IAEA-CN-184/68

Japan-IAEA Workshops on Advanced Safeguards for Future Nuclear Fuel Cycles

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Abstract. Beginning in 2007, the Japan Atomic Energy Agency (JAEA) and the International Atomic Energy Agency (IAEA) Department of Safeguards initiated a workshop series focused on advanced safeguards technologies for the future nuclear fuel cycle (NFC). The goals for these workshops were to address safeguards challenges, to share implementation experiences, to discuss fuel cycle plans and promising research and development, and to address other issues associated with safeguarding new fuel cycle facilities. Concurrently, the workshops also served to promote dialog and problem solving, and to foster closer collaborations for facility design and planning. These workshops have sought participation from IAEA Member States' support programmes (MSSP), the nuclear industry, R&D organizations, state systems of accounting and control (SSAC), regulators and inspectorates to ensure that all possible stakeholder views can be shared in an open process. Workshop presentations have covered, *inter alia*, national fuel cycle programs and plans, research progress in proliferation resistance (PR) and safeguardability, approaches for nuclear measurement accountancy of large material throughputs and difficult to access material, new and novel radiation detectors with increased sensitivity and automation, and lessons learned from recent development and operation of safeguards systems for complex facilities and the experiences of integrated safeguards (IS) in Japan. Although the title of the workshops presumes an emphasis on technology, participants recognized that early planning and organization, coupled with close cooperation among stakeholders, that is, through the application of "Safeguards by Design" (SBD) processes that include nuclear safety and security coordination, "Remote Inspections" and "Joint-Use of Equipment (JUE)" would be required to enable more successful implementations of safeguards at future NFC facilities. The needs to cultivate the future workforce, effectively preserve the knowledge of seasoned staff, and collect, analyze, apply, and manage large amounts of diverse information were also cited as important challenges. Working groups addressing specific subjects provided the stage for detailed discussions amongst the participants, which were then summarized and presented to the entire audience for consideration and feedback. The workshop venue has proved to be beneficial for conveying timely information and fostering direct interaction among stakeholders. Continuing these workshops on a two-year basis may also help to promote and sustain collaborations for planning and executing more successful safeguards implementations in advanced fuel cycle facilities, and thereby nurture a growing SBD culture. The workshops were highly valued by the participants and the next JAPAN-IAEA workshop on this topic is planned for 2011.

1. Introduction

In collaboration with the IAEA Department of Safeguards, the JAEA Nuclear Nonproliferation Science and Technology Center has hosted two workshops to highlight the safeguards challenges and new ideas for advanced NFCs under construction and in planning, and to promote international dialog on these issues. The first workshop took place 13 – 16 November 2007 and the second was held 10 – 13 November 2009, both in Tokai, Japan. Each workshop was attended by approximately 100 participants from numerous states and stakeholder organizations representing the nuclear industry, R&D organizations, safeguards inspectorates, SSACs, and MSSPs. The workshops also served to increase the awareness of the challenges and promising solutions, increase stakeholder interaction and transparency, provide a collaborative environment for developing solutions, and inspire proactive plans and activities.

The structure for each of the workshops followed a similar pattern. Plenary sessions highlighted programs related to new or ongoing NFCs and safeguards technology initiatives. The following sessions were introduced with questions intended to stimulate thinking for subsequent working group discussions that focused on developing recommendations for future safeguards R&D directions. Working group summaries were then presented to the plenary for further discussion. In conjunction with each workshop, JAEA provided the option to tour its Clean Laboratory for Environmental Analysis and Research (CLEAR) and Japan Proton Accelerator Research Complex (J-PARC) facilities.

2. Workshop technical presentations

JAEA and IAEA organizers of the workshops focused on the following topic areas:

- Current Status, Challenges and Future Prospects of Developing Safeguards Technologies for NFC Facilities
- Advanced Safeguards Concepts, Technology and SBD for the Future NFC
- New and Novel Safeguards Technologies
- Guidelines for Development of Future Safeguards Instrumentation
- Experiences and Lessons Learned

Highlights of the presentations from the plenary sessions and for the above topics are reported in sections 2.1 through 2.5 below. Detailed compilations of presentations are available from Refs. [1, 2].

2.1. Plenary Sessions

At the 2007 workshop, representatives from Japan, France, the United States and the European Community (EC) presented program plans and the progress to date of the "Japan Fast Reactor Cycle Technology", the "French Study on Transference from Light Water Reactors to Generation IV", and "Safeguards Research and Technology Development for the Global Nuclear Energy Partnership (GNEP)", respectively. The European Community (EC) presentation cited technology developments in partnership with the IAEA, human resource issues, and an overview of data security, analysis, and management needs and possible approaches.

In 2009, Japan presented its "Strategic Plan for Sustainable Safeguards", which is focussed on pursuing the most advanced safeguards systems as pioneer and practitioner, in acknowledgement of its responsibilities to assist in building and reinforcing the non-proliferation regime. The U.S. National Nuclear Security Agency explained its Next Generation Safeguards Initiative program plan, which emphasizes development of the policies, concepts, technologies, expertise, and infrastructure needed to sustain the evolution of the international safeguards mission for the next 25 years.

IAEA stated that its workshop expectation was guidance in seeking and acquiring safeguards tools for present and future missions. New challenges are posed by future NFC processes and facilities, e.g., reactors, maritime nuclear power, geological repositories, and new enrichment and reprocessing technologies, that will likely require new concepts and approaches and application-specific verification technologies; an enlarged nuclear sector, which could increase pathways for proliferation; and new roles for the IAEA, such as verification of disarmament.

2.2. Current Status, Challenges and Future Prospects of Developing Safeguards Technologies for NFC Facilities

Participants acknowledged that the anticipated worldwide growth in nuclear power through the next few decades, which includes plans for large-scale reprocessing facilities, light water power reactors, new reactor types, small scale research reactors, and centrifuge enrichment plants, should be met with plans for safeguards implementation as soon as possible, and in many cases, planning should already be underway. Another challenge is integrating proliferation resistance (PR) in NFC designs in a way that is acceptable to the international community. A near-term challenge continues to be implementation of safeguards under the current safeguards regime, which includes activities supporting comprehensive safeguards agreements, additional protocols, and IS.

The IAEA presented definitions for understanding safeguards in the context of PR. A study to address the challenge of safeguarding large-scale reprocessing plants advocated the use of process monitoring, on-line assay, more sensitive non-destructive assay (NDA) techniques, increased automation of safeguards data collection and processing, and use of multiple, parallel process lines to effectively reduce the nuclear material inventory volumes for measurement purposes. A case study that analyzed SBD and PR for aqueous reprocessing systems echoed many of the same conclusions regarding design of process inventory measurement systems to make detection of diversion more achievable. The results of implementing safeguards at two, metal-oxide (MOX) fuel fabrication facilities in the EC reported experiences in the use of some of these ideas.

2.3. Advanced Safeguards Concepts, Technologies and SBD for the Future NFC

Participant presentations noted the increase in the number and types of planned NFC facilities, nuclear power plants and research reactors. Some NFC designs, such as pebble bed, fast and molten salt reactors, are based on material geometries and processes not suited to either traditional item counting or bulk facility safeguards approaches. Some of these systems would be sealed to ensure safety and/or security of proprietary information, thus making nuclear material difficult to observe and track. Large-scale facilities with high material throughput and continuous operations also present challenges to traditional safeguards approaches. Methodologies for evaluating PR, for assisting the design of safeguards approaches, and incorporation of a risk analysis approach for safeguards system design were discussed. One presentation raised the issue of the growing needs for expanded safeguards technologies and capabilities, and specifically that of information technology, to meet the anticipated growth in the numbers and types of facilities that will be placed under safeguards.

The IAEA presented a comprehensive vision for applying safeguards at large centrifuge enrichment plants based on highly automated safeguards systems, reduced inspection frequency and effort, and improved timeliness and detection of highly enriched uranium and undeclared production of low enriched uranium. Full implementation of this scheme relies on improvements in safeguards systems for cylinder tracking, authentication of accountability load cells, and enrichment measurements. Other presentations gave details of how the vision might be achieved, including a method for 100% cylinder verification and full-volume assay, an approach for using inspection data analysis and other information sources to optimize inspection plans for more effective inspections and reductions in inspection frequency and burden to operators, and a rules-based approach to monitor continuous uranium hexafluoride feed and withdrawal stations to identify system problems and operational anomalies. Laser absorption spectrometry, under evaluation for enrichment measurements, was reported.

IAEA outlined the concept of remote inspections in which some inspection activities would be performed without the physical presence of an IAEA inspector. Remote inspections could be used to automate more activities and/or move them to IAEA headquarters, measure nuclear material in high radiation or inaccessible areas, make greater use of SSACs, Regional System of Accounting (RSAC) and facility operator information and activities, and therefore save travel time and costs. Remote inspections would complement unannounced, random, and complementary inspections, and allow the inspector to focus on high-value activities such as looking for undeclared nuclear material and activities, and supporting state evaluations. Remote inspections will be partly enabled by the ongoing efforts to increase standardization and automation of NDA and containment and surveillance (C/S) systems and reliance on the use of remote monitoring, whereby some inspection and system state of health data is now transmitted to IAEA headquarters from nuclear facilities through a variety of transmission schemes, including satellite communication in the future. Remote monitoring has already led to reduced inspection frequency and shorter inspections, identification of equipment failures at an early stage, and improved inspection planning. Some safeguards systems maintenance can now be accomplished remotely. The ability to automate data transfers and review inspection data from IAEA headquarters has improved inspector efficiency. Along with other improvements, however, there is a continuous need to maintain data security and integrity.

New NDA technologies and R&D programs were presented. The United States outlined its five-year plan to model and measure plutonium mass in spent fuel assemblies. One candidate approach is “lead slowing-down spectroscopy” for direct measurement of plutonium in spent fuel. NDA techniques for other applications included an approach for detecting pin diversion in pressurized water reactor spent fuel assemblies by simultaneously measuring assembly neutron and gamma flux profiles, liquid scintillators for neutron measurements that promise faster response than He-3 detectors and good source discrimination, and a combined radio-frequency tag and neutron detector. There were several presentations about gamma ray and neutron detection concepts based on new detector materials and geometries, advances in active interrogation, mapping radiation measurements in three-dimensional space, advanced analysis of detector data, and high precision NDA to complement destructive analysis (DA) methods. China described its use of passive neutron counting for characterizing waste and cited its advantages for large, dense, or heterogeneous samples, and shorter measurement times than that of calorimetry or DA.

Speakers presented status reports for several analytical laboratories. One presentation reported the development of a new, large-sized dried spike designed to mitigate the growing scarcity of Pu-239 reference material. Advances in DA and environmental sampling were reported, including a new methodology for on-site DA of uranium concentration and enrichment, and DA techniques that require no sample preparation. The IAEA presented lessons learned for planning future on-site laboratories, emphasizing the need for good coordination with the state, facility, and other stakeholders.

A report on joint-use of equipment (JUE) predicted an increase in JUE implementations to avoid unnecessary duplication of safeguards resources and to reduce radiation exposure to workers. To be successful, the equipment and safeguards approaches must be designed to ensure the IAEA's ability to draw independent safeguards conclusions and protect both IAEA's sensitive and operator's proprietary information.

The IAEA described its vision for SBD, reported on its 2008 SBD workshop, and outlined its plan to work with Member States to develop facility-specific SBD guidance. JAEA catalogued safeguards difficulties associated with large-scale, large inventory reprocessing plants and offered potential verification strategies, such as short-interval inventory measurements, improvements in radiation detection, new inventory measurement designs, and application of novel technologies for qualitative analyses. The IAEA presented progress in the development of a systematic approach to identifying technology needs and pairing them with promising technical solutions. The EC reported on its harmonized architecture approach to increase equipment standardization and component interoperability.

2.4. Novel Safeguards Technologies

The term "novel technologies" is defined by the IAEA Department of Safeguards as technologies not applied previously to safeguards purposes. In this context, the IAEA reviewed the needs, requirements, guiding principles, and trends for safeguards instrumentation planning and development, and the status of its current projects. Many of the technical presentations outlined novel ideas and approaches for solving safeguards challenges.

Related to future and planned NFC facilities, new ideas proposed for verifying processing streams in mass balance areas included the use of on-line Raman, visible/near visible infrared, or gamma spectroscopy; improvements in radiometric techniques; measurement of "indicator isotopes" to identify process conditions; and analysis of solution monitoring data to detect large, abrupt changes in tank volumes. One researcher described an approach to transmutate minor actinides of fast breeder reactors and thereby improve the PR of a nuclear fuel system.

Novel techniques and technologies that are under investigation represent a wide array of techniques and approaches. Laser-based technologies are promising for a number of applications, such as chemical detection and analysis, containment verification, item tracking, and tamper indicating applications. A neutrino detection study, planned at Japan's Joyo Fast Research Reactor to evaluate the feasibility of monitoring reactor operations, was described. Optically stimulated luminescent (OSL) materials, which can detect the radiation histories of various surface materials, might be useful for containment verification and complementary access inspections. There has been increasing interest in the use of radio-frequency tags and one presentation reported results of a project using them to track cylinder movement. Fourier transform infrared radiometry (FTIR) for standoff detection of chemicals of interest has been investigated as a possible method to detect undeclared facilities and activities

2.5. Experiences and Lessons Learned

The IAEA discussed the Japan MOX Fuel Fabrication Facility (J-MOX) Joint Technical Committee as a model for future development of facility-specific safeguards systems. The committee, which is composed of members from all relevant IAEA divisions, Japan government and industry organizations, and other suppliers and vendors, was instituted to ensure good coordination of safeguards equipment planning, design, and implementation as a result of lessons learned from safeguards systems implementation experiences at the RRP. The IAEA also reported on the transition to IS at nuclear fuel fabrication plants, and predicted a reduction of inspector time in the field and an overall increase in inspection efficiency. JAEA detailed its plans and preparations for implementing random interval inspections under IS, which were rehearsed and began routine operation at its Plutonium Fuel Production Facility in Tokai in 2008.

The experience of implementing the plutonium inventory management system at the Rokkasho Reprocessing Plant (RRP), a large-scale reprocessing plant in Japan, was reported. Development of an integrated perimeter monitoring system for illicit trafficking detection was described.

3. Working Group Discussions and Recommendations

Following the technical presentations, participants were divided into working groups, to address “Challenges for Safeguards in the Near Future”(2007 workshop), “Advanced Safeguards Concepts and SBD for the Future NFC” (2007 and 2009 workshops), and “Advanced Safeguards Technologies” (2009 workshop). The groups’ findings were discussed in a plenary forum. Observations and summaries combined from all working groups are presented in the sections below.

3.1. Human Resources

Workshop participants predicted a critical shortage of available human resources for IAEA and nuclear facilities unless reductions can be made in the human effort required for inspections and inspection support. They recommended update of employee selection criteria and acceleration of hiring programs to attract new talent and maintain the existing workforce quality through training. They said that the IAEA should also be concerned with developing or hiring fuel cycle experts, and preserving institutional knowledge.

3.2. Safeguards Accountancy Issues

Traditional nuclear material accountancy methods based on item counting and bulk facility approaches might not be applicable to new NFC designs, i.e., pebble bed and some fast reactors. Facility configurations might restrict inspector access for both quantitative and qualitative measurements. Current detectors are inadequate for measurement of fast breeder blanket fuels. To develop feasible verification schemes, participants suggested exploration of reverification technologies, and process monitoring combined with containment and surveillance systems; however, new approaches and measurement technologies should be examined as well.

Measurement error has to be significantly reduced or dealt with in a way that ensures early and timely detection of diversion. Participants posited a number of strategies that could be combined in various ways, including increased frequency of declarations, interim inventory accounting, fast measurement results vs. high accuracy, real-time measurements at key process points, incorporation of tracer techniques, on-site destructive analysis, rapid information processing, and increased use of containment and surveillance tools. To cope with a possible mismatch in workforce vs. workload, the group opined that perhaps verification of complete flow and inventory might not be needed if key flows and transition points could be measured and well characterized. From an SBD perspective, the facility should be built with several process lines that are operated in parallel so that measurement of the resulting smaller process inventories would reduce the burden on measurement accuracy.

3.3. Risk analysis

Participants endorsed increased use of risk analysis, which has been used extensively in the nuclear safety arena and more recently to mature proliferation resistance evaluation methodologies, in the development of safeguards approaches. Authentication should be a requirement for process monitoring and other data collection systems to minimize the risk of information falsification, which the IAEA should assume could happen in any state. Risk analysis should also be used to maintain the applicability of safeguards approaches as fuel cycle processes evolve, and risk assessments for each facility should be integrated with the State-level approach.

3.4. Advanced Safeguards Concepts

Participants applauded the efforts to establish common technical frameworks, platforms, and protocols to ensure reliable, sustainable, secure, efficient and effective collection and evaluation of safeguards relevant data. They encouraged maximum use of JUE in anticipation of new facilities that will be larger, more complex and more automated than their predecessors. They concurred with the use of remote inspections to make better use of the inspector's time, but cautioned that they will require expansion of facility-based safeguards systems and higher performance information technology tools for analysis and data management. The participants also encouraged development of tools needed for the detection of undeclared nuclear material and activities.

Participants reported progress in the development of PR concepts and methods for estimating the degree of PR of a nuclear fuel system. They agreed that PR techniques alone are not a complete solution and that a good balance with safeguards systems must be achieved. Some participants advocated IAEA taking the lead in use of PR and physical protection modelling methodologies in concert with design of advanced NFCs, and encouraged continued development of good coordination between PR and safeguards efforts.

Working group members addressed information needs for safeguards and advised looking for synergies that could be exploited to share information between the state and the IAEA. The requirements of the inspector to gain sufficient information to accomplish verification and the operator to protect proprietary information are often in conflict, but working out the practical solutions together provides a useful opportunity for building confidence and ensuring transparency. Participants encouraged the IAEA to strengthen partnerships with RSACs and SSACs, and where possible and feasible, have these partners take on some of the current work of the inspectors, e.g., application of seals. These partners should work together to maximize the use of JUE to reduce inspection and operator costs, assure information security, integrity, and usability, and build in convenience and practicality for the users.

3.5. SBD

Working groups supported the practice of designing safeguards systems for new nuclear facilities as early as possible and to work together and iteratively with facility designers and all relevant stakeholders to ensure coordination of safeguards with security and safety systems. SBD practices should reduce safeguards and facility lifecycle costs and therefore be an incentive for stakeholders. Regarding near-term SBD actions, workshop participants noted, for example, that some gas centrifuge plants were already under construction and wondered if it was too late to have SBD discussions. Some participants called for the IAEA to institute SBD guidelines for facility design and even establish a system facility design certification to ensure that safeguards requirements are met. Others disputed the idea of IAEA responsibility for certification especially in light of its already constrained budget and resources. Some argued that it was the responsibility of the facility owner to ensure that IAEA safeguards requirements can be met.

In discussing recommendations for the SBD topic, participants advocated simultaneous consideration of the State-level approach and facility-specific verification. This is envisioned as a risk-informed approach that is top-down vs. bottom-up, and which incorporates a comprehensive fuel cycle view vs. process control against operator declarations. SBD guidelines should incorporate characteristics of facility operation that improve the implementation of safeguards including transparency, predictability of operation and ease of inspector access in the facility. Participants encouraged the incorporation of proliferation resistance concepts and technologies in new NFC designs.

For implementing safeguards in new facilities based on existing NFC designs, participants stated that the IAEA should nevertheless interact with the designer, SSAC, regulator and operator as soon as possible to work toward mutually beneficial solutions. They recommended establishing a stakeholder communication forum, in which the mode of cooperation between facility, operation, inspector, and state is formalized. Topics of discussion should include, *inter alia*, safeguards designs concepts, process and nuclear material accountancy information, comparisons with similar facilities, how to minimize system requirements, instrumentation, and redundancy while ensuring effective collection of essential and relevant safeguards information.

An important insight from the group discussion was the idea of actively promoting SBD, which could be accomplished through a number of activities, including training IAEA staff, designers, regulators, SSACs and RSACs; incorporating safeguards requirements into nuclear regulations and seeking commitments from the states to incentivize SBD for new facility designs; and advertising and promoting SBD through outreach activities including professional meetings, working groups, and with industry and citizen organizations.

3.6. *IS*

IS implementation is still under evaluation at numerous sites. Experts proposed that aspects of IS might help to alleviate the some of the problems associated with expected shortages in human resource availability and increases in inspection costs, if inspector and operator workloads associated with implementation of new tools and safeguards approaches can be reduced. This would require the increased use of short notice random and random interval inspections as well as the implementation of remote inspections, in which the acquisition and processing of inspection information are completely automated. These actions would not replace the on-site human inspector, but increased automation will allow the inspector more time to apply his or her unique human skills to verification.

3.7. New and Novel Safeguards Technologies for the Future NFC

The IAEA's target application areas for novel technologies are verification, complementary access, and detection of undeclared activities and facilities. Updated and new tools are needed for design information verification and questionnaires, nuclear material accountancy, containment and surveillance, process monitoring, near real time accountancy, remote monitoring and remote inspections, random inspections, and on-site laboratory activities. Needed NDA advancements are increased sensitivity, increased automation, measurements correlated with three-dimensional space, and automated total plutonium inventory measurement. Smaller, lighter, faster, more highly integrated instruments are always desired. The demand for real-time data acquisition and analysis for meeting timeliness goals is increasing. Furthermore, state evaluation relies on the effective analyses of diverse sources of data, or "information-driven safeguards". Some data and other information should be tagged to geographical position information. The participants suggested investigation of information technology solutions from other industrial sectors for collecting, analyzing, and managing large quantities of data, and automating other tasks.

Working group participants encouraged the development of new and novel safeguards technologies, but cautioned that the solutions must match the needs and requirements for performance, cost, reliability, security, and sustainability. Some charged that IAEA should promote the goal of systems that reduce the amount of instrumentation, its complexity, and its dependence on human interaction. The IAEA goals of increased standardization of systems, remote monitoring of nuclear material movement and IAEA headquarters analysis of data support this strategy. Some environmental sample taking and analysis might be automated and/or augmented with on-site measurements. The IAEA should articulate needed timelines for technology development and seek good coordination with MSSPs and other providers and designers of technology.

3.8. Observations and Challenges

Participants reiterated the problems associated with measuring large throughputs of material in future facilities. Future safeguards approaches for dealing with this problem create new challenges for remote data acquisition, analysis of different data types from many sources, and managing larger and more diverse data sets. Some "solutions" for the IAEA, such as short notice random inspections, present new issues for the operator, who must maintain perpetual readiness. Successful implementations of new safeguards approaches and technologies will require a corresponding effort to replenish and reinforce the skills and capacity in the workforce. At the same time, existing safeguards approaches should be regularly reviewed and updated to optimize efficiency and effectiveness goals. One expert cited the need to recognize alternate nuclear materials (e.g., Np-237) in the current legal framework as a special fissionable material to be safeguarded. Such material will be increasingly abundant in future NFCs and appropriate verification techniques for pure, alternate and mixed alternate nuclear materials are needed for accountancy verification. Overall, the participants anticipated continued, relatively flat budgets for IAEA and most MSSP R&D organizations.

4. Next Steps

JAEA and IAEA plan to host a third workshop in the fall of 2011 to continue the discussions of the challenges, solutions, and progress on the topics related to advanced safeguards for new NFCs. It is hoped that this venue will continue to serve as a forum for open communication, frank discussions, and leveraging ideas from diverse sources to solve problems and to apprise stakeholders of plans and activities.

5. Conclusions

Japan has partnered with IAEA to hold two workshops on the topic of advanced safeguards for new NFCs. Workshops like these joint Japan-IAEA endeavours are important mechanisms for conveying timely and useful information, promoting and sustaining collaborations for planning and executing successful safeguards implementations, and they are helpful in nurturing a growing SBD culture. The main conclusions from both workshops are summarized below.

Important challenges to be addressed include development of new safeguards approaches and tools, specifically, accountancy methods for new NFC facilities, whose designs are not amenable to current accountancy processes; robust information tools to acquire, process, and manage large amounts of data from diverse sources; and recruiting and cultivating the future workforce for the inspectorate and nuclear facilities, while effectively preserving institutional knowledge.

Current efforts and plans target future safeguards tools and methods for completely automated remote inspections that complement on-site inspections, increased use of JUE to reduce costs and operator involvement, and the incorporation of new or novel technologies to solve new or ongoing safeguards problems.

Workshop presentations on lessons learned and subsequent workshop discussions emphasized that successful safeguards implementations rely on early and comprehensive planning and organization, close cooperation with stakeholders, and coordination of safeguards with security and safety practices and processes.

References

[1] IAEA Meetings and Conferences weblink: http://www-pub.iaea.org/mtcd/meetings/Announcements.asp?ConfID=1073.

[2] IAEA Meetings and Conferences weblink http://www-pub.iaea.org/mtcd/meetings/Announcements.asp?ConfID=39029.