JNMM

Journal of Nuclear

Materials Management

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Bittersweet Year Mixes Great Successes with Sad Goodbyes

The past year has been a successful one for the INMM. A part of this success results from the leadership of the Executive Committee, but much of the credit goes to the dedicated volunteers among the members and friends of the Institute. After the publication of the fall issue of the *JNMM*, I received many positive comments about the "new look" of the *Journal* and the high quality of its contents. Hats off to *JNMM* Managing Editor Renée McLean, Technical Editor Denny Mangan and his team of associate editors.

This year, we return to Phoenix for the 40th Annual Meeting. It is planned for July 25–29 at The Pointe Hilton Resort at Squaw Peak. Having just returned from a Technical Program Committee planning meeting, I am confident that Chair Charles Pietri and his committee have worked closely with the six technical divisions to put together a comprehensive and diverse program that reflects the increasingly interdisciplinary interests of the members of INMM. This year's program includes more than 300 contributed papers organized into 44 sessions. Preliminary programs will be going out very soon. After reviewing the contents of this year's program, I'm sure you will want to make plans to attend.

It is my pleasure to report that Steve Ortiz from Sandia National Laboratories is the new Physical Protection Technical Division chair. The Executive Committee joins me in welcoming Steve to his new position, and we look forward to working with him.

As you read this issue of the *JNMM*, you will notice a "New Member" section. Please take the time to read through the names of the individuals who have recently joined INMM. They represent a wide range of national and international technical backgrounds. Our organization will continue to grow and expand **only** as our members continue to contribute their time and knowhow to the Institute. We welcome these new members and encourage them to volunteer their time to support INMM.

In the past year, INMM has lost a number of colleagues. Please read the memoriam to Len Brenner, a long-time member and friend of the Institute, on page 4. In addition, just as we were preparing to print this issue of the *JNMM*, I was saddened to learn of the recent death of another INMM member and friend. Vladimir Kositsyn, head of the Analytical Department at the Institute of Bochvar in Moscow, passed away March 7. Many of us here in the U.S. worked with Vladimir, and we will miss him. He was a good friend to the Institute and was influential in our U.S.-Russian collaborative activities. In remembrances of Vladimir that were shared with me, his INMM colleagues noted his lively sense of humor and a legendary ability to overcome bureaucratic hurdles. Vladimir was only 61 when he died, making his short presence among us the all the more precious.

The technical meetings listed in the *JNMM* calendar on the inside back cover illustrate the broad range of activities of interest to nuclear materials management professionals. It takes many organizers and participants to make these activities a success. In closing, I would like to encourage each of you to get involved. Each of the articles in the *JNMM* identifies a person who may be contacted for further information. If you would like to increase your involvement in INMM, contact any one of these individuals.

The success of the INMM depends on you. I urge you to take an active part.

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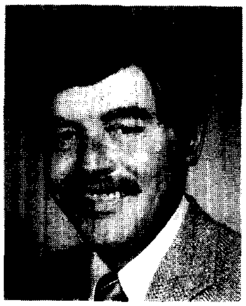
Satellite Imagery Technology Sets the Stage for Strengthened Safeguards



Early last fall, Gotthard Stein, one of the associate editors representing the INMM International Safeguards Technical Division, contacted me about the possibility of featuring several papers on the use of satellite imagery in international safeguards in a special issue of the *Journal*. In September, the International Atomic Energy Agency hosted a Technical Safeguards Workshop on the subject, "Sources and Applications of Commercial Satellite Imagery." "The workshop excited a very active participation, with contributions and demonstrations from several member states, most notably Canada, France, Germany, Japan, Spain, the U.K. and the U.S.A.," said Gotthard, who chaired the workshop. "There was very active discussion of the potential advantages of low- and intermediate-resolution imagery for an improved safeguards regime, the ultimate recommendation being a positive one." Five papers from this workshop (Canada, Germany, Japan, U.K. and U.S.A.) are published herein. As you read them, I believe you will appreciate the "very active participation" that Gotthard notes. I want to express my appreciation to Gotthard and the authors of the papers for their contributions on this very interesting topic and a possible wave of the future to support strengthened safeguards.

In addition to these satellite papers, this issue of the *Journal* includes articles offering insight on a variety of topics. Al Liebetrau's paper suggests that there are opportunities for meaningful professional cooperation with China; Tom Burr and his colleagues from Los Alamos National Laboratory discuss data mining and its applications to nondestructive assay; Kinji Koyama proposes a Fissile Material Cutoff Treaty verification regime modeled after IAEA safeguards; and John Matter and his colleagues provide a summary of the closing plenary session of last summer's Annual Meeting of the Institute. I believe you will find these papers interesting and thought provoking.

More JNMM News

Billy Cole, chair of the INMM Transportation and Packaging Technical Division, has nominated Scott Vance as the associate editor representing this division. Welcome aboard, Scott.

In the last issue of *JNMM*, I mentioned that we were developing a peer review process for technical papers submitted to the *Journal*. The draft of the process has been essentially completed and will be reviewed by the associate editors. We hope to fold out this process in the next issue of the *Journal*, and begin to implement the process with the Fall 1999 issue.

As always, I welcome any comments or suggestions you may have.

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Correction

As *JNMM* transitioned from being labeled by month to being labeled by season, some confusion about index numbering resulted. The correct index numbers are:

Fall 1997: Vol. 26, No. 1
Winter 1998: Vol. 26, No. 2
Spring 1998: Vol. 26, No. 3
Summer 1998: Vol. 26, No. 4
Fall 1998: Vol. 27, No. 1

JNMM regrets these errors and any confusion they may have caused.

Senior Membership Program Recognizes Commitment to INMM

In 1993, at the request of the INMM Executive Committee, the Membership Committee provided recommendations that led to the revision of the senior membership program. The Membership Committee's objective is to promote membership and active participation in the Institute, as well as to promote services designed to meet members' needs in the best way.

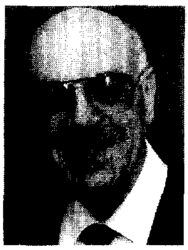
The senior membership program is intended to recognize members who, in addition to having 10 or more years of experience in the field of nuclear materials management, consistently contribute professionally to INMM programs through long-term support, dedication and leadership. The senior membership program is not designed only to recognize leaders — INMM Executive Committee members, division officers and committee chairs — but also members who actively support the INMM by participating in committees and regional chapters; by presenting technical papers and chairing sessions at INMM-sponsored meetings, seminars and workshops; and by preparing articles for the *Journal of Nuclear Materials Management*. Consistent contribution is defined as active support during each of the last five years and indications that such support will continue.

Members interested in attaining senior status must apply. Once achieved, senior membership continues until membership in the INMM is discontinued. After five years of service at the senior level, individuals are eligible for nomination as an INMM fellow.

Each spring, the Membership Committee reviews applications for the senior membership program and makes recommendations to the Executive Committee which makes the final decision about acceptance. Applicants are notified of their status in late spring. Those who are approved are formally inducted as INMM senior members at the annual business meeting, held in conjunction with our annual meeting, and then are publicly recognized as senior members during the annual awards banquet.

If you meet the above-noted qualifications for senior membership, please call INMM headquarters at 847/480-9573 for an application and return it to INMM, 60 Revere Drive, Suite 500, Northbrook, IL 60062. Senior membership status will be acknowledged at the annual meeting, July 25–29 in Phoenix, Ariz., U.S.A.

In Memoriam
Leonard M. Brenner (1922–1998)



The INMM lost a longtime, devoted member, Len Brenner, on Nov. 27, 1998. Mr. Brenner had a diverse, successful career in the nuclear industry.

After graduating from Brooklyn Polytechnic Institute with a degree in electrical engineering, Mr. Brenner went to work immediately for General Electric Co. in Schenectady, N.Y., where he was assigned to the Manhattan Project. For participating in the Manhattan Project, Mr. Brenner was commended for his contribution to building the Oak Ridge uranium diffusion plant.

In 1946, Mr. Brenner was invited to enter government service again when the United States established the Atomic Energy Commission. He served for 20 years with the AEC as a special assistant to the director of military applications, with responsibility for nuclear weapons security and related classification, public information, and technical documentation.

When the AEC established its Safeguards and Materials Management Division in 1968, Mr. Brenner served as its first deputy director. He developed safeguards and physical protection measures policies applicable to licensees as well as license-exempt activities. He was responsible for expanding the safeguards R&D program to address the needed measurement instrumentation improvements, physical protection approaches and transportation security systems that led to the Safe Secure Transport vehicle design. Mr. Brenner continued in this position for 20 years, making many technical and organizational improvements as the U.S. realized that safeguards and security were vital parts of a sound nuclear policy.

Mr. Brenner retired from the DOE in 1985, but he did not retire from service. He was assigned to the IAEA from 1986 to 1987, during which time he analyzed safeguards agreements and facility attachments for consistency and standardization. In 1986 he served as the U.S. technical-team leader on the international committee that developed the IAEA's recommendations for "Physical Protection Controls Within States," INFCIRC/225. His team's responsibilities included assuring that the final document accurately reflected Nuclear Regulatory Commission and DOE practices.

In 1988, Mr. Brenner helped formed 21st Century Industries Inc. He served as president of TCI until the time of his death.

Mr. Brenner was a walking archive of the nuclear industry from its birth to the present. He was a man of great integrity, demanding standards and exemplary professionalism. He will be missed by his colleagues, his friends and his family.

Chapters

Japan

The following individuals were designated as new officers for fiscal year 1999–2000 at the 87th Executive Committee Meeting:

- Syunji Shimoyama, Japan Atomic Power Co. Ltd. — chair
- Hiroyoshi Kurihara, Nuclear Material Control Center — vice chair
- Takeshi Osabe, Nuclear Material Control Center — secretary
- Keisuke Kaieda, Japan Atomic Energy Research Institute — treasurer

Members-at-large:

- Nobuo Isizuka, Japan Atomic Industrial Forum
- Mamoru Inoue, Japan Atomic Power Co. Ltd.
- Naohiro Suyama, Japan Nuclear Fuel Ltd.
- Hiromi Terada, Nuclear Material Control Center
- Sumio Yamagami, Mitsubishi Material Corp.
- Tsuyoshi Mishima, Japan Nuclear Cycle Development Institute

The 1998 annual business meeting was held Oct. 14, 1998, in Tokyo.

The 19th Annual Meeting was held in Tokyo Oct. 14–15, 1998. A total of 123 attendees and seven guest speakers participated, including guests from the U.S., Australia and the International Atomic Energy Agency. The technical session featured 16 papers. Cecil Sonnier, representing the INMM, gave the opening remarks. The theme of the opening plenary session on the first afternoon was "The Status of Physical Protection," and featured three guest speakers.

The chapter's executive committee approved plans to have the 20th Annual Meeting in Tokyo Nov. 4–5, 1999. M. Akiba (JNC) has been designated as the Program Committee chair. The committee is planning to include special 20th anniversary events, including a panel discussion tentatively titled "The Nuclear Power Development Program and Nuclear Nonproliferation in the Asia Region."

Takeshi Osabe
Secretary, INMM Japan Chapter
Nuclear Material Control Center
Tokyo, Japan

Korea

Chapter members elected new officers and members-at-large in October. The Executive Committee consists now of:

- B.-K. Kim, Technology Center for Nuclear Control, Korea Atomic Energy Research Institute — president
- Sung-Tack Shin, KIDA — vice president
- Hyun-Tae Kim, TCNC, KAERI — secretary
- Jong-Sook Hong, KAERI — treasurer

Members-at-large:

- Young-Myung Choi, KAERI
- Jin-Kyoung Kim, Ministry of Science and Technology
- Kun-Jai Lee, Korea Advanced Institute of Science and Technology
- Hyun-Soo Park, KAERI

There were 80 participants at the 2nd Annual Meeting and International Safeguards Seminar Oct. 19 at KAERI. The theme was "SSAC's Enhanced Role in the Integrated Safeguards System." Five lectures and six technical papers were presented, followed by a panel discussions. Materials presented at the seminar can be found at the TCNC Web site — http://www.tcnc.kaeri.re.kr — through the "INMM-KC" link.

B.-K. Kim
President, INMM Korea Chapter
TCNC, Korea Atomic Energy Research Institute
Taejon, Korea

Pacific Northwest

Planning is ongoing for the annual Pacific Northwest INMM Safeguards Symposium, tentatively scheduled for April 1999. It is being planned as a half-day event, with approximately eight papers being presented. Afterwards we are hoping to have a reception or a dinner meeting.

Instead of installing new officers for 1999, it was decided to retain the current chapter officers and board members for the year. This will provide stability within the chapter and allow for continuity in our planned 1999 activities.

A proposal was submitted to INMM headquarters to establish a scholarship fund in the name of R.J. Sorenson. The proposal was approved, and the program is being developed this year.

Brian Smith
Chair, INMM Pacific Northwest Chapter
Pacific Northwest National Laboratory
Richland, Washington, U.S.A.

Moscow

The most significant event in INMM Russia Chapter activities was the election meeting where the chapter leaders were elected for 1998–1999:

- Alexander Izmailov — chair
- Igor Bumblis — vice chair
- R. Timerbaev — second vice chair
- Andrei Zobov — secretary

At a meeting with Debbie Dickman, INMM president, and Obie Amacker, INMM past president, Nov. 5 in Obninsk, Russia, a report was delivered informing of chapter activities to date.

Alexander Izmailov
Chair, INMM Russia Chapter
ELEROM (MINATOM of Russia)
Moscow, Russia

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Technical Divisions

International Safeguards

The next meeting of the INMM International Safeguards Division will be from 8:30 a.m. to 12:00 p.m. May 7 in Seville, Spain, on the occasion of the ESARDA 21st Annual Symposium. The proposed topics for discussions are:

1. *Further discussions on the integration of INFCIRC/153 and INFCIRC/540.* The discussion on this topic at the July 1998 ISD meeting was extensive and interesting to all participants, but the subject is both broad and rapidly evolving. Therefore we propose to continue discussion on this topic. An IAEA representative has been asked to address the group with a brief presentation titled "Integrated Safeguards System: Progress Report."
2. *Issues surrounding a potential nuclear material cutoff treaty.* The IAEA is expected to play a major role in any future nuclear materials cutoff treaty. We propose to discuss the possible scope of such a cutoff treaty, methods for its verification, and the question of treatment of existing versus newly produced stocks of materials subject to the treaty. We will have short presentations on this subject by Gotthard Stein and Victor Bragin. The tentative title of Stein's presentation is "Discussion of Technical and Institutional Aspects of a Future Cutoff Convention." Such aspects would include scope, verification, the role of the IAEA, and the relation to comprehensive safeguards. The scope of Bragin's presentation is expected to address similar aspects.

Cecil Sonnier
Chair, INMM International Safeguards Division
Jupiter Corp.
Albuquerque, New Mexico, U.S.A.

Nonproliferation and Arms Control

The Nonproliferation and Arms Control Technical Division met at the 39th Annual Meeting in Naples, Fla., in July 1998. The group discussed the successes and failures in arranging "structured" topical sessions for the annual conference agenda. The members agreed that schedules and timelines give less advance opportunity to prepare specific papers, but that we should not give up on the idea.

There was considerable discussion about holding another division workshop, perhaps in the spring. It was agreed that this forum could and should be informative to policymakers in Washington, D.C. Suggestions were made that joint sponsorship with other INMM technical divisions and/or universities could make these workshops more effective and could help in the attempts to recruit new, younger members to the INMM.

C. Ruth Kempf
Chair, INMM Nonproliferation and Arms Control Division
Brookhaven National Lab
Upton, New York, U.S.A.

Waste Management

The Waste Management Division put together six waste management sessions for the 39th Annual Meeting in Naples, Fla. Approximately 45 speakers discussed waste management issues in sessions covering Yucca Mountain activities, waste measurements, packaging and transportation, and the reprocessing of spent nuclear fuel.

The 16th Annual Spent Fuel Management Seminar was held Jan. 13–15 at Loews L'Enfant Plaza Hotel in Washington, D.C. The program included six sessions:

I. Overview of Spent Fuel Management Programs and Policies
II. Spent Fuel Storage Technology
III. "Management of the Pool, Much More than Fuel" panel discussion
IV. Spent Fuel Storage Projects
V. Spent Fuel Transportation
VI. Status of Repository and Spent Fuel Disposal Projects

Two changes were made to the seminar format this year. The registration fees were increased slightly, and the Thursday luncheon was eliminated.

E.R. Johnson
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China: An Opportunity for Professional Cooperation

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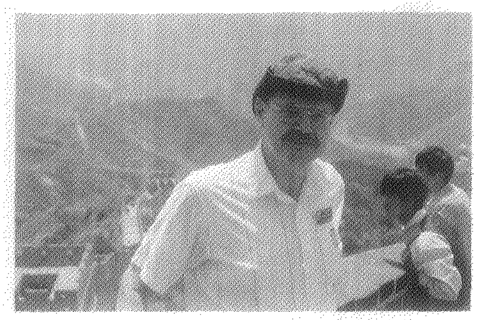
Preface

In the spring of 1998, I met two representatives of the Chinese Institute for Standardization of the Nuclear Industry at a joint meeting of the International Standards Organization Technical Committee 85 (ISO/TC 85)[1] and its working groups in Paris. According to Shou Yuemei, deputy director, the ISNI is responsible for monitoring international activities that pertain to standardization in the nuclear industry. In particular, Shou and her staff are responsible for maintaining a liaison with ISO/TC 85. I subsequently visited China with a delegation of statisticians organized by the Citizen Ambassador People-to-People Program under the auspices of the American Statistical Association. The primary purpose of that visit was to increase communication between statisticians in the United States and their professional counterparts in China. While in China, I visited the ISNI headquarters in Beijing at Shou's invitation. I found my hosts to be very interested in increased professional cooperation with colleagues in the Western world. This report is an outgrowth of my visit, and its primary purpose is to encourage increased professional contact with our Chinese colleagues through organizations such as the Institute of Nuclear Materials Management.



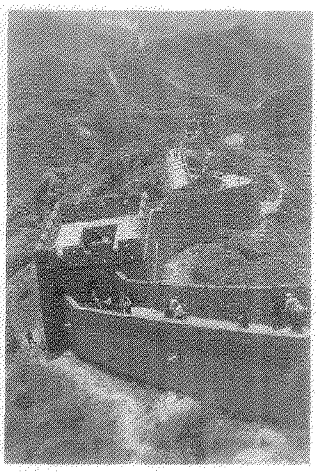
The author on the Great Wall during a recent visit to China.

Introduction

In recent years, China has undertaken the arduous task of moving from a "controlled" economy to a market economy. This transformation demands major investments in infrastructure development and industrial modernization. The energy requirements are enormous. According to some projections, China's energy consumption by the year 2025 is expected to increase more than fourfold from 1995 levels. As the most populous nation on earth, with nearly 25 percent of the world's population, any strategy that China adopts for meeting increased demands for energy is bound to have significant global consequences. Simply stated, the rest of the world has a vested interest in Chinese energy policy. Therefore, any increase in communication between China and the rest of the world is highly beneficial, both because it helps China to integrate more fully into the global community and because it helps the rest of the world to keep more fully informed about developments of vital interest in China.

Background

China has considerable natural resources for the production of energy, including coal, petroleum, and the largest hydropower potential of any country in the world. For these reasons, the Chinese government elected some time ago to depend largely upon coal and hydropower to meet its increasing demands for energy. This decision has had some undesirable consequences. The overwhelming reliance on high-sulphur coal as a fuel, for example, has produced a chronic air pollution problem in highly populated industrial areas that has, in turn, produced increased health costs and other undesirable environmental consequences such as acid rain. Large hydropower projects such as the Three Gorges Dam Project on the Yangtze



The Great Wall (Wanli Chang Cheng), shown here at Badaling near Beijing, still extends about 6,000 km (3,700 miles) in length. The Chinese have a long history of large engineering projects.

[1] TC 85 oversees the development and maintenance of international standards that pertain to the nuclear industry.

River, though they do not significantly increase air pollution, have other environmental costs. The decreased downriver flows and the altered flow patterns disrupt the ages-old cycle of flooding and soil replenishment, which in turn disrupts the production of vital food crops such as rice. A more immediate problem is the creation or exacerbation of water shortages for the large portion of the Chinese population that lives downstream from the project.

For the reasons cited, China is now rethinking its energy policies, and one likely result is increased reliance on nuclear energy. At present, China has three operating power reactors, all of the light-water PWR type. These reactors presently supply only about 1 percent of China's total energy needs. An additional eight reactors are currently in the planning stages or under construction.

Political Structure

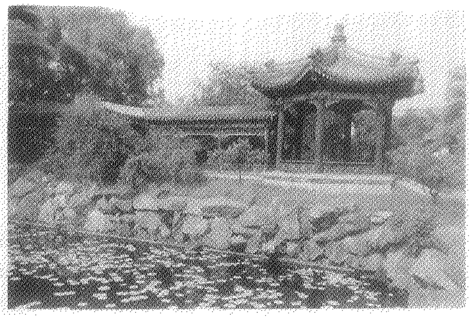
The People's Republic of China is a Communist state with a strong central government and 33 administrative divisions: 23 provinces, five autonomous regions and five municipalities, including Hong Kong. Government policies are developed and administered through agencies and organizations at the central level. The government in each administrative division is structured in the same way as the central government, and agencies in the administrative divisions are closely aligned with their parent organizations at the central level. This top-down structure headed by a strong central organization is well suited to implement and administer mandates and policy changes adopted at the federal level.

The Great Hall of the People (Renmin Dahuitang), viewed from the Square of Heavenly Peace (Tien'an Men Guanchang).

Through this strong centralized structure, China is attempting to manage an orderly transition from a managed economy to a market economy. Officials that I met at all governmental levels repeatedly voiced the conviction that they want to make this transition in a manner that integrates China into the international community and increases its role and influence there. The strategy seems to be to learn what has been done in other countries, and then use this knowledge to determine a suitable course of action for China, thereby possibly avoiding some of the costly mistakes and pitfalls that other countries have experienced. This strategy has been influenced by their earlier decision (which in hindsight and in the experience of others now appears to have been wrong) to place such great reliance on coal, and to a lesser extent on hydropower, to meet China's growing energy needs. At the time, the decision-makers underestimated the need for energy and misjudged (or ignored) the environmental consequences of the alternative they chose. Learning from this experience, China's leaders seem sincere in their desire to use all available experience before embarking on major development projects with national or international consequences.

Institute for Standardization of the Nuclear Industry

If the decision is made to increase China's reliance on nuclear energy, one organization poised to play an important role is the Chinese Institute for Standardization of the Nuclear Industry. The ISNI is responsible for research and management of technological standards in the nuclear industry in China and serves as a center for the collection and analysis of information pertaining to nuclear standardization. The ISNI is organized as an institute under the Chinese National Nuclear Corp. and is governed by the CNNC Bureau of Science and Technology. Founded in 1983, the ISNI is a comparatively young organization with a staff of approximately 100 people. The ISNI is located in Beijing near the beautiful Summer Palace, not far from Beijing University.



A view from one entrance to Beijing University, not far from the offices of the Chinese Institute for Standardization of the Nuclear Industry.

The ISNI identifies its main tasks as:

- Implementing the policy of the State Council in standardization activities.
- Investigating and evaluating national and foreign standards pertaining to the nuclear industry.
- Ensuring that the standardization system of the nuclear industry in China is consistent with the actual conditions in China.
- Organizing and undertaking activities for preparing, revising and maintaining Chinese national standards.
- Publishing standards for the Chinese nuclear industry.
- Assisting the CNNC in supervising and verifying the implementation of standards.
- Addressing issues of quality control concerning products of the nuclear industry.
- Participating in the nuclear energy standardization activities of ISO/TC 85 and the nuclear instrument standardization activities of IEC/TC 45.

The ISNI has established six divisions to accomplish these tasks:

- Reactor Engineering Standardization.
- Nuclear Chemical Engineering Standardization.
- Radiation Protection Standardization.
- Nuclear Instrument Standardization.
- Quality Supervision for Nuclear Products.
- Standards Information.

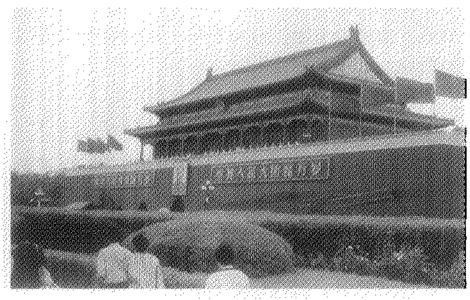
In pursuit of its international mandate, the ISNI has developed an internal structure that corresponds with that of the relevant international organizations. It has established two secretariats, the purpose of which is to promote and support its international activities. These are the Chinese National Technical Committee for Nuclear Energy Standardization (CSBTS/TC 58), which corresponds to ISO/TC 85, and the Chinese National Technical Committee for Nuclear Instrument Standardization (CSBTS/TC 30), which corresponds to IEC/TC 45.

During my visit to the ISNI, I met a number of people involved in the international activities of the organization that corresponds to ISO/TC 85. My host was Shou Yuemei. In addition to her duties as deputy director of the institute, she serves as secretary general of CSBTS/TC 58. Wu Luping, deputy chief of the Radiation Protection and Safety Division, serves as secretary of CSBTS/TC 58. Shou and Wu are assisted in these standards activities by a number of colleagues. Li Yunwen of the Radiation Protection and Safety Division serves as secretary of CSBTS/TC 58/SC 2, the Chinese counterpart to ISO/TC 85 Subcommittee 2. Lu Yunyan, deputy chief of the Nuclear Chemical Engineering Division, serves as secretary of CSBTS/TC 58/SC 5, the Chinese counterpart to ISO/TC 85 Subcommittee 5. Wang Jidong, chief of the Reactor Engineering Division, serves as secretary general of CSBTS/TC 58/SC 6, the Chinese counterpart to ISO/TC85 Subcommittee 6. Xiao Dingsheng serves as secretary of this subcommittee.

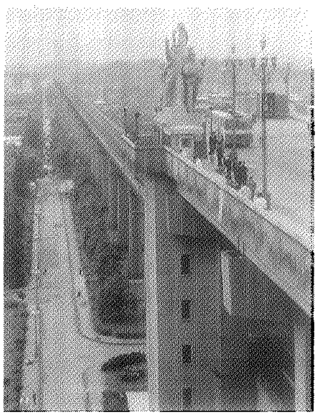
The ISNI will have an increasingly important role as the Chinese government moves toward expanding its nuclear capability. This organization has the internal responsibility for leading the standardization effort in the Chinese nuclear industry. Moreover, through its present contacts, it has the responsibility to coordinate its internal activities with those of other standardization organizations of both national and international scope.

Opportunity for Increased Cooperation

The people I met at the ISNI (and in other governmental agencies) are keenly interested in, and, given cultural and language barriers, surprisingly well informed about, activities in the U.S. and Europe. During my visit, we discussed a wide range of topics that demonstrated this interest and knowledge, including reactor aging, nuclear waste disposal, the organization of the U.S. national laboratory system, and differences between professional and standards organizations in the U.S. and China. My hosts demonstrated a strong interest in our professional organizations and expressed a strong desire for increased professional interactions. In a recent communication, Shou reiterated her interest in support, cooperation, and information for drafting regulations, guides and standards that pertain to the safeguarding of nuclear materials. She specifically requested more information about the Institute of Nuclear Materials Management. It would be mutually beneficial to expand communication with our Chinese colleagues. We should offer an enthusiastic and positive response to their expressions of interest.



Tien'an Men Gate (Gate of Heavenly Peace), once the main gate to the Imperial Palace (Gugong), also known as the Forbidden City.



View from the bridge over the Changjiang (Yangtze River) at Nanjing. This bridge, completed in 1968, has two levels, one of which supports a 7-km-long railroad line.

Professional organizations such as the INMM are particularly well suited to lead efforts to increase communication. First, professional organizations represent a broad cross section of the profession. Second, they generally have greater resources than a small number of individuals, but are less constrained by profit motives and schedules than the typical company or corporation. A professional organization can therefore be more flexible in the allocation of its resources and more patient in setting timetables to accomplish its objectives. Both flexibility and patience will be required to achieve increased levels of communication with the Chinese in the long term.

Toward Closer Professional Ties

The INMM can reply to the initial inquiry from the Chinese by saying that we are also interested in increasing interaction with them. Some ways of following up this reply are obvious. We can send information about the organization and objectives of the INMM, and we can follow these with a complimentary subscription to the *Journal of Nuclear Materials Management* and related publications for their library.

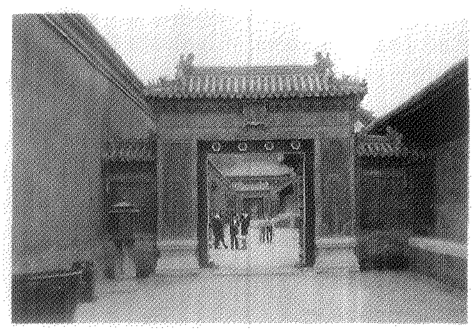
At the next level, we can also extend special invitations to attend workshops and meetings, especially the INMM Annual Meeting and possibly INMM chapter meetings in Japan. In extending such invitations, however, we must be cognizant of the fact that resources in China are limited. Therefore, some sort of financial support (possibly in the form of a travel stipend or fellowship) may be required to achieve a meaningful level of participation. Variations include occasionally holding meetings in China, or at least in Asia. We can also seek or invite joint sponsorship of meetings and other professional activities. An example of such an activity is the waste management conference that is held in Asia each fall under the joint sponsorship of several international and local professional organizations.

Finally, we can explore the possibility of establishing a chapter of the INMM in China (that would be centered in Beijing). With chapters already in existence in Vienna, Japan and Russia, the precedent for establishing new INMM chapters is well established. The formation of a Chinese chapter is likely to require several organizational meetings between interested INMM members and key persons in China. However, for reasons that are explained below, it may be necessary to find some mechanism other than voluntary individual memberships to secure individual participation. One possibility that comes to mind is some form of chapter membership, whereby individuals belong to the chapter and the chapter in turn pays a single group fee to the INMM. (The fee could be waived if necessary).

At this point, one can only suggest possible ways to develop stronger ties between professional organizations in the Western world and in China. The most promising course of action will emerge from in-depth discussions that take place following initial contacts. As professional relationships develop, it is helpful to be aware of certain cultural differences that can significantly effect the course of events.

Awareness of Cultural Differences

As we seek to develop stronger professional ties with China, we must be cognizant of some basic differences in approach between China and the U.S, and more generally, between China and the Western world. These differences will certainly present challenges as we seek to improve communication, but they will also provide important opportunities for both sides to learn new approaches and develop common solutions to mutual problems. This is especially true for professional organizations such as the INMM because the organization of — and attitudes toward — professional activity are so different.



View from inside the Imperial Palace.

In China, professional activity is tied much more closely to work activity than is customary in the Western world. A distinctive feature of Chinese professional organizations is that they tend to assume a structure that is identical to that of the underlying business or government activity they support. Thus, the structure of a professional organization is, in effect, a carbon copy of the corresponding corporate or government structure. For example, the head of a government organization (e.g., the Bureau of Economic Statistics) is also the head of the corresponding professional organization (e.g., the Chinese Statistical Association). The organizational structure of the ISNI illustrates this principle through the way that it adapts to the organizations with which it is responsible for maintaining contact.

Just as the structure of a professional organization in China differs from that which we know, so too are there differences in the attitude toward — and the nature of — professional activity. In China, particularly outside of academic circles, professional membership tends to be closely tied to one's organization, and professional activity is viewed as a work-day activity that is part of one's job assignment. The concept of a professional organization that is separate from the work structure it supports is unfamiliar to the Chinese. Consequently, there is little or no voluntary professional activity outside of the daily work structure. This is in direct contrast to the situation in the U.S., where professional organizations cut across job-related organizational lines, and professional involvement is viewed primarily as a voluntary activity.

Finally, it must be remembered that Chinese society is highly authoritarian, whereas ours is not. This difference has significant implications for how one gets things done. In our society, we are accustomed to directly contacting the person or organization that can provide the information or help we need. This does not work in China, where an employee typically does not act without the knowledge and consent of his or her manager. A direct request for information or help will undoubtedly receive a polite response. However, the request is unlikely to elicit the desired help unless it is made to the appropriate authority and passed down the management chain. The Westerner who does not understand this will be viewed as impolite or pushy and undoubtedly will be frustrated by the perceived unresponsiveness of his contact.

This conduct has implications concerning how we deal with Chinese colleagues. We may not, for example, succeed in requesting the participation of a particular individual, particularly if we approach that individual directly. Participation is accomplished through an invitation to the appropriate persons in the organization, and, once the decision to participate is secured, decisions about the attendance of specific individuals will be made at the designated level in management structure (but most likely not by the individual himself).

Cultural differences certainly present challenges to those attempting to establish effective means of communication. However, they can be overcome, provided both sides come with consistency of purpose, mutual good will, a willingness to be flexible and a genuine desire to succeed. Indeed, the satisfaction of overcoming these differences is one of the most gratifying rewards — both personally and professionally — to come from such a crosscultural exchange.

Summary and Recommendations

I have argued that it is of mutual benefit for the Western world and China to develop closer ties. The Chinese have expressed a desire for increased professional interaction, and we should respond positively to this desire. Organizations such as the INMM are well suited to lead the effort to increase communication with Chinese colleagues. It will require consistency of purpose, flexibility and patience on both sides to succeed. Nevertheless, present conditions are favorable, and the potential rewards of stronger professional relationships are great. I encourage the INMM to accept this exciting opportunity for expanding it global leadership role.

Potential Application of Commercial Satellite Imagery in International Safeguards

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Early results of the work described in this paper were presented at the INMM 39th Annual Meeting in Naples, Fla., U.S.A.[1]

Abstract

This paper describes an investigation of the potential use of commercial satellite imagery in the International Atomic Energy Agency's Strengthened Safeguards System. The work is carried out to provide input to IAEA internal discussions regarding the potential applications of satellite imagery, including identification of the type of expertise required to support such activity. The main aims of the study are to identify and to demonstrate, with concrete examples, potential uses of satellite imagery in international safeguards. The paper reports on the effect of image resolution, in the range of 120 m (infrared) to simulated 1 m (panchromatic); the use of various spectra (microwave, visible and thermal infrared); some aspects of change detection; and detecting undeclared facilities. We use examples that include a multiunit nuclear complex, a nuclear research site, single-unit nuclear generating stations and mine sites. A draft report documenting the results to date has been completed and submitted to the IAEA. This report will be revised for confirmation of the findings when high-resolution satellite imagery in the range of 1 m becomes available, hopefully in early 1999.

Introduction

Background, Objectives and Scope

Several studies (references 2, 3 and 4) have demonstrated the general capabilities of commercial satellite imagery in making broad or general observations for monitoring activities which could lead to follow-up IAEA investigations of undeclared activities or suspected clandestine operations by member states. Analysis using satellite imagery as a preinvestigation tool could provide an effective means to minimize the cost of monitoring and verification by international inspectors.

This study is a cooperative effort between the Atomic Energy Control Board's Canadian Safeguards Support Program and Canada's Department of Foreign Affairs and International Trade's Verification Research Program. The main objective of the project is to provide technical input to the IAEA internal discussions on this topic, with emphasis on the practical applications that could benefit IAEA inspectors. Legal and political issues are outside the scope of this work.

The aims of the study are to investigate, using concrete examples, the following tasks:

- evaluation of imagery spatial resolution;
- comparison between multispectral and panchromatic imagery;
- comparison between synthetic aperture radar and panchromatic imagery;
- monitoring of reactor operation using thermal-infrared imagery;
- evaluation of member-state declaration;
- inspection aid;
- change detection;
- detecting undeclared activities using open-source information.

Figure 1

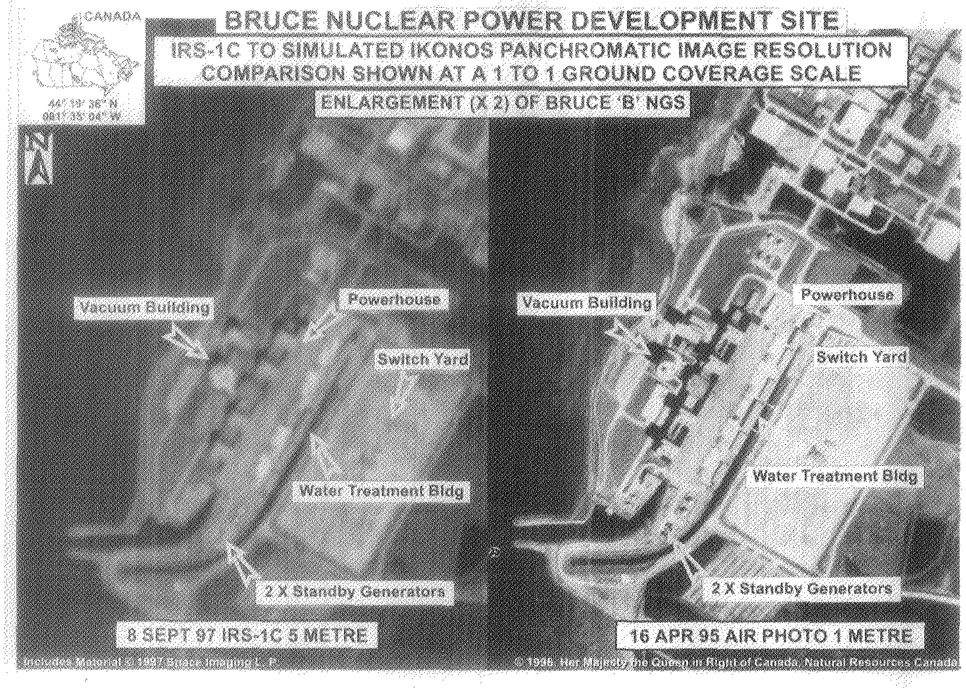
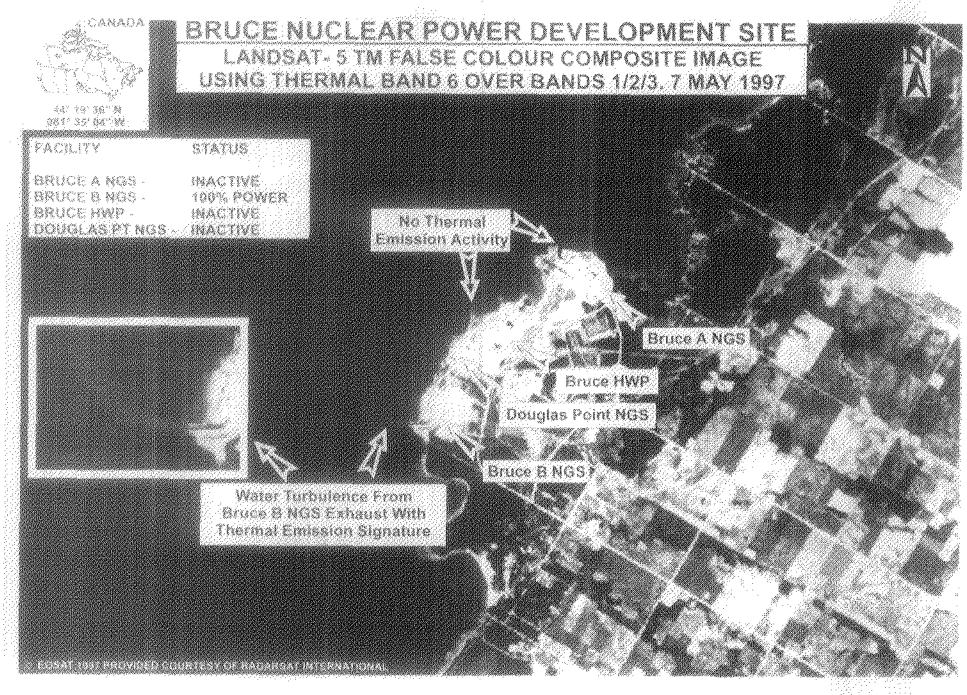


Figure 2



The sensor capabilities, the costs and the imagery obtained for the Canadian sites used in this study are discussed below.

Sensor Capabilities

One radar and seven electro-optical/multispectral commercial satellites are available today with spatial resolutions ranging from 30 m (120 m for infrared) to 2 m. These sensors provide imagery of sufficient quality to provide accurate assessment of infrastructure change detection and activity monitoring. By the year 2002, there are expected to be additional imaging systems deployed, with accuracy of 5 m or better. Four of these will provide 1-m resolution imagery.

Costs

The average cost per image is about $1,500 (U.S.) for electro-optical imagery. The current cost of radar imagery is approximately twice this amount. A high-quality personal computer with a large monitor and peripherals and software applications would be required to perform imagery analysis and produce a high-quality printout of the results. The total cost of such a system would be in the range of $10,000-$20,000 (U.S.), depending on the configuration of the system. It is expected that the cost of imagery and computer hardware and software will continue to decrease due to market competition. For projects involving a large collection of images, the costs for archiving images are additional to the above and should be considered in the overall budget planning.

Imagery and Sites Used in This Study

Imagery from Landsat-5, SPOT-2, IRS-1C, Radarsat-1 and aerial photographs was purchased for this study. The majority of the imagery and photographs were for the Bruce Nuclear Power Development site. This is a large Canadian nuclear facility, where the multiunit reactors at Bruce A and B, the decommissioned Douglas Point reactor and the Bruce Heavy Water plants are located. Other images were for the Gentilly-2 and Point Lepreau reactors, the Chalk River Nuclear Laboratories, several uranium mines in the provinces of Ontario and Saskatchewan, a uranium refinery in Ontario and a diamond mine in the Canadian Northwest Territories.

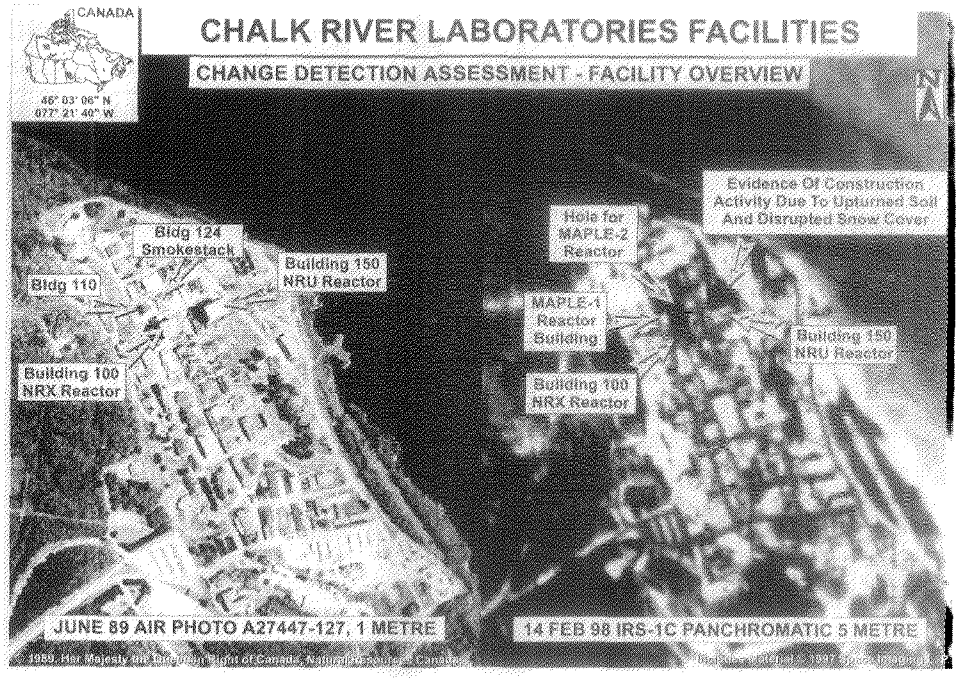
Results

For brevity considerations, only a small selection of imagery is presented in this paper. More detailed information, and imagery in color, will be found in reference 5. It should be noted that, due to printing degradation, the graphics presented in this paper are not as clear as the original imagery. In the case of multispectral imagery, black-and-white reproduction of a color image, e.g. Figure 2, significantly reduces the clarity of the images.

Evaluation of Imagery Resolution

Using Landsat-5 (30 m), SPOT-2 (10 m), IRS-1C (5 m) and simulated air photos (1 m), a comparison of imagery resolution was carried out. At 30-m resolution, major features such as the four-unit Bruce A and Bruce B reactors, the single-unit (decommissioned) Douglas Point reactor and the Bruce Heavy Water plants can be discerned. At 10-m resolution, large buildings and structures such as the vacuum building, the four reactor buildings, the powerhouse and the switch yard can be seen. Additionally, a 10-m resolution permits the interpreter to observe with an acceptable degree of clarity objects such as fuel storage tanks. At 5-m resolution, smaller objects such as the water treatment buildings and the pump houses can be discerned. Figure 1 shows a comparison between the IRS-1C (5 m) and an airborne image simulating the expected quality of IKONOS, a 1-m sensor scheduled to be launched in the spring of 1999. An aerial photograph was used to show the potential clarity and the amount of detail this new high-resolution sensor would provide. Even with no magnification, objects as small as the standby generators can be clearly identified.

Figure 3



Radar Imagery

Radar imagery was also analyzed for the Bruce site to investigate its potential capabilities in detecting structures and objects that have height and depth. In addition, radar fine-beam-mode imagery (8 m) was compared with a digitally altered IRS-1C image for the Bruce site in a demonstration that radar imagery could be used to verify the authenticity of panchromatic imagery. It should be noted that radar imagery is the most difficult to alter.

Monitoring Reactor Operation Using Thermal-Infrared Band of Multispectral Imagery

Several Landsat images were obtained for the Bruce, Gentilly-2 and Point Lepreau sites to investigate the potential use of thermal-infrared imagery to monitor reactor operation. Figure 2 (even in this black-and-white reproduction of the original color imagery) shows clear evidence of the thermal signatures indicating reactor operation at the Bruce B reactors, and no thermal signatures (indicating shutdown condition) for the Bruce A reactors, the Douglas Point reactor and the Bruce Heavy Water plants. Similarly, strong thermal signatures were also observed for the Gentilly-2 reactor, indicating a reactor in operation. However, we have not yet been successful in detecting thermal signatures for the Point Lepreau reactor, which is located in the Bay of Fundy, where the sea water is cold and the tides are very strong. In addition, the cooling-water discharge pipe is deeply submerged and designed to minimize the discharge temperature. A detailed discussion on the effects of ambient temperatures and tidal conditions on the thermal signatures of the cooling-water discharges from several power plants can be found in reference 6.

Evaluation of Member State Declaration and Use as an Inspection Aid

IRS-1C imagery was compared with Bruce site diagrams, which were used as examples of the information submitted under the Canadian Member State Declaration. It was evident from this comparison that numerous changes had taken place between the time several years ago when the site diagrams were prepared and the more recent situation when the IRS-1C imagery was taken in September 1997. In addition to the above verification aspect, IRS-1C imagery was used to produce a more up-to-date site diagram, complete with roadway and building identification. This serves as an example of potential use of satellite imagery for preinspection preparation.

Change Detection

The objective of this exercise is to demonstrate the use of imagery to detect changes that may not have been declared. The example chosen was to detect construction activities around the area where the two new radioisotope production reactors (MAPLE-1 and -2) are being built at Chalk River Laboratories. The air photo (1-m resolution) on the left half of Figure 3 (taken before the construction) shows clearly the details of buildings 100, 110, and 124 and the smokestack in June 1989. The IRS-1C (5 m) taken during the construction (winter 1998) indicates the disappearance of the buildings and the smokestack mentioned above. That area is now occupied by the MAPLE-1 reactor building and a dark area where the hole for the MAPLE-2 reactor and the foundation for the common processing facility for the two reactors are located. The site was covered with snow, as indicated by the white patches. With a 5-m resolution, it is not possible to determine the depth of the dark area next to the MAPLE-1 building. However, it should be possible to verify with stereo imagery at higher resolution (e.g., 1 m) or with radar imagery for its ability to detect depth (since the hole would act as a reflector) if it was actually a hole. Radarsat had been tasked to obtain an image for verification of the above effect, and the results indicated that construction activities could be detected within the construction zone by the intense radar energy returns from objects and features that have height and depth. The brightness and pattern of the energy returns seems to indicate the presence of concrete walls, piles of construction materials, and the open-lattice design of a typical construction boom crane.

Detecting Undeclared Activities

A mine in an isolated area in the Canadian Northwest Territories was selected from a single newspaper report naming the Lac de Gras locality, in a simulation of detecting undeclared activities. In this exercise the analysts were supplied with open-source information, the newspaper articles on the alleged activities (diamond discovery in the Northwest Territories) and publicly available maps. The analysts' task was to locate the mining site using satellite imagery and ascertain the claim that production would commence in the fall of 1998. A search of archived images was carried out using the supplied information. Because the relevant time period was during the winter in the Northwest Territories, when there is no light, the search was focused on radar imagery. A good Radarsat image of the suspected area was available, from which the mine site was located, as shown in Figure 4. The major features in the Radarsat image, such as the Koala Pit, the main construction activities and the airstrip, confirmed the existence of the mine. This was later verified by the air photos and other open-source information provided by BHP Diamonds and Dia Met Minerals Ltd. (Figure 5). The possibility of further confirmation by acquiring an electro-optical image of the area of interest was investigated. Three attempts to acquire an IRS-1C 5-m panchromatic image were made during the summer of 1998. However, due to adverse environmental conditions in the area, all three attempts were unsuccessful. The failure of the electro-optical sensor in acquiring an image of a mine site further reinforces the need to employ alternative sensors such as radar. Employing a radar sensor permits nearly guaranteed information acquisition over a large search area. Not only did the Radarsat-1 satellite acquire the image during a period of darkness in the Northwest Territories, but it also provided the coverage in a timely manner. Pending a successful launch of IKONOS-1, we may acquire an image to confirm, for example, if a drill rig or

Figure 4

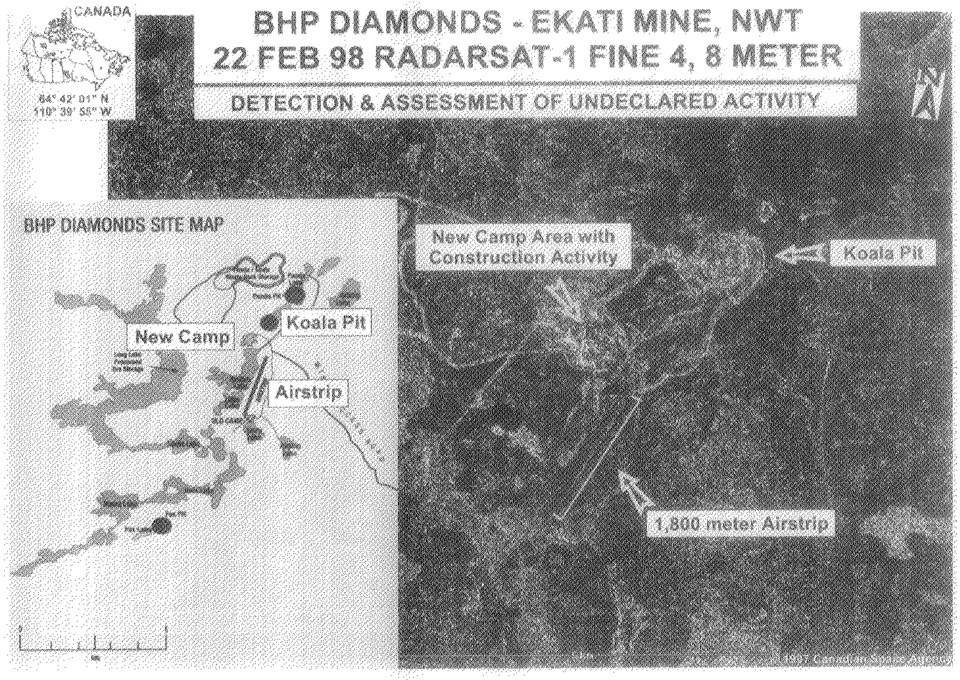
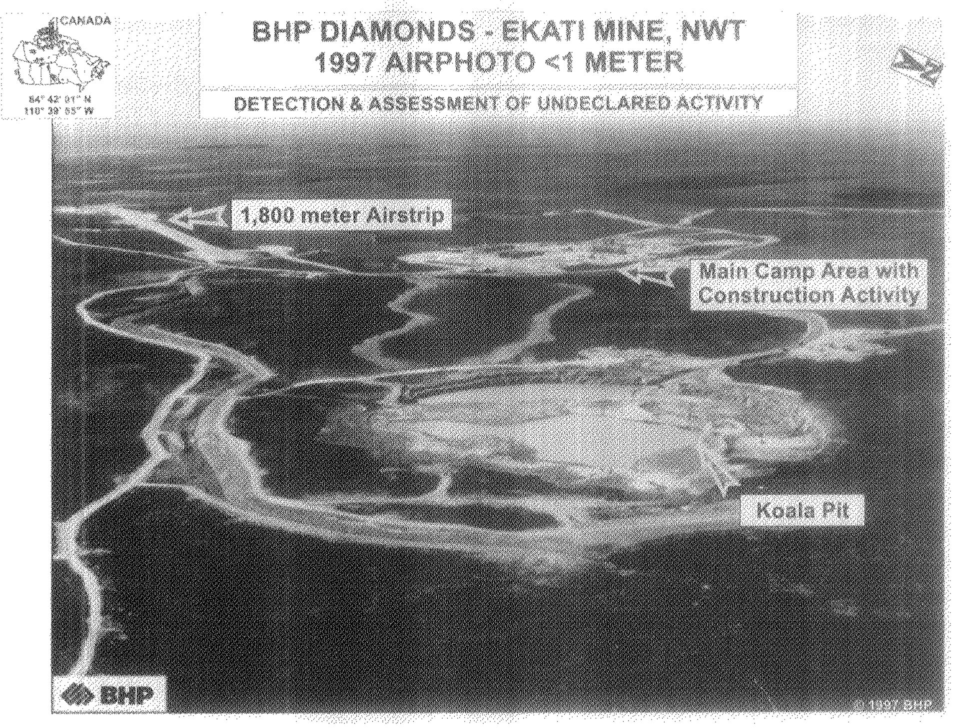


Figure 5



similar equipment could be identified with 1-m resolution imagery.

Conclusions

The results available to date support the following conclusions:

- By the year 2002, there will be more than a dozen imaging satellites operated by various countries to provide imagery on a commercial basis. This market availability is expected to reduce the cost of imagery.
- Each level of imagery resolution may be useful, depending on the application. A 30-m resolution would be sufficient to identify large objects or features that may be useful for locating or identifying a site. However, clear identification of small objects such as standby generators would require resolution in the 1-m range.
- The use of satellite-borne thermal-band infrared imagery has been used to detect the thermal emissions of operating nuclear power plants, but has some restrictions in application due to facility design and environmental and sensor limitations.
- Radar imagery would be useful for detecting small structures and roadways and for determining whether an electro-optical image has been altered. A good feature worth mentioning is that radar sensors are capable of imaging during day or night and in all weather conditions, making them a valuable tool for detecting sites located near the polar regions or in areas which are often under cloud cover or affected by bad weather, or when timeliness is of utmost concern.
- Imagery could be used as an effective tool to detect change, verify member state declarations and provide up-to-date inspection aids, such as maps.
- Combined with open-source information, satellite imagery could be used in an assessment of allegations of potential clandestine operations, which could lead to an on-site inspection of the suspected area.
- Also, such combined open-source information, including air photos, could be collected and managed by a Geographical Information System software such as ArcView to provide baseline information about nuclear facilities for future reference, or for submission by member states to the IAEA under the Additional Protocol for Safeguards.

Future Work

An order has also been placed for IKONOS-1 images for some of the sites used in this study. When the images become available, analysis will resume for optical confirmation of the findings that used simulated imagery. This will also provide an opportunity to assess the quality of the images produced by the IKONOS-1, the first commercial satellite that would give resolution in the range of 1 m.

Multispectral imagery has the potential to provide useful information about the type of mineral deposits (nuclear material or non-nuclear material), characteristics of emissions from facilities and impact of radioactivity (e.g., from hidden sources) on vegetation growth. Hyperspectral imagery would do an even better job than multispectral in this regard. We are exploring the potential application of multispectral and hyperspectral remote sensing in international safeguards. The areas of interest are nuclear-related material identification, initially from an airborne platform and later from commercial satellites.

The technical issues involved in the development of a GIS-based safeguards information system is also being explored. A prototype is being developed jointly by the University of Calgary and the Atomic Energy Control Board of Canada to illustrate the concept of using GIS to facilitate the management, inventory, analysis and reporting of safeguards information, including satellite imagery.

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Information System for management of safeguards information.

Richard Keeffe has a bachelor's degree in physics and a master's degree in material science. He has been working in the areas of international safeguards and nuclear nonproliferation for more than 20 years. His experiences include import/export control, nonproliferation, safeguards implementation and safeguards R&D. He heads the Safeguards and Support Section of the Non-Proliferation, Safeguards and Security Division of the Atomic Energy Control Board of Canada.

Phillip J. Baines graduated from the University of Toronto with a bachelor's degree in engineering science, with an aerospace option, and a master's degree in mechanical engineering. He has worked at Spar Aerospace Ltd. Space Systems since 1982. From 1982 to 1987, he worked on various studies investigating the use of civilian remote-sensing satellites for arms control verification and has briefed NATO ministers and U.N. ambassadors about this peaceful use of space technology. During that time, he also taught a spacecraft-design course at the University of Toronto. From 1988 to 1992, he worked on the development of a gimballed data-relay antenna for the International Space Station Alpha program and a large deployable antenna for geostationary mobile communications satellites. Since 1997, he has been seconded by the Department of Foreign Affairs and International Trade to research verification technologies for application to existing and future arms control agreements.

Jean-Pierre Paquette's career in the field of imagery interpretation and data analysis commenced in 1981 while he was in the Canadian Forces Intelligence Branch, where he specialized as an imagery analyst. As a consultant, he has provided services to government, nongovernmental organizations and commercial clients. His imagery analysis work includes analysis during the 1990–91 Persian Gulf War, work on arms control verification and nonproliferation issues, analysis during the 1992–95 Yugoslav/Balkan crisis, refugee monitoring (the 1996 Zaire/Rwanda refugee situation), infrastructure studies, industrial production analysis, industrial pollution monitoring, support of search-and-rescue efforts, and development of potential applications of commercial satellite imagery in international safeguards.

Wide-Area Change Detection: The Use of Multitemporal Landsat Images for Nuclear Safeguards

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Abstract
Statistical change-detection techniques using multispectral, multitemporal Landsat imagery are investigated in the context of nuclear safeguards.

Introduction
In May 1997, the Board of Governors of the International Atomic Energy Agency, meeting in Vienna, Austria, passed a model protocol that was intended to improve and strengthen verification of the nonproliferation commitments of its member states. The key objective of the new measures agreed upon in the protocol is to enhance the IAEA's capability to detect possible clandestine nuclear activities and thus to increase confidence that member states carry out their obligations. In addition to enhanced access for inspectors and extended routine declarations, these new measures will include the use of open-source information, collected with state-of-the-art technologies, to enable the IAEA to draw its conclusions more effectively and in a way that is transparent for the member states. One such open source of information is the vast amount of remote-sensing data gathered by commercial satellites. At present, most of the routinely available images are of too low a spatial resolution to allow detailed interpretation for safeguards purposes. However, this situation will change in the very near future with the launching of platforms capable of resolutions on the order of 1 m.

One potential application of the presently available, relatively low resolution imagery is for wide-area change detection, that is, to pinpoint those parts of a scene in which significant changes have taken place which can then be screened with other information for further investigation. Much of the data available is multispectral in nature (Landsat, SPOT, IRS) so that methods that make optimal use of all spectral channels simultaneously are of particular interest.

Singh[1] discusses a variety of change-detection techniques for satellite and airborne imagery. These include arithmetic operations, methods of principal component analysis, postclassification comparison and multitemporal classification. In this report, we investigate two methods based upon linear transformations of multispectral Landsat data, namely multivariate alteration detection[2] and iterated principal component analysis.[3] A variety of multitemporal Landsat scenes (up to about 900 km^2) presently available to us are processed with these methods and then fused to higher resolution and/or higher definition background images (e.g. panchromatic KVR-1000, aerial photographs, first principal components or ordinary maps) for better reference. Results indicate that the techniques are useful, giving sensitive indication as to where man-made changes may have taken place.

Multispectral, Multitemporal Methods
Multivariate alteration detection

A relatively new procedure for detecting changes in multitemporal Landsat images is the so-called multivariate alteration detection technique proposed recently by Nielsen and Conradsen.[2] This method is based on a classical statistical transformation, referred to as canonical correlation analysis, and will be summarized briefly here.

If we represent multispectral pixel intensities measured at two different times by random vectors X and Y:

$$X = \begin{pmatrix} X_1 \\ \vdots \\ X_N \end{pmatrix} \qquad Y = \begin{pmatrix} Y_1 \\ \vdots \\ Y_N \end{pmatrix}$$

N being the number of spectral components, then we seek linear combinations

$$u = a^T X = a_1 X_1 + \ldots + a_N X_n$$
$$v = b^T Y = b_1 Y_1 + \ldots + b_N Y_n$$

such that the difference of the transformed vectors has maximum variance:

$$\mathrm{var}(u - v) = \mathrm{var}(a^T X - b^T Y) \rightarrow \text{maximum},$$

subject to the constraints

$$\mathrm{var}(u) = \mathrm{var}(v) = 1. \tag{1}$$

Under these constraints

$$\mathrm{var}(u - v) = \mathrm{var}(u) + \mathrm{var}(v) - 2\mathrm{cov}(u,v) = 2[1 - \mathrm{corr}(u,v)]. \tag{2}$$

Because we are dealing with change detection, we require that the random variables u and v be positively correlated, that is

$$\mathrm{corr}(u,v) = \mathrm{corr}(a^TX, b^TY) > 0.$$

Therefore we seek vectors a and b, which *minimize* the positive correlation $\mathrm{corr}(u,v)$.

Without loss of generality we can assume that the expected values of X and Y are nil. Then for multivariate, normally distributed data, the combined random vector is distributed as

$$\begin{pmatrix} X \\ Y \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \Sigma_{xx} & \Sigma_{xy} \\ \Sigma_{yx} & \Sigma_{yy} \end{pmatrix}\right] \tag{3}$$

The canonical correlation analysis begins by searching for linear combinations of X and Y with *maximum* correlation. With the definition of variance we have

$$\mathrm{var}(u) = a^T\Sigma_{xx}a, \quad \mathrm{var}(v) = b^T\Sigma_{yy}b.$$

The correlation between u and v is defined as

$$\rho = \mathrm{corr}(u,v) = \frac{\mathrm{cov}(u,v)}{\sqrt{\mathrm{var}(u)\mathrm{var}(v)}} = \frac{a^T\Sigma_{xy}b}{\sqrt{a^T\Sigma_{xx}a\,b^T\Sigma_{yy}b}} \tag{4}$$

Introducing the Lagrange multipliers $\nu/2$ and $\mu/2$, maximizing the correlation ρ under the constraints in equation 1 is equivalent to maximizing the unconstrained Lagrange function

$$L = a^T\Sigma_{xy}b - \frac{\nu}{2}(a^T\Sigma_{xx}a - 1) - \frac{\mu}{2}(b^T\Sigma_{yy}b - 1).$$

Differentiating, we obtain

$$\frac{\delta L}{\delta a} = \Sigma_{xy}b - \frac{\nu}{2}2\Sigma_{xx}a = 0$$

$$\frac{\delta L}{\delta b} = \Sigma_{yx}a - \frac{\mu}{2}2\Sigma_{yy}b = 0$$

or

$$a = \frac{1}{\nu}\Sigma_{xx}^{-1}\Sigma_{xy}b$$

$$b = \frac{1}{\mu}\Sigma_{yy}^{-1}\Sigma_{yx}a.$$

Substituting for a and b in equation 4, we obtain

$$\rho^2 = \frac{a^T\Sigma_{xy}\Sigma_{yy}^{-1}\Sigma_{yx}a}{a^T\Sigma_{xx}a}$$

$$\rho^2 = \frac{b^T\Sigma_{yx}\Sigma_{xx}^{-1}\Sigma_{xy}b}{b^T\Sigma_{yy}b}$$

which are equivalent to the two generalized eigenvalue problems

$$\begin{aligned} \Sigma_{xy}\Sigma_{yy}^{-1}\Sigma_{yx}a &= \rho^2\Sigma_{xx}a \\ \Sigma_{yx}\Sigma_{xx}^{-1}\Sigma_{xy}b &= \rho^2\Sigma_{yy}b. \end{aligned} \tag{5}$$

Thus the desired projections $u = a^TX$ are given by the eigenvectors $a^1 \ldots a^N$ corresponding to the generalized eigenvalues

$$\rho^2 \sim \lambda^1 \geq \ldots \geq \lambda^N$$

of $\Sigma_{xy}\Sigma_{yy}^{-1}\Sigma_{yx}$ with respect to Σ_{xx}. Similarly the desired projections $v = b^TY$ are given by the eigenvectors $b^1 \ldots b^N$ of $\Sigma_{yx}\Sigma_{xx}^{-1}\Sigma_{xy}$ with respect to Σ_{yy} corresponding to the same eigenvalues.

Under these transformations, we can write equation 2 as

$$\mathrm{var}(u - v) = 2[1 - \mathrm{corr}(u,v)] = 2(1 - \rho^2) \sim 2(1 - \lambda^\rho),\ \rho = 1 \ldots N. \tag{6}$$

The transformation corresponding to the smallest eigenvalue, namely (a^N, b^N), will thus give maximal variance for the difference $u - v$. Nielsen and Conradsen[2] refer to the N difference components

$$u^\rho - v^\rho = a^{\rho T}X - b^{\rho T}Y,\ \rho = 1 \ldots N$$

as the multivariate alteration detection components of the combined bitemporal image.

Interpretation of the difference images is facilitated by noting the covariance between the original random vectors X and Y and the transformed differences $u - v$. With the definitions

$$U = (u^1, \ldots, u^N)^T \qquad V = (v^1, \ldots, v^N)^T$$
$$A = [a^1, \ldots, a^N] \qquad B = [b^1, \ldots, b^N],$$

we can write the canonical correlation transformation as

$$U = A^TX, \quad V = B^TY. \tag{7}$$

We then obtain

$$\begin{aligned} \mathrm{cov}(X, U - V) &= \Sigma_{xx}A - \Sigma_{xy}B \\ \mathrm{cov}(Y, U - V) &= \Sigma_{yx}A - \Sigma_{yy}B. \end{aligned} \tag{8}$$

Iterated principal component analysis

Representing multispectral pixel intensities measured at two different times by random vectors $X(T_1)$ and $X(T_2)$:

$$X(T_1) = \begin{pmatrix} X_1(T_1) \\ \vdots \\ X_N(T_1) \end{pmatrix} \quad X(T_2) = \begin{pmatrix} X_1(T_2) \\ \vdots \\ X_N(T_2) \end{pmatrix}$$

we consider a bitemporal feature space for the ith component

$$X_i = [X_i(T_1), X_i(T_2)], \ \ i = 1...N.$$

See Figure 1.

For each spectral band we seek linear combinations

$$Y = a^T X = a_1 X_i(T_1) + a_2 X_i(T_2)$$

such that the transformed vector has maximum variance:

$$\text{var}(Y) = \text{var}(a^T X) \rightarrow \text{maximum}.$$

This establishes the first principal axis, along which the temporally correlated pixels (no-change pixels) will lie. Hence the projection of pixel intensity orthogonal to the first principal axis, i.e. the second principal component, is a measure of change. The principal axes may be determined by diagonalizing the sample covariance matrix for the bitemporal image. The eigenvectors then give the principal axis directions, while the corresponding eigenvalues are the variances on the data along these directions. Thus a change threshold in units of standards deviation along the second principal axis (change axis) is determined by the square root of the smaller of the two eigenvalues of the covariance matrix.

Estimating the principal axes with randomly sampled pixels will in general cause an error, since the change pixels are themselves included in the sample. Wiemker *et al*[3] suggested an iterative algorithm in which the pixels determining the covariance matrix are weighted according to their probability of being no-change pixels. In our work, a different procedure is applied: After initial determination of the covariance matrix, those pixels with second principal components larger than three standard deviations are excluded from the sample and the covariance matrix re-estimated and again diagonalized. This is repeated until the principal components no longer change.

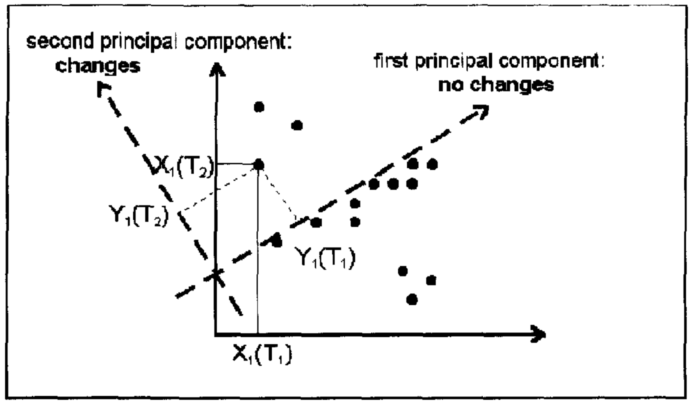
Software

In order to examine the usefulness of the most recent advanced techniques for satellite-image processing and to complement existing commercial packages, we have developed the image-processing environment NNSAT. This working environment is written entirely in Object Pascal/DELPHI and is based on high-level, object-oriented routines for matrix manipulation. Because of the need for garbage collection, the routines are somewhat less efficient than conventional matrix calculations. This disadvantage is more than compensated for by the rapid prototyping capability of the system. Complicated algorithms can be programmed transparently and tested quickly.

At present, the environment provides the following capabilities:

A. Preprocessing and data reduction
- Topographical image correction

Figure 1: Principal component analysis



- Principal component analysis

B. Bitemporal change detection
- Iterated principal component analysis
- Multivariate alteration detection

C. False color composites and image fusion
- False color composites of principal and MAD components
- Merging of false color composites with thermal channels
- Fusion of false color components with panchromatic images
- Fusion of cluster analyses with panchromatic images

D. Unsupervised pixel-based classification
- Hierarchical agglomerative clustering
- K-means clustering
- Fuzzy K-means clustering
- Fuzzy maximum-likelihood clustering
- Kohonen self-organizing feature map

E. Training data
- Interactive selection and manipulation of training regions
- Graphical display of training data
- Separability calculations

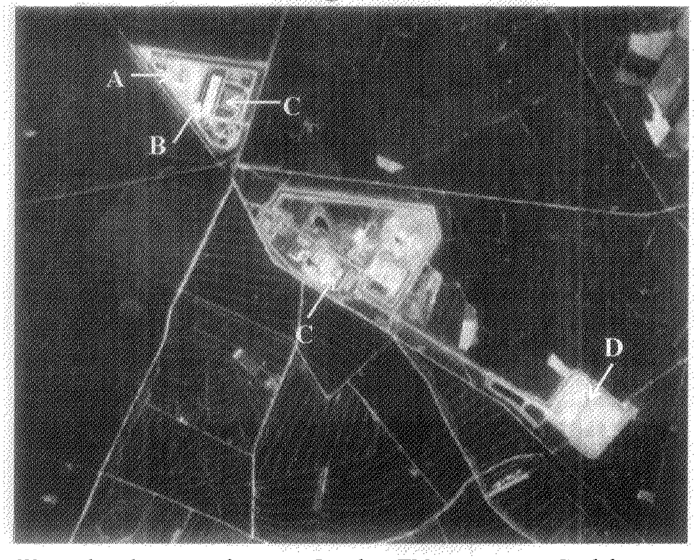
F. Supervised pixel-based classification
- Conventional Bayes maximum likelihood
- Two layer feed-forward neural network (trained with Kalman filter or scaled conjugate gradient)
- Probabilistic neural network
- Cascade correlation neural network

G. Statistics
- Confusion matrices
- Classification accuracy
- Kappa value
- McNemar test
- Bootstrapping

H. Postclassification spatial correlation correction
- Probabilistic label relaxation

As an example, the implementation of the MAD transformation in NNSAT is shown in the code excerpt in Appendix A. The multitemporal/multispectral images are sampled randomly to determine the covariance matrices. Then the two generalized eigenvalue problems (equations 5) are solved, and the sampled pixels are transformed with the sign of the eigenvectors chosen so as to ensure positive correlation. The scaling factors for the

Figure 2



We analyzed extracts from two Landsat TM scenes over Gorleben acquired on Aug. 24, 1984, and Aug. 31, 1989. Considering the lack of atmospheric correction, it is fortunate that these images were recorded in the same month. The Landsat TM images were combined with a high-resolution KVR-1000 image from a CD-ROM which is commercially available in Germany (D-Sat2). It contains images from all over Germany at various resolutions, down to 5 m. Unfortunately, no details about the dates were available. The image over Gorleben probably dates from the early 1990s. The KVR-1000 image shows the plants that are located at Gorleben.

A. *One pilot-conditioning facility that is expected to go into operation in 1999. The buildings were finished in 1996.*
B. *One interim storage facility for spent fuel elements, which was built between 1981 and 1983 and put into operation in 1995.*
C. *One interim storage facility for low-level radioactive waste. This plant was built at the same time as the previous one and started in 1984.*
D. *One exploratory mine. The explorations to prove the suitability of the salt dome for a final repository of high-level radioactive waste will continue until 2003.*
E. *Mining debris heap of removed overburden.*

transformed difference images are then determined from the variances of each MAD component and the means of the transformed samples. Finally the entire image is transformed pixel by pixel, with the absolute values of the MAD components written to output files.

The NNSAT environment allows for the combination of any three MAD components (or iterated PCA components) as a false color composite with arbitrary thresholds (in standard deviations) set on each component. The result can then be fused with a high-resolution image (or digitalized map) registered to the multispectral images in order to locate the region of change more accurately.

Examples and conclusions

All image-to-image registrations (bitemporal as well as for fusion with higher-resolution images) were carried out using a first-order nearest-neighbor algorithm. Fusion of change-detection false color composites with high-resolution images

Figure 3a

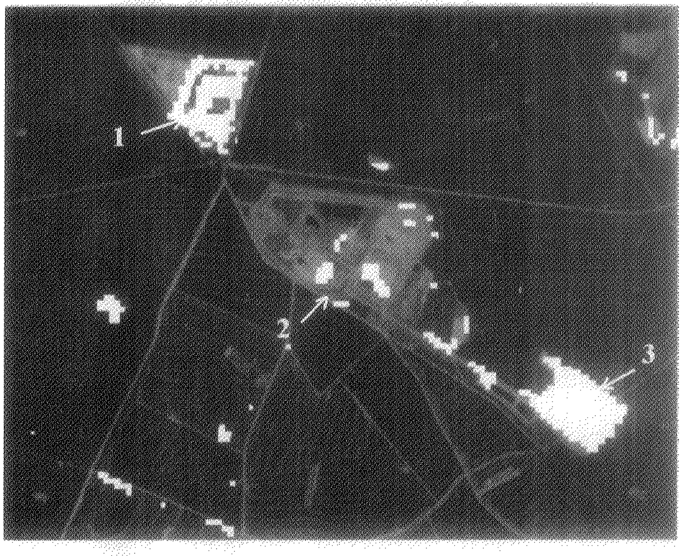
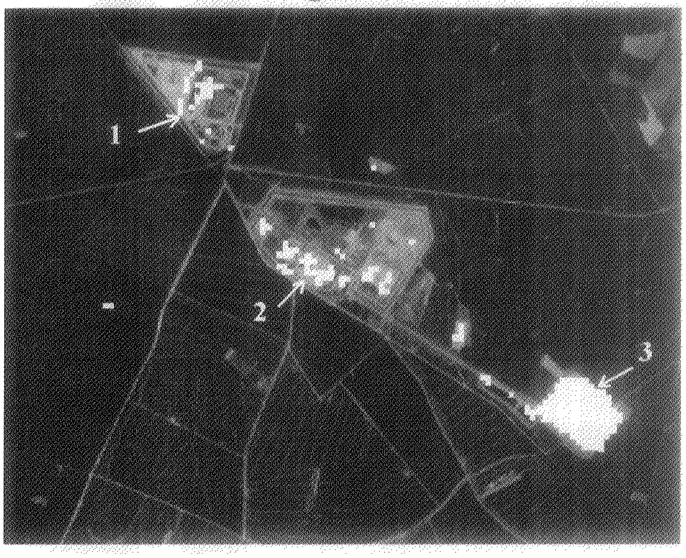


Figure 3b



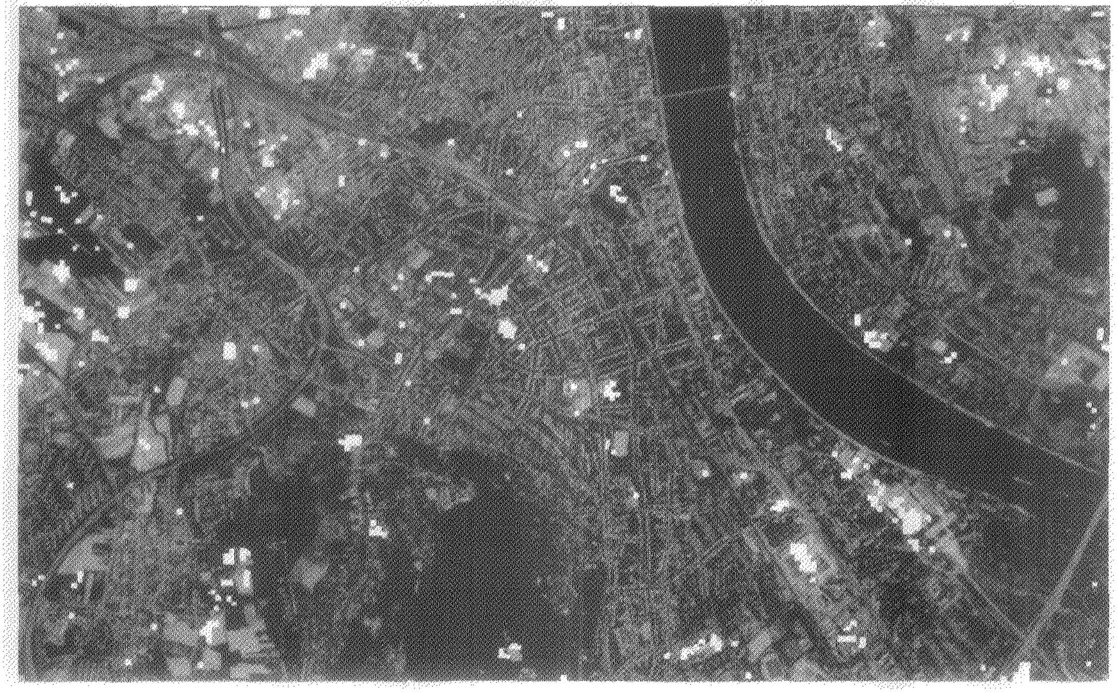
Nuclear fuel storage and exploratory mine at Gorleben, Germany. Analysis of extracts from two Landsat TM5 scenes over Gorleben acquired on Aug. 24, 1984, and Aug. 31, 1989.

3a. *IPCA: The iterated second component indicates the changes. Shown is the iterated second principal component for the channels 5 (red), 4 (green) and 3 (blue) exceeding three standard deviations, fused with a high-resolution KVR-1000 image.*

3b. *MAD: Multivariate alteration detection components indicate the changes. MAD components 1, 2 and 3 larger than five standard deviations are shown, fused with a high-resolution KVR-1000 image. The following changes could be identified.*

1. *Alterations in consequence of construction works on the interim storage area (in connection with the construction of the pilot-conditioning facility).*
2. *Changes resulting from the exploratory mine.*
3. *Formation of the mining debris heap of removed overburden between 1984 and 1989.*

Figure 4



Bonn, Germany. Wide-area change detection for two Landsat images that were taken 10 years apart (July 1984 and July 1994). The MAD difference image is fused with an aerial photograph. The pixels indicate changes with more than three standard deviations in MAD components 2, 3 and 4. Most of the indicated changed can be identified as major construction projects that took place in the intervening 10 years.

involved the transformation from RGB color coordinates to IHS (intensity, hue, saturation), the replacement of the I-component with the gray-scale intensity of the high-resolution image, and finally transformation back to the RGB system. If no appropriate high-resolution data were available, one of the principal components of the Landsat image was used as background image for fusion.

It is virtually impossible to convey the results of a multispectral, multitemporal analysis in black and white. We have therefore prepared 10 figures (numbered 2 through 11) which may be viewed via the Internet at http://www.fz-juelich.tff/inmm. Only three of these have been appended to this paper, namely Figures 2, 3 and 4.

Figures 2–11 show the results of a number of change-detection analyses using MAD and IPCA. Many of the scenes are not associated with particular nuclear or military facilities, but rather were chosen to illustrate the usefulness of the methods for pinpointing significant man-made changes in large areas (up to 900 km^2). The time between bitemporal images ranges from eight days (Nevada Test Site) to 10 years (City of Bonn). Even in the latter case, most of the areas indicated as having undergone change can be related to construction and land-use alterations known to have taken place during the intervening time.

A particular advantage of the MAD analysis is that, if the bitemporal images are taken at different seasons, so that considerable differences in vegetation reflectances are present, these differences tend to concentrate in the higher order MAD components (with minimum correlation). Small-scale changes associated with buildings, roads, etc. then show up clearly in the lower components. This effect is particularly evident in the Bonn and Kyshtym images.

The interpretation of the change detection results is qualitative and interactive. In the MAD analyses, one has first to identify those MAD components that enhance the changes of interest (e.g. roads and buildings vs. vegetation), and then set appropriate significance thresholds. The relatively low spatial resolution is often an advantage, since large scenes can be processed quickly and displayed in their entirety.

In view of the improving resolution of commercially available satellite images, these methods will become increasingly useful for safeguards purposes in the near future. The commercial satellite-images market is developing rapidly[4]:

1999: Space Imaging EOSAT plans to launch its first IKONOS satellite with a resolution of 1 m (panchromatic) and 3–4 m (multispectral).

1999: A similar system is scheduled for launching by Orbital Imaging Corp.

2001: Radarsat 2 will go into orbit with a resolution of 3 m.

2001: SPOT 5 is planned, with a panchromatic resolution of 2.5 m and multispectral resolution of 10–20 m.

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Appendix A: Implementation of the MAD transformation in NNSAT.

```
With activescene do begin
       oldCap:= Caption;
       Caption:= 'NNSAT: running MAD ...';
       sf:= TsceneF.create(NNSatF);
       sf.onDblClick:= onDblClickAbortNow;
       screen.cursor:= crHourGlass;
{      sample the images }
       zs:= featureSample(samplesMT);
{      channels for T1 }
       xs:= zs.getSubmatrix(1,1,zs.m,mtChannels);
{      channels for T2 }
       ys:= zs.getSubmatrix(1,mtChannels+1,zs.m,2*mtChannels);
{      estimate the covariance matrix over all channels }
       Caption:= 'NNSAT: running MAD ... covariance matrix ...';
       S:= zs.covariance;
{      determine the canonical correlation transformation matrices }
       S11:= S.getSubmatrix(1,1,mtChannels,mtChannels);
       S22:= S.getSubmatrix(mtChannels+1,mtChannels+1,2*mtChannels,2*mtChannels);
       S12:= S.getSubmatrix(1,mtChannels+1,mtChannels,2*mtChannels);
       S21:= S.getSubmatrix(mtChannels+1,1,2*mtChannels,mtChannels);
       S1:= S12.dot(S22.inverse).dot(S21);
       S2:= S21.dot(S11.inverse).dot(S12);
{      save correlation matrix for output }
       S:= zs.correlation;
{      solve generalized eigenvalue problem }
       E:= S1.generalizedEigenvalues(S11);
       A:= S1.generalizedEigenvectors(S11);
       Tmatrix.gc;
       B:= S2.generalizedEigenvectors(S22);
       Tmatrix.gc;
{      do a MAD transformation of samples to get contrast enhancement limits:
       first: the canonical transformations }
       Caption:= 'NNSAT: running MAD ... transformation of samples ...';
       Us:= xs.dot(A);
       Vs:= ys.dot(B);
{      second: ensure positive correlation between Us and Vs }
       for j:= 1 to mtChannels do begin
              Uj:= Us.Column[j];
              Vj:= Vs.Column[j];
              C:= Uj.appendColumns(Vj).covariance;
              if C[1,2]<0 then
                     B.Column[j]:= B.Column[j].chs;
              Tmatrix.gc
       end;
{      third: project again with the new B }
       Vs:= ys.dot(B);
{      finally: determine MADs and extrema }
       MAD:= Us.minus(Vs).thread(absf);
       min:= MAD.mean; // mostly no change
{      sigma(U-V)) = sqrt(2(1-rho)) where rho = sqrt(generalized eigenvalue)
       saturation is set here at at satMAD*sigma(U-V) }
       max:= min.plus(E.thread(sqrtf).splus(-1).sProduct(2).
              chs.thread(sqrtf).sProduct(satMAD));
       Tmatrix.gc;
{      record the covariances between original and MAD-transformed variables }
       Cx:= S11.dot(A).minus(S12.dot(B));
       Cy:= S21.dot(A).minus(S22.dot(B));
       disableMenus;
       Caption:= 'NNSAT: running MAD ...';
        try
       freset;
       sf.Caption:= 'Projecting, DblClick to abort ...';
       screen.Cursor:= crDefault;
{      MAD transformation of entire image }
       for i:= 0 to rows-1 do begin
              for j:= 0 to cols-1 do begin
                     z:= nextFeatureVector;
                     x:= z.getSubmatrix(1,1,1,mtChannels);
                     y:= z.getSubmatrix(1,mtChannels+1,1,2*mtChannels);
                     mad:= x.dot(A).minus(y.dot(B)).thread(absf);
{                    linear contrast enhancement }
                     mad:= mad.minus(min).quotient(max.minus(min)).sProduct(255);
                     for k:= 1 to mtChannels do begin
                            rr:= abs(mad[1,k]);
                            if rr>255 then rr:= 255;
                            rowArrays[k,j]:= round(rr);
                     end;
                     Tmatrix.gc;
                     sf.canvas.pixels[j,i]:=
                            RGB(rowArrays[1,j],rowArrays[1,j],rowArrays[1,j])
              end;
{      save to file }
              for k:= 1 to mtChannels do blockwrite(f[-5],rowArrays[k],cols);
              Application.ProcessMessages;
              if abortNow then break
       end;
{      save the eigenvalues and correlations in the first row of the file }
       fReset;
       E.outToCompressed(f[-5]); S.outToCompressed(f[-5]);
       Cx.outToCompressed(f[-5]);Cy.outToCompressed(f[-5]);
        finally
{      tidy up }
       Caption:= oldCap;
       if not abortNow then sf.composite2Click(sender) else
              sf.Caption:= activeScene.name+'...interrupted';
       abortNow:= false;
       enableMenus;
        end
        end
```

Japanese Earth Observation Satellite Program and Its Potential Contribution to IAEA Safeguards Activities

■

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■

Abstract
This paper intends to show the outline of the Japanese Earth-observation satellite program and its potential contribution to the International Atomic Energy Agency's safeguards activities. It introduces a summary of some Japanese studies on satellite imagery and safeguards, the history of the Japanese Earth-observation satellite program and the overview of the Advanced Land Observing Satellite. Data availability and restrictions are discussed, and some recommendations to the IAEA are described.

Introduction
Since the U.S. National Aeronautics and Space Administration launched its first Earth-observation satellite in 1972, many countries have launched various kinds of Earth-observation satellites. Almost all of the data from Earth-observation satellites is widely distributed and commercially available in the market today. Some companies are planning to launch their own Earth-observation satellites and enter the business in the near future.

The IAEA decided to initiate a study on the use of satellite imagery for its safeguards activities and held a seminar and workshop. In these meetings, experts on satellite imagery and safeguards discussed the availability, effectiveness, limitations, restrictions and legal issues of satellite imagery for international safeguards activities.

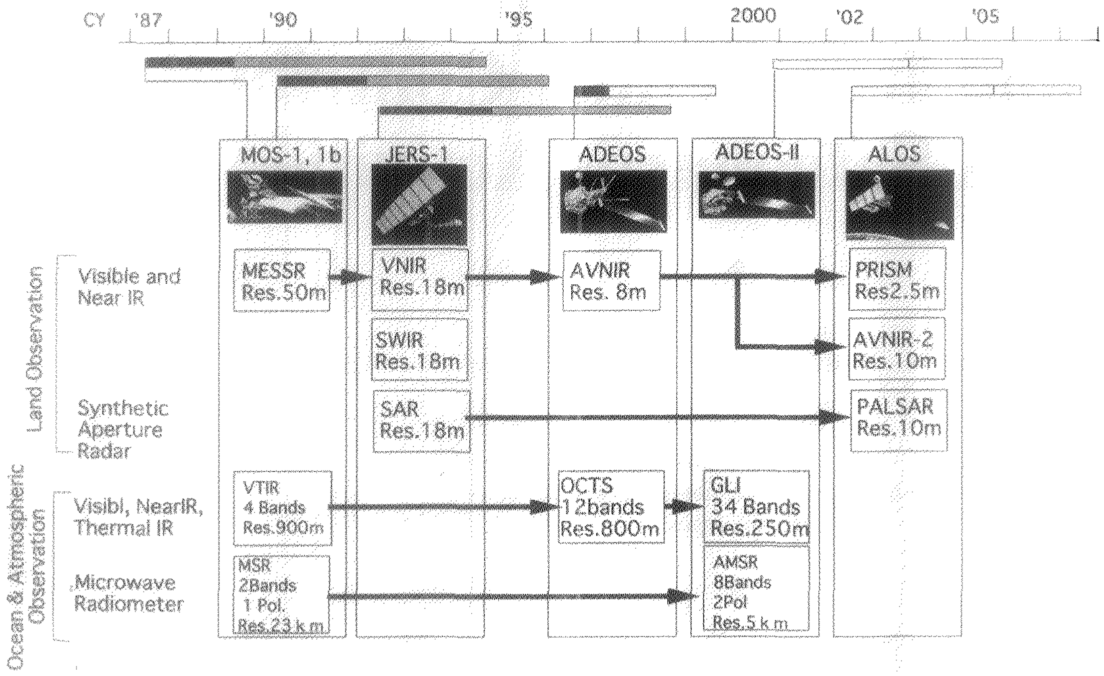
Safeguards-related Studies in Japan
In Japan, some studies on satellite imagery and safeguards were conducted by some groups of experts. Tokai University[1] demonstrated the effectiveness of satellite imagery for safeguards and nuclear nonproliferation and proposed the establishment of an international satellite-monitoring organization. Nikkei Research Institute of Industry and Market[2] conducted a study on the global information infrastructure for the safe use of nuclear energy. This study clarified the needs for promoting atomic energy safety, nuclear nonproliferation and public acceptance of atomic energy utilization. It proposed a global information infrastructure that consists of reactor-monitoring telemetry, communications satellites and remote-sensing satellites. The Nuclear Safety Research Association[3] studied the radiation effects of the Chernobyl accident and proposed the establishment of an atomic energy support system that would consist of a safety support subsystem, disaster mitigation subsystem and nuclear nonproliferation subsystem, including remote-sensing satellites.

These studies mainly focused on the augmentation of public acceptance for atomic energy utilization and proposed to use satellite imagery for this purpose. These studies also proposed the use of satellite imagery for international safeguards activities.

The Japanese Earth-observation Satellite Program[5]
Japan's Earth-observation satellite program began with the Marine Observation Satellite (MOS-1 and MOS-1b) in February 1987. The Japanese Earth Resources Satellite (JERS-1) followed this in February 1992. JERS-1 has an 18-m-resolution optical sensor and an 18-m-resolution L-band (1.2 GHz) synthetic aperture radar on board. The Advanced Earth Observing Satellite (ADEOS) was launched in August 1996. However, operation was terminated by a solar array accident in June 1997. It marked a significant increase in capability and provided 8-m-resolution panchromatic and 16-m-resolution multispectral optical data, in addition to data from six other scientific sensors.

The Advanced Earth Observing Satellite II (ADEOS-II) will be launched in November 2000. The resolution of the ADEOS-II

Figure 1. The History of the Japanese Earth-observation Satellite Program.



sensors is limited to 250 m because it focuses on global environmental change. The Advanced Land Observing Satellite (ALOS) is planned for launch in August 2002. The panchromatic optical resolution of the ALOS is improved to 2.5 m. The multispectral and L-band SAR resolution is 10 m.

Japanese Earth-observation satellites are divided into two categories: a land-observation satellite series and an ocean and atmospheric satellite series. The land-observation satellite series is mainly for practical use, and high-resolution observation is one of the most important characteristics. On the other hand, the ocean and atmospheric satellite series is mainly for scientific use and is characterized by multichannel observation. The history of Japan's Earth-observation program is shown in Figure 1.

The Advanced Land Observing Satellite[4,6]

The mission objective of the ALOS is to advance land-observing technology and to contribute to cartography, regional observation, disaster monitoring and Earth resource survey. The ALOS has three major sensors: Panchromatic Remote Sensing Instruments for Stereo Mapping (PRISM), an Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) and a Phased Array L-band Synthetic Aperture Radar (PALSAR). The ALOS is a large-scale satellite, weighing 3,850 kg. An overview of the ALOS is shown in Figure 2.

The PRISM provides 2.5-m-resolution panchromatic imagery and 3- to 5-m-accuracy digital altitude data with triplet stereo-mapping capability. Observation swath width is 35 km in triplet stereo observation mode and 70 km in nadir observation mode. This data is mainly for cartography and will be used to generate and revise 1:25,000-scale maps and digital data for the Geographical Information System. Simulated 2.5-m- and 10-m-resolution panchromatic images are shown in Figure 3.

The AVNIR-2 is an improved version of ADEOS/AVNIR. It provides multispectral 10-m-resolution imagery. PALSAR is an improved version of JERS-1/SAR. Japan's National Space Development Agency and Ministry of International Trade and Industry are jointly developing PALSAR. AVNIR-2 and PALSAR are used mainly for regional observation, disaster monitoring and Earth resource survey. For the disaster monitoring mission, AVNIR-2 and PALSAR have a pointing capability and can provide an image of anywhere in the world within 48 hours.

ALOS has some more unique characteristics. Intersatellite communication capability allows real-time observation and data acquisition via Japanese and European data-relay satellites. High-precision satellite position and altitude-determination systems enable users to locate the exact position of any ground objects without any ground reference points.

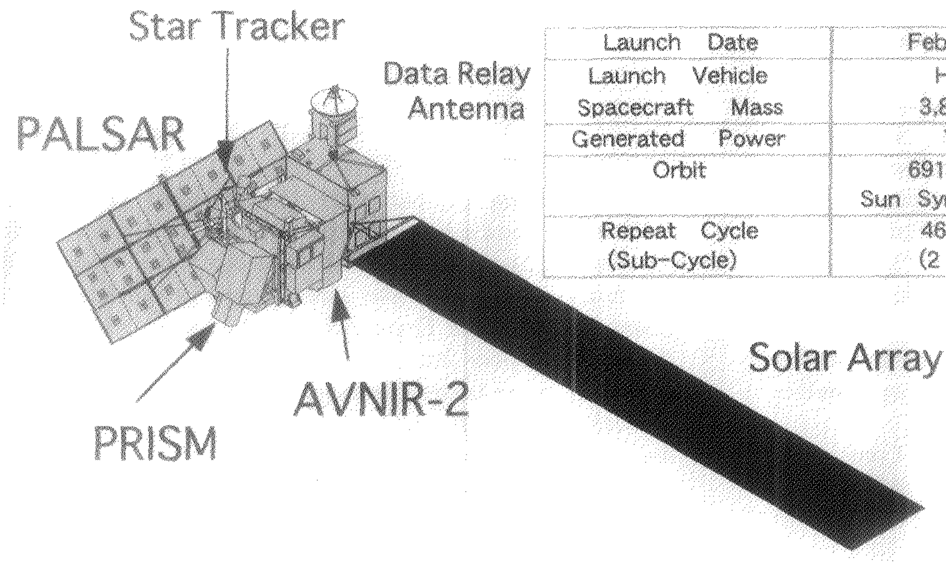
The resolution of the ALOS sensor is not so high when it is compared with planned commercial high-resolution satellites. However, the ALOS is able to provide imagery with many other unique characteristics. For example, the wide swath width (70 km) of the ALOS enables regular observation of any area every 46 days without any preorders. This capability is critical when a user hopes to hide his intent of observation from the observed state.

Data Policy[5]

ADEOS Data Policy (1992) currently covers all of NASDA's Earth-observation satellite data distribution, although the policy for ALOS is under discussion. Any data from Japanese Earth-observation satellites is open to the public and available on a nondiscriminatory basis and in a timely manner.

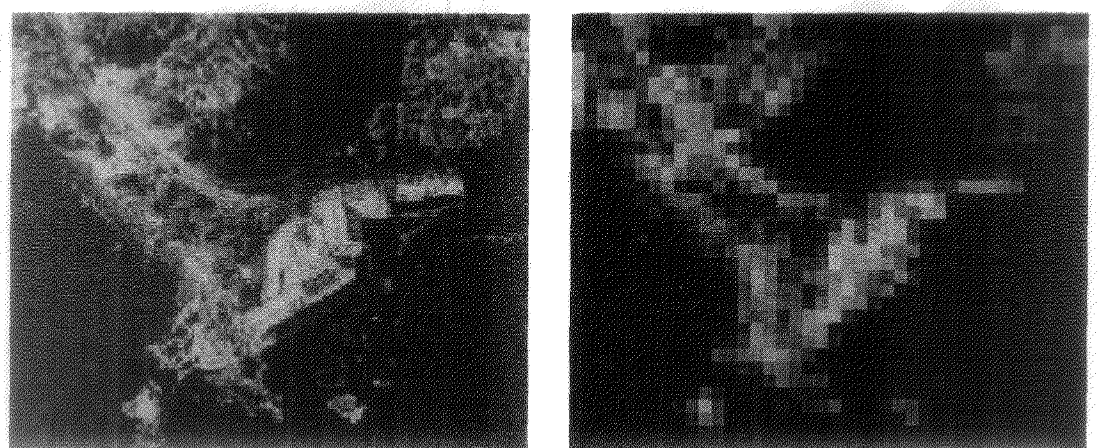
There are three categories for distribution. For use under a joint research agreement between NASDA and partners such as Principle Investigators or other cooperating entities, data is distributed for free, provided that results are jointly owned by the partner(s) and NASDA. For research and public use, data is distributed for the cost of reproduction, provided that a copy of the technical report is submitted to NASDA. For general use, including commercial use, data is distributed for market price by the Remote Sensing Technology Center of Japan. For IAEA safeguard activities, any of these categories may be applied. In the case of ADEOS/AVNIR panchromatic data (8-m resolution,

Figure 2. ALOS Overview.



Launch Date	Feb. 2003
Launch Vehicle	H-IIA
Spacecraft Mass	3,850kg
Generated Power	7kW
Orbit	691.65km Sun Synchronous
Repeat Cycle (Sub-Cycle)	46 days (2 days)

Figure 3. Simulated 2.5-m- and 10-m-resolution panchromatic images.



80 km x 80 km scene, Level 1b processed data), the price is 7,500 yen (or $64) for research and public use and 180,000 yen (or $154) for general use.

There are some restrictions for data use. Data must be used for peaceful purposes. Copying, reproduction or distribution of unenhanced data (purchased data) to third parties is generally not allowed. Special arrangement and payment of royalty are required for this purpose. Generally speaking, when the data is enhanced by a user and products do not retain a pixel structure and by no means can be led back to standard products that retain the original appearance, the user has the right to copy, reproduce and distribute the enhanced data.

Conclusion

The effectiveness of satellite imagery for IAEA safeguards activities has already been demonstrated in many studies.[7,8] Japanese Earth-observation satellites, especially the ALOS, have enough potential for contribution to IAEA safeguards activities, and these satellites have some unique characteristics that commercial high-resolution satellites will not provide. There are some possibilities for NASDA to provide satellite imagery to the IAEA at a lower price under some arrangements. Combining many kinds of satellite imagery with other open-source data is the most promising way for better results. It is recommended that the IAEA seek every possibility to get more kinds of data in a cost-effective manner.

One of the biggest issues may be copyright restrictions. It is also recommended for the IAEA to clarify its copying and redistribution requirements and negotiate with satellite data providers, because each provider has its own data policy.

Satellite imagery does not replace on-site inspection. However, it is a powerful aid that allows inspectors to get two-dimensional and multitemporal information. Satellite imagery and basic technology for analysis is becoming widely available and is nothing special anymore. It should be treated the same as other open-source data. We encourage IAEA inspectors to become more familiar with satellite imagery and utilize it in their daily activities.

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Civil Radar Observation Satellites for IAEA Safeguards

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This paper is based on a longer study being carried out under a joint task of the U.K. and Federal Republic of Germany R&D Programmes in Support of IAEA Safeguards. Views expressed in this paper do not necessarily represent the policies of the U.K. and German governments.

Introduction

It is well recognized that both the U.S.A. and the former U.S.S.R. used some of their space assets in support of their strategic forces. A byproduct of this was the use of observation satellites for monitoring the compliance with the terms of their bilateral arms control treaties. Thus, monitoring from space formed a vital element of the U.S. and Russian national technical means of verification of their bilateral agreements. However, not all nations have access to such capabilities, even though they are parties to several important multilateral arms control treaties. Moreover, neither the U.S.A. nor Russia have been willing to share widely either the technology or the information obtained by their national technical means. This may give an impetus for the development of a multilateral technical means of verification. In this process, the commercial remote-sensing satellites could play an important role.

Arms control, disarmament and confidence-building measures are some of the important elements of security. If a multilateral arms control agreement is to be credible, it needs to be effectively verified. A number of such treaties have provisions for on-site inspections for their verification. However, these are usually carried out in a very limited way and only at declared sites because the inspected state is generally reluctant to make itself too transparent. Therefore, a nonintrusive way needs to be examined. It has been suggested that civil earth-orbiting observation satellites could be used to monitor multilateral agreements such as the 1970 Treaty on Nonproliferation of Nuclear Weapons.[1] Treaties such as this and the 1997 Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and their Destruction (Chemical Weapons Convention) are examples of the multilateral measures that require effective verification on a multilateral basis, that is, the multilateral technical means of verification. There are a number of other already-existing treaties, the effectiveness of which could be enhanced by such verification procedures. A number of countries now have the capability to build and launch civil observation satellites. Moreover, the advent of high-performance commercial optical and radar remote-sensing satellites now makes it possible for all to use the technology for verifying multilateral treaties, as the images may be purchased by anyone.

Verification is usually carried out by a suitable organization. The concept of international or even multinational verification agencies needs to be considered, with observations from space as a critical element. It should be recognized that observations from space could form the first layer of a multilayer verification system. The next layer could be aerial inspection and then, finally, the on-site inspection. Moreover, a considerable amount of information that needs to be collected and used is available from open sources.

An international satellite-monitoring agency to verify arms control treaties and monitor crisis areas was proposed by France in 1978.[2] A U.N. expert group study on ISMA was published in 1981.[3] In this context, it should be mentioned that, as a result of the resolution 43/81B passed by the General Assembly of the United Nations in 1988, the role of the United Nations in the field of verification was examined by a group of governmental experts.[4] The study concluded that the United Nations should consider seriously the multilateral aspects of verification.

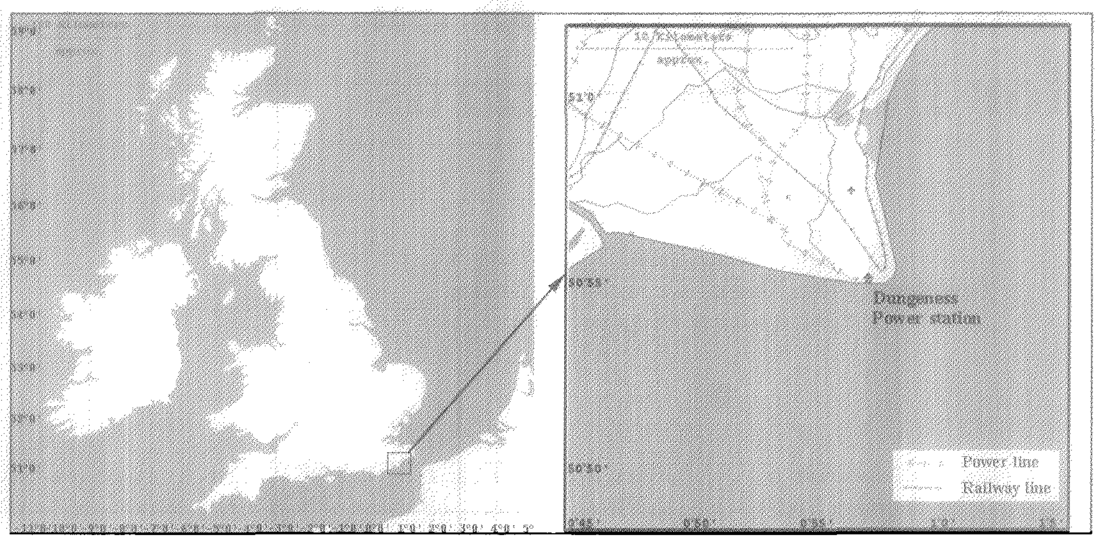
The complexity of political problems associated with the creation and operation of an international system led some to propose a regional satellite-monitoring agency. The European region was proposed as the first region where such an agency could be created.[5] The Western European Union created the first RSMA in 1990.[6] It was declared operational in 1991 in Madrid, Spain. This agency began by using civil remote-sensing satellites and continues to use them as one source of information for its tasks.

Could a U.N. specialized agency such as the IAEA use commercial satellite images to enhance its safeguards procedures? Are there any legal constraints? It is useful to examine this now, when the IAEA is considering the possible use of satellite imageries for its safeguards applications.

Thus, in this paper the following are examined:

a) some legal aspects relevant to remote sensing from space, and
b) the use of radar images to detect warm water in the sea, discharged from a civil nuclear power reactor, and other

Figure 1



A full map of the U.K. in which the location of the Dungeness Power Station is shown; the inset shows its immediate surroundings.

signatures such as power lines and railway tracks.

Throughout this study, all the information was derived from open sources. This is to indicate that much information that could be useful for the IAEA to compare with that supplied by a state party to a safeguards agreement is available already in the open literature. The importance of maps, particularly of the area around a facility, is shown. Generally, a state may not provide such maps.

Some Legal Aspects of Observations from Space

None of the space-related multilateral treaties, conventions or principles adopted by the United Nation General Assembly[7] prohibit the use of satellites for observation of the surface of the earth. In fact, most of them emphasize that outer space in not a monopoly of any state and that it should be used for peaceful purposes and in such a way that it is beneficial to all mankind. For example, in the 1967 Outer Space Treaty it is stated that "[t]he exploration and use of outer space ... shall be carried out for the benefit and in the interests of all countries ... Outer space ... shall be free for exploration and use by all States without discrimination of any kind" (Article I). Furthermore, "States Parties to the Treaty shall carry on activities on the exploration and use of outer space ... in accordance with international law, including the Charter of the United Nations" (Article III). These were already reflected in the 1963 Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space, the precursor of the 1967 Outer Space Treaty. Therefore, more countries are now beginning to use outer space for remote sensing.

The 1986 Remote Sensing Principles (Principles II, III and IV) reiterate the above. Moreover, it also states that "States carrying out remote-sensing activities shall promote international cooperation in these activities. To this end, they shall make available to other States opportunities for participation therein" (Principle V). Under both the Remote Sensing Principles (Principle IX) and the Registration Convention, "a State carrying out a programme of remote sensing shall inform the Secretary General of the United Nations of its activities in this field. It shall, moreover, make available any other relevant information to the greatest extent feasible and practicable to any other State, particularly any developing country that is affected by the programme, at its request" (Principle IX). It is not clear whether the sensing country is required to give the imagery data or just the launch and the satellite information to others and the sensed country. However, according to the Principle XII of the Remote Sensing Principles, "[a]s soon as the primary data and the processed data concerning the territory under its jurisdiction are produced, the sensed State shall have access to them on a nondiscriminatory basis and on reasonable cost terms." If the IAEA uses satellite imageries, then it may give them to the sensed country as part of its compliance report.

According to the U.N. Charter, its purpose is "[t]o maintain international peace and security, and to that end: to take effective collective measures for the prevention and removal of threats to the peace" (Article I). If arms control agreements are the foundation for international security, their verification is crucial, so all technical resources have to be used. This includes observations from space. As the IAEA, with its membership of 128 states, is linked to the United Nations, its collective actions on verification comply with the U.N. Charter and, therefore, should not have any legal constraint in using the information acquired from space. It should be remembered that all the IAEA members are those with significant nuclear activities or having interest in the applications of nuclear energy.

From the above it can be seen that there appears to be no legal constraints should the IAEA decide to use satellite imagery to enhance its safeguards procedures. In view of this, the study on the use of commercial satellite imagery for safeguards purposes is worth pursuing. In the following section, radar images over a U.K. power reactor facility are examined. This is to detect the effects, if any, on the water surface where warm water from the nuclear complex has been discharged and also to see whether such a sensor could detect power lines, railway tracks and any other useful signatures.

Observation of the Dungeness Nuclear Power Station in the U.K. by a Space-based Radar

Use of Maps

There are two power stations at this site: Dungeness A, consisting of two Magnox-type reactors, and Dungeness B, with two

Figure 2a

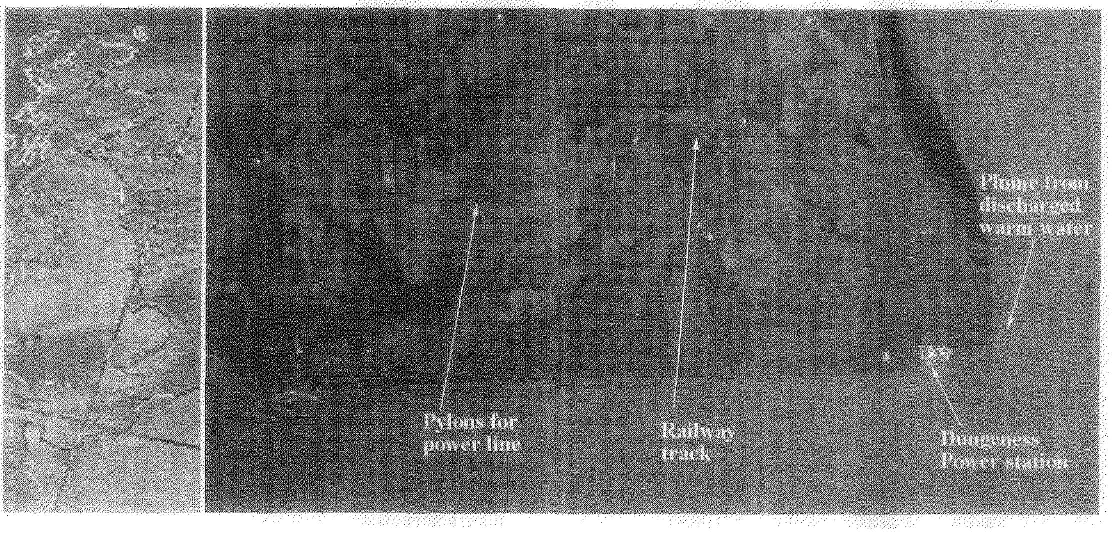
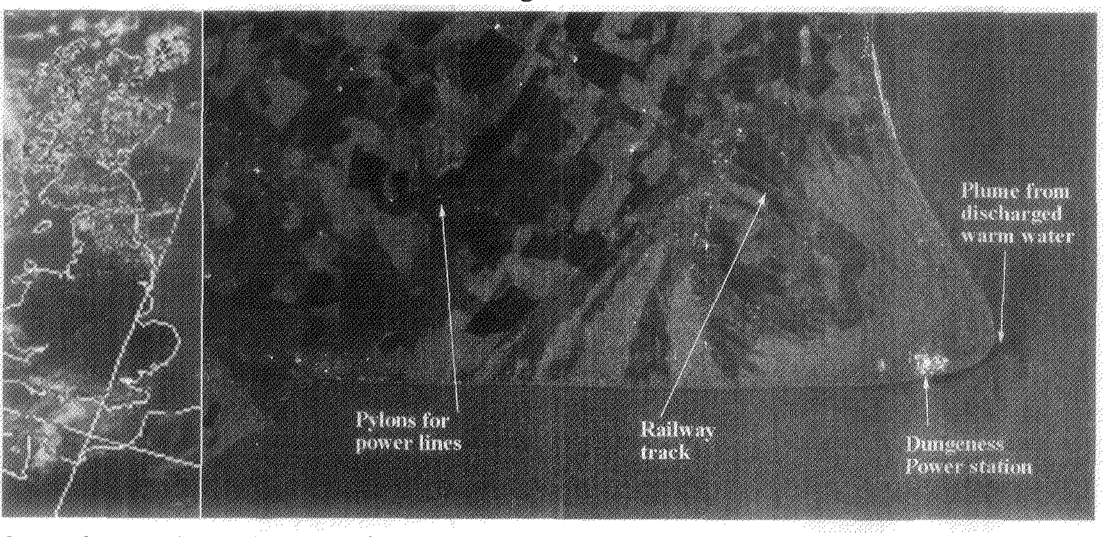


Figure 2b



Images from weather satellites, reproduced here from the Internet, show Dungeness on Dec. 31, 1996, obscured by clouds, while in the ERS-2 image, acquired on the same day, the reactor complex and the surrounding area can be clearly seen (a); Figure 2b shows the same scene June 4, 1996, when the sky was free of clouds.

Source: ESA and weather satellite images from the Internet.

advanced gas-cooled reactors.[8] Each Magnox and AGR reactor produces 285MWe and 660Mwe, respectively. The site is located on a promontory on the south coast of the county of Kent, U.K. It is a bleak, triangular-shaped site, consisting mainly of gravel, jutting out into the English Channel (Figure 1). There is a modern lighthouse nearby. The inset in this figure shows a more detailed map of the area.

The maps were acquired from the U.S. National Imagery and Mapping Agency.[9] There are four volumes of CD-ROMs containing maps of the whole earth. They also contain such data as geographical, cultural and political information. From such data, maps like the one in the inset could be constructed. The scale of the U.K. map is 1:4,000,000, and that of the inset is 1:230,000. It is interesting to note that while the NIMA maps can be built up with a considerable amount of details of all kinds, the location of the Dungeness power station site is not given. The lighthouse is not shown either.

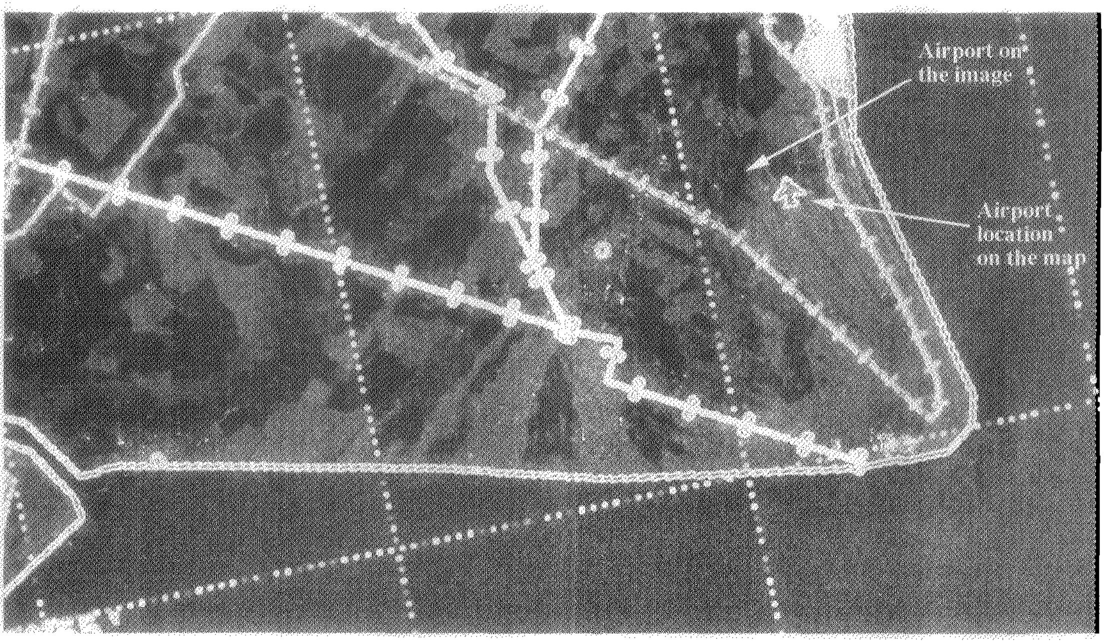
Under the safeguards agreement with the IAEA, a state is required to give such information as the site diagrams and the size of the associated nuclear facilities. The state may not give such details as the network of roads and railway lines nor, for that matter, the power lines, if any, associated with the nuclear facility. The maps of the type shown in Figure 1 could be useful.

Imagery from a Radar Sensor

In this paper, some images from satellites carrying radar sensors are examined. Given that most of the land areas on the earth are generally covered by clouds, radar, with its ability to penetrate clouds and with it not requiring daylight, offers the potential for an effective use of observation satellites for safeguards purposes. For example, it was shown that, on average, the chance of the large part of the land mass having clear sky was only about 20 percent between June and August and only about 10 percent between December and February over a period between 1971 and 1981.[10] Moreover, it was also found that often Landsat images are not regularly available over an area of interest and, when they are available, the clouds hamper frequent observations. At present, this satellite is an important one since it is the only one with a thermal sensor that can be used for the determination of the status of a facility. Thus, it is suggested that a radar sensor might be able to detect, *inter alia*, warm-water discharges into the sea or a river. The advantage in this case is that there are two European (ERS-1 and -2) and one Canadian (Radarsat) radar satellites in orbit. Japan also has a radar satellite, but the data from this satellite is not widely commercialized.

Thus, the use of images from radar satellites over the Dungeness Power Station in the U.K. is explored briefly in this paper. A radar sensor should also be able to detect metallic perimeter fences, power lines and railway tracks, all of which might be useful signatures for the discrimination between a civil power reac-

Figure 3



The site map from Figure 1 was corrected for scale and orientation and superimposed on the ERS-2 image acquired on June 4, 1996.

In addition to the two occasions illustrated in the Figure 2, the detection of the discharged warm water into the sea was attempted on three other occasions using the radar images. Figure 4 shows an extract from an image acquired by the European satellite ERS-2 on Nov. 7, 1995. It can be seen that just below the reactor there is a dark area on the surface of the sea. This represents the plume of warm water being discharged from the reactor facility. Apart from a few very bright signatures representing buildings, it is not easy to recognize the reactors. However, the pylons for the power cables and the railway line can be detected. Another image, acquired by the Canadian Radarsat satellite on June 10, 1996, is shown in Figure 5. The radar operated in the standard-beam mode with a resolution of about 30 m. This is similar to the European ERS satellite. A very slight indication of the warm water discharged into the sea can be detected. On the other hand, in the third image, acquired by the Radarsat on Nov. 18, 1997, no plume can be detected (see Figure 6). In this image, while the power line can be just detected, the railway track reflects the radar beam more strongly than in the other images. The radar beam was operating in a fine mode with higher resolution (about 10 m). It was concluded that the reactors, perhaps not all, were operating on Nov. 7, 1995, and on June 10, 1996, but not on Nov. 18, 1997. The confirmation from the reactor operators and observations from satellites are shown in Table I. It can be seen from the images that the prediction was correct on only three occasions. One reason for this may be that the satellite was over the reactor site before the warm-water plume had developed fully. Moreover, from the images it is not possible to determine how many reactors were in operation because no attempts were made to calibrate the radar response and the water temperature.

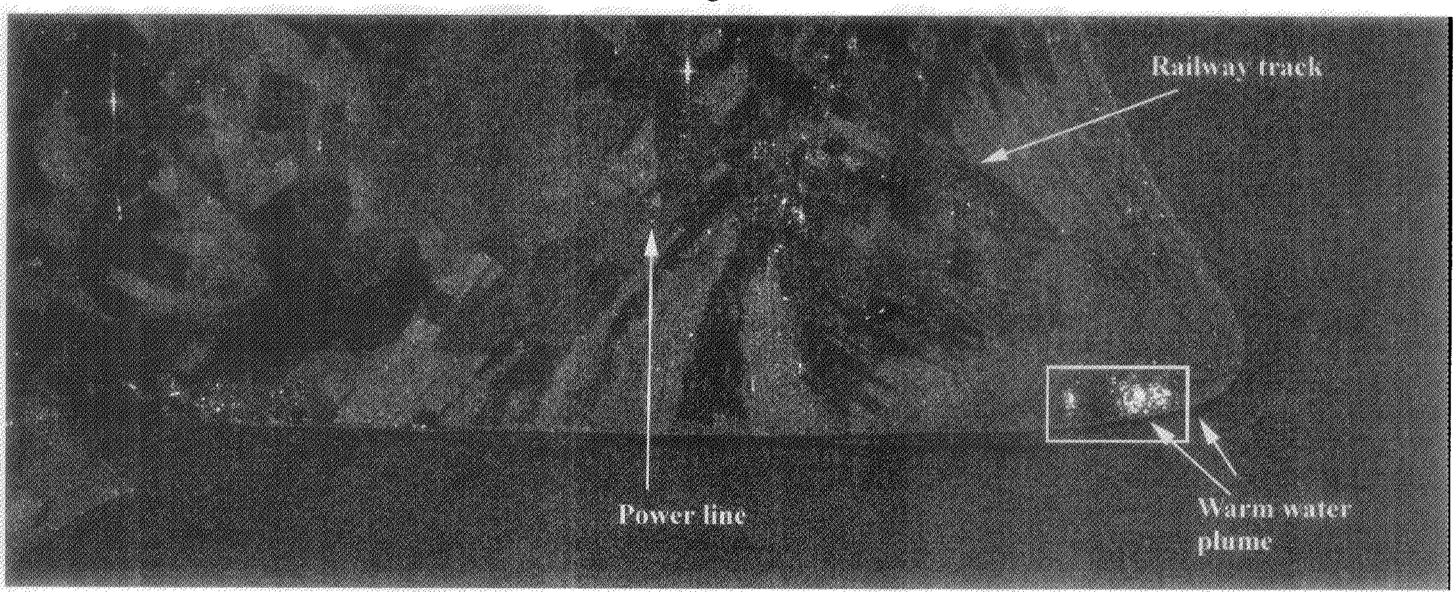
In Figure 7, the three radar images are reproduced for comparison. The Radarsat has two operating modes: fine beam, with a resolution of about 10 m, and a standard mode, with a resolution of about 25 m. The resolution of the ERS is only slightly worse (about 30 m) than the standard-beam mode of the Radarsat. It can be seen that the fine-beam mode of the Radarsat can resolve more details of the reactor complex (B). Moreover, at A, from the possible power distribution building, the output power lines can be seen in more detail than in the other two scenes. However, in this high-resolution radar image, the power line is not easily detectable but the railway line is clearly visible.

tor and a reactor used for the production of plutonium. In this paper, a civil nuclear power station at Dungeness is examined.

Microwave radiation from a radar sensor on board a satellite can penetrate through clouds. Thus, a number of images acquired from the European radar satellite ERS-2 and the Canadian Radarsat satellite are examined. The ability of a radar sensor to see through clouds is clearly illustrated in Figure 2, in which images acquired by a weather satellite showing the state of the clouds over the Dungeness Power Station are compared with those from ERS-2. The weather satellite images were taken from the Internet.

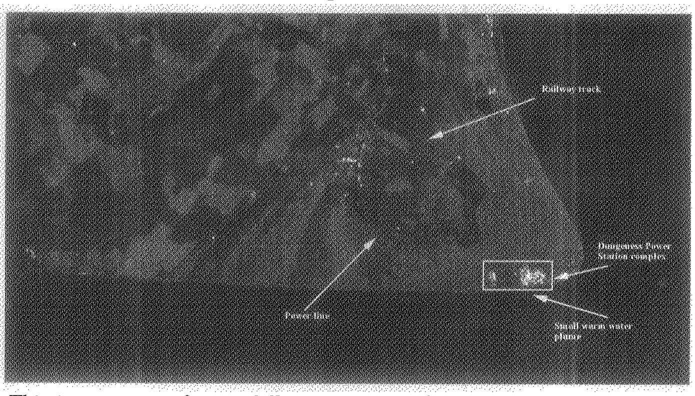
From the radar image on the right in Figure 2a, details such as the Dungeness power reactor complex, the pylons for the power lines and the railway track can be detected in spite of the cloud cover. Not only these, but the plume resulting from the discharged water from the reactor complex can also be seen. The difference here is that the plume is brighter compared with that in Figure 2b. This may be due to rain and/or wind effects causing some disturbances on the surface of the water, scattering the radar beam. The power line and the railway tracks were identified by overlaying the map of the site from Figure 1. The scale and the orientation of the map were matched with the ERS-2 image acquired on June 4, 1996, over the reactor site. This is shown in Figure 3. Generally, the fresh nuclear fuel is brought to a reactor by road while the irradiated fuel from a power reactor is either stored on site or transported to a reprocessing facility by rail. In the U.K., the spent fuel is not generally stored on site. While, in the case of the Dungeness Power Station, the railway does not come into the facility, an access to it is close by. Generally, a plutonium production reactor has a small reprocessing plant within the complex, eliminating transportation of the irradiated fuel. The spent fuel is then reprocessed and the waste product usually stored on site.

Figure 4



An extract from a full scene acquired by the European ERS-2 satellite Nov. 7, 1995, over the U.K. Dungeness Nuclear Power Station.

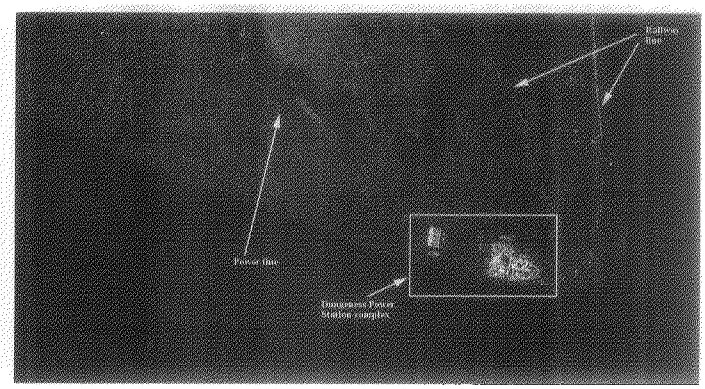
Figure 5



This is an extract from a full scene acquired over the Dungeness Power Station by the Canadian Radarsat satellite in June 10, 1996, in its standard-beam mode.

Source: Radarsat.

Figure 6



This is an extract from a full scene acquired over the Dungeness Power Station by the Canadian Radarsat satellite Nov. 18, 1997, in its fine-beam mode.

Some Conclusions

A brief examination of the space law indicates that there would be no legal constraints for the IAEA to acquire satellite images from commercial sources and use them for its safeguards applications. According to the Remote Sensing Principles, the only requirement is that the IAEA provides the sensed state with the images it has acquired. This it would do in any case as part of its report on the safeguards results.

From the analyses of the images, it can be seen that, with the use of radar sensors, day-and-night, all-weather capabilities offer the potential for monitoring some nuclear activities for safeguards purposes. With relatively high resolution radar sensors such as the Canadian Radarsat, it may even be possible to detect changes in a nuclear facility. If the usefulness of radar sensors to detect thermal plumes in water can be established, these sensors will have an important application for safeguards purposes. There are several radar satellites in orbit but, at present, there is only one optical satellite (Landsat-5) with a thermal sensor on board. Moreover, features such as perimeter fences, power lines and railway tracks can be detected by relatively poor resolution radar sensors, which are on board ERS satellites. This is not possible with even the Russian high-resolution optical sensor unless there is a good contrast.

The use of maps cannot be emphasized more. While the operator of a nuclear facility may give detailed site maps, they may not provide the IAEA with maps of the surroundings, which could show such features as the power lines and railway tracks. Here, openly available digital maps such as those from U.S. National Imagery and Mapping Agency can be very useful.

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Table I. Summary of the results of the radar-image analysis.

Date of observation from satellite	Results from different satellite observations		Information from reactor operator
	ERS-2	RADARSAT	
November 7, 1995	Some reactors operating		—
June 4, 1996	Some reactors operating		Two reactors were operating
June 12, 1996		Some reactors operating	Only reactor 22 was on
December 31, 1996	All reactors may have been operating		Three reactors were operating
November 18, 1997		None operating	Only reactor 22 was on

tion." In *Commercial Observation Satellites and International Security*, M. Krepon *et al.* (eds.) Basingstoke, U.K.: MacMillan, 1990, pp. 142–150.

2. U.N. document A/S-10/AC.1/7, May–June 1978.

3. "Study on the implications of establishing an international satellite monitoring agency." U.N. Report A/AC 206/14, Aug. 6, 1981.

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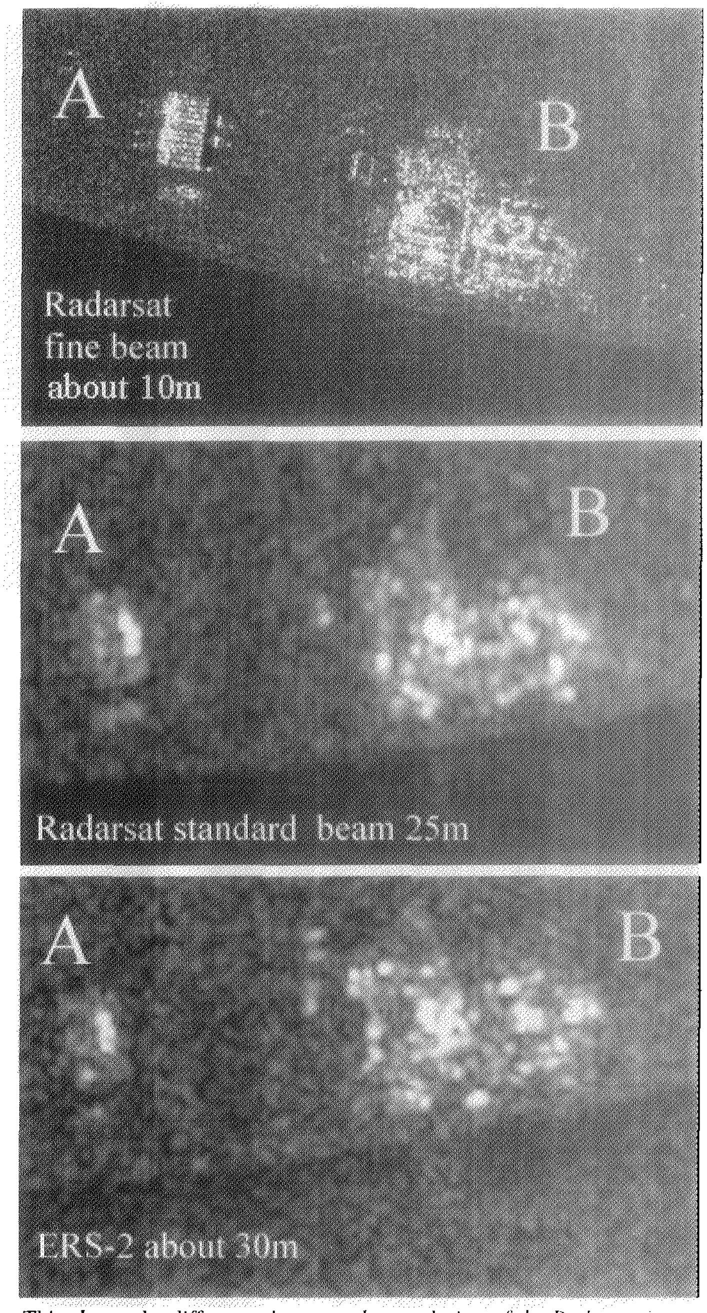
5. B. Jasani. "A regional satellite monitoring agency." *Environmental Conservation* 10(3): 255–56 (1983); and "Verification of arms reduction in Europe from space." In Proceedings of a symposium on observation satellites, "A European means of verifying disarmament." Assembly of Western European Union, Rome, March 27–28, 1990, pp. 62–69.

6. B. Jasani and S. Mara. "The Western European Union Satellite Centre." *Journal of the British Interplanetary Society* 46(6): 208–211 (June 1993).

7. There are 10 multilateral treaties and conventions that regulate activities of states in outer space: (1) the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (The Outer Space Treaty); (2) the 1968 Agreement of the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space; (3) the 1972 Convention on International Liability for Damage Caused by Space Objects; (4) the 1976 Convention on Registration of Objects Launched into Outer Space; (5) the 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies; (6) the International Telecommunication Convention, the final documents of which were signed in 1982; (7) Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space; (8) Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television

Figure 7



This shows the difference between the resolution of the Radarsat in two modes and the ERS sensor.

Broadcasting; (9) Principles Relating to Remote Sensing of the Earth from Space; and (10) Principles Relevant to the Use of Nuclear Power Sources in Outer Space.

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Safeguards and Satellite Imagery: Potential Applications

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Abstract
Commercial satellite imagery provides the International Atomic Energy Agency with yet another vantage point from which to monitor a state's nuclear activities. The most practical uses of remote sensing for safeguards include serving as an inspection aid, detecting changes at certain types of facilities and sites, and corroborating state declarations on the nuclear fuel cycle and nuclear-related activities as well as open-source information. Although the IAEA's experience with member state information may lead some observers to conclude that high-resolution satellite imagery could yield a significantly better ability to detect undeclared activities, a realistic assessment must conclude that a credible capability for wide-area monitoring with satellite images is not cost-effective. The agency and member states will need to balance carefully the value added by CSI with the costs it could entail.

Introduction
The International Atomic Energy Agency has been aggressively pursuing new concepts, techniques and advanced technology to strengthen safeguards implementation since the discovery of clandestine activities in Iraq and North Korea. Although this has always been within the mandate of the agency, the exploitation of technology in the service of safeguards has been propelled by the renewed political interest of member states and real technological advances. Nowhere is this more vivid than in the field of information and computing. In particular, advances in commercial satellite imagery and data analysis offer a new avenue of technology for the IAEA to pursue.

The genesis of the Secretariat's current efforts to assess the potential utility of commercial satellite imagery for safeguards lies specifically in a 1993 recommendation by the Standing Advisory Group on Safeguards Implementation and, more broadly, in the IAEA's efforts to exploit open-source information within the context of the strengthened safeguards system.[1] In part, delays in satellite launches have made it difficult to estimate the usefulness and costs of CSI for safeguards tasks. Impending launches and recent analyses by member states of the uses of imagery with up to 30-m resolutions make it clearer that commercial technology exists today that is potentially useful for safeguards. A critical requirement for successful exploitation of a new technology, however, must be a careful specification of agency needs and how CSI can meet those needs. While this seems to be simple advice, the real challenge is in the details.

Space: From Spies to Safeguards
The glamour of satellite images derives partly from the technological achievement of taking pictures from space and partly from the history, mostly U.S. and Russian, of using satellite photos for covert observation. Some of the technological advantages of "spy" or military satellites however, have spilled over into the civilian sector. Images with ground resolutions of less than 5 m, once obtainable only through "national technical means," are now being made available commercially for a wide variety of civilian uses. In addition to technology spillover, the market has expanded in several ways. Whereas the United States dominated the early commercial market, the deployment of French, Russian, Indian, Japanese and Canadian satellites has expanded the numbers of suppliers as well as the types and uses of satellite imagery for remote geographical sensing. Moreover, private firms, once primarily providers of government-owned data, now plan to provide their own satellites.[2] The commercialization of satellite launches, rather than just the data distribution, will increase the number and quality of high-resolution images available in archives.

The appeal of commercial satellite imagery to the IAEA, however, is not confined to the quality of image resolution. In that case, the agency would be better served by using aircraft-generated imagery, which accounts for almost half of the market now in surface remote sensing.[3] The use of overflights for safeguards would require significant negotiations and, very likely, legal permissions, whereas tasking satellites for images seems to entail very few requirements.[4] CSI is appealing precisely because it is an open source of information.

One caveat should be noted. It is possible for states to place restrictions on what information (e.g. "floors" on ground resolutions or geographical constraints) is made publicly available. The 1967 Outer Space Treaty, the 1972 Liability Convention and the 1975 Registration Convention established the principle of national jurisdiction over satellites, including commercial remote-sensing satellites. The Outer Space Treaty requires private companies to obtain licenses for their satellites from their national government and national governments to list satellites in the U.N. registry.[5] Some states impose conditions on suppliers through laws governing data distribution. For example, in the United States, the Land Remote Sensing Policy Act of 1992 and the March 1994 Policy on Remote Sensing require commercial firms to make available to the U.S. government a list of satellite taskings (although this, presumably, would not affect requests for images from archives). The 1994 policy also contains a national security clause, in which the U.S. government may restrict data distribution for national security reasons.[6] Other states may impose fewer restrictions. For example, Japan has no specific domestic legislation governing remote sensing, no legislation to limit observation areas and no requirement to provide specific information (e.g., name, order, tasking or shipping) to the Japanese government.[7]

Uses of Remote Sensing

Remote sensing has at least three characteristics that are potentially relevant to safeguards:

- the ability to image large areas
- the ability to detect changes over time
- the ability to obtain "visual access" where physical access is not possible.

The first and second of these three characteristics have made satellite imagery useful in obtaining information pertinent to regions, e.g., environmental changes such as patterns of land use and deforestation. The last two characteristics have been particularly useful for monitoring arms control agreements. Snapshots of the declared nuclear fuel cycle could aid the agency in verifying the correctness of member states' declarations on their nuclear fuel cycles under Article 2 of INFCIRC/540. A secondary role could be to enhance the agency's ability to detect undeclared nuclear activities countrywide, if wide-area monitoring could be proven cost-effective. In such a role, remote sensing could be useful to the extent that it could point the way to areas or facilities to which inspectors would like to gain access. This proposition, however, could be expensive. The ability to monitor changes at declared facilities could also be useful in certain circumstances. This could help monitor, in a broad way, the correctness of states' reporting. Finally, the need for visual access where physical access is not possible is less clear. Even in arms control agreements, the trend has been away from using satellite monitoring (e.g., the Comprehensive Test Ban Treaty and the Chemical Weapons Convention) toward on-site inspections. With the provisions for enhanced access in Articles 4 and 5 of INFCIRC/540, the agency does not have to substitute visual access for physical access. However, the extent to which CSI enhances transparency could prove useful.

Remote Sensing and the Nuclear Fuel Cycle

The Secretariat's analysis of imagery's usefulness to detect the presence of undeclared fuel cycle activities and for analyzing the status, features and level of production of known activities yielded the following assessment:

- *High* — uranium mining
- *Medium* — uranium extraction by *in situ* leaching, uranium extraction from sea water, gaseous diffusion and aerodynamic enrichment and reprocessing
- *Low* — uranium from phosphate, conversion, EMIS and reactors.
- *None* — thorium from uranium ore, gas centrifuge and MLIS enrichment, AVLIS and plasma separation enrichment, and fuel fabrication.[8]

This analysis did not differentiate between the ability of satellite imagery to detect undeclared activities and its ability to analyze the characteristics of known activities. A key question, then, is the utility of satellite imagery for what is often termed "wide-area monitoring." For purposes of detection, satellite imagery is useful to detect new, undeclared construction. This could be used to trigger inspections on the ground, since characterization of such sites by CSI is more difficult. For example, reactors can be identified by the presence of containment buildings in some cases and of high-voltage power lines and cooling towers. These last two characteristics, however, are also common to conventional power plants. Unfortunately, the types of reactors of most proliferation concern — critical assemblies, research reactors and production reactors — are less likely to be detected by satellites due to several factors, including their size and operating conditions. In the case of gaseous diffusion and aerodynamic enrichment plants, high power requirements and large, multiple buildings for different enrichment stages would be detectable. EMIS, one of the technologies pursued by Iraq, also has high power requirements but can be housed in smaller buildings. Other technologies for enrichment — gas centrifuge, molecular laser isotope separation, atomic vapor laser isotope separation, chemical exchange, ion exchange and plasma separation — offer few signatures for detection via remote sensing. In addition, attempts to conceal production could render the task of satellite imagery much more difficult; it is not clear that imagery could detect small underground reactors, or small-scale centrifuge enrichment or reprocessing plants.

Role of CSI in Safeguards

IAEA safeguards goals derive from two technical objectives of verification: to detect the diversion of one significant quantity of nuclear material from facilities and to deter undeclared activities by the risk of early detection. Verification measures to detect diversion are divided roughly into four tasks: verification of design information, material control and accountancy, verifying material flows and verifying the absence of undeclared production (plutonium production in reactors, plutonium separation in reprocessing facilities and high-enriched uranium in LEU plants). Of these tasks, overhead imagery could assist inspectors in preparing for design verification inspections through the creation of line drawings of facilities and site maps.

Verifying the absence of production at declared sites poses much more difficult challenges, and the contribution of satellite imagery is likely to be small. In the case where there is a declared reactor, thermal imagery could be used to monitor reactor operations by looking at cooling-water discharge.[9] This technique would be most useful where the operating status of the reactor is in question. At sites where there is a declared enrichment capability, imagery can detect the significant power requirements that some types of enrichment require, but would be less useful at pilot-scale plants. Similarly, imagery can be used to detect general changes (e.g., levels of activity) at sites where there is a declared reprocessing capability, but this is likely to add little to the other techniques the agency has on hand or is investigating (e.g., environmental sampling). In sum, imagery would be most useful in these situations to monitor ongoing status and detection of changes at such facilities.

One of the lessons of Iraq was the need for enhanced access at declared sites to detect undeclared activities. Rather than just detecting undeclared irradiation in a reactor, undeclared high enrichment or undeclared reprocessing at a reprocessing plant, measures are needed to detect changes such as the expansion of existing utilities or structures, changes in general or specific activity levels or the construction of new facilities. In particular, imagery can help corroborate reporting under Article 2 a. iii of INFCIRC/540, which requires a description of all buildings on each site, as well as a map. By providing inspectors with an overall picture of a site, imagery can help improve orientation. Moreover, sophisticated simulation software can be combined with terrain contour mapping to create a simulated "fly-by" of facilities for orientation purposes. In particular, imagery can provide an up-to-date reference against which diagrams can be compared and contrasted and discrepancies noted.

Imagery could also help the IAEA identify sites or locations that have not been declared, but might be, in the agency's view, functionally related to activities of a declared site. Under Article 2 b. ii of INFCIRC/540, the agency must make a specific request for information about such locations or sites from a state. CSI could be used to help analyze those locations or sites and help the agency determine whether or not it should make a specific request.

A New Observational Vantage Point

In an elegant summation of the safeguards system, the IAEA director general's report "Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System" (GOV/2863, May 6, 1996) described inspection activities and information as establishing an "observational vantage point." From this point, there would be a good chance of detecting diversion of declared nuclear material and providing credible assurance of the absence of undeclared nuclear material and activities. The report also noted that it would be up to member states to decide whether the observational vantage point will be on a "high hill with strong glasses or on some lower hill with weak glasses." Although this analogy was meant to challenge member states on their political willingness to strengthen the safeguards system as a whole, it begs the literal question of how CSI — the strongest glasses on the highest hill — can shape the observational vantage point of safeguards.

The Strengthened Safeguards System seeks to expand the observational vantage point of safeguards. Whereas the safeguards system was originally designed to focus primarily on detecting diversion of declared nuclear material at declared facilities, additional measures now seek to broaden the scope of agency efforts to encompass (at least in reporting, information analysis and complementary access) a wide range of nuclear-related activities. The new measures reinvigorate agency focus on the completeness, not just the correctness, of declarations. These new measures will require qualitative judgments, in addition to the quantitative judgments rendered by nuclear material accounting. The measures also have the effect of increasing the transparency of states' nuclear-related activities.[10]

Where does commercial satellite imagery fit in? In some respects, CSI is the orphaned child of strengthened safeguards. Although satellite imagery helped tip off the IAEA that there were gaps in the safeguards system, these gaps were not to be filled by a technical solution. Nonetheless, CSI can make some contribution to the objectives of safeguards in states with comprehensive safeguards agreements and the model protocol — assuring the completeness and correctness of states' declaration, providing credible assurance of the absence of undeclared activities and improving efficiency.

Completeness and Correctness

As noted earlier, new measures are aimed at enhancing the agency's ability to verify the completeness of states' declarations. In addition to the information states provide to the agency, the IAEA will use open-source information. Satellite imagery, as noted in the Secretariat's working document on the potential uses of CSI, can help confirm or give added credibility to information acquired or generated by the agency, as well as help assess the credibility of open-source information. The use of imagery to assist inspectors in the verification of design information can contribute to the agency's assessment of the correctness of declarations.

Credible Assurance of the Absence of Undeclared Activities

Although a wide-area monitoring capability using satellite imagery is likely to be beyond the agency's capabilities, satellite imagery can enhance assurance of the absence of undeclared activities in other ways. The availability of images with higher ground resolutions means that imagery does not have to be used just to detect undeclared facilities, but can be used to identify and characterize attributes of declared facilities and, in some cases, production levels. As mentioned earlier, the ability to detect changes in infrastructure and activity levels can be used to corroborate state-provided information.

Satellite imagery could also have a deterrent effect by virtue of the increased transparency it provides. The calculation of deterrence is complex, however. For a start, one would need to take into account what a state and facility operators know about commercial satellite capabilities, their ability to deploy countermeasures, and their perceptions of the agency's ability to assess acquired data and willingness to act upon it. On the other hand, a critical caveat in the wording of the safeguards objectives is the deterrence "by risk of early detection." Probably the most important contribution CSI could make in altering the calculation of deterrence is providing the potential for very early detection of undeclared activities at declared sites.

Improving Efficiency

Measures to improve efficiency in safeguards range widely, from better seals with fewer defects to increased cooperation with state systems of accounting and control. Some simply reduce costs while others seek to reduce inspection effort. It has been suggested that the use of satellite imagery could reduce inspections. It is possible that design verification inspections could be conducted more efficiently with the aid of reference materials derived from satellite imagery, thus shaving some person-days of inspection. It should be noted, however, that design verification inspections, conducted before the introduction of nuclear material, are useful precisely because inspectors have greater access in some cases (e.g., at reprocessing facilities). In terms of inspection preparation costs, CSI is likely to add another category of expenses.

With respect to the use of imagery to verify changes in the status of some facilities, some reduction in inspections is possible in the early stages of construction, but would be less desirable as construction proceeds. When facilities are shut down and decommissioned, it is possible to verify their nonoperational status through thermal imagery.

It is difficult to imagine reductions in inspections designed to corroborate information on a state's nuclear fuel cycle, primarily because we do not yet know the level of inspection effort associated with those activities. Article 4a of INFCIRC/540 states that verification of the information provided by the state using complementary access will not be mechanistic or systematic. In this light, the potential for reducing inspections appears to be small. This is not to say, however, that CSI would not be a more efficient method of corroborating such information than inspections.

Finally, there is the question of costs associated with the potential use of commercial satellite imagery for wide-area monitoring. First, as with any wide-area monitoring, a baseline assessment would be necessary. This means that the agency would have to collect images of member states currently stored in archives. Since there are likely to be gaps, the agency would probably have to task satellites to procure images where there are gaps in the archives. The current estimated cost of an image from archives is $1,500, although most experts agree that this cost will decrease. Tasking satellites for images is more expensive. If we assume that images are acquired with a 40 km x 40 km scene size, the number of images required per country could be quite large.

As with other wide-area monitoring techniques, screening methods could be used to narrow the areas to be monitored. One method would be to monitor only those areas with infrastructure such as roads, power lines, etc. One would presumably need to check occasionally that infrastructure was not being developed in areas previously screened out. Even with screening methods, which can be quite effective in reducing the target area, the cost of procuring images for a country as large as, for example, Brazil, would be prohibitive. Germany, with a landmass of 349,520 square kilometers, would require close to 200 images. In 1997, the agency applied safeguards in 56 states with agreements pursuant to either the NPT or to both the NPT and the Treaty of Tlatelolco. If we assume that the agency conducted a baseline assessment of 25 countries with an estimated 100 photos per country, this would cost just under $4 million. In addition to a baseline assessment, the agency would have to establish a protocol for collecting images on a wide-area basis over time. When one considers that the annual cost of implementing Parts I and II of Programme 93+2 is estimated at roughly $5 million to $6 million in the early years, it appears that a wide-area monitoring program would be prohibitively expensive, with an uncertain level of effectiveness.[11] In addition to the cost of procuring images, the agency will have to procure hardware, software and analysts.

CSI and Future Tasks

The IAEA has been asked increasingly to take on broader verification roles. These include monitoring the Trilateral Initiative, which places nuclear material no longer needed for defense purposes by Russia and the United States under verification, and potentially, a fissile material production cutoff treaty. The verification methods for the Trilateral Initiative do not currently call for satellite monitoring. Given the likelihood that such material may be stored at sensitive sites, it is proportionately unlikely that CSI would be a verification method of choice. With respect to the fissile material cutoff treaty, it is too soon to tell what the verification regime for the FMCT will look like, let alone the obligations. However, there may be a potential use for satellite imagery to monitor the continued shutdown of reprocessing and enrichment plants and possibly production reactors under the FMCT. Presumably this would be in conjunction with some form of on-site inspection, whether routine or *ad hoc*.

Conclusions

Satellite imagery from national technical means was critical in convincing the Board of Governors of the existence of undeclared activities in North Korea. Although the agency's experience with member state information may lead some observers to conclude that high-resolution CSI could provide a significantly better ability to detect undeclared activities, a credible capability for wide-area monitoring with satellite images is not yet cost-effective. The agency has neither the resources nor the mandate to conduct the kind of intelligence gathering that member states conduct. The practical uses of satellite imagery for safeguards may be far more quotidian. Indeed, there will be little glamour involved in ordering, purchasing and filing images from existing commercial archives, not to mention information analysis.

There is undoubtedly merit in having yet another vantage point from which to monitor a state's nuclear activities. The most practical uses of remote sensing for safeguards include serving as an inspection aid, detecting changes at certain types of facilities and at sites, and corroborating state declarations on the nuclear fuel cycle and nuclear-related activities as well as open-source information. CSI may provide an important link between information analysis and inspections. Moreover, since we do not yet know how to assess the level of assurance provided by the new information under the model protocol, the use of CSI as a corroborating measure could be useful in the short term. As always, the agency and member states will need to balance carefully the value added by CSI with the costs it could entail.

References

1. The Standing Advisory Group on Safeguards Implementation recommended that the IAEA Secretariat "assess the usefulness, technical feasibility, associated costs and acceptability of the Agency obtaining satellite imagery from commercial sources."

2. In 1987, the French space agency Centre National Etudes Spatial, launched the first SPOT satellite; SPOT Image SA has marketed the data. In Canada, the Radarsat satellite is owned and operated by the Canadian Space Agency under Industry Canada. Indian satellites are government-owned and -operated but privately marketed. The Japanese program is administered by the National Space Development Agency; data is marketed by RESTEC, a foundation established in 1975 under the guidance of the Japanese Ministry of International Trade and Industry and NASDA. Likewise, Russian satellites are government-owned, and data is marketed by Soyuzkarta, a private firm. In the United States, Landsat is operated by the National Aeronautics and Space Administration and marketed by Space Imaging EOSAT, a private company. Although Space Imaging EOSAT planned to launch the IKONOS-1 in 1998, this has been delayed until June 1999. Two other firms, EarthWatch Inc. and Orbital Imaging Corp., plan to launch satellites in the next few years. The success of private firms in launching their own satellites depends on many factors, but among the most important may be the growth in sales of raw satellite data. This is critical, since the costs to develop, launch and operate a remote-sensing satellite have ranged from $100 million to $800 million, depending on satellite capability and weight. See Office of Technology Assessment, "Remotely Sensed Data: Technology, Management and Markets," Washington, DC: U.S. Government Printing Office, September 1994, p. 111.

3. In addition, aircraft can fly under cloud cover. Some of the disadvantages associated with aircraft imagery include the fact that each tasking requires a dedicated flight, and aircraft are less likely to provide digital multispectral data. Ibid., pp. 107–108. The entry into force of the Open Skies Treaty raises the question of whether states party to that treaty would consider overflights for safeguards favorably. There is some overlap between Open Skies signatories and IAEA member states with comprehensive safeguards agreements. The actual flights are conducted for military transparency purposes and therefore have different targets and, possibly, different sensor suites than might be appropriate for safeguards purposes.

4. It is not clear that the international principles that govern remote sensing of the earth for environmental purposes — "Principles Relating to Remote Sensing of the Earth from Space," which date from 1986 — apply to the IAEA's use of CSI for safeguards. If they did apply, however, "sensed" states would have access to primary data and processed data (as defined in the principles) on a nondiscriminatory basis and at reasonable cost. There does not seem to be a requirement to supply data that is further analyzed to the sensed state. See A/RES/41/65, "Principles Relating to Remote Sensing of the Earth from Space," passed by the 95th Plenary meeting of the United Nations General Assembly in 1986.

5. See "Remotely Sensed Data: Technology, Management and Markets," op. cit., p. 121.

6. The policy requires the licensee "to maintain a record of all satellite tasking for the previous year and to allow the USG access to this record." It also requires the licensee "to use a data downlink format that allows the U.S. government access and use of the data during periods when national security, international obligations and/or foreign policies may be compromised as provided for in the Land Remote Sensing Policy Act of 1992." Further, during such periods, the licensee may be "required to limit data collection and/or distribution by the system to the extent necessitated by the given situation. The U.S. government also requires U.S. companies that have been issued operating licenses under the Act to notify the U.S. government of its intent to enter into significant or substantial agreements with new foreign customers." Overall, U.S. commercial firms will not be able to sell imagery with resolutions under 0.82 m. Within the United States, some areas will be off-limits for reasons of national security, e.g., Camp David. Source: White House Press Office, March 10, 1994.

7. Presentation by Takashi Hamazaki, National Space Development Agency of Japan, at the IAEA technical workshop "Safeguards: Sources and Applications of Commercial Satellite Imagery." Sept. 16–17, 1998, Vienna, Austria.

8. The participants in the September technical meeting held at the IAEA suggested that the potential for satellite imagery to detect undeclared reactors and gaseous diffusion enrichment plants was high rather than low and medium, respectively, and that the ability to detect EMIS enrichment was medium, rather than low.

9. The ability to monitor cooling-water discharge is more effective in shallow water and dependent on temperature and tidal conditions. Presentation by Richard Keeffe, Q.S. (Bob) Truong, Phillip Baines and Jean-Pierre Paquette at the IAEA technical workshop "Safeguards: Sources and Applications of Commercial Satellite Imagery." Sept. 16–17, 1998, Vienna, Austria.

10. See John Carlson, "Safeguards as an Evolutionary System," a paper for the meeting of the INMM Japan Chapter, Oct. 14, 1998.

11. GOV/2863 estimated the implementation of strengthened safeguards at $4.2 million in the regular budget in 1997 and 1998, with $1.1 million and $2.3 million in extrabudgetary contributions in 1997 and 1998, respectively. See GOV/2863, Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System: Proposals for Implementation under Complementary Legal Authority, Annex I, May 6, 1996, p. 11.

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Data Mining: Applications to Nondestructive Assay Data

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Abstract
Data mining is the 1990s term for discovering useful information in large (usually high-dimensional) data sets. The availability of fast and inexpensive computers has resulted in widespread use of many computer-intensive data-mining procedures. Some data-mining practitioners have thrown caution to the wind; consequently, misleading performance claims abound. However, with appropriate corrections for the effect of choosing the best data model from among a large class of candidate models, there is much to be gained by mining data sets for information. This paper focuses on data-mining techniques that are well suited to enhance the performance and understanding of nondestructive assay methods for the assay of special nuclear material. There have been a few recent applications of data-mining techniques to NDA, so it is timely to review their limitations and benefits. We first give a brief history of the data-mining methods that are most suited for NDA applications. We next present analysis results for a subset of a large data set of ^{252}Cf shuffler assays (via neutron counting) of large containers with known amounts of plutonium in known locations in known matrices. We conclude with a brief review of other candidate NDA applications for data-mining tools.

Introduction
We will informally define data mining to be the activity of discovering useful information in large (usually high-dimensional) data sets. For example, baseball fans know that statisticians have discovered gems such as "the batter is batting over .400 with two outs after the seventh inning in home games when the home team is losing by two runs or less." Presumably, the best coaches know whether such information is actually useful, but they are not talking.

Many ideas that now enjoy widespread use in data-mining applications were developed by statisticians years before the age of fast computers. In the 1960s, G. Box, J. Tukey, P. Huber and others introduced robust statistical procedures that were less sensitive to outliers than were conventional methods. For example, suppose we model $y = \beta_0 + \beta_1 x + R$, where y is neutron-count rate, x is grams of special nuclear material and R is random error. If, among n (x,y) pairs, there were a single large x value and the corresponding y value was (by chance) rather small, we might severely underestimate β_1 using ordinary least squares. The version of robust least squares that minimizes the sum of the absolute estimated errors (mean absolute deviation) might dramatically improve our estimate of β_1.

In the 1970s, J. Tukey and others used a suite of simple methods (most of which could be done by hand) for exploratory data analysis. EDA dispelled the traditional dogma that one is not allowed to look at the data prior to modeling. A key notion was to decompose the data into data = fit + residual, and then iteratively examine the residuals for patterns that could refine the fit. Another notion was that there seldom is a single correct answer or model. Good models are simple, concise and reasonably accurate. One common EDA activity is called clustering or unsupervised learning, in which we attempt to discover natural groupings for the data. Also, the usual Gaussian theory for linear models was extended to include the exponential family (which includes the Poisson and binomial distributions) for the class of generalized linear models. This greatly improved the available classes of fitted models.

In the 1980s, resampling methods such as the bootstrap, jackknife, and cross-validation came into common usage. A simple setting for cross-validation is the following. Suppose we have n (x,y) pairs and we wish to fit $y = f(x) + R$, and we consider a wide range of candidate forms for $f()$, including linear, locally linear, etc. How would we test the final selected model? One way is to randomly divide the data into 10 sections, and then create 10 training/testing sets using 90 percent of the data to train and 10 percent to test. Also, in the area of pattern recognition, computer-intensive methods such as CART (classification and regression tree) were developed. Pattern recognition is also called classification, where the response y is categorical (for example, $y = 0$ means the disease is absent, and $y = 1$ means the disease is present).

In the early 1990s, J. Friedman, T. Hastie and others introduced adaptive modeling to fit $f()$. Successful examples include the generalized additive model, neural networks and multivariate adaptive regression with splines. These flexible families also extended the choices for pattern recognition problems. Also, an idea from the machine-learning community (boosting) began to demonstrate its ability to reduce misclassification rates by retraining on cases that are misclassified in the training data.

We are now seeing fruitful results that combine implementation of established ideas with new computer-intensive methods that could only be achieved in an era of fast computing. For a more complete review of data-mining applications, see reference 1.

Despite the real successes and promising hopes, some degree of caution is always warranted. For example, one currently popular application area for data mining is in retail marketing. Shoppers are often given shopper ID cards that track their spending patterns. Retail chain stores record the checkout-counter data and observe correlations among items purchased. One well-known study observed a strong correlation (among many thousands of spurious correlations) between diaper sales and beer sales. Humorous pictures of large-bellied adults wearing diapers made for good headlines. Eventually, the explanation emerged that young fathers would make a late-night run to the store for diapers and would buy some beer while they were there. Apparently, there really was a suitable explanation for what might have been a spurious correlation. However, it is not difficult to imagine that when thousands of correlations are calculated, many will be large by chance alone rather than because there is an underlying reason. Most of the spurious correlations will be smaller in the next similar data set, but the true correlations will tend to remain large. This is an example of fitting a model to a data set (the example model relates beer sales to diaper sales), which should be validated on a new data set. In the case that data are inexpensive to acquire, we have a simple procedure: find the best few models on the training data, and reserve testing data to test the model. In many NDA settings, the data-set sizes will not permit us the luxury of having both a large training set and a large testing set. Therefore, it is important to consider how best to balance the competing goals of good model selection and good model validation or testing. For this goal, modern notions of cross-validation and generalized degrees of freedom will be useful. The idea behind the GDF is to measure the effect of selecting the best model from a long list of candidate models (reference 2).

Data Mining Applied to NDA

One of the current challenges to NDA is to measure waste, scrap and residue items, which can vary considerably in their radiation attenuation properties. A recurring theme in NDA is that items exhibit varying degrees of self-shielding due to the matrix of non-special nuclear material within the item and the distribution and self-shielding of the special nuclear material itself, which often depends on sample lumpiness. A helpful way to view this problem is to imagine putting 30 g of plutonium inside various containers with various matrices and to vary how the 30 g is distributed within each container, ranging from a single lump at various positions to a homogeneous powder throughout the container. The measured radiation will vary considerably, so that any assay based on measured radiation will either attempt to correct for the matrix and sample distribution or will have a large measurement bias for each container. The challenge is to either (1) directly estimate the degree of self-shielding or (2) indirectly estimate the degree of self-shielding by using wide ranges of matrices in calibration experiments. In either case, the goal is to estimate the source radiation well so the item can be assayed with good accuracy and precision. To attempt method 1, NDA experts are beginning to combine information from disparate sensors, such as neutron and gamma counters. An example is to first use tomographic gamma scanning to estimate the positions of the source and then use the californium shuffler (^{252}Cf shuffler, a neutron-counting method) with a matrix correction to make the assay. New or revived analysis methods are likely to be useful in either approach, but this paper focuses on the second approach using ^{252}Cf shuffler data. The two approaches we consider are (a) to estimate a high-dimensional calibration function (multivariate calibration) and (b) to recognize the matrix class of an item (pattern recognition) and then use a matrix class calibration constant. For approach a, we have applied 10 methods, including the alternating conditional expectation method, projection pursuit regression, generalized additive models, neural networks, multivariate adaptive regression with splines, and several forms of linear regression. For approach b, we have applied both k-means and hierarchical clustering to cluster matrices and have applied k-nearest neighbor, decision trees and mixture-discriminant analysis to classify matrices into matrix classes.

NDA Measurement Challenges and Review of Relevant Data-Mining Activities

Space does not permit a complete review of the application of data mining activities to NDA data. References 3–7 are a good starting point for a review. We mention here only some of the methods that most closely relate to the example we consider below. Broadly speaking, our interest is in multivariate calibration, and the challenge is to reduce measurement bias. The error model to guide us is $M = T + B_{\text{item}} + B_{\text{inst}} + R$ where M is the measured mass, T is the true mass, B_{item} is the item-specific bias, B_{inst} is the measurement-instrument-specific bias, and R is the random error. Replicate measurements on the same item allow us to estimate the standard deviation σ_R of R. Ordinary calibration data on known standards allows us to estimate σ_{Binst}, but it is always challenging to estimate σ_{Bitem}. In fact, because B_{item} varies from item to item, we could model it as random error, but items having the same characteristics tend to have similar biases so it is preferred to model B_{item} as being random within a class of matrices, as was outlined in reference 8.

To reduce σ_{Bitem}, some NDA methods attempt to measure directly the attenuation properties of each volume element of an item, as well as the mass of special nuclear material in each volume element. Key examples are the segmented gamma scanner and the tomographic gamma scanner. For neutron counting, the ^{252}Cf shuffler provides less detailed information about the sample, but neutron flux monitors can identify important matrix properties of the sample, and spatial variation in the delayed neutron counters can identify important sample position properties. It would be valuable to combine TGS-based sample information with ^{252}Cf shuffler data. However, that would require making both TGS and shuffler assays of each sample, and, in some cases, matrix density might preclude making a good TGS measurement. (Gammas are strongly attenuated by high-density materials, while neutrons are strongly attenuated by low-density materials, particularly hydrogen-bearing material.) We therefore believe it is valuable to see how accurate ^{252}Cf shuffler data alone can be, as we do in our example below. The relevant data-fusion activities for our example include exploratory data analysis such as clustering, classifying and detecting outliers. Finding outliers in one dimension is usually not difficult, but finding outliers in higher dimensions is challenging, especially because the presence of one outlier can hide (mask) other less severe outliers. Clustering high-dimensional data is a common exploratory technique in many fields, but we are not aware of published clustering applications in NDA data analysis. We will present some clustering results in our example. Pattern recognition (classifying test objects after being presented training data in which the class and predictor variables are given for each case) could become useful in various applications of waste characterization. For example, we might need to know if certain shielding materials are present inside a container or if the special nuclear material mass is above a regulatory limit. In both cases, the response variable is dichotomous (present/absent or above/below limit) so either example could be viewed usefully as a pattern-recognition problem.

Review of Other Data-mining Activities in NDA

In reference 3, the authors applied the alternating conditional expectation method to the highly enriched uranium samples (avoiding outlier matrices) from the large data set described in reference 9 and reduced the relative standard deviation of corrected counts (and hence also of corrected assays because we are reporting *relative* standard deviation) from approximately 29% to approximately 15%. This is a good example of approach a. Our efforts focused on the plutonium samples of this same data set and included the goal of comparing approaches a and b. Another similar effort used neutron-transport equations and detailed calibration data to estimate the special nuclear material mass at each of typically about 30 volume elements in a 55-gallon container (reference 4). This approach is both potentially the most accurate and the most time-consuming because it requires a separate calibration for each matrix. Perhaps it will be possible to reduce the calibration requirement to a separation calibration for each class of matrices. However, we will see in our example that it can be challenging to define a matrix "class." More recently the authors in reference 6 successfully used ACE to combine TGS and the add-a-source neutron multiplicity measurement, and the authors in reference 7 used ACE to select predictors (this activity is sometimes called feature selection) followed by a neural network trained using a generalized regression technique applied to the combined thermal/epithermal neutron instrument. Some of the analyses of the ^{252}Cf shuffler assay data presented in the next section was presented in reference 5.

Example Application of Clustering and Classifying

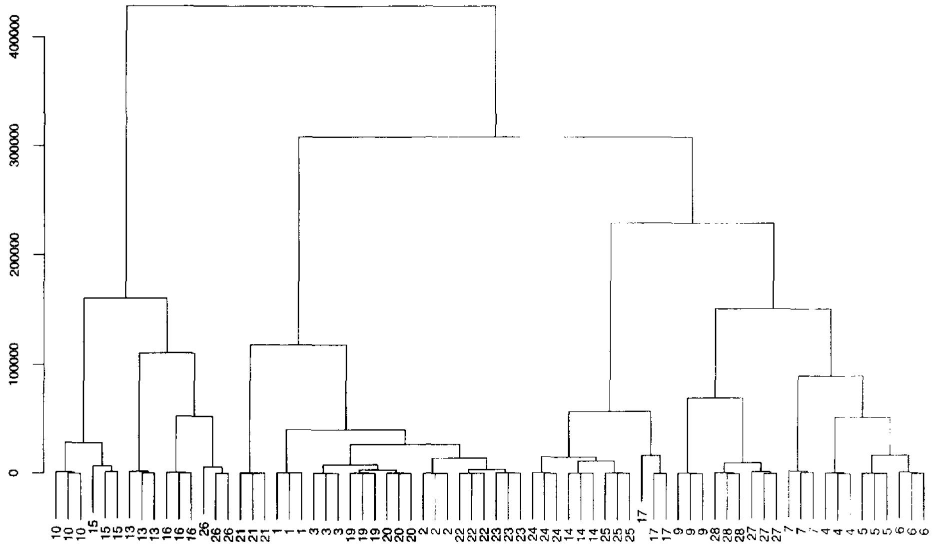
This example involves 236 ^{252}Cf shuffler assays of plutonium in 21 different matrices. A sample of 27.904 g of plutonium was located at 15 positions within each matrix (five vertical and three radial displacements from the center). Some matrices had samples placed at only the near, mid- and far displacements from the center, and there were two repeated assays, giving a total of 236 assays of 21 matrices. It is a subset (with three outlier matrices removed) of the data set that is fully described in reference 9.

Briefly, the shuffler principle is to irradiate the sample using neutrons from ^{252}Cf during the active interrogation stage, remove the ^{252}Cf, then repeat the process about 30 times. The ^{252}Cf neutrons will induce fissions in the plutonium. When these fission products decay, delayed neutrons are produced. Neutron flux monitors count neutrons during the active interrogation stage (the bare monitors count slow neutrons, the cadmium-covered monitors count fast neutrons) and delayed-neutron counters on the top, bottom and side of the container count delayed neutrons during the passive stage. Because plutonium has an appreciable rate of spontaneous fission, the active stage is not needed to induce fissions, but it does provide information about the matrix, similar in concept to the TGS in transmission mode. Also, the sample response will depend on the energy of the ^{252}Cf neutrons, which can be altered by adding a neutron-moderating sleeve around the sample. Here we discuss only the case with the sleeve absent. We have three neutron counts that could each be calibrated to estimate sample mass: total neutrons, real neutron coincidences (neutrons that are produced from the same fission event and so arrive at the detector at nearly the same time) and delayed neutrons. Currently the ^{252}Cf shuffler is certified only in the active stage, which involves counting delayed neutrons. To keep this discussion brief, we will primarily discuss only the delayed neutron rates (DN), but we will give preliminary results from combining the assay from all three neutron counts. Some of the predictors were thought to relate to the matrix and others to both the matrix and the sample position (neutron flux monitors relate to the matrix, and ratios of top-to-bottom or top-to-side delayed-neutron detectors relate to the sample position and matrix). To confirm that the flux monitors could distinguish the matrix, we randomly selected three assays from each of the 21 matrices, which resulted in different sample positions for each matrix. Using hierarchical clustering as shown in Figure 1 (with either Euclidean or Mahalanobis distance as the metric to compare cases), we confirmed that the predictors that involved the flux monitors could be used to determine which matrix was being assayed. Note that the three randomly selected assays for a given matrix always cluster and that we could further cluster the 21 matrices into five to six classes of matrices to adequately explain the data. Hierarchical clustering did not separate the matrices when we used the predictors (DN detectors) that were thought to relate to both matrix and position. Again using the flux monitor predictors, we also applied k-nearest-neighbor pattern recognition, in which the matrix prediction for a test case was the matrix of the nearest training case, with distance measured in predictor space using the predictors involving the flux monitors. We used only one randomly selected assay from each matrix as the training data. Usually, the performance of knn is very sensitive to the metric, but we used both scaled-to-unit variance predictors and unscaled predictors and got 100-percent correct classification. We also grouped the matrices into five classes using the centers of each cluster as the representative case (the centers were defined as the vector-valued average of 10 randomly selected matrices per class) for each class and got 100-percent correct classification of the held-out 186 test cases. Reference 9 divided the matrices into five classes on the basis of the neutron-moderating properties of the matrix:

1. no important impact on neutrons,
2. moderate (slow down) neutrons,
3. absorb neutrons, moderate and absorb,
4. homogeneous matrix, or
5. inhomogeneous matrix.

If we attempt to recognize the matrix class using those classes, we get a lower percentage (approximately 35 percent) of correct classification. These estimated classification results depend on which cases are chosen for training and which are for testing, so we randomly choose the training cases. In other words, the *a priori* class assignments given in reference 9 do not quite agree with the data-driven class assignments. That does not mean that the *a priori* class assignments are wrong, but it suggests that data-driven class assignments could be more useful for assay purposes. In our assay methods we tried using both data-driven class assignments (use hierarchical clustering to decide how many classes of matrices are present) and the *a priori* class assignments. Our results were consistently better for the data-driven class assignments, so we report only those results here. We believe there would be benefit in further work in this area of comparing *a priori* class assignments to data-driven class assignments to better understand the matrices and the measurement system.

Figure 1.



Hierarchical clustering of 21 matrices. The matrices are numbered from 1 to 29, and 21 of the 29 are in this subset of the data. The individual matrices each form a cluster, and we could form five to six matrix classes to represent this data well.

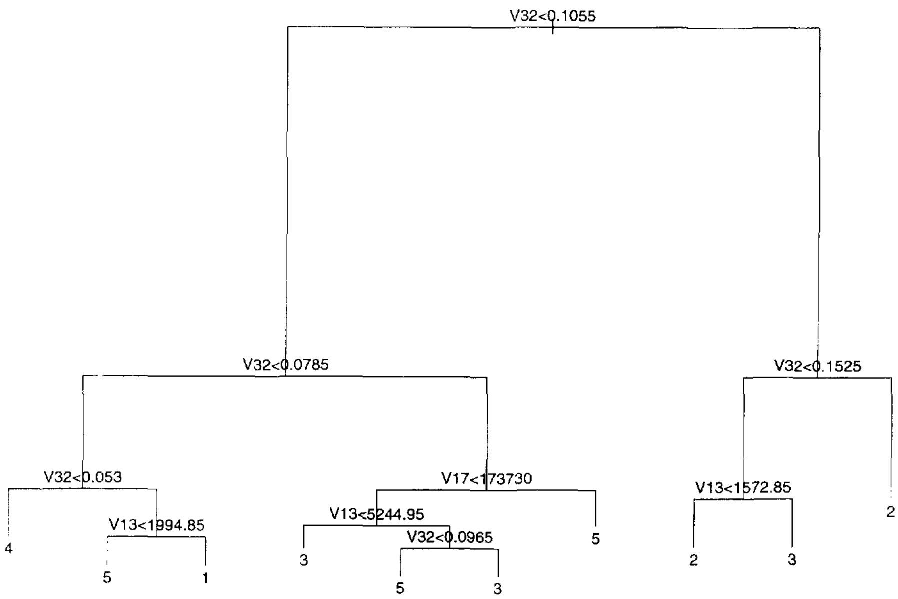
We will present four methods of estimating the plutonium mass.

1. Include predictor variables that relate to the matrix and to the sample position among a list of 27 candidate predictor variables $(x_1, x_2, \ldots, x_p)$ (11 are thought to be most related to matrix and sample position and 16 are thought to be most related to the matrix) and fit the model

$$y = \mathrm{DN/M} = f(x_1, x_2, \ldots, x_p) + R, \quad (1)$$

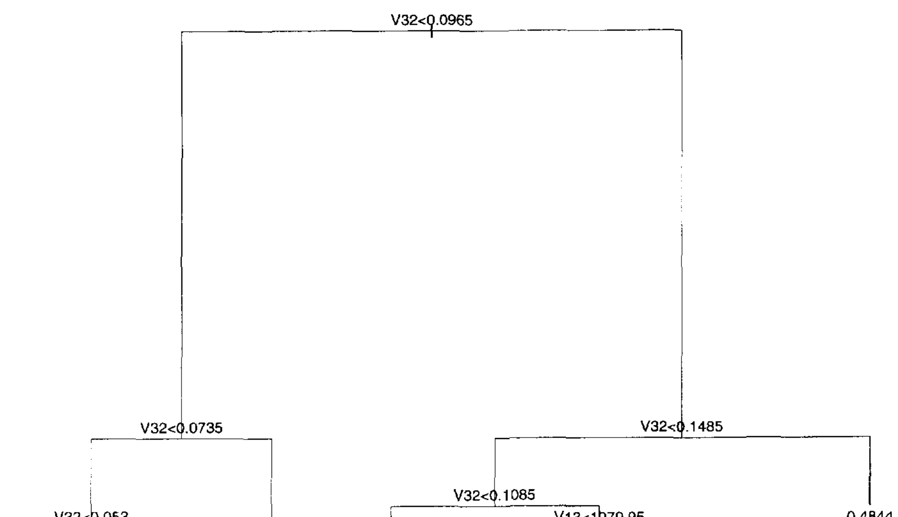
where R is a random error and $f()$ is an item-specific calibration function. We also fit M/DN, which would be the "inverse calibration method," but do not present those results here as they were slightly inferior to the classical calibration method. We used 10 methods to estimate $f()$: linear regression (ordinary least squares, which is nonrobust to outliers, and two robust-to-outlier methods), projection pursuit regression, ACE, generalized additive models, GLM, locally linear models, multivariate adaptive regression with splines, and feed-forward neural nets with one hidden layer and with various numbers of nodes in the hidden layer. All of these methods are discussed in reference 10. ACE was successfully used in reference 3 for another subset of this large data set (highly enriched uranium assays without moderating sleeve with some outlier matrices removed), but the approach was slightly different than presented here. In reference 3, the ACE algorithm was applied first to find a matrix correction and second to find a position correction. Here we did not separate the task into two steps, so methods such as ACE, which assume that $f()$ is additive, were less likely to perform as well. A key idea in most of these methods is that we almost never have enough data to fit arbitrary high-dimensional f's. So a good compromise is to restrict $f()$ to be *additive* in some predictors (perhaps in transformations of the original predictors). For example, assume $f(x_1, x_2, \ldots, x_p) = f_1(x_1) + f_2(x_2) + \ldots$, where the individual f's can be arbitrary but the effect of x_2, for example, does not depend on the level of x_1, so $f()$ is additive. Our version of MARS allows up to three-variable interactions, effectively adding terms such as $f_{ijk}(x_i, x_j, x_k)$ to the approximation of $f(x_1, x_2, \ldots, x_p)$. Generally, we prefer additive models (no

Figure 2.



Classification tree to predict the matrix class of a given sample. After an exhaustive search among all the candidate predictors at each node of the tree, CART chose to use only the three variables named V32, V17, and V13 of the 27 candidate predictors. These three variables are the normalized side bank standard deviation, the cadmium flux monitor counts, and the He-4 flux monitor counts. The tree's matrix class predictions (1 to 5) are given at the terminal nodes.

Figure 3.



Regression tree to predict the class-specific calibration function for a given sample. Tree predictions (given at the bottom of the tree) are the average of DN/M for all training cases in the terminal node. Variables V32 and V13 are the normalized side bank standard deviation and the He-4 flux monitor counts, respectively.

interaction terms) wherever possible, but the authors in reference 3 went to considerable effort to ensure that an additive model such as ACE would be effective (the effect of the source position depends on the matrix, so the source position predictors do interact with the matrix predictors.)

2. Determine the matrix or class of matrices to which a given sample belongs. Use a matrix-specific or class-specific (class of matrices) calibration constant, where the effect of sample position is somehow included. There are several approaches to this method. We could classify matrices using only the 27 predictors, without regard to the response (DN/M) and hope that DN/M is more consistent within classes than between classes. Unfortunately, that has not worked well to date. In fact, DN/M varies considerably within each matrix class (whether we use data-driven class assignments via clustering or whether we use the *a priori* class assignments). The approach we present here is to cluster first and then classify the training data according to the DN/M values. We then search for a function of the predictors that predicts the class (according to DN/M value) well. Our best classification method for this aspect of the problem has been a decision tree (CART, described in reference 10). If the decision tree thinks that a matrix belongs to matrix class 1, then the class 1 calibration constant (deduced from the training data for the training matrices in class 1) will be used. Approximately 30 percent of the test matrices are misclassified by our typical decision tree so approximately 30 percent of the matrices are assayed using a calibration constant for the wrong matrix class. An example decision tree is given in Figure 2, where the numbers in the terminal nodes are the tree's matrix class prediction for any test case in that node.
3. As a compromise between approaches 1 and 2, fit a regression tree (again using CART methodology) in which all cases in a terminal node have the same predicted DN/M, equal to the average DN/M of all training cases having that terminal node. An example is given in Figure 3. The predictions of such a regression tree can be quite discontinuous (two cases having similar predictors need not have similar predictions if those two cases end up in different terminal nodes). If this is judged to be unreasonable, a "smoother" method such as multivariate adaptive regression with splines would be preferred.

Table I.

Method	Rep1	Rep2	Rep1	Rep2	Rep1	Rep2
	ntrain = 200		*ntrain = 118*		*ntrain = 75*	
1. MARS	4.74	4.57	4.58	3.29	8.02	10.13
2. CART	17.65	23.36	42.10	24.49	26.76	33.26
3. Regression Tree	15.23	17.87	15.10	16.65	13.12	28.14
4. Naive	103.3	136.0	77.24	90.22	73.25	106.82

The total measurement error variance, σ^2_T resulting from four assay methods for two randomly selected (Rep1 and Rep2) training sets of sizes 200, 118, and 75 out of 236 cases. The best high-dimensional function estimation method of the 10 considered was consistently MARS, provided we did not extrapolate outside the training data.

4. The naive approach is to assume $f(x_1, x_2,.., x_p) = k$ regardless of the values of the predictor variables so we have one global calibration.

For all four approaches we tried three training sizes: 200, 118, and 75 (85 percent, 50 percent and 32 percent, respectively, of 236). For each training size we randomly selected the training cases and those remaining were test cases. We repeated the random selection twice for each case. Let y be the estimated plutonium mass for each test case. Table I lists the total measurement error variance, $\sigma^2_T = \text{avg}[(y - 27.904)^2]$, where the average is over the test cases for the best (MARS) of the 10 methods of approach 1 and of the other three approaches. Our methods all give very small apparent bias, so most of this total measurement error is due to random rather than systematic error.

Note that $\sigma_T/27.904 = 103.3^{0.5}/27.904 = 36\%$ for Rep1 with the naive approach with ntrain = 200, so there is considerable variation in the matrix and sample position. As an aside, the standard–deviation-to-mean ratio for the two repeated assays was 11% and 0.6%. The assay protocol was typical for shuffler assays, so we expected this ratio to be approximately 1.0%, so the 11% result is unexpectedly large for a repeated measurement. If we insist on declaring a winning method, the winner is MARS ($4.74^{0.5}/27.904 = 7.7\%$). We fit several MARS models, but most selected the following predictors in their final model (allowing up to three-variable interactions): the He-3 and/or He-4 flux monitor counts, the normalized side bank counts standard deviation, the bare-to-cadmium flux monitor counts ratio (these predictors were usually chosen by CART also), and the top-to-bottom detector counts ratio (not usually chosen by CART).

Note the considerable variation in performance between Rep1 and Rep2 for all methods except MARS. Because of the wide range of matrices among these 21 matrices and because of our random division into training and testing sets, we are more surprised by the small variation in the MARS result than by the large variation in the other results. Incidentally, we nearly overlooked the strength of MARS on this data because we initially considered only σ^2_T averaged over the test cases, without looking at the individual errors for each test case. The MARS estimate of DN/M was occasionally very nearly 0, which led to very bad predictions upon inversion to estimate M. These occasional very bad predictions made huge contributions to our estimate of σ^2_T so MARS was not a strong performer among the 10 candidates. This bothersome feature is not eliminated when we fit M/DN because of some very low DN counts. We therefore modified the MARS output to refuse to extrapolate outside the training data. The modified-MARS-predicted DN/M was the MARS-predicted DN/M case (99 percent of cases) if that fell within the range of DN/M observed in the training data. MARS predictions of DN/M that were larger than the maximum of DN/M in the training cases were set to the maximum of DN/M in the training set, and similarly for the minimum.

Finally, we note the possibility of combining three candidate predictors in the sleeve-absent case. We could calibrate using either real coincident neutrons or total neutrons during the passive stage, or using the delayed neutrons that result from the induced fissions. For this subset of the data, the best single predictor is the delayed neutrons, followed by the total neutrons, then the coincident neutrons. For Rep1 with 200 training cases, the modified-MARS-based total variances for coincident neutrons, total neutrons and delayed neutrons were 29.42, 28.2, and 4.74, respectively. When we combine all three assay methods (with weights inversely proportional to variance), we reduce the total variance in the test set to $\sigma^2_T = 3.67$. We could also combine all four methods (rather than use only the modified-MARS estimate) and reduce the total variance slightly more.

Correcting for the Effects of Data Mining

Reference 2 introduced the generalized degrees of freedom concept to include the effect of model selection. The idea is essentially that if we repeated the model selection process on hypothetical repeats of the same data set (with new sets of random errors so the data sets would not be identical in values, only in probability distribution), we would not always select the same model. This effect can be studied by Monte Carlo simulation of hypothetical repeat data sets, and the GDF is defined (informally here, see appendix for formal definition) as the sum of the average sensitivities of the fitted values of the response to small changes in the response.

A good estimate of the variance, σ^2, of the resulting random errors is then the ordinary residual sum of squares (sum of squared errors), divided by $(n - \text{GDF})$, where GDF replaces the usual DF = number of parameters estimated in the chosen model. If we use RSS/DF, we ignore the fact that the chosen model was selected via a search after viewing the training data, rather than in advance. Therefore, it is more appropriate to use RSS/$(n - \text{GDF})$. As an example, applying algorithm 1 from reference 2 to the best-fitting regression tree, with all 236 cases of the 27.904 g of plutonium in various matrices, we find DF = 7 (seven terminal nodes) and GDF = 45.4. The resulting effect revises our estimate of the percent relative standard deviation upward from 9.3% to 11.2%. As an aside, because σ^2 appears to depend on $f()$ in this case, it is better to slightly modify this procedure, but the results will be essentially the same. Because the revision upward from 9.3% to 11.2% was modest, we gain more confidence that there is a real signal in this data (the GDF-based estimate of σ^2 tends to be drastically different from the DF-based estimate only when there is no real signal, that is, when the fitted $f()$ arises from spurious relations due to having a large dimension — number of candidate predictors — and a modest number of cases.)

A more established way to measure the effects of model selection is to report performance on test data (as in Table I, where, for the regression tree in Rep1 with ntrain = 200, we estimate $\sigma = 15.23^{0.5}/27.904 = 13.8\%$). On occasion, it is worthwhile to choose the test cases in such a way that the predictors in the test set are close to the predictors in the training set. For more detail on the merits of such data splitting, see reference 11.

Summary and Conclusions

The application of data-mining methods to NDA data is very promising. Careful attention to the details of model selection and testing are required, but these are not difficult and can be enlightening. As we develop better instruments or improve how we combine instruments, we should continue to analyze closely good data sets such as the one we analyzed here. Benefits can be subtle. If we find outlying matrices, then we would want to know the reason and whether we could build diagnostic methods that tell us when our calibration is not relevant to an item because in some metric it is too far from any of the calibration standards. We have not yet achieved such a diagnostic in this case because our metrics in predictor space did not imply that "close in predictor space" implied "close in response (DN/M) space." That is why our approach 2 performed relatively poorly. There are many possibilities for developing diagnostics that indicate when a sample is too unlike any of the calibration standards. For example, in some cases the samples could be assayed while upright and while turned over, and could be assayed both with and without the moderating sleeve. If assays from all of the assay protocols from the total, coincident and delayed neutrons were very dissimilar, then we might suspect that the mass prediction was poor. It would also be useful to eliminate as many of our 27 candidate predictors as possible to make any analysis method easier. Therefore, we plan to apply feature selection methods (in addition to the types that CART, MARS or projection pursuit regression use) and to determine whether we can begin the problem with fewer predictors (perhaps derived features of the original ones). It is possible that we could find an appropriate subset of the candidate predictors for which "close in predictor space" does imply "close in response space." Probably the most well-known feature selection method is principle component analysis. However, a preliminary principle component analysis did not suggest that we could simply replace the 27 predictors with a modest number of derived predictors (derived by using linear combinations of the original predictors where the linear combination is based on the eigenvectors of the correlation or covariance matrix of the original predictors). Therefore, we plan to try other dimension-reduction techniques, perhaps based on stochastic searches among the 2^{27} possible predictor subsets. We are encouraged by the strong performance of the modified MARS method, but we are very cautious about recommending it for general use without further experience on this type of data. Finally, we have presented some approaches for quantifying the effect of model selection. The new GDF concept is promising when the data set is not large enough to simply reserve 20 percent to 30 percent for testing. Because we rarely have many standards that can be used to train multivariate calibration methods in the manner presented here, we anticipate that it will be critical to get the most information possible out of limited data sets (possibly supplemented with simulated standards).

The application of new and developing data-mining methods will enhance analysis of NDA data. New application areas not yet mentioned here include pattern recognition for weapons dismantlement and multivariate spectral analyses. Honest performance estimates are always desired and rarely simple to provide when the effect of model selection must be considered. Methods such as data splitting and GDF will complement the simpler method of reserving test data when the amount of data is a limitation.

Appendix

Here we define the GDF and give an algorithm to estimate the GDF. See reference 2 for further details.

Definition 1. The GDF for a modeling procedure M with data (y_i, x_i) for $i = 1,2,...,n$ are given by

$$\mathrm{GDF} = \sum_{i=1}^{n} h_i^{M}(\mu), \text{ where}$$

$$h_i^{M}(\mu) = \lim_{\delta \to 0} E_\mu\left[\frac{\hat{\mu}(y + \delta e_i) - \hat{\mu}(y)}{\delta}\right].$$

The idea is to quantify how much the estimated mean of y, denoted μ, would change if the observed y values were perturbed slightly by random errors.

Algorithm 1 to estimate $h_i^M(\mu)$.

- Choose τ in $[0.5\sigma, \sigma]$.
- Repeat $t = 1,2,...,T$ (use $T > n$).
- Generate $\Delta_t = (\delta_{t1}, \delta_{t2}, ..., \delta_{tn})$ from the density $\Pi(1/\tau^n)\, \phi(\delta_{ti}/\tau)$ [ϕ is the Gaussian density].
- Evaluate $\mu_t(y + \Delta_t)$ using the modeling procedure M.
- Calculate h_i^M as the regression slope from

$$\hat{\mu}(y + \Delta_t) = \alpha + \hat{h}_i \delta_{ti}, \; t = 1,2,...,T.$$

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What the Verification Regime Under a Fissile Material Cutoff Treaty Could Be Like: A Preliminary View

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Abstract
The scope of a fissile material cutoff treaty is still a matter of negotiation in the Ad Hoc Committee on an FMCT of the Conference on Disarmament. It will be quite different from that of the IAEA safeguards. However, most of measures to be applied to an FMCT verification would be similar to those of the IAEA safeguards, which are defined in the Model Safeguards Agreement (INFCIRC/153) and the Additional Model Protocol (INFCIRC/540). This paper attempts to give an outline of an FMCT verification regime based upon the experience of the IAEA safeguards system and the Programme 93+2 for strengthening the effectiveness and improving the efficiency of the IAEA safeguards system.

Some General Considerations
In examining what shape an FMCT verification regime ought to take, the basic aim to be borne in mind should be to establish one that is so efficient and effective as to fully ensure the treaty's credibility. It is also important to pursue the examination with the financial implications of the regime constantly in view so that the states participating in the treaty will not find the costs of launching and operating the regime too expensive to bear.

There is a danger of failing to generate adequate interest among and involvement in the treaty by the countries whose participation is indispensable, i.e. the nuclear weapon states and certain countries outside the Non-Proliferation Treaty, if too ambitious an approach is taken with respect to the degree of comprehensiveness and intrusiveness of the verification scope and measures. Such an approach could also result in excessive financial burdens. Conversely, should the approach prove to be too restrictive, the FMCT itself would be deprived of its significance. There is, therefore, a need to strike a good balance in this respect.

IAEA's Role
The IAEA safeguards, i.e. those as set forth in INFCIRC/153, have been in operation since 1971, fulfilling their mission assigned by the NPT. They are being integrated with the Additional Model Protocol (INFCIRC/540, 1997) in the wake of the experiences in Iraq, and this integration will provide a new safeguards system not only significantly strengthened but more cost-effective.

In the interest of establishing an efficient and effective FMCT verification regime, it therefore follows that the IAEA's expertise and experience should be used in full. It is essential that the agency should be involved in the treaty-negotiating process in a substantive way from the very beginning, and it is desirable to put in place some forum such as a working group on verification, enabling specialized consideration of the subject to start early in the process. Because a great number of the verification procedures, measures and criteria required for an FMCT would be identical or similar in character to those already in place under the IAEA safeguards, it seems appropriate that the agency should act as the body implementing verification of the FMCT as well.

The nuclear weapons states and certain countries outside the NPT, in respect of which the FMCT verification is conducted, would need to conclude new (or revised) agreements with the agency, and it would be necessary for these states and the agency to discuss what such agreements should be like in parallel with the treaty negotiations. In this connection, it should be noted that, as regards those countries which already have the IAEA safeguards agreements based on the current INFCIRC/153 model agreement, nothing additional will be required of them.

Scope of the Verification
The objective of the verification is to verify compliance with the obligations of an FMCT and — to put it more specifically, following the relevant expressions in the IAEA safeguards — it should lie in a timely detection of (1) any undeclared production of fissile material for nuclear weapons or other explosive devices and (2) any diversion of such material produced after the entry into force of the FMCT.

To meet these needs, the following should be subject to ver-

Table I.
Significant Quantity Values and Timeliness Goals being used for IAEA Safeguards

Material Type	Significant Quantity[1]	Timeliness Goal[2]
Unirradiated direct-use material[3]		
Pu	8 kg total element Pu	1 month
HEU (20-percent enriched and above)	25 kg U-235	1 month
U-233	8 kg U-233	1 month
Irradiated direct-use material[4]		
Pu	8 kg total element Pu	3 months
HEU (20-percent enriched and above)	25 kg U-235	3 months
U-233	8 kg U-233	3 months
Indirect-use material[5]		
LEU (less than 20-percent enriched)	75 kg U-235	1 year
NEU (natural uranium)	10 t natural U	1 year
DLU (depleted uranium)	20 t depleted U	1 year
Thorium	20 t Thorium	1 year

Table II.
Proposed Classification of Fissile Material for FMCT.

Grade	Material
Weapon grade	Pu[6] (Pu-240 < 19%), no fission products U-233, no fission products HEU[7] (50% < U-235), no fission products
Explosive grade	Pu[8] (19% < Pu-240), no fission products HEU (MEU)[9] (20% < U-235 < 50%), no fission products
Indirect use	Weapon-grade fissile material with fission products[10] Explosive-grade fissile material with fission products[10] LEU (0.7% < U-235 < 20%) NU (DU) (U-235 < 0.7%)

Note: Direct-use material as defined in IAEA criteria corresponds to weapon-grade and explosive-grade fissile materials as described in this table.

ification under the FMCT:

i. All enrichment and reprocessing facilities.
ii. The fissile materials produced after the cutoff date.

In addition, the FMCT verification regime should provide certain nonroutine mechanisms to check undeclared activities in violation of the treaty.

Making Declarations and Establishing an Accountancy System

There are two important steps each country subject to an FMCT verification would have to take to enable the verification to be carried out. One is to make declarations. This is necessary because every verification activity is in effect performed on the basis of the information declared by the country concerned, testing reliability and credibility of such information. Thus, each country concerned is to declare all relevant information about each of the enrichment and reprocessing facilities, including its design, location, type of process used, operational status and annual production capacity used prior to the cutoff date to produce fissile material for nuclear weapons. Likewise, information would have to be declared about inventories, from time to time, of fissile materials subject to verification under the FMCT. As will be dealt with later, what is known as the expanded declaration would also have to be made. The other step is to establish a national system along the lines of the State's System of Accounting for and Control of Nuclear Material in the IAEA safeguards.

Verification Differentiation According to Different Grades of Fissile Material

With respect to the specific levels, both in terms of given quantities of fissile material and timeliness factors of detection, which are referred to in taking verification measures, it seems to make sense to base an FMCT verification regime on the same significant quantity values and timeliness goals as prescribed in the IAEA safeguards. These are shown in Table I.

In conducting the FMCT verification, primary focus should be upon the weapon grade of fissile materials and facilities constructed to produce them, while the explosive grade could be given a secondary attention. Indirect-use materials may be addressed only if deemed necessary. Therefore, it seems sensible to have a way of differentiation in the degree of intensity of verification activities according to different grades of fissile material. Table II, compiled using certain U.S. Department of Energy documents as reference, is one illustration attempting to demonstrate how fissile material might be classified according to differences in grade.

There seems to be global consensus that such differentiation reflects the current practice of nuclear nonproliferation policy, such as the KEDO program being carried out under the Agreed Framework between the U.S. and North Korea, and the program of weapon-grade plutonium irradiation by MOX that was discussed as a major issue at the Moscow Summit in April 1996, and the Denver Summit in June 1997.

Verification Measures I: Facilities in Operation and Fissile Materials Produced

1. With respect to facilities in operation and fissile materials produced after the cutoff date, verification will have to rely on material accountancy (MA) as a safeguards measure of fundamental importance, with containment and surveillance (C/S) as an important complementary measure. It should suffice to carry out verification in the following manner:
   i. For the products of weapon- and explosive-grade fissile

materials defined in Table 2:

— MA of all the products and C/S, if appropriate.

ii. For enrichment facilities:

— MA of HEU products if production takes place.

In order to confirm no production of HEU:

— Limited-frequency unannounced access to cascade area.

— Environmental sampling.

iii. For reprocessing facilities:

— MA of head end and product, near-real-time MA in process area, and C/S, if appropriate.

2. However, if there is no reasonable assurance that there is no undeclared activity and facility to produce the direct-use material, the following two supplementary measures should be required:

   — Supplementary measures against possible undeclared activities on enrichment, where MA of feed materials is required.

   — Supplementary measures for possible undeclared activities on reprocessing, where MA of spent fuels (irradiated direct-use materials) is required.

3. Routine inspections are necessary to carry out the physical inventory verification. For interim verification for timely detection of undeclared production and diversion, nonnotice (or short-notice) random inspections may be called for instead of the routine inspection, because unattended nondestructive assay measurements and continuous-monitoring technologies with appropriate C/S measures have made several types of unattended verifications possible.

4. The question of verifying the production of naval fuel, although falling under the category of facilities in operation, will be addressed in the section below titled "Nonexplosive Military Use."

Verification Measures II: Closed-Down Facilities

1. As regards closed-down facilities, measures would be applied to confirm the absence of any undeclared operation at those facilities, i.e. that operations have been stopped to produce fissile material. Measures applied can be similar to those being developed by the IAEA for similar purposes.

2. Key verification measures would be:

   i. Continuous monitoring of some key plant parameters to ensure that the facility is not in operation.

   ii. Nonnotice random inspection to confirm the facility's operational status.

   iii. Routine inspection (or visit) to check the health status of the monitoring system and its maintenance. This approach should also be applied to Pu and U-233 production reactors, if there is no reasonable assurance regarding undeclared activities concerning reprocessing.

Note: "Closed-down facility" means an installation where operations have been stopped and fissile material removed but which has not been decommissioned. (Article 18 d of INFCIRC/540). "Decommissioned facility" means an installation at which residual structures and equipment essential for its use have been removed or rendered inoperable so that it is not used to store and can no longer be used to handle, process or utilize fissile material (Article 18 c of INFCIRC/540).

Verification Measures III: Nonexplosive Military Use

A typical example of nonexplosive military use of fissile material is that for naval propulsion reactors in which HEU is used. While the matter of such use of fissile material should be addressed in the FMCT verification regime so that the fissile material production for such use may be made subject to verification appropriately, provisions applicable to such use itself could well be substantively identical to those laid down in Article 14 of INFCIRC/153.

Verification Measures IV: Termination of Verification

The termination of verification of fissile material should again be addressed in the same way as in the IAEA safeguards. That is to say that the decision to terminate would be made upon the fulfilment of the termination criteria defined in Article 11 of INFCIRC/153.

Verification Measures V: Undeclared Activities

A set of comprehensive measures against undeclared materials, facilities and activities has been established by INFCIRC/540, considerably strengthening the effectiveness of the IAEA safeguards system and improving its efficiency. These measures should also be applied within the framework of FMCT verification.

The principal measures defined in INFCIRC/540 are (i) the provision of expanded declaration and (ii) the provision of complementary access.

1. Under the provision of expanded declaration, the state shall provide the agency with a declaration containing a general description and information specifying the location of nuclear fuel cycle R&D activities not involving nuclear material subject to the NPT safeguards, a general description of each building on each site in which a nuclear facility exists, information regarding source material not yet subject to the NPT safeguards, and general future plans relevant to the development of nuclear fuel cycle. The declared information is evaluated comprehensively for its consistency with all other information available to the agency.

2. Under the provision of complementary access, the agency has the right of access to any location declared by the expanded declaration in order to resolve any question or inconsistency arising from the evaluation of the expanded declaration, and to ensure the absence of undeclared nuclear materials and activities. Therefore, it generally would be possible to obtain reasonable assurance to conclude that there is no undeclared nuclear materials, facilities and activities.

3. In the case of nuclear weapon states, however, they have the obligation, under Article 1 of the NPT, not to disclose any sensitive information on manufacturing nuclear weapons or

other nuclear explosive devices to non-nuclear weapon states. Moreover, there may be other constraints to make it difficult for them to come forward with otherwise fuller declarations for such reasons as defense and security considerations. This may constitute a significant loophole in the FMCT verification regime, which cannot be addressed by any verification measures mentioned above. Hence, the FMCT verification regime should provide a new inspection scheme similar to the challenge inspection provided in the CWC. Such inspection is to be carried out by the agency's staff, nominated by nuclear weapons states.

4. These schemes would be highly effective in deterring — by the risk of discovery — undeclared activities, and thus they can be instrumental in reducing the overall costs of the verification regime.

Managed Access

It is expected that most of facilities subject to FMCT verification would be located within proliferation-sensitive sites, which are not designed to be placed under the international verification regime. Problems also would exist in a site where military and civilian fuel cycle facilities and activities are not entirely separated. Moreover, all nuclear weapon states have to fulfill their obligation to prevent any dissemination of information concerning nuclear weapons or nuclear explosive devices under Article 1 of the NPT. Difficulties in managing such sensitive information would arise in conducting verification activities at a site where a nuclear weapon program is still carried out. There is no clear way in sight yet to solve this problem, but there would have to be a reasonable solution for it before the entry into force of an FMCT.

The scheme of managed access defined in Article 7 of INFCIRC/540 was developed taking into account such situations and is expected to work effectively to prevent any dissemination of sensitive information, but no procedures have been developed yet even for non-nuclear weapon states. Detailed procedures for managed access to be applied to such a sensitive facility in nuclear weapon states should be developed within that group of states because it is essential to gain access to proliferation-sensitive information, especially concerning weaponization, nuclear weapons, nuclear explosive devices, etc. The procedures developed should be both effective enough to prevent the dissemination of such sensitive information yet transparent to all member states with respect to the areas of concern.

Transparency and Irreversibility

One remaining issue concerns how to deal with fissile materials not subject to the FMCT verification. There is no doubt that each nuclear weapon state is in possession of fissile materials that are not covered by the FMCT, but that have the same physical and chemical characteristics as those subject to the FMCT, such as stockpiles mainly consisting of weapon-grade HEU and separated plutonium. As a way to deal with this issue, a phased approach has been proposed by Australia. There exist also significant amounts of fissile materials for civilian use that are under the IAEA safeguards, with some of them even based upon voluntary agreements with the IAEA. The future study regarding the FMCT verification regime should deal with how to distinguish those materials from irrelevant materials with credible assurance, and how to assure irreversibility to warrant that there is no transfer of fissile material for use in production of nuclear weapons or other explosive devices.

With regard to transparency, the state declaration should cover all enrichment and reprocessing facilities regardless of their scale of operation or current operation activity. If there is no credible assurance about this declaration, some follow-up verification activities must be carried out to meet the objectives of the treaty, which would be expanded to verification of source materials to produce weapon-grade fissile material, such as spent fuel and low-enriched uranium.

Concluding Remarks

The IAEA safeguards, as strengthened with the measures defined in INFCIRC/540 integrated into them, seem to be effective and efficient enough to detect any diversion or misuse of nuclear materials subject to them, even if there is an intention to hide or conceal existing undeclared nuclear materials or activities under a national nuclear program. Although the strengthened IAEA safeguards verification system is still in the process of being developed in its practical application (safeguards approach, verification and evaluation procedures, evaluation criteria, etc.), it would provide a good basis for an FMCT verification regime, serving as a point of reference for the latter's more important aspects, including that of financial implications. It has become evident through this preliminary survey that there are many issues that need to be addressed in depth to arrive at a viable FMCT verification regime. The issues directly related to national security concerns and proliferation of sensitive information appear to be of particular difficulty. Yet it is imperative that all these issues be fully clarified in order to obtain a full picture of the regime.

An Ad Hoc Committee on an FMCT was established under the Conference on Disarmament in August 1998. From what is stated in the preceding paragraph, it is essential for the negotiation body of the committee to be made adequately aware of technical problems that have to be solved before being in a position to have an appropriate verification regime in place. To attain this, necessary technical consideration of the problems involved would have to get under way early in the negotiation process. It is suggested that a forum with such consideration as its task, say a working group on FMCT verification, should be formed as early as possible.

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Notes

1. The approximate quantities of nuclear material in respect of which the possibility of manufacturing a nuclear explosive device cannot be excluded.
2. The period of time used as the objective for timely detection of a diversion.
3. Direct-use material which does not contain substantial amounts of fission products. This includes purified plutonium and uranium enriched to 20 percent or above; it also includes reprocessing plant solutions from the dissolver onwards. Fuel containing direct-use material is considered as unirradiated for verification and timely detection purposes until it is placed in a reactor core.
4. Direct-use material which contains substantial amounts of fission products. This includes core fuel and spent fuel.
5. Includes uranium enriched to less than 20 percent, natural uranium, depleted uranium and thorium. LEU, NU and DU in reactor core and spent fuel at research reactors where reporting of plutonium production is not required is considered to be indirect-use material.
6. Encompasses both weapon-grade Pu (Pu-240 < 7%) and fuel-grade Pu (19% < Pu-240 < 7%) as defined in "Plutonium: The First 50 Years", U.S. DOE.
7. High-grade material of HEU (50% < U-235) defined in Order of DOE-5632.2A.
8. Power reactor grade Pu (19% < Pu-240) defined in "Plutonium: The First 50 Years."
9. Low-grade material of HEU (20% < U-235 < 50%) defined in Order of DOE-5632.2A.
10. Weapon-grade and explosive-grade fissile materials with fission products are combined into "Irradiated Direct-use" in IAEA criteria. These two cannot be used to manufacture nuclear weapons or explosive nuclear devices without reprocessing.

Summary of the Closing Plenary Session of the INMM 39th Annual Meeting

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This article is a summary of the closing plenary session of the INMM 39th Annual Meeting held in Naples, Fla., July 30, 1998. This session was organized by the Government Industry Liaison Committee and chaired by John Matter. There were four invited speakers who addressed special topics of current interest to the INMM membership.

- Richard J.K. Stratford, director, Office of Nuclear Energy Affairs, U.S. Department of State (replacing Robert Einhorn, deputy assistant secretary of state for nonproliferation).
- Leonard S. Spector, director, Office of Arms Control and Nonproliferation, U.S. Department of Energy (replacing Rose E. Gottemoeller, director, Office of Nonproliferation and National Security).
- William M. Knauf, chief of staff, National Security Programs, Sandia National Laboratories (replacing Roger L. Hagengruber, senior vice president, National Security Programs, Sandia National Laboratories).
- Helen M. Bird, program manager, Office of Arms Control and Nonproliferation, U.S. Department of Energy.

China, India, and Pakistan, and the Proliferation Challenge

Remarks by Richard J.K. Stratford
Summary by Robert G. Behrens and James R. Lemley

The first speaker of the closing plenary session was Richard Stratford, director of the Office of Nuclear Energy Affairs at the U.S. Department of State. Stratford addressed the topic of "China, India, and Pakistan, and the Proliferation Challenge" and presented an academic analysis of foreign policy alternatives for addressing nuclear weapons testing in South Asia, noting that his remarks were made on a personal basis and did not necessarily reflect the official views of the Department of State.

Stratford's remarks were presented as two case studies: one study that has been completed (China) and the other that is in progress (India and Pakistan). His talk dramatically illustrated that foreign policy issues are linked and that progress is more likely to be achieved through flexibility than by treating nonproliferation issues in isolation.

Stratford prefaced his presentation with an overview of the nuclear nonproliferation regime, which he characterized as having four parts:

- The Nuclear Nonproliferation Treaty, which established a dividing line between those states with nuclear weapons capability at the time the treaty was created and those that had not detonated a nuclear explosive by that time;
- The International Atomic Energy Agency and its international safeguards system, implemented pursuant to the NPT or other treaty or unilateral commitment by an inspected party;
- Multilateral nonproliferation efforts, including export-control arrangements adopted by members of the Nuclear Suppliers Group or the Zangger Committee; and
- U.S. bilateral efforts involving peaceful nuclear cooperation with states that accept international safeguards, U.S. domestic export controls of sensitive and dual-use technologies, and sanctions related to certain activities.

States such as India, Pakistan and Israel have not been willing thus far to adhere to the NPT or to accept IAEA safeguards on all their nuclear activities, i.e., to forsake the nuclear weapons option. For dealing with such states, the international community's primary response has been to attempt to delay the acquisition of nuclear weapons through implementation of export controls to cut off sources of supply. In some respects, export controls can be an effective tool, but they do not solve the problem. Ultimately, one must change the mind of a potential proliferant. Stratford then discussed U.S. nonproliferation efforts with respect to China and India/Pakistan.

From the early days of the Pakistani nuclear weapons program, the U.S. had been concerned about whether Chinese assistance to Pakistan's nuclear program was assisting Pakistan's nuclear weapons efforts. The U.S. believed it was important to ensure that no such assistance (i.e., to unsafeguarded activities) was being provided or would be provided. One possible vehicle for leverage was the fact that, in 1982, China expressed interest in acquiring U.S. peaceful nuclear technology. The U.S proceeded to negotiate an agreement for peaceful nuclear cooperation with China, and used those negotiations to obtain Chinese assurance that China would not assist the nuclear weapons efforts of other countries. The agreement was signed in late 1985, although the U.S. Congress mandated the development of verification arrangements for U.S. exports and the submission of presidential certifications on China's nonproliferation credentials. In 1986, a verification system in lieu of safeguards was negotiated between the U.S. and China. However, the certifications were not sent forward because of lingering concerns about the nature of Chinese assistance to Pakistan.

Over the next few years, China's nonproliferation policy continued to evolve, and in 1992 China signed the NPT and thereby obligated itself by treaty not to assist other countries to acquire nuclear weapons. China's interest in acquiring nuclear power technology also continued to grow. In 1994, China had significant plans to expand its nuclear power program. Secretary of Energy Hazel O'Leary was going to China in 1995 to discuss various types of cooperation, and the State Department asked her to raise with the Chinese reopening discussions about the implementation of the U.S.-China peaceful nuclear cooperation agreement. China responded positively. From the U.S. point of view, the results of that negotiation would have to provide the basis for the U.S. president to make the certification that China is not assisting countries to acquire nuclear weapons. Discussions began with China in early 1995. However, in May 1995 those discussions were interrupted due to the controversy over the visit to the U.S. by the president of Taiwan.

The discussions resumed in late 1996 after relations had warmed. However, in February 1996 a new issue arose. The media reported that China had shipped ring magnets to Pakistan that could be used in Pakistan's unsafeguarded uranium-enrichment facility. This led to a series of intensive discussions with China about the shipment of nuclear technology to Pakistan and its ramifications with respect to China's obligations under the NPT. Ultimately, these discussions led to a Chinese public statement on May 11, 1996, that China does not provide assistance to unsafeguarded nuclear facilities.

Overall, the U.S. objectives in negotiating with China were: 1) to terminate any assistance to Pakistan's unsafeguarded nuclear activities, 2) to terminate Chinese assistance to Iran's peaceful nuclear program, 3) to promulgate and implement nuclear and dual-use export controls in China, and 4) to have China join one of the multilateral nonproliferation groups. In May 1997, the decision was made to have a U.S.-China summit in Washington. As a result of the pressure of an upcoming summit, the U.S. was able to obtain its objectives in all four areas.

1. The May 1996 statement by China of no assistance to unsafeguarded facilities provided the basis for the necessary presidential nonproliferation certifications.
2. China stated it would not engage in new nuclear cooperation with Iran and would complete all remaining cooperation within a relatively short period of time.
3. In May 1997, the Chinese issued a State Council decree that established export controls and, by September 1997, they had issued full nuclear export-control regulations with a control list. (The Chinese could not get complete dual-use export-control regulations in place in time for the summit, but they were eventually issued on June 14, 1998.)
4. China joined the Zangger Committee in October 1997.

The other nonproliferation case study deals with the long-standing intractable issue of nuclear weapons development in South Asia, with both Pakistan and India testing nuclear explosives in the spring of 1998. Stratford noted that states stay outside the NPT regime for a variety of reasons. Pakistan stayed out because of deterrence against India. India still has not signed the NPT because of a belief that the NPT is discriminatory and protects the nuclear weapons programs of the P-5. There may also be an Indian belief that a nuclear weapons capability conveys great-power status or demonstrates technological and military prowess. Pakistan has not signed partly as a response to India, and because not signing is politically driven, not security-driven.

What would influence India to adhere to the NPT? Global nuclear disarmament? START II and START III? What if the perceived China or Pakistan threat was nullified? Stratford suggests that none of these issues would provide sufficient incentive for India to sign the NPT for a variety of reasons.

What would influence Pakistan to sign the NPT? Would they sign if India did? Perhaps, if dismantling a nuclear weapons program was seen as verifiable. Probably nothing else would influence Pakistan to sign because attempts to that end, including assistance programs, have been unsuccessful for 20 years.

What would influence India to cap its nuclear program? A comprehensive test ban might work because India has tested and no longer needs to test. Perhaps a fissile material cutoff treaty would work, because India has more fissile material than Pakistan. Sanctions might work if they were flexible and discretionary. Sanctions cannot be applied in exactly the same manner to both Pakistan and India because there would be a disproportionate impact on the countries. Sanctions are supposed to apply pressure and influence, not destroy the economy of the country being sanctioned.

What does India want? It wants status as a global power, a U.N. Security Council seat, perhaps status as a nuclear weapons state, global disarmament, nuclear cooperation and advanced technology. Perhaps India's desire for advanced technology could provide incentive to sign the NPT.

What does Pakistan want? It wants to deter India, it wants to be seen politically as standing up to India and it wants to resolve the Kashmir situation.

What does the U.S. want? First, it wants a political dialogue between India and Pakistan that leads to better relations and a peaceful resolution to the Kashmir problem. The U.S. also wants no more nuclear testing, adherence to the CTBT without conditions, entry into good-faith negotiations on a fissile materials cutoff treaty, restraint in the production of fissile material pending completion of the cutoff treaty, no deployment of nuclear weapons or missile delivery systems and formalization of existing policies of restraint in the area of export control.

How does the U.S. achieve these objectives? First, it needs to fully appreciate the impact of imposing sanctions. The U.S. also needs to understand what India and Pakistan can give up politically (perhaps CTBT and FMCT). The bottom line is that the U.S. does not want two new fully deployed nuclear weapons programs. Thus, in the short term, the U.S. needs to get both Pakistan and India to agree not to deploy what they may already have.

The India-Pakistan situation has caused the U.S. to evaluate the entirety of the sanctions regime. There is a serious effort underway within the US. to make sanctions work better. Moreover, the U.S. cannot legislate what is required to lift sanctions. There must be give-and-take in the negotiations. In the near term, U.S. President Bill Clinton was to make a decision as to whether he would travel to South Asia in the fall of 1998. Obviously, both politics and diplomacy were bound up in the decision. In the long run, all of this must lead to a positive and forward-looking relationship with the countries of South Asia. In two to three years, the U.S. cannot be in a situation where it has a negative or hateful relationship with the world's largest democracy. It is, therefore, crucial to pursue a positive outcome to the India-Pakistan testing issue as quickly as possible.

The Role of the U.S. Department of Energy in Nuclear Nonproliferation

Remarks by Leonard S. Spector
Summary by Amy B. Whitworth

Leonard Spector began by noting the progress that has been made since the beginning of the Atomic Age and how we continue to broaden our knowledge so that we may safely recognize the full benefits of the atom. He emphasized that the strength of the international nonproliferation regime is critical to world security and that the collective expertise of those involved in nuclear materials management has been key to nonproliferation and arms control activities. Having gained expertise from the development of the nuclear weapons programs, the national laboratories have been instrumental in addressing international nonproliferation challenges and securing peace.

The precedent-setting work accomplished with nonproliferation efforts in Russia has exceeded expectations. Whereas Russia and the U.S. were on opposite sides during the Cold War, they are now working together in a cooperative manner to increase materials protection, control and accountability, and actively developing transparency regimes to confirm nuclear dismantlement activities. In the past four years of its program activities, the Department of Energy, national laboratories and contractor personnel have secured large caches of nuclear weapons-usable materials, enough for several thousand nuclear weapons.

The United States government, with the technical expertise of the DOE, is working around the globe to prevent the proliferation of nuclear weapons and ensure the peaceful use of nuclear technology. It is working in North Korea to ensure that its nuclear program does not progress to a level at which nuclear weapons could be produced. Significant amounts of plutonium in breeder reactor blanket material are being secured in Kazakhstan with the aid of the DOE. DOE is also ensuring the adequacy of physical protection measures at research reactor sites around the world and working to return U.S.-origin spent research reactor fuel to the United States to prevent it from diversion or misuse in nonpeaceful nuclear applications.

Spector also noted the cultural change that has allowed us to cooperate internationally to further nuclear technology and security while maintaining protection of information to prevent the proliferation of nuclear weapons. This change has facilitated international inspection of DOE facilities and increased our abilities to secure nuclear materials in Russia and the other Newly Independent States. Key to this change is the concept and acceptance of "transparency." The development and implementation of transparency measures have been challenging as they attempt to bring clarity and understanding to a system never designed with transparency in mind and operated under a system of intense secrecy. Spector cited the HEU Purchase Agreement and Trilateral Initiative as examples of the importance of transparency.

Progress in the application of transparency measures on materials declared excess to national security needs in nuclear weapon states has been measurable. At past IAEA General Conferences, former DOE secretaries have announced the availability of increased amounts of U.S. excess fissile material for international inspection and urged other nuclear weapon states to follow suit. The recent declaration of excess material in the United Kingdom and the decision to make some of that material available for international inspection is a great success in the U.S. and Russian efforts in transparency. Spector looks forward to the day when the French and Chinese make similar declarations, as this would result in increased efforts by the P-5 to end the arms race and reduce the role played internationally by nuclear weapons.

In his concluding remarks, Spector warned that, while the U.S. has achieved great progress in the recent past, security can easily be threatened by the proliferation of nuclear materials and know-how. Therefore it is critical to remain vigilant in all nuclear materials security responsibilities.

Executive Review of U.S. Department of Energy Special Nuclear Material Protection Programs

Remarks by William M. Knauf
Summary by M. Teresa Olascoaga

Introduction

William Knauf, chief of staff and executive assistant to Roger Hagengruber, senior vice president for National Security Programs at Sandia National Laboratories, presented a summary of the DOE's Special Nuclear Material Protection Program review, led by Hagengruber for the secretary of energy.

During the past several years, there has been a tendency to overlook the domestic safeguards and security program as more complex global issues have emerged. This is seen as one phase in the cycle described in an article by Desmond, Zak and Tape, "The First 50 Years: A Review of the DOE Domestic Safeguards and Security Program," that appeared in the Spring 1998 issue of the *Journal of Nuclear Materials Management.*

In November 1997, former Secretary of Energy Federico Peña asked Deputy Secretary Elizabeth Moler to help him find a way to bring nuclear material protection to a higher level of attention within the Department of Energy. In response to his request Moler proposed an initiative that consisted of a three-part architecture:

1. A Security Oversight Panel: A panel of experts and leaders representing the entire community concerned with nuclear material issues related to national defense, at the level of the director of the Central Intelligence Agency and the secretaries of energy, defense and state. This panel is to convene periodically to discuss a specific agenda of issues related to nuclear material protection.
2. A DOE Security Council: A panel of DOE leaders, including Under Secretary Ernest Moniz; the assistant secretaries for defense programs, environmental management, and environment safety and health; the director of the Office of Arms Control and Nonproliferation; and an operations office manager. (Bruce Twining of the DOE Albuquerque Operations Office is the current field representative.) The council is to convene more frequently than the oversight panel to address issues of significance related to DOE's nuclear material protection program.
3. An Expanded Special Review: An initiative intended to take stock of the direction being taken by the domestic safeguards and security program.

The review has focused on overall security system performance, as opposed to assessing compliance of a specific site system to the design-basis threat alone. Although the profiling has included some element of observation and measurement of effectiveness, there was no evaluation of programs in the context of grading. This review was not designed as an inspection or as any of the other more traditional oversight activities.

The review was designed around a three-phased concept. Phase I was the scoping activity that Knauf discussed in his presentation. One of the outcomes of the first phase would be an identification of the priority issues requiring action by the DOE to assure an enhanced materials protection program. The plans for a Phase II will be based on the prioritization of initiatives developed and identified during the site visits in the first phase based on a more comprehensive site-specific analysis. This more detailed assessment would include both near- and long-term recommendations and action plans to strengthen the facilities protection program. The Phase II activities would be the installation of those near-term improvements/changes to the operations. Finally, Phase III will address the longer-term recommendations, with the objective of putting in place at each facility an integrated and cost-effective safeguards and security system that provides necessary and sufficient protection against the required design-basis threat for all special nuclear material targets.

Knauf noted that the commissioning of this executive review indicates a renewed commitment on the part of DOE and the U.S. to a stronger and more dynamic program of nuclear material protection in the DOE complex.

Special Review Team Composition

A key objective of this special review for domestic security is to frame the challenges for the future strategically, i.e., to lay the groundwork for institutionalizing an effective and agile program of the future based on the appropriate priority on nuclear materials protection in the DOE complex. Roger Hagengruber was asked to lead this review not as a representative of Sandia National Laboratories but as an individual with subject-matter expertise and experience, particularly in terms of accountability in an operational environment. As Sandia's senior vice president for national security programs, Hagengruber is required to maintain an effective balance between nuclear materials protection (safeguards and security) and weapons and nonproliferation R&D programs. This role has provided him with experience in balancing the needs and requirements of a materials protection program with the available resources to meet programmatic commitments. Additionally, the combination of Hagengruber's organizational responsibility for Sandia's security systems organization and his many years experience with national security compartmented programs serve to qualify him uniquely for the assignment to conduct this review.

Hagengruber, recognizing the pitfalls of working in a vacuum, sought the participation of other experts to advise him and to validate his perspective. He formed a group of advisers from the DOE nuclear community (senior reviewers). These advisers consisted of senior, very experienced veterans, including retired DOE deputy secretaries, executive-level program managers and operations-office managers. These senior advisers shared one common characteristic: They have always been bold and dynamic in dealing with programmatic and business challenges, particularly those faced when they were in positions of significant responsibility and accountability.

Hagengruber also was assisted by a technical group (the technical team) that included a core cadre of security specialists from Sandia National Laboratories, DOE's lead laboratory for physical security. He further augmented the team with material control and accounting experts from Los Alamos National Laboratory and selected supporting consultants.

Special Review Approach

The special review required the technical team, in collaboration with the management of the operating site and facilities, to gain an understanding of the facilities and operations where nuclear material of significance is present in the DOE complex and to determine if that protection is effective. Facilities and operations at 12 sites were examined. They were Rocky Flats Environmental Technology Site, the Oak Ridge Y-12 Plant, the Savannah River Site, Pantex, Hanford, Los Alamos National Laboratory, the Transportation Safeguards Division, Sandia National Laboratories, Lawrence Livermore National Laboratory, Idaho National Engineering and Environmental Laboratories, Argonne National Laboratory — West, and the Nevada Test Site.

Before any fieldwork began, Hagengruber met with the principal DOE program office managers (defense programs; environmental management; energy efficiency and renewable energy; and nuclear energy, science and technology) and with DOE nonproliferation and national security and environment safety and health managers to gain a better understanding of protection program management and policy formulation. This was an important aspect of the review, given the goal of institutionalizing a sustained management effort and setting an effective nuclear material protection course for the future.

Reflecting on his own professional experience, Hagengruber recognized the need to review DOE's material protection program in the context of changing times and the associated evolving missions of its facilities and operations. In the late 1970s and early 1980s, the DOE complex had a very specific national security purpose, and DOE's programs for operation, material protection and oversight were tailored to meet the challenges of that purpose. Performance testing of material protection systems was introduced during those years; it helped to stimulate management attention and raise safeguards and security to a higher priority, resulting in more resource allocation to protection programs and, above all, operational improvements. These programs were left to lie fallow as other priorities emerged during the 1990s and as missions were redefined. The secretary of energy has directed the DOE to recommit to the goals of nuclear material protection while, in response to those redefined missions and priorities, the DOE complex transitions from an era of production to the challenges of managing and protecting SNM in storage, in transport and throughout the disposal processes.

After developing a review plan and a schedule at each facility in cooperation with program and site management, the technical team typically visited the site for two to three days. They held discussions with site personnel, toured site facilities and reviewed site security documents and plans. During their review, the technical team shared and coordinated all of their observations with site management and staff. At the end of their visit, a summary of observations was provided to and validated with site personnel.

Following a briefing by the technical team, Hagengruber and the senior reviewers visited each of the reviewed sites. They toured selected site facilities and discussed their observations with senior site and DOE managers. Hagengruber held private meetings with both DOE and contractor senior managers and provided a classified threat briefing to specified DOE site management and staff. He also led a discussion at each site involving the senior reviewers and the site personnel, in which observations were discussed and a dialogue regarding recommendations and suggestions was begun based on the observations made by the technical team and the senior reviewers.

Special Review Results

Knauf was unable to be specific about the results of the review because, at the time of the presentation, Hagengruber had not yet reported his observations to the acting secretary of energy. Results of the review were discussed with Acting Secretary Elizabeth Moler Aug. 10, 1998, prior to a briefing with the DOE Security Council Aug. 11. These briefings served as a formal report of the conclusions drawn from the Phase I review and contained recommendations addressing all elements of the safeguards and security program, including organization, policy formulation and implementation, and interactions in the operating environment.

[Note: A brief summary of the special review results, not provided during the presentation of this paper, is provided in this article because the appropriate DOE management has now been briefed.]

The review indicated that, in the current operating environment, there is more available and accessible nuclear material in different places and in different forms than was formerly the case. There are new processes being implemented that call for different approaches to the protection and management of SNM inventories. Moving material from one site to another as facilities are closed, e.g., Rocky Flats, also poses new challenges. In general, the Phase I analysis indicated that there is no crisis in security, but there is a need in specific cases to reconsider protection system designs consistent with changes in the threat, the type and accessibility of nuclear material, and the operating environment.

Hagengruber provided a number of recommendations for actions to address the issues that were identified during his study. Emphasizing that there is not a crisis in security, Hagengruber's study documented and acknowledged that there are compliance issues throughout the DOE complex that create vulnerabilities associated with critical reviews. Much of the lack of compliance and related lack of closure and formality observed in the operation of the DOE protection programs seems to reflect that a larger vulnerability comes from the internal processes (e.g. roles and mission responsibilities) of the DOE itself. Accordingly, the study's recommendations include the following.

- Declare an initiative to restructure protection program management by moving to an integrated security management approach. This would provide clear assignments and delegations of roles, responsibilities, authorities and accountabilities for the DOE.
- Create an organizational focal point for safeguards and security program management. Integrate the function so it reports to the deputy secretary and includes all those current headquarters activities essential to high-level program integration and which would enable efficient strategic management of the materials protection program.
- Change the current site safeguards and security planning process and clearly establish line-management authority and accountability. The field office manager should have the authority of the secretary to sign this license.
- Change the design-basis threat approach and process.
- Provide a modest increase in funding for materials protection program-related research and development, some selected site upgrades and restructuring. Also, continue to pursue the deputy secretary's initiative to develop a multiyear safeguards and security plan (Phase II) and to commit to the implementation of the actions identified in the plan (Phase III).

Conclusion

It is hoped that the observations of the special review team will result in greater support for the ongoing DOE headquarters' effort to realign the dômestic nuclear material protection program with current missions and operating conditions. This requires taking protection measures that, in part, are still effective and tailoring them to meet the challenges of a new era in the materials protection mission. Hagengruber has expressed the hope that some successful and meaningful change will be generated by this study, particularly in light of the high-level recommitment to nuclear material protection throughout headquarters and the field.

When he reported the study results to DOE headquarters management, Hagengruber observed, "An opportunity exists to take the high ground and to declare leadership in government 're-engineering.' In doing it in the right way, it will not be seen as an attempt to deal with problems and critics, but rather as an effort to restructure our management and operation of DOE's protection programs to better fit the 21st century ... not to repair, but to build. Excellent opportunities exist to use new approaches to re-engineer for all the sites and to do it in a positive way."

Operation Auburn Endeavor

Remarks by Helen M. Bird
Summary by Bruce W. Moran

Helen Bird was the program manager responsible for Operation Auburn Endeavor in the U.S. Department of Energy's Office of Arms Control and Nonproliferation. Operation Auburn Endeavor was the code name provided to the transport of highly enriched uranium from the Republic of Georgia to the United Kingdom. Auburn Endeavor was conducted as a part of the U.S. commitment to reducing the global nuclear danger and resulted from U.S. activities conducted by DOE's Materials Protection, Control and Accounting task force and nonproliferation organizations.

In 1996, a U.S.-led physical protection team visited the Tbilisi Applied Research Center in the Republic of Georgia as part of the Nunn-Lugar Cooperative Threat Reduction Program. The team included members from the DOE MPC&A task force, led by Michael Haase; the U.K.; and the International Atomic Energy Agency. The team found 4.3 kg of inadequately protected fresh HEU and about 800 g of irradiated HEU of varying quality, resulting from experiments conducted at the research reactor.

Georgia was concerned with the long-term security of the material. Although the HEU material at this site was not enough to make a bomb, it was feared that a rogue nation or terrorist organization could collect this material and, adding it to other material, make a bomb. Georgia could not afford a program to improve the protection of the material at a research reactor that had been closed since 1988. Thus, they sought assistance to resolve the problem in accordance with their responsibilities under their nonproliferation obligations. The MPC&A task force determined that long-term upgrades were not sustainable due to poor security at the site, the lack of consistent access to electricity and the volatile situation in the general region of the Caucasus. Interim actions were required to protect the HEU until removal of the material could be effected.

In May 1996, the task force installed, in one week, temporary physical protection upgrades. Nondestructive assay measurements were performed to characterize the materials. The DOE Office of Arms Control and Nonproliferation, along with experts from the Oak Ridge Y-12 Plant and NAC International, developed detailed plans for the packaging and transport of the material. The U.K. agreed to the transport of the material to their processing facility in Dounreay, Scotland. Prior to the actual packaging and transport operation, DOE conducted a thorough safety evaluation and site survey of the research center, procured the equipment to be used in the operation, and planned the transport route, logistics and everything else that was needed to eliminate delays in the work schedule.

The packaging and transfer operations were initiated April 17, 1998, and completed April 22, well ahead of schedule due to the team's enthusiasm, good planning and the good weather. There were no problems with the equipment. The material was picked up in Georgia by two Air Force C-5 cargo aircraft and transported to the U.K. Upon the arrival of the material, the U.K. took responsibility for the transport to Dounreay. The material was transferred to Dounreay at night by truck April 24.

The major considerations in undertaking this international nonproliferation activity were the partnerships needed. Bird emphasized the importance of the international and U.S. interagency cooperation. This was a lesson learned during Project Sapphire and reinforced during this operation. Removal of at-risk HEU from one country to another is complicated. Without the assistance of Georgia, the U.K. and the IAEA, Operation Auburn Endeavor could not have been completed. The Georgians explained how the facility worked and provided people to support the packaging process. The U.K. agreed to take the HEU quickly and without reservation. The IAEA was kept informed throughout the process and was invited to verify the movement of the material. In June 1998, the IAEA was provided with the NDA measurements taken during the trip. The Republic of Georgia supported the entire effort, exemplifying their commitment to the Nuclear Nonproliferation Treaty and nonproliferation in general.

Additionally, close interagency cooperation between the State Department, DOE and Department of Defense on many different aspects of the operation had to occur. The DOE provided the planning and the technical expertise from the DOE complex. The DOE's greatest concern was the safety of the operation. The State Department provided negotiation expertise; the Department of Defense provided coordination and security, as well as the transportation arrangements. Quick response was possible once decisions were made to minimize the vulnerability of the HEU to prevent potential theft or accident. Fast solutions were found to physical protection difficulties and potential threats to the HEU. Transport of the HEU had to occur as quickly and quietly as possible.

Technological solutions were identified to assist in those cases where there was no standard solution to a problem. For Operation Auburn Endeavor, a special transport cask was designed by NAC, built and put into use quickly. The transfer of HEU across international boundaries required a variety of expertise from nuclear scientists and careful planning. Logistics was a large part of the process.

Chapters

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Southwest

The Southwest Regional Chapter held its annual elections in October. Thanks are extended to the candidates and all of you who voted. The results are:

- Cindy Murdock — president
- Chad Olinger — vice president
- Cary Crawford — secretary/treasurer

Members-at-large:

- Al Garrett
- John Jackson
- Relf Price
- John Tuttle

The Executive Committee met at the Nonproliferation and National Security Institute Dec. 7 to plan for the year. The chapter's goals this year are to increase chapter membership and advance the chapter's educational outreach program. The chapter's technical meeting is being planned for the spring in Denver.

Cary Crawford
Secretary/treasurer, INMM Southwest Chapter
Wackenhut Services Inc.
Albuquerque, New Mexico, U.S.A.

Vienna

The election of chapter officers was held in August. Chapter Executive Committee members for 1998-99 are:

- Jaime Vidaurre-Henry — president
- Anita Nilsson — vice president
- Lorilee Brownell — secretary
- Richard Hartzig — treasurer
- Jill Cooley — past president

Members-at-large:

- Reinhard Antonczyk (second year of two-year term)
- Ira Goldman (first year of two-year term)

At a chapter luncheon meeting Sept. 24, Thomas Lewis, director of the Support Service Group of the Space Imaging Corp., spoke on the topic of commercial satellite imagery and potential applications for IAEA safeguards.

The chapter had another luncheon meeting Nov. 19. Chung-Won Cho, councilor of scientific affairs at the Permanent Mission of the Republic of Korea, spoke about the role of State Systems of Accounting and Controls for nuclear materials in the Strengthened Safeguards System.

The International Science Fair took place Dec. 5 at the Lycée Française in Vienna, Austria. The INMM Vienna Chapter was one of the sponsors. Mark Assur of the U.S. Mission in Vienna chaired the event. The theme was "Oceans and the Environment."

Jaime Vidaurre-Henry
President, INMM Vienna Chapter
International Atomic Energy Agency
Vienna, Austria

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May 2–7
IEST 45th Annual Technical Meeting and Exposition, Ontario Convention Center and Ontario DoubleTree Hotel, Ontario, California. Sponsor: IEST. Contact: IEST; phone, 847/255-2561; fax, 847/255-1699; e-mail, iest@iest.org; Web site, http://www.iest.org.

May 10–14
18th International Conference on Incineration and Thermal Treatment Technologies, Radisson Twin Towers, Orlando, Florida. Sponsor: University of California, Irvine. Contact: Lori Barnow Cohen; phone, 949/824-5859; fax, 949/824-8539; e-mail, lbarnow@uci.edu.

May 19–21
NEI Nuclear Energy Assembly, The Washington Monarch Hotel, Washington, D.C. Sponsor: Nuclear Energy Institute. Contact: NEI Conference Office; phone, 202/739-8000; fax, 202/872-0560.

June 6–10
ANS Annual Meeting, Boston Marriott Copley Place, Boston, Massachusetts. Sponsor: American Nuclear Society. Contact: Richard J. Cacciapouti; phone, 978/568-2140; fax, 978/568-3700; e-mail, cacciapo@yankee.com; Web site, http://www.ans.org.

June 28–July 2
10th Annual Engineering and Science Conference, Obninsk, Russia. Sponsor: Nuclear Society of Russia. Contact: S.V. Kriukov, Nuclear Society of Russia; phone, 095-196-73-00; fax, 095-196-18-36.

July 25–29
INMM 40th Annual Meeting, The Pointe Hilton Resort at Squaw Peak, Phoenix, Arizona. Contact: INMM; phone, 847/480-9573; fax, 847/480-9282; e-mail, inmm@inmm.org; Web site, http://www.inmm.org.

September 20–24
6th International Conference on Facility Operations–Safeguards Interface, Jackson Hole, Wyoming. Sponsor: ANS. Contact: Mike Ehinger; phone, 423/574-7132; fax, 423/574-3900; e-mail, mhe@ornl.gov.

October 3–6
NEI International Uranium Fuel Seminar 99, The Sagamore on Lake George, Bolton Landing, New York. Sponsor: Nuclear Energy Institute. Contact: NEI; phone, 202/739-8000; fax, 202/739-8171.