowly, if at all, to fast reactors technologies, South Korea has expended significant resources on fast-reactor R&D, in part because of its lack of indigenous uranium resources. The South Korean team believes that pyroprocessing is an economically attractive alternative even for the current once-through fuel cycle; that is, it need not await the development of fast reactors because of the high cost of spent-fuel storage and eventual disposition in South Korea. Consequently, the EAI team views the development of commercial pyroprocessing capabilities as much more time urgent than CISAC TEP analysis implies.

Regardless of future fuel cycle choices, it is essential for South Korea to take immediate actions to restore the public's trust in the nuclear industry. The government must deal resolutely with the industry's alleged corruption problems and strengthen the government's regulatory organizations dealing with all aspects of South Korea's nuclear industry as well as instill greater transparency and attention to quality matters in the Korean nuclear industry. This issue is closely tied to nuclear safety, which must remain the nuclear industry's highest priority. If South Korea does not take the necessary steps to demonstrably assure nuclear safety, its domestic nuclear market may collapse and its export market may never materialize. Part of the solution is to institute a very rigorous quality assurance program with requisite documentation, an area in which South Korea could learn from U.S. experience. Both of these priorities require much greater transparency of South Korea's nuclear industry and governmental agencies.

Although the prospective terms for renewing the 123 Agreement were not a direct part of this study, we offer some overarching observations. As already noted, the renewal should strive to develop a ROK – U.S. partnership that reflects the enormous progress made in South Korea's

economic, political and industrial standing in the world since 1974, as well as the decreasing influence the United States has in global nuclear futures resulting from its declining leadership in the nuclear industry. Second, instead of trying to apply the so-called nonproliferation “gold standard” adopted for the UAE, Washington should strive for a criteria-based standard that better reflects a country’s technical, political, regulatory, and industrial capacity, as well as its nonproliferation record. In other words, the provisions should be South Korea specific, not carry the baggage of the UAE agreement or of the historical precedents of the Japan or India deals.

We also believe that the South Korean agreement should not be constrained by the North Korean nuclear problem. North Korea has clearly violated the letter and the spirit of the 1992 North-South agreement. Moreover, aside from providing Pyongyang with grist for its propaganda machine, the nature of South Korea’s civilian nuclear capabilities has little, if any, influence on North Korea’s nuclear weapons program. What’s at stake in Pyongyang’s calculus in the potential elimination of nuclear weapons is much greater than whether or not Seoul develops some of the same fuel-cycle capabilities that the North has already pursued for decades in violation of the NPT and the Denuclearization Agreement.

The controversies over the terms of renewal for the 123 Agreement have overshadowed what we view as the most important domestic and international consequence of South Korea’s meteoric rise as an industrial power and nuclear energy power – that is, it has emerged as a model state for future nuclear power aspirants. South Korea has excelled in what we consider the most important parts of the nuclear fuel cycle. Its early strategy to focus on getting nuclear electricity on the grid as quickly as possible, while concurrently developing the requisite domestic technology base for reactor fabrication and construction in combination with modern fuel fabrication has served the country well. South Korea wisely avoided the contentious front-end issue of enrichment and back-end reprocessing issues. The only serious shortcoming is its ability to deal with spent fuel. Our analysis indicates that this could be achieved quite readily with an intermediate centralized spent-fuel storage facility. Such a move will buy time to deal with reprocessing and future fuel-cycle choices. A forward-looking nuclear partnership agreement will accelerate South Korea’s global nuclear leadership while concurrently helping the United States strengthen its nuclear industry and maintain its influence in global nuclear governance.

SECTION II: INTRODUCTION

Nuclear power is an essential element of South Korea's continued industrialization and economic development. For nuclear electricity to expand it must be safe and secure, economically competitive, not lead to the proliferation of nuclear weapons, and demonstrate a path forward for the disposition of nuclear waste – a tall order. In this study we focused primarily on issues of nonproliferation, but also touched on other aspects of nuclear energy, since these issues are intricately intertwined. We evaluated South Korea's reactor and fuel-cycle choices, both from technological and economic points of view, and how these are affected by U.S. – South Korea relations and domestic politics. The study was conducted by researchers from CISAC and EAI. In this report we provide both joint assessments and individual views from ROK and American scholars, but even the individual assessments were informed by dialogue with the other party.

Although we are fully cognizant of the importance of the terms of renewal of the U.S.-ROK Agreement for Peaceful Nuclear Cooperation (the 123 Agreement), this study was focused on a comprehensive look at South Korea's fuel cycle choices and at the future of nuclear cooperation, primarily with the United States. The study was designed to examine nuclear power development and nonproliferation issues in South Korea, prospects for South Korean nuclear power exports and global nuclear governance.

CISAC engaged a team of technical specialists, political and social scientists, and nuclear practitioners to examine these crucial issues. The EAI engaged a team of South Korean specialists. The research teams listed in Appendix I. The CISAC team was headed by Prof. Siegfried S. Hecker, principal investigator, and Dr. Chaim Braun, consulting professor. The EAI team was headed by EAI Chairman Young-Sun Ha, and Prof. Chaesung Chun.

Study design and methodology

CISAC employed a diverse team of scholars from Stanford University with expertise in both the technical and policy nuclear power issues associated. EAI also employed a diverse team of scholars and practitioners from universities and nuclear industry in Korea with expertise in both policy and technical area of nuclear power. To meet the objectives of the study, it was important to have broad and deep exchanges of views between South Korea and U.S. scholars. Consequently a number of workshops and conferences were held to provide critical input to our analysis. On August 6-7, 2012, CISAC and EAI scholars met for an introductory workshop titled "U.S. – ROK Cooperation for Global Nuclear Governance," at the East Asia Institute (EAI) in Seoul, Republic of Korea. This was followed by a meeting hosted at CISAC at Stanford University on October 19, 2012 titled "U.S. – ROK Cooperation for Global Nuclear Governance." EAI scholars had a workshop at the Monterey Institute of International Studies with Dr. William Potter, Director of Center for Nonproliferation Studies and other experts to share the vision of ROK-U.S. nuclear partnership on October 20, 2012. EAI scholars also visited Belfer Center for Science and International Affairs at Harvard University to discuss the above issue with experts in this field including Dr. William Tobey at November 15, 2012. CISAC's Dr. Chaim Braun and EAI scholars traveled to a meeting hosted by EAI and the Center for Strategic and International Studies (CSIS) in Washington D.C. titled "Conference on U.S. – ROK Cooperation for Global Nuclear

Governance” on November 16, 2012. CISAC and EAI scholars also traveled to Washington D.C. May 16-17, 2013 to participate in two EAI-organized roundtables and one conference co-hosted with CSIS. The roundtables were titled “Roundtable on the 123 Agreement and the Future ROK-U.S. Nuclear Cooperation” and “Roundtable on Mounting North Korea’s Threat: How to Interpret and How to Respond.” The conference was titled “Strengthening ROK-U.S. Strategic Cooperation Nuclear Governance and the North Korean Problem.” Finally, CISAC and EAI scholars met in Seoul, Republic of Korea on September 13, 2013 in a conference titled “Future Direction for ROK-U.S. Nuclear Cooperation,” with the aim of discussing and exchanging results from the collaborative research effort. The agendas for these workshops and conferences are presented in Appendix II.

This study was informed by a previous study conducted jointly with the University of California Berkeley Nuclear Engineering Department on “Scientific and Institutional Aspects of Advanced Systems for Spent Nuclear Fuels in Emerging Nuclear Countries,” sponsored by the Korea Atomic Energy Research Institute.¹ The study concluded that despite South Korea’s impressive progress in nuclear power and R&D, its reliance on nuclear energy to power its grid for the past 30-plus years has resulted in a short-term challenge of how to manage its increasing accumulation of spent nuclear fuel, which is currently stored in spent-fuel ponds located near South Korea’s 21 nuclear reactors. It was recognized that solutions to deal with spent fuel in South Korea could have regional and geopolitical implications, which, in turn, make all back-end fuel-cycle issues contentious politically. It was also concluded that there are no proliferation-proof technologies – all must incorporate technological, institutional and political considerations.

The current Stanford University and EAI study team made numerous site visits to be able to make first-hand assessments of the state and direction of South Korea’s nuclear industry and its R&D capabilities. A list of sites and contacts are provided in Appendix III. Based on our interactions with South Korean scholars, the workshops and conferences, and our site visits, we made a small change in the focus of our study. We chose to analyze South Korea’s domestic nuclear issues and prospects, its export potential, and South Korea’s role in global nuclear governance. For all three segments, we specifically focused on analyzing the potential benefit of bilateral U.S. -ROK cooperation, regional cooperation, and multilateral cooperation. The rest of the report is organized into the following sections: Section III. Domestic nuclear industry issues and export potential; Section IV. Global nuclear governance; Section V. U.S. – ROK nuclear cooperation; Section VI in which we provide some overarching comments for considerations for the future of the 123 agreement before concluding in Section VII with some specific recommendations for future U.S. – ROK nuclear cooperation.

¹ Siegfried Hecker, Edward Blandford, Alan Hanson, Thomas Isaacs, & Niko Milonopoulos, J. Ahn, R. Borrelli, J. Choi, L. Kim, P. Peterson & J. Yoon, and Y. Hwang, Center for International Security and Cooperation Report, Stanford University, February 2012.

SECTION III: DOMESTIC NUCLEAR INDUSTRY ISSUES AND EXPORT POTENTIAL

This section represents the findings and analysis of the CISAC research team. It was informed by many interactions with the EAI team and other ROK scholars. During our first meeting at EAI, Prof. Ha Young-Sun suggested that we construct a matrix of the political, economic, and technical (PET) issues associated with all aspects of the nuclear fuel cycle and consider the impact and importance of cooperation on bilateral, regional and multinational bases. We found this approach to be an effective way to analyze domestic and export issues for South Korea's nuclear industry. We divided the fuel cycle into the following categories for purpose of in-depth examination:

- Uranium mining and conversion
- Uranium enrichment
- Fuel fabrication
- Reactor fabrication and construction
- Spent fuel storage
- Fuel reprocessing
- Spent fuel disposal
- High-level waste disposal

Based on our discussions with South Korean scholars and officials, the drivers for the domestic nuclear program and nuclear export remain strong, even in light of the events at Fukushima. The goals for the domestic industry and exports remain similar to those expressed in the first National Energy Master Plan of 2008, which covers the 2008-2030 period. Nuclear generation is expected to increase its share of the domestic electricity market in South Korea. The target was to construct 11 additional reactors to provide 41 percent of total generating capacity and 60 percent of power supply in South Korea by 2030. The export market is considered critical to South Korea's nuclear industry. The plan is to build South Korea's nuclear industry into a global leader. Preliminary targets are 80 reactors by 2030 and 20 % of the world market.

We analyzed these objectives and constructed a TEP (technical, economic and political) matrix of the elements of the nuclear fuel cycle listed above. We chose to invert the PET analysis into a TEP analysis because the political issues, especially as they pertain to the nuclear fuel cycle, are so contentious today that they often preclude a thorough assessment of the technical and economic issues. We also recognize that some of the fuel-cycle categories are interdependent. For example, different reactor options require different front and back-end fuel-cycle options. Nevertheless, we found it useful to break down the fuel cycle into individual components to allow us to assess options from the TEP points of view.

However, before discussing the results of our analysis in the matrix shown in Table 1, it is important to re-emphasize the importance of nuclear safety and transparency in the success of South Korea's nuclear energy program by examining recent issues in the nuclear industry worldwide.

The Fukushima nuclear accident had the immediate impact of taking the six reactors at the Fukushima-Daichi site off Japan's electrical grid. However, the scrutiny brought by the Fukushima

accident of nuclear power sector governance and the soundness of the regulatory system in Japan has had a traumatic effect on all nuclear power in Japan. It has reduced the number of operating nuclear power reactors from 50 to two, and the state of affairs make one question not just the rate at which the remaining 48 reactors will be restarted, but whether some or most of them will be restarted at all. The nuclear power outage is a major economic blow to Japan, as it relies on imports to meet almost all of its energy needs. The share of thermal power in Japan's power generation mix rose from about 60 percent in 2010 to nearly 90 percent in 2012, which added substantially to its trade deficit and its economic competitiveness.

Utilities in the United States have announced that five of 104 U.S. nuclear reactors will be taken off the grid; three of them have had major mechanical problems and all of them are deeply affected by the decline of natural gas prices in the United States. In some U.S. states, the current marginal electricity production costs from gas fired combined cycle plants is lower than the corresponding costs from nuclear power plants, which impacts the rationale for keeping those nuclear plants on line, let alone extending their operating lifetime. South Korea is not immune to a potential major disruption in its nuclear reactor fleet, though it is not likely to experience such low natural gas prices in the near term.

Some of the most disturbing news during the past year has been revelations about counterfeit equipment parts and corruption in South Korea's nuclear industry. These issues raise serious concern about integrity in some elements of South Korea's nuclear and regulatory establishments, the lack of transparency in the industry, and the rigor of the government's regulatory and oversight functions. These issues must be addressed immediately by the nuclear industry and the government to restore the public's trust in the industry. These issues are also of extreme importance to the prospects of future South Korean nuclear power plant exports. We offer some additional comments on the importance of transparency in the section on global nuclear governance, but we believe it is essential to emphasize here that South Korea's commitment to safety and transparency must be absolute and unquestioned if it is to meet its goals for nuclear energy both domestically and worldwide. Professors Michael May and Edward Blandford also offer a paper in Section IV emphasizing specific aspects of transparency and their importance in a successful nuclear industry.

The TEP (Technical, Economic and Political Factors) Matrix

We constructed the matrix shown in Table 1 based on our analysis. This matrix was constructed by the CISAC team, but informed by interactions with ROK colleagues and site visits to many ROK nuclear facilities.

Table 1: The Stanford team's perspective of the technical, economic and political factors associated with the nuclear fuel cycle in South Korea.

	Technical	Economic	Political	Political US View
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			ROK*	
Uranium mining & conversion	+	+	+	NA
Uranium enrichment	+	+	++	-
Fuel fabrication	+++	+++	+++	+++
Reactor fabrication & construction	+++	+++	+++	+++
Spent-fuel storage	+++	+++	-	+++
Spent-fuel reprocessing	++	0	+++	-
Spent-fuel disposal	+	++	-	++
HLW disposal	+++	++	-	++

*The ROK political view is our assessment based on discussions with South Korean scholars and officials.

Key to symbols: 0 not important + somewhat important ++ important
 +++ very important – problematic NA not applicable

We provide a brief narrative to explain Table 1.

Uranium mining and conversion: There are no known commercial deposits of uranium in South Korea. We assign some technical importance to this issue in case South Korea decides to pursue extraction of uranium from seawater. This technology is currently not economically feasible, but should not be ruled out for the future. At the economic level, South Korea attaches importance to diversifying its international sources of uranium and developing mining partnership with resource-rich countries such as Kazakhstan, Australia and Mongolia. On uranium conversion South Korea views this as a complementary activity to fuel manufacturing (especially the re-conversion from uranium hexafluoride back to uranium oxide). Mastery of this activity is commercially useful to Korea Nuclear Fuel Corporation (KNFC).

Uranium enrichment: We see no technical benefits of South Korea pursuing enrichment technologies on its own. The technologies are proliferation sensitive. Centrifuge technology, the current technology of choice worldwide, is quite well developed and protected both from a proprietary and proliferation point of view. Currently there exists a global oversupply of enrichment capacity so Korea's entry into the enrichment business will not fill an unmet demand. Potential development and commercialization of laser enrichment technologies should not be dismissed. However, because of proliferation concerns, any uranium enrichment capability is better pursued multilaterally, if at all. It is possible that South Korea could benefit economically from developing centrifuge enrichment capabilities both for its domestic and export markets. However, the proliferation concerns make it politically problematic – it appears to be generally supported in South Korea and strongly opposed by the U.S. government. South Korea has several

policy options available to it. One of these options is to buy a significant stake in a U.S. enrichment corporation or in other international enrichment enterprises that will welcome its ownership stake. This would involve commercial participation in an enrichment plant located elsewhere.

Fuel fabrication: South Korea has developed world-class fuel fabrication capabilities with a determined and successful effort that allowed it to produce its first domestic pressurized light-water reactor (PWR) fuel in 1989 and it has continued to increase its independent capabilities with increasingly sophisticated technologies over the last two decades. This step of the fuel cycle is challenging from the technical as well as from the quality assurance perspective, and it poses no proliferation risk. It requires sophisticated engineering, manufacturing and materials capabilities and control. South Korea's investment in this step was an astute technical and economic decision that will serve the nuclear industry (both in its domestic and export markets) well. It is particularly advantageous because the fuel business typically spans the lifetime of reactors, which can extend to 60 years. As the South Korea continues to build reactors domestically and export them to other countries, this market activity will increase in importance in the future.

Reactor fabrication and construction: South Korea has also developed a world-class industrial capability for the fabrication of virtually all reactor components and all balance of plant equipment. South Korea has demonstrated excellent capabilities in nuclear plant design and construction. It has exported major reactor equipment items to China, the United States (based on U.S. design and manufactured in South Korea), and soon to the United Arab Emirates (UAE). South Korea had manufactured and was ready to ship nuclear plant components to North Korea as a part of the Korea Energy Development Organization (KEDO) before it was terminated. Again, the strategy of building a nuclear industry dating back to having to cope with the oil shock in the early 1970s was brilliantly conceived and executed. South Korea's nuclear industry is among the best in the world right now, as was demonstrated by South Korea being awarded the contract to build four light-water reactors (LWRs) for the UAE.

Spent-fuel storage: Currently, all spent nuclear fuel (SNF) from operating ROK nuclear power plants (NPPs) is stored at plant sites, mostly in the SNF pools attached to each reactor. This practice is referred to as on-site wet storage. It is expected that the SNF storage pools in these NPPs will be full (saturated) prior to 2020.² South Korea may arrange for several additional years of pool storage via various mechanisms, but these temporary measures will all eventually run their course, SNF pools will approach full saturation by 2030, and the fundamental problem of SNF disposition will remain. Our research has demonstrated that South Korea will clearly have to move toward dry-cask interim storage. There are significant technical and economic benefits from such a move. Politically, interim storage faces significant challenges domestically, although it is recognized that it will have to be pursued at some level. Interim storage is a step that is strongly encouraged by the U.S. government.

Spent-fuel reprocessing: This has been the most contentious part of the ROK – U.S. nuclear relationship over the past few years. The 40-year old 123 Agreement disallows

²C. Braun and R. Forrest, "Considerations Regarding ROK Spent Nuclear Fuel Management Options," Nuclear Engineering and Technology - Journal of the Korean Nuclear Society, Vol. 45, No. 4, Page 427 (12 pgs.), Year 2013-08.

reprocessing of U.S.-origin fuel in the South Korea without specific U.S. prior consent. South Korea has invested heavily in R&D on pyroprocessing, a technologically attractive option for dealing with spent fuel. It has unsuccessfully attempted to have Washington agree to more than just a continuation of pyroprocessing R&D. American opposition to any reprocessing remains strong because of Washington's global proliferation concerns. The potential nonproliferation benefits of pyroprocessing over commercial aqueous processing (PUREX) remain contested. We see potentially significant technical benefits from pyroprocessing, but do not believe that it will result in significant economic benefits until the introduction of fast reactor technologies, a process that may take even longer time period than mastering pyroprocessing. There are substantial technical challenges because pyroprocessed fuel must be remotely fabricated into fuel assemblies specifically designed for fast reactors. The pyroprocessing technology and fuel-cycle economics are not sufficiently understood at this point to assess its economic viability. Without successful concurrent development of fast reactors the rationale for pyroprocessing as a component of a waste management strategy is weakened. The storage of pyroprocessed and re-manufactured fuel assemblies in the absence of fast reactors will represent a significant safeguards challenge and economic cost. As indicated, politically there is a strong push for this technology in South Korea and strong opposition from Washington. The U.S. government favors allowing the current 10-year R&D agreement to take its course and postponing any decision to move toward commercial operations.

Spent-fuel disposal: In the absence of commercial reprocessing, it will be important to develop appropriate options for permanent spent-fuel disposal. There are significant technical challenges worthy of the South Korea's substantial technical talents in all nuclear fields. There are also potentially strong economic motivations to develop these capabilities. There is strong public opposition in South Korea to permanent spent-fuel disposal, which is not surprising in light of the total failure of the United States to deal with this problem. Since the U.S. Yucca Mountain Project was canceled, Washington has begun to tackle this issue in a more comprehensive fashion based on recommendations of the recent Blue Ribbon Commission on America's Nuclear Future.³ Washington views the open fuel cycle and eventual permanent disposal as an important political plus, both domestically and internationally. South Korea may be well served by looking at the examples of Sweden and Finland, where public involvement appears to be leading to consensus-based siting of repositories. If South Korea pursues a substantial interim spent-fuel storage program, then a decision for permanent disposal becomes less time critical, but still important since the public is concerned about interim storage without some indication that a permanent storage option is viable.

High-level waste disposal: We list this in addition to spent-fuel disposal because even if the fuel cycle is closed by reprocessing, it will be necessary to dispose of high-level waste instead of spent fuel. The issues are quite similar, although there are advantages to such repositories because the long-lived actinides, such as plutonium, are removed from the waste. This reduces the total amount of waste that requires disposal. However, the magnitude of such benefits in terms of repository size and requirements are still disputed in the technical and political communities. Nevertheless the geotechnical requirements of spent-fuel or high-level waste repositories are

³Report of the Blue Ribbon Commission on America's Nuclear Future. Report released January 26, 2012. Accessed at <http://cybercemetery.unt.edu/archive/brc/20120620211605/http://brc.gov//>

similar and regardless of which fuel-cycle option South Korea eventually chooses, it will have to develop a repository program.

Priorities based on the TEP matrix and the benefits of nuclear cooperation

We integrated the TEP considerations of Table 1 into assessments of the short-term and long-term importance for the domestic industry and a single factor for export. The results are summarized in Table 2. In addition, we provide an assessment of the role of nuclear cooperation at the bilateral (ROK – U.S.), regional, and multinational level.

Table 2: U.S. perceptions of priorities for ROK nuclear sector based on TEP analysis

	Domestic Short term	Domestic Long term	Export	Bilateral cooperation with U.S.	Regional cooperation	Multinational cooperation
Uranium mining & conversion	0	+	+	+	+	++
Uranium enrichment	0	+	++	++	+	++
Fuel fabrication	+++	+++	+++	+++	++	++
Reactor fabrication & construction	+++	+++	+++	++	+	+++
Spent-fuel storage	+++	+++	+++	+++	+++	+++
Spent-fuel reprocessing	0	++	+	++	+	+
Spent-fuel disposal	0	+++	++	++	+++	++
HLW disposal	0	+++	++	++	++	+

Key: 0 – not important + somewhat important ++ important +++ very important.

We provide a brief narrative to explain Table 2.

Uranium mining and conversion: As indicated above, South Korea relies on foreign sources of uranium. In the long term, uranium mining from seawater may become attractive. Cooperation is important at all levels as South Korea buys commercial interests in foreign uranium mines and enterprises. Uranium conversion and reconversion will continue to have some importance. On the multinational level, it will be in South Korea's interest to help build a robust international fuel bank to help buffer against potential supply disruption. The fuel bank is in reality only an enriched uranium bank, but South Korea's robust fuel fabrication capabilities turn it into a fuel bank.

Uranium enrichment: We find it inadvisable to pursue domestic enrichment in the short term because of the low technical and economic benefits, the ready global availability of

enrichment services, and the substantial political downsides of pursuing such an option. For the longer term and possibly to enhance South Korea's reactor and fuel-cycle facility export potential, developing domestic enrichment capabilities to provide a hedge against supply disruption or large price fluctuations may be advisable. However, because of proliferation concerns, such capabilities should be pursued only through cooperative ventures. Such a policy would also be consistent with South Korea's desire to play a leadership role in global nuclear governance. In such a role, Seoul may well want to promote limitations on new unilateral enrichment enterprises anywhere in the world. There are numerous potential pathways for cooperative enrichment ventures, ranging from bilateral ones such as the existing stake South Korea has purchased in the Georges Besse II plant in France, possible deals with U.S. enrichment ventures, regional Northeast Asia consortia, or current or future multinational ventures, located either in South Korea or abroad. Dr. Braun and Dr. Forrest expand on such arrangements in a paper provided in Section V. In the longer term, South Korea may also consider partnering with other countries to develop the potentially technically and economically attractive atomic vapor laser enrichment process. However, such an activity would have to be pursued while being fully cognizant of proliferation concerns.

Fuel fabrication: South Korea's world-class fuel fabrication facilities will serve it well both in the short and long term in the domestic market and in the export market. South Korea can enhance its export potential through cooperation at all three levels. In Northeast Asia, China and Japan have already mastered this technology, thus limiting the South Korea's ability to capture more of the regional fabrication market. On a multinational level, South Korea's fuel fabrication capabilities will be critical to supply fuel for South Korean reactor exports. Continued R&D for fuels for the next generation of reactors is imperative for South Korea to fully develop its domestic and export market capabilities. South Korea must work cooperatively with foreign reactor vendors and with potential customers abroad to grow its fuels export business. As pointed out above, the fuel business typically spans the lifetime of reactors, which can extend to 60 years.

Reactor fabrication and construction: The South Korean government must take immediate steps to demonstrate that it is correcting the nuclear industry's alleged corruption problems, to develop more rigorous and independent oversight of the industry and to increase transparency in the entire nuclear fuel-cycle industry. In addition Korean industry and its regulators must improve the quality assurance processes and paper trails related to nuclear plant components and fuel assemblies manufacturing. Without such demonstrated changes, the safety of South Korea's reactor fleet and its exports will be questioned causing a potential collapse of both markets. Nuclear safety is a never-ending job that requires global cooperation and interaction. Closer cooperation with the U.S. Nuclear Regulatory Commission (NRC) and U.S. reactor vendors and operators will be beneficial to both countries. Much could be gained regionally from a Northeast Asia nuclear safety consortium, involving China, Japan and South Korea, and perhaps, some day, North Korea. Dr. Braun elaborates on this proposal in his paper in Appendix V. Korea should also seek to enhance and upgrade the activities of the Asian part of the World Association of Nuclear Operators (WANO).

South Korea has domestically designed and built nuclear reactors for two decades. It expanded into the international reactor exports market in 2011 and has been working with U.S., Japanese and other partners on multilateral nuclear plant export opportunities. The much anticipated global nuclear renaissance appears to have stalled, except for China, which is gearing up to become both

a major domestic and export supplier. Hence, competition for new international reactor orders will be keen and will likely involve teams of multinational suppliers. The ability to manufacture the reactor, the fuel, and the turbines, at high quality and reasonable price, has greatly enhanced South Korea's attractiveness as lead nuclear system supplier in such multinational arrangements. Moreover, South Korea's overall industry flexibility and the nimbleness of its decision-making process and supply arrangements may give it a large share of the international market. We suggest that South Korea and the United States collaborate on Gen III+/Gen IV (next generation) nuclear power reactors as well as small modular reactors (SMRs). Such collaboration could help to rebuild U.S. capabilities in its nuclear supply chain and team up the two countries in the new field of commercial SMRs, which were developed both in the U.S. and in Korea. Again, Dr. Braun discusses more specific ideas on bilateral cooperation on new reactor design and implementation in Section V.

Spent-fuel storage: Regardless of how the domestic nuclear power market develops and whether or not South Korea reprocesses its spent fuel, South Korea must take immediate actions to develop interim spent-fuel storage capacity⁴. As mentioned above, several options can extend the capacity of wet spent-fuel storage, but these buy only limited time. South Korea has begun to implement a temporary solution by licensing on-site, dry-cask storage facilities at a few of its plants, such as Wolsong and Hanul (formerly Ulchin) and it has begun limited operation of storing CANDU fuel on-site at Wolsong. An alternative would be construction of a centralized, away-from-reactors dry-cask storage facility combined with transportation of the spent fuel from power plant sites to such a facility. Such a centralized facility is referred to generically as an Independent Spent Fuel Storage Installation (ISFSI). If a pyroprocessing facility is eventually found appropriate and is built, then it would be advantageous to co-locate an ISFSI at what could be considered a national back-end fuel cycle center.

The analysis presented by Braun and Forrest indicates that even if reprocessing is implemented in a timely fashion in South Korea, it will not obviate the need for centralized dry-cask storage. Therefore, the development of dry-cask storage is critical for South Korea's domestic market both in the short and the long term. Dry-cask storage will provide at least a 50-year time window to develop technical options for reprocessing and for permanent disposition of either spent fuel or high-level waste, as well as fast reactors technology which might burn recycled fissile materials. It is technology neutral on the back end, that is, it does not depend on the ultimate spent-fuel management scheme. Since public opposition to most nuclear storage options, be they for spent fuel or for nuclear waste, remains strong, it behooves the South Korean nuclear industry and the government to develop initiatives to increase public understanding and win public support. Although it is generally believed that South Korea's public will not approve the siting of an ISFSI without the government having a concrete plan for final waste disposition, this issue is so critical to the future of nuclear power in South Korea that a continued effort to involve the public and get timely concurrence for an ISFSI is warranted. Once South Korea has demonstrated domestic dry-cask storage capabilities, such capabilities will also present a potentially lucrative export fuel-cycle service market to accompany its reactor and other fuel-cycle exports.

⁴ C. Braun and R. Forrest, "Considerations Regarding ROK Spent Nuclear Fuel Management Options," Nuclear Engineering and Technology - Journal of the Korean Nuclear Society, Vol. 45, No. 4, Page 427 (12 pgs.), Year 2013-08.

We view spent-fuel storage as an excellent area for cooperation at all three levels shown in Table 2. It is especially important for ROK-U.S. cooperation since the United States has much technical, licensing and operating experience for dry-cask storage sites. It may be particularly advantageous for South Korea to launch a dry-cask storage demonstration project with U.S. participation. Regional⁵ and international⁶ cooperative schemes also hold significant promise for dealing with the spent-fuel problem, while promoting good nonproliferation practices. Additionally, development of a robust capacity for spent fuel storage would strengthen South Korea's position in exporting reactor technology, allowing them to market a fuller fuel cycle package internationally.

Spent-fuel reprocessing: Our analysis indicates reprocessing spent fuel, either by the conventional PUREX process or pyroprocessing, is not critical to South Korea's short-term domestic program or its export market. Even if pyroprocessing can be shown to be technically and economically viable, its commercial development cannot be achieved sufficiently rapidly to deal with South Korea's near-term spent fuel accumulation problem. Moreover, pyroprocessing development faces considerable U.S. opposition. We believe South Korea's best option in the short term is to continue its robust pyroprocessing research program, preferably in cooperation with the United States as it is currently envisioned in the 10-year joint R&D program. In parallel South Korea should pursue a centralized spent fuel storage program thus demonstrating a comprehensive spent fuel management strategy, as mentioned above.

In the longer term, the best prospects for the application of pyroprocessing are as a part of a fast reactor development program. Although fast reactors are part of the U.S. Gen. IV reactor development program, it is unlikely that fast reactors will become part of the operational U.S. reactor fleet until well into the second half of this century. Nevertheless, several other countries have more aggressive plans and South Korea has expended significant resources on fast-reactor research, in part because of its lack of indigenous uranium resources. The combination of pyroprocessing and fast reactors may also eventually reduce the burden on nuclear waste repositories. The interim dry-cask storage concept keeps that option open in that it will allow such technologies to deal with the stored waste even after long interim storage times. South Korea could also benefit from cooperation with the U.S. and others in reprocessing technologies, including pyroprocessing. It already has a successful R&D cooperation with the United States and can develop similar cooperative programs regionally and internationally.

According to Man-Sung Yim's paper in the appendix, South Korean analysts believe that pyroprocessing is an economically attractive alternative even for the current once-through fuel cycle; that is, it need not await the development of fast reactors because of the high cost of spent-fuel storage and eventual disposition in South Korea. Consequently, they believe that the development of commercial pyroprocessing capabilities are much more time urgent than our analysis indicates. Pyroprocessing also provides the potential for total actinide recycle for spent nuclear fuel without performing the separation of individual nuclides. The technology also provides the best option for the preparation of metallic fuels for transuranic material recycling in a fast reactor. As the salt solvents and liquid metal used in the process are resistant to radiation

⁵*The Back-End of the Nuclear Fuel Cycle: An Innovative Storage Concept*, Robert Rosner, Stephen M. Goldberg, and James P. Malone (American Academy of Arts and Sciences, 2012).

⁶*Multinational Approaches to the Nuclear Fuel Cycle*, Charles McCombie and Thomas Isaacs, Noramly Bin Muslim, Tariq Rauf, Atsuyuki Suzuki, Frank von Hippel, and Ellen Tauscher (American Academy of Arts and Sciences, 2010).

damage, radiation stability of these materials enables the processing of spent fuels with short cooling periods. This helps to avoid the accumulation of decay products and reduce the cost associated with spent fuel storage. An integral fuel cycle concept can then be realized. With pyroprocessing, the irradiation, processing, and fabrication facilities can all be co-located without the need for out-of-site transportation. This facilitates safeguarding effort as all fissile materials can be confined to a single monitored site, except for externally supplied uranium and trace amount of actinides in wastes. Pyroprocessing also eases the burden of geologic disposal of nuclear waste. It allows separation of uranium, plutonium, minor actinides, and various fission products. These separated elements include high decay heat-emitting nuclides and major sources of health risks from geologic disposal.

Bong-Geun Jun's paper in the appendix demonstrates the view that Korea's solution to the spent fuel issue was to develop a new and advanced spent fuel processing technology, called pyroprocessing, with built-in proliferation-resistant characteristics. Pyroprocessing extracts plutonium and other minor actinides together, unlike the traditional "wet" reprocessing technology to separate pure plutonium, a bomb material.

Korea wants to develop the pyroprocessing technology jointly with the U.S. for several good reasons. First, once developed, this new technology could help solve spent fuel disposal problem in both countries. Pyroprocessing could drastically reduce the volume of high level wastes or increase storage volume in a given space, by reducing toxicity, heat and waste volumes. Second, it provides a proliferation-resistant spent fuel management alternative to traditional reprocessing. Since pyroprocessing does not separate pure plutonium, it would also help reduce nuclear terrorism risks around the world. Both small and big nuclear power producing countries could get these benefits. For example, big nuclear energy countries could provide pyroprocessing services to smaller ones so that the latter stays away from seeking their own reprocessing capability.

Pyroprocessing in Korea is also an essential part of a bigger nuclear energy research program to provide nuclear fuels to the fourth generation nuclear energy system, based on fast reactor. As an energy resource poor country, South Korea cannot stand idle in the middle of global competition to tap the full potential of nuclear energy for a greater energy security. In the U.S., skepticism on the feasibility of the fourth generation fast reactor systems runs high. On the other hand, France, Belgium, China, Russia, India and Japan continue to expand their fast reactor development programs. Despite technical difficulties yet, the fast reactor system is expected not only to strengthen energy security but also to help solve the spent fuel problem by recycling LWR spent fuels. This new system, once realized, also helps ease nuclear security and nonproliferation concerns by burning spent fuel.

We believe that a good estimate of the economics of pyroprocessing will have to be informed by additional R&D and, eventually, a pilot facility. In any case, interim dry-cask storage will help to buy time to make such assessments.

Spent-fuel disposal: Geologic repositories are considered the best choice for disposal of spent fuel in the absence of commercial reprocessing. This is not a short-term problem because the interim storage option has been shown to be a viable short and medium-term solution. However, long-term disposal of spent fuel is a critical complement to interim storage in the absence of commercial reprocessing. As mentioned, interim storage provides more time to develop potential reprocessing options and to deal with permanent spent-fuel disposal. Even if South Korea

demonstrates a viable reprocessing option, it is likely that some of its backlog of spent fuel is technically and economically better disposed via geologic repositories. Hence, the development of permanent spent-fuel repositories is critical to the future of South Korea's nuclear program.

South Korea faces challenges similar to those in the United States and other countries in gaining public acceptance of permanent spent-fuel or nuclear waste repositories. In fact, the failure of the U.S. Yucca Mountain repository project exacerbates South Korea's problem. The recent U.S. Blue Ribbon Commission report and the experience of Sweden and Finland in siting and construction of their repositories offer valuable guidance for South Korea's future efforts. All forms of cooperation are encouraged in this area. South Korea can bring its excellent technical R&D skills and industrial capabilities to this important problem, which may have long-term export benefits.

High-level waste disposal: If the fuel cycle is closed by reprocessing, it will be necessary to dispose of high-level waste instead of spent fuel, most likely in geologic repositories. The issues are quite similar, including the most difficult one of gaining public acceptance. Much like for spent-fuel disposal, this is not a short-term problem, but does constitute a long-term problem for the domestic nuclear industry. It also affects the export market, as a successful disposal program will positively influence South Korea's nuclear fuel-cycle export potential. Also as is the case for spent-fuel disposal, there is ample opportunity for cooperation at all levels. This option will be required for eventual disposal of fast reactors' spent fuel in the long-term.

Recommendations based on TEP analysis

Our analysis shows that the two most important priorities for South Korea's domestic nuclear market are 1) to take immediate actions to restore the public's trust in the nuclear industry. The government must deal resolutely with the industry's alleged corruption problems and strengthen the government's regulatory organizations dealing with all aspects of South Korea's nuclear industry and 2) to commit to a centralized intermediate spent-fuel storage program to deal with the short-term storage problems and buy time to develop long-term fuel-cycle options and permanent disposal solutions.

The first issue is closely tied to nuclear safety, which must remain the nuclear industry's highest priority. If South Korea does not take the necessary steps to demonstrably assure nuclear safety, its domestic nuclear market may collapse and its export market may never materialize. Part of the solution is to institute a very rigorous quality assurance program with the requisite paper trails, where South Korea could learn from U.S. experience. Both of these priorities require much greater transparency of South Korea's nuclear industry and governmental agencies. (In Section IV, May and Blandford present a study on the importance of transparency with examples from different major nuclear civilian powers). South Korea must also develop a much more inclusive relationship with the public for both priorities – nuclear safety and nuclear spent-fuel storage. Both areas can benefit substantially from international cooperation at all levels as indicated in Table 2. Similar approaches are necessary for developing acceptable solutions to long-term spent-fuel or high-level waste disposal options.

To examine options for interim storage and how it is tied to long-term disposition, we suggest the South Korea consider the establishment of a joint ROK-U.S. study group on nuclear spent-fuel

storage and disposition as a follow up on the recommendations of the U.S. Blue Ribbon Commission on America's Nuclear Future. The currently contentious issues of enrichment on the front end of the fuel cycle and reprocessing (either by pyroprocessing or other means) on the back end should be approached primarily from a long-term perspective. Enrichment is not needed in the short term and pyroprocessing cannot be developed on a commercial basis in the short term. Yet, it appears prudent to keep both options open for the long term, particularly as South Korea explores the most attractive fuel-cycle and future reactor options. The current 10-year joint ROK-U.S. pyroprocessing R&D program will result in a more informed decision for the long-term. Both enrichment and reprocessing are politically contentious because of global proliferation concerns. However, a number of recent proposals for cooperation on regional or multinational levels offer promising avenues for dealing with the proliferation concerns. The Stanford team suggests a number of specific options for such cooperation as described in Appendix V. We acknowledge the fact that the EAI team views the issues of enrichment and pyroprocessing as being more time urgent than the CISAC analysis indicates.

SECTION IV: GLOBAL NUCLEAR GOVERNANCE

CISAC and EAI explored how cooperation between the United States and South Korea could help to meet the new challenges to the global nuclear regime. Many experts consider the nonproliferation regime to be under great stress, to a large extent because of North Korea's nuclear weapons and the noncompliance of Iran with its nuclear nonproliferation treaty (NPT) obligations. Moreover, the announced intent of many states to pursue new nuclear power programs will greatly complicate nonproliferation objectives, especially since most of these states do not have the technical expertise or legal and regulatory mechanisms necessary to cope with nuclear power, nor do most of them have open, transparent governmental institutions required for best safety and security practices⁷.

Another significant development is the gradual shift of nuclear reactor construction expertise to Asia, particularly Japan and South Korea, with China not far behind. Russia and France, though, have maintained leadership positions in the nuclear exports market. The United States has been steadily losing its supply-chain capabilities for reactor construction and the fuel cycle. Since it has been the standard bearer for nuclear safety and nuclear security in the past as well as now, it is important for the newly emerging nuclear power supply countries to step up their role in promoting safe and secure nuclear power globally. It appears that Japan may take itself out of this role because of the potential phase out of domestic nuclear power as a result of the Fukushima accident, though Japan is still interested in nuclear exports regardless of what happens in its domestic market. South Korea is prepared to fill the role of a major nuclear exporter. It can help to champion best nuclear safety and security practices, related to nuclear plants and nuclear fuel manufacturing. Such an initiative would not only establish it as a major global player, but it would also benefit its domestic nuclear program and its export potential. Seoul will, of course, have to get its own nuclear safety house in order first.

The EAI papers by Bong-Geun Jun and Chaesung Chun in Appendix IV describe South Korea's rise not only in international economic and political prominence, but also in its preparedness to step up to help forge a new global nuclear governance. They point out how the May 2013 Joint Declaration in Commemoration of the 60th Anniversary of the Alliance of South Korea and the United States stressed the increasingly global nature of the partnership. The declaration promised to strengthen ROK – U.S. efforts to address global challenges such as peaceful uses of nuclear energy, nuclear safety, nonproliferation along with climate change, energy security, human rights, and countering terrorism. Their papers point out the challenges posed to global nuclear governance by the lack of IAEA resources, the lack of “good governance” characteristics of new, aspiring nuclear states, and the weakening of U.S. influence on the global nuclear regime because of the decline of its domestic nuclear power industry. They also point out the need to balance the U.S. focus on nonproliferation with other key factors such as nuclear security, deterrence, and the importance of security alliances in how nuclear energy is pursued in South Korea.

Then, unlike other major plants exporters like France and Russia, Korean nuclear plants have embedded U.S.-origin nuclear technology. This means that the U.S. government can exercise its right of (re)export control licensing in accordance with its own regulations and pursue bilateral nuclear cooperation agreements with importers of South Korean power plants. Russians

⁷ S.E. Miller and S.D. Sagan, *Daedalus* Fall 2009, Vol. 138, No. 4: pp. 7-18.)

traditionally do not ask for higher standards of nuclear control when exporting nuclear plants as was witnessed in Iran. China is also insensitive to such demands as was shown in its nuclear export to Pakistan. China is conjectured to enter global nuclear power plants export market with very cheap power plants possibly within a decade. These trends could undermine not only commercial interests of Korean and American firms, but also global nuclear nonproliferation, security and safety regimes.

The CISAC paper on “Next Steps in Global Governance of Nuclear Power” by Dr. Michael May in Appendix IV presents an overview of the present status of the global nuclear regime and explores next steps in global nuclear governance. It explains the challenges faced on three fronts: 1) International safeguards, 2) Nuclear safety and physical protection of nuclear facilities, and 3) Export control. He suggests a number of potential initiatives for ROK and U.S. scholars to study jointly to improve global nuclear governance. Prof. May and Prof. Blandford examine both the importance of transparency in the nuclear industry and provide case studies for several nuclear energy countries. Their conclusions about the utmost importance of transparency in all aspects of the nuclear fuel cycle and nuclear operations is particularly important considering the Fukushima accident and the recent concerns about corruption in ROK’s nuclear industry.

The paper by Prof. Scott Sagan in Appendix IV explores a novel role that South Korea may wish to play in global nuclear governance. Many countries contend that the abolition of nuclear weapons is not possible because the nuclear weapons states (NWS) are not holding up their end of the NPT bargain by inadequately complying with Article VI, the elimination of nuclear weapons. He argues that the commonly accepted framing of the NPT as a bargain between nuclear weapons states accepting the responsibility for disarmament and non-nuclear weapons states (NNWS) accepting safeguards on their nuclear facilities is historically inaccurate and politically unfortunate.⁸ He maintains that Articles IV and VI of the NPT apply to both and, hence, one needs to craft a more comprehensive and equitable implementation of the basic NPT bargain.

For example, the spread of nuclear power around the globe will create virtual nuclear weapons states if no acceptable regulations are created and enforced to prevent the spread of sensitive nuclear technologies. Nuclear abolition will be impossible unless all countries, NWS and NNWS, share this responsibility. It would be advantageous for South Korea to consider promoting such new approaches to the elimination of nuclear weapons and to global nuclear governance more generally. South Korea has already taken several important steps toward playing a more central role in the global nuclear regime. For example, it hosted the 2012 Seoul Nuclear Security Summit, which helped focus the world’s attention to the serious threat of nuclear terrorism. South Korea could also play a potential leadership role in reforming export controls on nuclear technologies and take a leadership role in international control of the fuel cycle.

⁸ See Scott D. Sagan, “Shared Responsibilities for Nuclear Disarmament: A Global Debate,” American Academy of Arts and Sciences, 2010 (Responses by James M. Acton, Jayantha Dhanapala, Mustafa Kibaroglu, Harald Mueller, Yukio Satoh, Mohamed I. Shaker, and Achilles Zaluvar).

SECTION V: SOUTH KOREA – U.S. NUCLEAR COOPERATION

It was universally agreed that in spite of differences in South Korean and American views of future directions of nuclear power in South Korea, it was imperative for both countries to enhance nuclear cooperation and to restructure it to reflect the nuclear realities in both countries, as well as globally. With South Korea's meteoric economic rise and U.S. decline in nuclear capabilities, nuclear cooperation will be as important to the United States as it will be to South Korea. In other words, Washington has as much to gain from nuclear cooperation, as does Seoul.

The papers by Man-Sung Yim and Seong-ho Sheen in Appendix V make a compelling case for building a strong ROK – U.S. partnership. The papers and presentations by Chaim Braun and Robert Forrest reinforce many of the same suggestions and provide some specific examples of concrete ROK – U.S. nuclear collaborations. Table 2 also shows how regional and multinational collaboration can help to attain necessary fuel-cycle capabilities. Braun also makes some specific suggestions in his papers and presentations in Appendix V. Among the recommendations made are: Suggestions for ROK buy-in into a U.S. enrichment corporation at a significant ownership level; Joint program for demonstration pilot ISFSI; Cooperation on fast reactor and fuel cycle development with the U.S. concentrating on the reactor part and the ROK on fuel cycle issues; Development of a regional nuclear safety regime based on plant to plant cooperation and exchange of safety best practices; and long-term development of a regional plan to provide safety practices support to the North Korean Experimental LWR under the auspices of the Six Parties negotiations. These are offered as examples of what could be explored, rather than detailed road maps for cooperation.

SECTION VI: COMMENTS ON SOUTH KOREA – U.S. NUCLEAR COOPERATION AND THE 123 AGREEMENT

In March 2013, McGoldrick and Kim⁹ examined the key issues for renewal of the 40-year old 123 Agreement from both ROK and U.S. perspectives, and provided several potential options on how to proceed with a new agreement. However, the two governments decided to extend the agreement for two years, which decreases the urgency of coming to closure on the renewal, but it does not make the problem go away. We will not list the issues here since both sides have aired them adequately, and McGoldrick and Kim provide a good summary. We will also refrain from making direct suggestions for specifics of a new agreement because any final document will reflect the political process, which is difficult to assess at this point. Instead, we make some overarching observations and suggestions based on our study and the analysis presented above.

- 1) The agreement must reflect the enormous progress South Korea has made in its economic, political and industrial standing in the world since 1974. Its civilian nuclear capabilities have risen from their infancy to a position of world leadership. These changes must be reflected in an agreement that features partnership and a two-way flow of technologies and industrial capacity. The United States has allowed its nuclear supply chain to collapse and it should look to South Korea for joint ventures to help what is left of its domestic nuclear industry and the potential export market. Washington must also recognize that whereas nearly three-quarters of the nuclear fuel powering South Korea's reactors today has U.S. origin, thereby giving the United States control over its use, most of South Korea's future reactor fuel supply will come from resource-rich countries such as Kazakhstan and Australia. Consequently, U.S. leverage over South Korea's nuclear program could decrease; ultimately, the U.S. will still retain some influence given that most Korean nuclear plants are based in part on U.S. technology.
- 2) The so-called "Gold Standard" for U.S. 123 agreements was crafted for the very special case of the United Arab Emirates. It prohibits all development of domestic front-end and back-end fuel-cycle capabilities. It makes little sense and, in fact, may be counterproductive to adopt this standard for a country like South Korea, which is politically, economically and technically dramatically different. Washington should instead craft a criteria-based standard that better reflects a country's technical, political, regulatory, and industrial capacity, as well as its nonproliferation record.
- 3) Washington is also cognizant of the regional and international implications of the terms of future 123 agreements. This is especially true for South Korea and Northeast Asia because of the ongoing nuclear crisis in North Korea. There are conflicting views as to whether or not the 1992 North-South nuclear treaty is still in effect. We maintain, given North Korea's clear violation of the letter and spirit of this treaty, South Korea is not obligated to adhere to the treaty's provisions; this is based on the clear wording of the Vienna Convention on

⁹ F. McGoldrick and Duyeon Kim, "Decision Time: U.S. - South Korea Peaceful Nuclear Cooperation," Korea Economic Institute of America, March 14, 2013. <http://keia.org/publication/decision-time-us-south-korea-peaceful-nuclear-cooperation>

Treaties on this subject.¹⁰ Nevertheless, some American policy analysts and government officials claim that allowing any front or back-end fuel-cycle capabilities in South Korea will make it more difficult to denuclearize North Korea. Although Pyongyang will certainly mobilize its propaganda machine to make such claims, we do not concur with this view. We believe that the nature of South Korea's civilian nuclear capabilities has little, if any, influence on North Korea's nuclear weapons program. What's at stake in Pyongyang's calculus in the potential elimination of nuclear weapons is much greater than whether or not Seoul develops some of the same fuel-cycle capabilities that the North has already pursued for decades. If Pyongyang is willing to seriously consider the elimination of its nuclear weapons program, then potential civilian facilities in North Korea should be compared to those of South Korea. We do not see that as an obstacle to the military denuclearization of the Korean peninsula.

Japan presents a very different regional issue. Many South Korean policy analysts and government officials claim that South Korea should be given the same nuclear privileges as Japan in terms of programmatic consent rights for reprocessing and possibly enrichment activities considering South Korea's meteoric rise in international stature. We live in different times with different domestic and global issues and priorities. The South Korean agreement should be constructed to reflect current technical, economic and political realities, not just drive for the symbolism of equal treatment with Japan.

- 4) Finally, the ROK-U.S. alliance is strong politically, militarily and economically. Seoul should not allow the 123 Agreement to become the litmus test of the alliance in spite of the fact that the agreement has taken on inordinate symbolic importance in South Korea.

South Korea as a model state for the development of nuclear power and nuclear industry

The ongoing controversy over the terms of renewal of the 123 Agreement has overshadowed what we view as the most important domestic and international consequence of South Korea's meteoric rise as an industrial power and nuclear energy power – that is, it has emerged as a model state for future nuclear power aspirants. A careful analysis of the TEP matrices shows that South Korea has excelled in what we consider the most important parts of the nuclear fuel cycle. Its early strategy to focus on getting nuclear electricity on the grid as quickly as possible, while concurrently developing the requisite domestic technology base for reactor fabrication and construction in combination with modern fuel fabrication was brilliantly conceived and executed. South Korea wisely avoided the contentious front-end issue of enrichment. It has continued to rely on ample international enrichment services.

The only serious shortcoming is its ability to deal with spent fuel. Our analysis indicates that this could be achieved quite readily with an intermediate centralized spent-fuel storage facility. Such a move will buy time to deal with reprocessing and future fuel-cycle choices. Since South Korea will

¹⁰ The Vienna Convention on Treaties states in Article 60: "A material breach of a bilateral treaty by one of the parties entitles the other to invoke the breach as a ground for terminating the treaty or suspending its operation in whole or in part." http://untreaty.un.org/ilc/texts/instruments/english/conventions/1_1_1969.pdf. While the DPRK is not a signatory to the Vienna Convention, this article, along with much of the treaty, has become accepted as customary international law.

not be able to avoid the need for some centralized spent fuel storage, as our analysis indicates, it behooves South Korea to develop a world class model spent fuel centralized dry cask storage program which will serve it well in both its domestic and export nuclear energy markets.

Hence, we view South Korea's nuclear program a success story to be emulated by other countries that either have nascent industrial capabilities or are dedicated to develop such capabilities. The current 123 agreement controversies should not detract from this success story.

SECTION VII: SUMMARY AND RECOMMENDATIONS

This study provided an excellent opportunity for South Korean and American scholars to explore future nuclear cooperation between their countries, to generate specific ideas for such cooperation, and to provide ideas on how to strengthen global nuclear governance. The study underscored the enormous progress made by South Korea in its nuclear program and how this progress can be translated into helping both countries nuclear industries, their export potential and in strengthening nuclear safety, security and nonproliferation practices worldwide.

We present the recommendations made by each team because they demonstrate how similar our conclusions are and that there is so much to be gained by forging a new cooperative partnership between our countries.

The EAI team made the following specific recommendations:

1. ***They need to respect each other's position.*** It is well recognized that the two governments have a different focus on the nuclear energy issue. Serious cooperation occurs when there are different interests. It is possible when countries recognize there is bigger benefit from cooperation than no cooperation. The two governments should develop ways to collaboratively strengthen their respective industrial leadership in global nuclear business and should actively seek opportunities for joint nuclear export.
2. ***The two governments should not let the negotiation get distracted by other issues.*** The negotiation should focus on its original purpose. That is renewing the peaceful use of nuclear energy partnership and nothing else. It should not become a test case for the alliance. Both governments should not let the negotiation be hijacked by political interest groups or other agendas. Seoul should make it clear the negotiation has nothing to do with the North Korean nuclear issue. At the same time, it has to reassure the other parties that its fuel cycle agenda has nothing to do with a weapons program.
3. ***Within the framework of nuclear energy partnership, they need to broaden the agenda.*** The revision does not have to be only about enrichment and reprocessing. The two should discuss broadening their nuclear partnership in the global non-proliferation regime, the next generation of nuclear energy, the various stages and means of nuclear waste management, nuclear security and safety, and joint collaboration in the nuclear energy market. The two governments should use this opportunity to make their nuclear partnership more comprehensive and oriented to the future. The two governments should work together to help newcomer countries to develop and maintain infrastructure for nuclear safety, security, and nonproliferation.
4. ***In making a future-oriented partnership, they should come up with unique and creative method for ROK-US nuclear partnership.*** In other words, this partnership should not try to simply follow previous cases, such as the US-Japan, US-India, or US-UAE nuclear agreements. All those partnerships came at different times and in varied contexts and conditions. The ROK-US partnership should be negotiated on in its own terms and context. The two governments should accelerate the current collaboration in

pyroprocessing technology development to effectively safeguards the technology and make it commercially viable. Also the two governments should explore ways to work together to secure nuclear fuel supply for the ROK by effectively utilizing uranium enrichment capacity of the U.S.

5. ***Do not hurry.*** The two understand that the negotiation will not be easy. If they find each other's position uncompromising and intractable, they should wait until things change and a new opportunity arrives.

The CISAC team made the following recommendations:

1. ***Recognize that South Korea has emerged as a model nuclear state.*** Current controversies over an extension of the ROK – U.S. nuclear cooperation agreement appear to overlook this accomplishment. Because of South Korea's meteoric rise as an industrial power and the choices it has made to date have allowed it to emerge as a model state for future nuclear power aspirants. South Korea has excelled in what we consider the most important parts of the nuclear fuel cycle; that is, the middle. Its early strategy to focus on getting nuclear electricity on the grid as quickly as possible, while concurrently developing the requisite domestic technology base for reactor fabrication and construction in combination with modern fuel fabrication has served the country well. South Korea wisely avoided the contentious front-end enrichment and back-end reprocessing issues. These issues can now be addressed for the longer term through bilateral or international cooperation. The only serious immediate shortcoming is South Korea's ability to deal with spent fuel.
2. ***Finding a solution to spent-fuel storage is the most immediate nuclear fuel-cycle issue.*** Although several temporary solutions are possible for the short term, South Korea must move to the construction of a centralized, away-from-reactors dry-cask storage, which will require a major effort to convince a skeptical public. Dry-cask storage will provide at least a 50-year time buffer to develop technical options for reprocessing and for permanent disposition of either spent fuel or high-level waste, as well as fast reactors technology which might burn recycled fissile materials. An immediate step that should be considered is to establish a joint ROK-U.S. study group on nuclear spent-fuel storage and disposition as a follow up on the recommendations of the U.S. Blue Ribbon Commission on America's Nuclear Future.
3. ***South Korea's nuclear industry must regain the public's trust for the integrity of its operations and nuclear safety.*** Regardless of future fuel-cycle choices, it is essential for South Korea to take immediate actions to restore the public's trust in the nuclear industry following allegations of the use of counterfeit parts in reactor construction. The government must deal resolutely with the industry's alleged corruption problems and strengthen the government's regulatory organizations dealing with all aspects of South Korea's nuclear industry as well as instill greater transparency and attention to quality matters in its nuclear industry.

4. ***The next cooperative agreement should be a partnership between the United States and South Korea.*** That partnership must reflect the enormous progress made in South Korea's economic, political and industrial standing in the world since 1974, as well as the decreasing influence the United States has in global nuclear futures resulting from its declining leadership in the nuclear industry.
5. ***The agreement should be tailored specifically to fit the ROK – U.S. relationship.*** Rather than trying to apply the so-called nonproliferation “gold standard” adopted for the UAE, Washington should strive for a criteria-based standard that better reflects a country's technical, political, regulatory, and industrial capacity, as well as its nonproliferation record. In other words, the provisions should be South Korea specific, not carry the baggage of the UAE agreement or of the historical precedents of the Japan or India deals.
6. ***The agreement should not be constrained by the North Korean nuclear problem.*** North Korea has clearly violated the letter and the spirit of the 1992 North-South agreement. Moreover, aside from providing Pyongyang with grist for its propaganda machine, the nature of South Korea's civilian nuclear capabilities has little, if any, influence on North Korea's nuclear weapons program. What's at stake in Pyongyang's calculus in the potential elimination of nuclear weapons is much greater than whether or not Seoul develops some of the same fuel-cycle capabilities that the North has already pursued for decades in violation of the NPT and the Denuclearization Agreement.

APPENDIX I

CISAC AND EAI RESEARCH TEAMS

The primary CISAC team consists of: Prof. Siegfried S. Hecker, principal investigator, Dr. Chaim Braun, consulting professor and research specialist, Mr. Niko Milonopoulos and Mr. Peter Davis, research assistants, Prof. Scott D. Sagan, Professor of Political Science, Senior Fellow, Freeman Spogli Institute for International Studies and CISAC. Prof. Michael May, Professor (Research) Emeritus, Department of Management Science and Engineering, CISAC, Director Emeritus, Lawrence Livermore National Laboratory. Dr. Robert Forrest, Post-doctoral Fellow, CISAC. Prof. Edward D. Blandford, Assistant Professor of Nuclear Energy, University of New Mexico. Prof. Gi-wook Shin, Director, Shorenstein Asia Pacific Research Center (APARC), Stanford University. Mr. W. David Straub, Associate Director, APARC.

The primary EAI team consists of: Chairman Young-Sun Ha, principal investigator, President Sook-Jong Lee, Sungkyunkwan University, Prof. Chaesung Chun, Chair of EAI Asia Security Center, Seoul National University, Prof. Bong-Geun Jun, Korea National Diplomatic Academy, Prof. Seong-ho Sheen, Seoul National University, Prof. Man-Sung Yim, Korea Advanced Institute of Science and Technology, Dr. Sungyeol Choi, Seoul National University, President Tae-Woo Kim, Korea Nuclear Association for International Cooperation, Ms. Ha-jeong Kim, Mr. Jung Kim, and Mr. Jin Seok Bae, program officer, EAI.

APPENDICES II-V

Note that Appendices II-V contain information related to CISAC-EAI collaborations, including conference agendas, presentation information, and numerous papers. These are cited throughout the text of the report. These appendices are available upon request.

Please contact Peter Davis, research assistant to Siegfried Hecker, at ped1123@stanford.edu if you would like a copy of any of the information in the appendices. Alternatively, you can contact Dr. Hecker at shecker@stanford.edu.