09-A-196-INMM

THE PROSPECT OF A REVITALIZED RUSSIAN AND AMERICAN NUCLEAR SAFEGUARDS PARTNERSHIP

Philip Casey Durst (a) and Claudio A. Gariazzo (b)

(a) Durst Nuclear Engineering and Consulting Inc.,
PO Box 944, Richland, WA, 99352 USA
E-mail address: casey@durstnuclear.com

(b) Texas A & M University,
3473 College Station, TX, 77843 USA
E-mail address: cgariazzo@tamu.edu

ABSTRACT

Recent developments in the world have provided an opportunity for the Russian Federation and United States of America to form a stronger partnership in support of Nuclear Safeguards and the Non-proliferation Regime. There is a natural fit between these two countries, because they have a need to mutually demonstrate verifiable and meaningful nuclear arms reduction under the Treaty on the Non-proliferation of Nuclear Weapons (NPT). They also have a mutual interest in ensuring that nuclear material is effectively safeguarded worldwide. To this end, this paper outlines how this partnership could be further advanced, with recommendations for specific nuclear safeguards collaboration and research. It also outlines how this collaboration could lead to a bilateral inspectorate, akin to ABACC or EURATOM, which could potentially inspect member states. This bilateral partnership could ultimately become a regional inspectorate covering the North Asia and Pacific region, supplementing safeguards efforts of the International Atomic Energy Agency (IAEA), thereby ensuring more effective nuclear safeguards and security in the region.

INTRODUCTION

The challenges that have confronted the Russian Federation and the United States of America in their bilateral relations have lessened their communication, affecting the pace of nuclear arms reduction and the implementation of international nuclear material safeguards. At the end of 2008, the Strategic Nuclear Arms Reduction Treaty (START-I) had effectively stalled out, although there are hopeful signs that the current treaty, which is set to expire on December 5, 2009, may be extended by both parties.[1] Even though both countries have Voluntary Offer Safeguards Agreements with the International Atomic Energy Agency (IAEA), international nuclear safeguards inspections in all of the nuclear weapons states are minimal and a fraction of the safeguards effort expended because of the limited resources of the IAEA. This gives the impression to the non-nuclear weapons states that there is a double standard when it comes to international nuclear safeguards. The impression of this double standard is also considered a reason why many countries have not yet concluded an Additional Protocol to their safeguards agreement, as recommended for all states by the IAEA Board of Governors.[2] In addition, pursuant to Article-VI of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), nuclear weapons states are required to make substantive efforts towards arms reduction and the gradual elimination of nuclear weapons.[3] Because these efforts are not as visible and the apparent pace in nuclear arms reduction is not as progressive as it has been in the past, the international community is starting to doubt that progress is actually being made. This undermines the leadership of Russia and the United States of America in the international nuclear non-proliferation and international nuclear safeguards regime. If this apparent loss of faith in the nuclear non-proliferation regime were to spread, it could lead to the expiration of the NPT and the fracturing of the non-proliferation regime. Because of the legacy of the nuclear arms race between Russia and the United States, there is a special onus on both countries to pursue nuclear arms reduction and international nuclear safeguards and non-proliferation. This shared obligation could be the foundation for a reinvigorated nuclear safeguards partnership.

Furthermore, the IAEA, which is chartered with verifying the compliance of states with their international nuclear safeguards agreements, is challenged by an expanding nuclear safeguards and non-proliferation mission with limited financial and human resources. These duties expanded dramatically under the 93+2 Strengthened Safeguards Programme, requiring the IAEA to search for undeclared nuclear material and facilities, as had been discovered in Iraq following the first Gulf War. The IAEA's human and financial resources remain limited, impacting its abilities to perform its newly mandated duties. This becomes of greater concern considering the expansion of the nuclear power industry, as many countries around the world seek nuclear power as an alternative to coal and oil fired power plants.

AN OPPORTUNITY

The breakout of the NPT by a state to build nuclear weapons, or the act of terrorists to divert nuclear material and assemble a crude nuclear weapon or radiological bomb, would most likely threaten the U.S., Russia, or their allies. For this reason, there is a clear and present danger posed to both countries and an urgent need to act in partnership to minimize, if not eliminate this threat. During the Cold War, both the United States and the former Soviet Union, developed spheres of influence based on fundamental political and ideological differences. Both developed nuclear technology for advanced weapons, but also for a variety of peaceful purposes including electrical power production, nuclear medicine, cancer treatment, and deep space exploration. Consequently, both developed advanced and sophisticated nuclear technology that could permit fuller use and recycling of available nuclear resources, such as uranium, plutonium and thorium, as well as the treatment, consolidation, and long-term storage of highly radioactive waste. The nuclear developments within the former Soviet Union are remarkable, considering the lack of industrial development in that country during the 1930's and the devastation in the 1940's as a consequence of the Second World War. Russian nuclear science, research and technology remains internationally renowned and on the cutting edge, despite the profound impacts from the restructuring of the country's economy following the dissolution of the former Soviet Union. Despite the relative prosperity and economic growth in the United States during this same period, nuclear power was restricted to nuclear power generation, with no construction of new nuclear power plants after the 1980's. Commercial industrialization of uranium enrichment, spent nuclear fuel reprocessing, and uranium and plutonium recycling were put on hold. This has created a situation in which the United States now seeks the assistance of Japanese and European partners to build new nuclear power reactors, uranium enrichment, and spent fuel reprocessing plants. Despite this turn of events, the United States developed this technology in the past and retains a technological base for implementing effective nuclear safeguards at such facilities. The opportunity that now presents itself is that the United States and Russian Federation could work more energetically in collaboration to restore the momentum in their nuclear arms reduction efforts, with visible milestones for the world to gauge their progress. In parallel, both countries could expand collaboration in developing advanced methods and equipment for more effectively safeguarding nuclear fuel cycle facilities. Collaboration could also be renewed in the verification of nuclear weapons and dismantlement progress under a rejuvenated START Treaty.

AN OUTLINE FOR SAFEGUARDS SCIENTIFIC COLLABORATION

An outline for scientific collaboration that would advance international nuclear safeguards and non-proliferation, jointly using the scientific resources of both countries, is envisioned as follows:

Enhanced Safeguards for Uranium Enrichment

Because of the expansion of nuclear power worldwide, there is a commensurate demand for uranium enrichment. Large industrial facilities are being constructed in the United States, France, and China, with the expansion of existing industrial facilities in the United Kingdom, the Netherlands, and Russia. Also relevant is the planned operation of new enrichment plants in Brazil and the Islamic Republic of Iran. To more effectively safeguard these plants, experts have concluded that the UF_6 process streams need to be verified by on-line unattended monitors.[4] These monitors could verify the identification, mass and enrichment of UF_6 in the feed, enriched product, and depleted tails cylinders transferred to and from the UF_6 handling area in an enrichment plant. Alternatively, on-line mass flow and enrichment monitors could be developed for monitoring the UF_6 feed, product and tails pipelines in an enrichment plant. Scientists and engineers from American and Russian laboratories, institutes, and universities could use joint computer resources to optimize the conceptual design of the nuclear material detectors and joint laboratories and pilot facilities to demonstrate the performance of such monitors. The use of Russian enrichment plants or pilot plants could be the key to demonstrating the performance of these monitors in an industrial environment. Without such on-line monitors, the IAEA would continue to use human resources to verify the process flows of uranium in enrichment plants - at a time when the IAEA needs more effective and efficient safeguards methods.

If Russia and the United States could successfully develop and demonstrate such process flow monitors, the implementation of international nuclear safeguards at enrichment plants in the United States and Russia would be enhanced, as well as safeguards at enrichment plants worldwide. These process flow monitors could also be used to implement the Fissile Material Cut-Off Treaty (FMCT), by confirming that enrichment plants in Nuclear Weapons States are not producing highly enriched uranium ($\geq$20% U-235).

Improved Monitoring of Spent Fuel Storage and Shipments

There are huge accumulations of spent nuclear fuel in the world today. The IAEA estimates that the world stockpile of spent nuclear fuel will be 340 000 metric tonnes by 2010.[5] Such fuel is lethally radioactive and needs to be safely stored in interim storage pending spent fuel reprocessing or deep geologic burial. Despite the high radioactivity, the spent fuel contains over 90 percent of the original uranium and fissile plutonium that was produced in the reactor. Both metals have high energy content and are economically worth recovering, especially as other energy resources become depleted. Towards this end, the Russian Federation is expanding the spent fuel storage capacity at the Mayak reprocessing plant from 3 500 to 44 000 tonnes.[6] As a potential international nuclear fuel cycle facility, this spent fuel storage facility and reprocessing plant could help alleviate the pressure of storing spent fuel at existing commercial reactors, where storage space is becoming scarce. Many reactors are also building away-from-reactor (AFR) storage silos of heavily reinforced concrete that would contain the spent fuel on the reactor site inside a protected perimeter. However, such dispersed above-ground storage facilities could present an attractive target for terrorists. It would be safer to accumulate the spent fuel stockpiles in a few international centers in remote locations, adjacent to international reprocessing centers. This scheme would necessitate that spent fuel be shipped in large numbers from existing locations to the spent fuel storage centers. To improve the monitoring and safeguarding of such shipments, more effective spent fuel transfer cask and storage silo monitors need to be developed. Technology exists to monitor the shipment of spent fuel transfer casks in real-time to track the shipment and to detect any possible accident or hijacking of spent fuel at the earliest stages. The monitors could also possess features to detect high temperature from fire, shock from an accident, or high radiation from a possible container breach. Integrated monitors could similarly be developed for monitoring spent fuel storage silos as well. Such monitors could ultimately be integrated into a National or International Spent Fuel Tracking Center, which would be connected with the monitors by telemetry to determine the location, disposition and status of all spent fuel storage and transfer casks at all times. This scheme would also improve the safety and safeguarding of spent fuel shipped from reactors to interim spent fuel storage centers in the United States within the decade.

Russian and American scientists and engineers could perfect the design of such monitors and demonstrate them on spent fuel storage and transfer casks within the United States and Russia. The commercial benefit of enhancing the safeguarding of interim storage for spent nuclear fuel, prior to reprocessing or final geologic storage is great, because there is a present and ready market for interim spent fuel storage. Countries that are densely populated with a large number of nuclear reactors, such as Japan and Korea, could potentially use such storage facilities since storage at their reactor sites is reaching capacity. The revenue generated from the storage facilities could help off-set the cost of developing the spent fuel shipping and storage cask monitors to ensure that they can be effectively monitored and protected at all times.

Reprocessed Uranium to Prevent Production of Weapons-Grade HEU
Russian colleagues have described the use of reprocessed uranium, which is higher in U-232 and U-236, to denature feed to an enrichment plant to prevent the possible production of highly enriched uranium (HEU) by recycle.[7] Large amounts of reprocessed uranium have accumulated in the United States, United Kingdom, France, Russia and Japan, as a result of present and former spent fuel reprocessing campaigns. Stocks of reprocessed uranium worldwide, from both civil and military programs, are estimated to be on the order of 300 000 metric tonnes.[8] This uranium could be recycled as feed to enrichment plants. Such schemes have been tested in many countries with enrichment technology. However, reprocessed uranium possesses other isotopes of uranium, namely U-232 and U-236, which are more radioactive than the primary isotopes found in naturally occurring uranium: U-238 and U-235. This makes reprocessed uranium more radioactive than natural feed and complicates the direct handling of UF_6 in conversion, uranium enrichment, and fuel fabrication. Despite this, Russian colleagues have shown that the reprocessed uranium makes the enrichment of such material to levels on the order of that suitable for a nuclear weapon, (apx. 90%) impractical, due to dilution of the U-235 with U-232 and U-236 and because of the increased radiation field. U-232 and U-236 will preferentially travel with U-235 during the enrichment process (by virtue of being lighter than U-238). This will dilute or "denature" the enriched U-235 product stream. The appeal of this process is that there is an abundance of reprocessed uranium. Most reprocessors consider reprocessed uranium to be a form of "low-level" waste, until the economics for recycling uranium improve. The use of reprocessed uranium for denaturing UF_6 feed to an enrichment plant would severely hinder the production of weapons grade uranium from such feed. However, the use of reprocessed uranium would also increase the radiation fields in UF_6 conversion, enrichment and fuel fabrication plants. Such radiation fields could be accommodated using additional shielding and robotic equipment for the semi-remote fabrication of fuel for commercial reactors. Uranium feed exporters could supply reprocessed uranium in the form of UF_6 to states that seek to convert or enrich uranium, which have yet to establish their international safeguards credentials or "bona fides". Supply of the uranium feed could be guaranteed, but the feedstock would be reprocessed uranium.

In terms of collaboration, Russian and American scientists and engineers could computer model the increased radiation dose rates from reprocessed uranium from UF_6 conversion through enrichment to fuel fabrication, with an eye towards determining the additional design features required to maintain radiation exposure to current acceptable low levels. Modeling could also determine the precise radiation and dilution penalties to be expected from using reprocessed uranium. Additional demonstration tests could be performed using Russian fuel cycle pilot-scale facilities and laboratories to demonstrate whether the results are as predicted by the computer simulation and modeling and to validate the expected denaturing effect of using reprocessed uranium.

Enhanced Safeguards for Spent Fuel Receipts and Reprocessing
Nuclear power is an acceptable alternative energy, especially when one considers the current rapid depletion rate of existing carbon-based fuels, the transfer of wealth associated with this high rate of consumption, and the generation of CO_2 and other

industrial gas emissions that could alter the world's climate. However, like oil, there are also finite resources of uranium and thorium. At current rates of consumption, it is estimated that there are approximately 100 years worth of exploitable uranium resources, using current mining and recovery technology.[9] However, if spent fuel were reprocessed and the uranium and plutonium were recycled to make new nuclear fuel, these uranium resources could be extended by an estimated factor of 5 to 10 times. This could effectively extend the use of these resources for 500 years or more. To do this, issues need to be addressed to improve the safeguarding of nuclear fuel reprocessing plants.[10] The first need is for a more effective and accurate verification of the nuclear material (uranium, plutonium and actinide) content of spent fuel. Currently, IAEA inspectors verify spent nuclear fuel by checking the Cerenkov nuclear radiation (radioactive glow) or by total gamma and neutron radiation. However, these methods are semi-qualitative and cannot determine whether individual spent fuel pins have been removed – a scenario for removing and diverting a portion of the spent fuel. For these reasons, there is a need to develop more quantitative non-destructive assay techniques for verifying the receipt and nuclear material content of spent nuclear fuel, especially for the more prolific light water reactor (LWR) fuel.

Another issue of great concern is the large number of dissolved spent fuel solution samples and sampling effort required by the IAEA to verify the input of mixed uranium and plutonium fed to the extraction process. This makes the safeguarding of such plants highly labor intensive for the IAEA. The safeguarding of the single Rokkashomura Reprocessing Plant in Japan by the IAEA, consumes an estimated one third to one quarter of the inspection resources of the IAEA Division of Safeguards Operations-A, responsible for implementing safeguards in Asia. If more reprocessing plants were under international safeguards, the drain on safeguards inspection resources for sample taking and analysis would be staggering. However, it is possible to devise an on-line assay system that would analyze the spent fuel dissolver solution, without the need for taking samples each time. Such on-line assay schemes have been developed for other chemical process and petrochemical plants over the last thirty years. Clearly, the high radiation field complicates the assay, but there are new and advanced gamma, neutron, and other assay techniques that could be used for the on-line assay of spent fuel dissolver solution being fed to a reprocessing plant. Prospective collaboration could involve joint computer modeling of the spent fuel and response of the improved on-line detectors or analytical system. Joint experiments using actual small batches of spent fuel and on-line measurement of the process solution in a pilot-plant could be demonstrated using Russian hot cell facilities and pilot-plants. If the quantitative verification of spent fuel and on-line assay of dissolver solution could be demonstrated, the safeguarding of reprocessing plants could then be performed by "remote monitoring" and short notice random inspections – an inspection regime far more efficient than the current approach. Such unattended "remote monitors" could also be used to implement the Fissile Material Cut-Off Treaty (FMCT), by confirming the shut-down status of monitored reprocessing facilities in Nuclear Weapons States.

Assessing the Risk of Nuclear Material Diversion from Nuclear Facilities
Currently, the IAEA uses the Safeguards Criteria in the *IAEA Safeguards Manual* to evaluate whether safeguards goals and objectives are met.[11] These criteria are generally prescriptive, although they have the overarching goal of detecting the diversion of one significant quantity (SQ) of nuclear material within a timely period.[*] [12] The timeliness period is based on the time required for converting the diverted nuclear material into a crude atom bomb and the significant quantity approximately represents the amount of nuclear material required. This is not just the amount for the bomb, but also includes material that would be necessarily lost in the chemical conversion and machining steps. These safeguards criteria tend to be facility specific, although they can be universally applied to all facilities of a given type, i.e. power reactors, research reactors, enrichment plants, etc. In many cases, the IAEA is attempting to develop safeguards objectives for each state, for the sake of implementing safeguards on a "state-level", i.e. attempting to detect the diversion of nuclear material across the entire state's nuclear infrastructure, rather than just at a facility level. In this case, the expanded safeguards objectives include: i) verifying the non-diversion of nuclear material in declared nuclear facilities, as per the Criteria, ii) confirming the absence of facility misuse, and iii) detecting the presence of undeclared nuclear material and activities in the state as a whole. In the latter, safeguards inspectors are aided by the safeguards measures under the Additional Protocol. At the facility level, the Safeguards Criteria still remains largely prescriptive, dictating inspection frequency, nuclear material verification requirements, measurement accuracy, etc. For greater efficiency, Russian colleagues have proposed the use of Probabilistic Risk Assessment (PRA) techniques, such as have been applied to the analysis of nuclear reactors to quantify the risk of, and consequences from a postulated nuclear accident. In principle, the same idea could be applied to assessing nuclear facilities for risk of diversion. The benefit is that this analysis would be more analytic and systematic. It would also indicate the probability of diversion and possibly the expected consequences of the diversion (i.e. how much nuclear material could be diverted).

Towards this end, American and Russian institutes and laboratories could develop more comprehensive diversion models for all major nuclear facility types and determine if PRA could be applied to evaluating the implementation of safeguards at nuclear facilities, in lieu of the prescriptive safeguards criteria. If this were done, it might be possible to scale back inspection activities in countries that have signed the Additional Protocol and which have established international safeguards "bona fides". Inspection resources could be more efficiently allocated to countries and facilities based on assessed quantitative diversion risk. The process would be non-discriminatory, since it would be based on universal PRA diversion models for each facility type. Once these models are developed, they could be validated at nuclear facilities in the United States and Russia, which would provide additional opportunity for joint work and collaboration.

---

[*] The IAEA safeguards goal for plutonium is to detect a diversion of 8 kg within one month of possible diversion. The goal for highly enriched uranium is to detect a diversion of 25 kg of U-235 in the form of HEU ($\geq$20% U-235), within one month of possible diversion. For low enriched uranium (<20% U-235), the goal is to detect a diversion of 75 kg of U-235, within one year of possible diversion.

Monitoring and Tracking Harmful Radioactive Sources

The goal of international nuclear safeguards is to detect the diversion of significant quantities of plutonium, uranium and thorium, which could be used to produce a crude atom bomb. Also of concern is the detection and interdiction of radioactive sources, which could be used to create a radiological device or "dirty bomb". This has historically not been the focus of the Safeguards Department at the IAEA, but it has come under the purview of the Office of Nuclear Security at the IAEA. This division is particularly lacking in regular budget and its mission is intrinsically limited by funding.[13] The goal of this division is to detect radioactive sources and nuclear materials that are being smuggled across borders, which could be used to cause public harm. To date, the focus has been on enlisting states to participate in an Illicit Trafficking Database (ITDB), which documents the seizure of nuclear materials and radioactive sources that are intercepted by national authorities at border crossings. Currently, there are 100 states participating in this database. However, this concentrates on nuclear material and radioactive sources that are intercepted by national authorities at border crossings. It generally does not address the significant risk of nuclear material and radioactive sources that are held in stockpile within the country, which may be inadequately inventoried and insecurely stored. To address this problem, a more holistic procedure for labeling, inventorying, packaging, monitoring, and tracking radioactive sources could be developed and demonstrated at a scientific institute, such as the Kurchatov Institute in Russia.

American and Russian scientists and engineers could develop enhanced tags and labels that could be universally applied to all radioactive material and radioactive source containers, which could embody records of the contents and be electronically monitored and tracked. As a consequence, the process for cataloguing and monitoring radioactive material and sources would be demonstrated. The Kurchatov Institute in particular has a wide variety of radioactive sources and samples of nuclear materials with different chemical and isotopic compositions and mixtures. Many of these samples and sources are thought of as "waste materials" and are viewed only as a storage and disposal headache. However, regarding nuclear materials, "One man's trash, is another man's treasure." Because of the diversity of these nuclear materials, they could be leased to American laboratories to perform non-destructive assay tests on exotic nuclear materials, for which samples may be limited or non-existent in the United States. This could help defray the cost of the nuclear material sample and source cataloguing activity at Kurchatov, and at other nuclear laboratories and facilities in Russia. Optimized labeling and inventory software and processes could also "spin back" to the United States to improve the inventorying and monitoring of nuclear material and radioactive sources here as well. The lessons learned and best practices demonstrated in this endeavor could be shared with the IAEA, and in partnership with the World Institute of Nuclear Security (WINS), to improve the nuclear security of nuclear material and radioactive sources world-wide.[14] What is important is to recognize the potential threat posed by radioactive sources and nuclear materials if left un-catalogued, unmonitored and improperly stored.

THE ULTIMATE VISION – A RENEWED RUSSIAN & AMERICAN SAFEGUARDS PARTNERSHIP

The ultimate vision is for Russians and Americans to work more cooperatively, collectively, and urgently to address the current issues concerning the safeguarding of nuclear material internationally, and to minimize, if not reverse, the spread of nuclear weapons. Since Russia and the United States possess the largest stockpile of nuclear weapons, the onus is on them to revitalize the process. Of course, this challenge is not trivial, but in fact, they have the most to gain. They or their allies would most likely be the target resulting from a diversion or misuse of nuclear material – either in the form of a crude atom bomb or in a radiological device (dirty bomb). Renewing the pledge to demonstrate more substantive progress in nuclear arms reduction is the first step. Agreeing to work more energetically and collectively on outstanding nuclear safeguards and security issues is the second step. This should not be piecemeal, but should be dynamic, aggressive, and well supported by both governments. Otherwise, the further expansion of nuclear power could be at risk. The accidents at the Chernobyl and Three Mile Island nuclear power stations effectively put the nuclear power option on hold for twenty years, while the safety issues were more effectively addressed. Both governments and their respective scientific communities need to address outstanding safeguards issues to ensure that a diversion of nuclear material does not have catastrophic consequences.

The third, and perhaps ultimate, step is for the United States and the Russian Federation to consider a bilateral nuclear inspectorate that would work intimately, using joint resources to address the safeguards issues noted and inspect domestic civil nuclear facilities. There are examples of successful bilateral and regional inspectorates, including EURATOM in the European Union and ABACC for Argentina and Brazil. Initially, this entity could concentrate on the research and development as outlined. However, it could advance to the stage of a regional inspectorate that could inspect nuclear facilities as a joint-team in Russia and the United States, as is done in the United Kingdom, France and Germany. Ultimately, it is possible that this regional inspectorate could include Japan, South Korea, and Canada, and become a regional inspectorate for North Asia and the Pacific – "NordPac". All the countries listed have established good safeguards credentials. This would be a precondition for membership. A regional inspectorate that covers the North Asia and Pacific region could perform safeguards inspections following the criteria and guidelines established by the IAEA. This would be analogous to the "Partnership Approach" that EURATOM has with the IAEA.[15] Under this approach, EURATOM performs safeguards inspections in the European Union, supplementing the safeguards inspection effort of the IAEA. The IAEA can randomly select to participate in inspections on a case by case basis, to ensure that the methods and procedures are up to international standard. Following the collapse of the former Soviet Union, this Partnership Approach allowed the IAEA to apply more inspection resources to the Newly Independent States, while EURATOM assumed more inspection burden in Western Europe. The same could be the case in the North Asia and Pacific region. NordPac could perform inspections in Russia, the United States, Canada, Japan, and Korea, while the IAEA concentrates on inspections in countries that have not yet established safeguards "bona fides". This would dramatically increase the ability of the IAEA to direct its safeguards inspection resources at countries requiring the greatest attention for international security. Even in bilateral form, a Russian/American Safeguards Inspectorate would have the great benefit of training the next generation of Russian and American nuclear safeguards scientists and experts and also convey to the international community their commitment to safeguarding nuclear material within their borders.

REFERENCES

[1] *The Moscow Times*: "U.S. Arms Negotiator to Visit," Associated Press and Moscow Times Reports, Monday, December 15, 2008, page-3.

[2] International Atomic Energy Agency (IAEA): *Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards*, INFCIRC/540 (corrected), Vienna, Austria, December, 1998.

[3] International Atomic Energy Agency (IAEA): *Treaty on the Non-Proliferation of Nuclear Weapons (NPT)*, INFCIRC/140, Vienna, Austria, April 22, 1970.

[4] United States Department of Energy (DOE), National Nuclear Security Administration (NNSA): "Enhanced Safeguards at Gas Centrifuge Enrichment Plants – Developments and Recommendations," DOE Oak Ridge National Laboratory Report #ORNL/TM-2008/180, (restricted distribution), Oak Ridge, Tennessee, December, 2008.

[5] International Atomic Energy Agency (IAEA): *Management of Reprocessed Uranium – Current Status and Future Prospects*, IAEA-TECDOC-1529, Vienna, Austria, February, 2007.

[6] RIA Novosti News Agency: "Putin Approves $83 Billion Financing Program for Rosatom until 2015," Moscow, September 30, 2008.

[7] Alekseev, P.N.; Borisevich, V.D., et al. (Kurchatov Institute and Moscow Engineering Physics Institute (MEPhI)): "Concept of Application of Recycled Uranium to Increase the Security of Export Deliveries of Light Water Reactor Fuel," Kurchatov and MEPhI, Moscow, 2008.

[8] World Nuclear Association: "Military Warheads as a Source of Nuclear Fuel," January, 2009.

[9] OECD Nuclear Energy Agency (NEA) and International Atomic Energy Agency (IAEA): *Uranium 2007: Resources, Production, and Demand,* A Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, Paris, 2008.

[10] United States Department of Energy (DOE), National Nuclear Security Administration (NNSA): "Advanced Safeguards Approaches for New Reprocessing Facilities," DOE Pacific Northwest National Laboratory Report #PNNL-16674, Richland, Washington, June, 2007.

[11] International Atomic Energy Agency (IAEA), Department of Safeguards: *IAEA Safeguards Manual*, Parts SMI and SMC, "Safeguards Criteria and Annexes," Vienna, Austria, January, 2004.

[12] International Atomic Energy Agency (IAEA): *IAEA Safeguards Glossary – 2001 Edition*, Table-II, "Significant Quantities," Vienna, Austria, 2002, page-23.

[13] *Nuclear News Magazine*: "Sustainability is Key to Global Nuclear Security," December, 2008, pp-28 to 30.

[14] World Institute of Nuclear Security (WINS): "Introducing WINS – World Institute for Nuclear Security," (brochure), Vienna, Austria, 2009.

[15] Thorstensen, S. and Chitumbo, K.: "Increased Cooperation between the IAEA and Euratom – The New Partnership Approach," Proceedings of the International Safeguards Symposium, Vienna, Austria, 1994, pp-271-283.