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INMM workshops offer hot-off-the-press information

Recently I attended a review meeting on the Surplus Fissile Materials Control and Disposition Project, sponsored by the U.S. Department of Energy. The person responsible for the meeting showed a viewgraph that simply stated, "The main thing is to make the main thing the main thing." As I reflect on our professional society and the issues that face nuclear materials management, I firmly believe our society is the main thing when it comes to professional societies supporting the main thing today in the nuclear field, namely, the management of nuclear materials.

I can recall several years ago, when the INMM executive committee considered changing the name of our society to reflect more of the issues of those days. We debated the pros and cons and concluded that a change would not be warranted. In retrospect, it appears that our founding fathers had considerable vision in selecting the name of the Institute. We could not think of a more appropriate name today.

Several people expressed to me the benefits of our workshops, particularly the fact that the information shared in the workshops is timely and hot-off-the-press. We have had three workshops and one technical division meeting during this fiscal year, which began Oct. 1, 1993, and all focused on timely issues.

The Waste Management technical division, chaired by Ed Johnson, held a workshop in January in Washington, D.C. Attended by 175 people, the principle issue addressed was the question of when the DOE will commence accepting fuel for storage and disposal, and this was thoroughly discussed by the director of the DOE's Office of Civilian Radioactive Waste Management, a staff member of the Senate Energy and Natural Resources Committee, a member of the Nuclear Waste Institute and the U.S. Nuclear Waste Negotiator. Another major issue was the use of the multi-purpose canister in the combined utility/DOE system. Also discussed was the disposal of DOE-owned spent fuel.

The Nonproliferation and Arms Control technical division, chaired by Ruth Kempf, also held a workshop in Washington, and focused on activities associated with the ongoing efforts with the independent states of the former Soviet Union.

This workshop, held in early April with an attendance of 60, was certainly timely. The keynote speaker, Wolfgang Panofsky, is a major author of the recent National Academy of Science study titled *Management and Disposition of Excess Weapons Plutonium.* The results of this study are widely known and are being used as the foundation for several new initiatives. To highlight the timeliness of the workshop, a representative of the DOE began his talk with, "The treaty of the week, at least as of today…," and he discussed the latest regarding the joint reciprocal inspections between Russia and the United States in the area of weapons dismantlement. In this issue, you will find several of the papers presented at the workshop.

Bruce Moran organized the third workshop, sponsored by the Materials Control and Accounting technical division, which is chaired by Rich Strittmatter. It was held in May at Oak Ridge, hosted by Martin Marietta Energy Systems, and 70 attended. Issues focused on nuclear materials in the DOE complex, including storage versus reprocessing, plutonium and uranium storage standards and the varying focus of diverse DOE orders. I urge you to read the report prepared by Bruce in this issue.

In the last issue of the *Journal*, I briefly discussed the technical division meeting I referred to above, the International Safeguards technical division meeting held in March in Vienna at the International Atomic Energy Agency. The main topic was transparency, and Division Chair Cecil Sonnier included a report in this issue of the *Journal*, encompassing four white papers on the topic, which I believe you will find quite interesting.

The workshops and meetings highlight the benefit to the profession, and together with our annual meeting, provide the forum for exchanging important views.

We received word from Willy Higinbotham that because of illness, he will not be able to support the Institute, and particularly the *Journal*, as he has in the past. All of us express our sincere gratitude to Willy. He has helped considerably in improving the professionalism of our Journal, and he has been one of our staunchest supporters. Thank you, Willy!

Dennis Mangan, Chair
Institute of Nuclear Materials Management
Sandia National Laboratories
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The six INMM divisions are a great service of the Institute

This issue contains a description of a workshop sponsored by our new Nonproliferation and Arms Control Division, a description of a meeting held recently in Vienna by our International Safeguards Division, and technical paper from both topical meetings. The previous issue contained an article by Pierre Saverot on low-level waste treatment. The next issue will contain a second article on the subject, representing an activity of our Waste Management Division, which has sponsored 11 annual symposia on management of spent reactor fuel.

With all this activity going on, it seems to be a fitting time to review how the Institute has developed in order to be of greater service to its expanding membership.

Although I have been writing this column for 21 years, I am not one of the original material managers. They were those who were responsible for accounting for the nuclear materials at government and privately owned nuclear facilities from 1954 until 1967. Although they were responsible for accounting for the materials, waste discards were estimated and the materials were controlled by the production managers. The modern era for U.S. national safeguards began in 1967 when the Atomic Energy Commission established new safeguards offices to define and enforce national safeguards regulations and to provide technical support to the International Atomic Energy Agency (IAEA).

Anticipating ratification of the Nonproliferation Treaty (NPT), the IAEA-sponsored safeguards symposia in 1969 and 1970, which were attended by many of us who had recently become involved in safeguards. We tended to assume that material accounting was the basic safeguards measure for national safeguards as it was for the IAEA.

The first INMM annual meeting that many of us attended was held in Las Vegas in 1970. Sam Edlow explained that a cylinder with highly enriched UF-6 was lost during a shipment. Obviously, something more than materials accounting was needed. The newcomers began to work with the materials managers on the next annual meeting, to expand its scope and invite papers from overseas. In 1973, Mason Willrich and Theodore Taylor warned that subnational adversaries could steal highly enriched uranium or plutonium by force. Suddenly, physical protection became the focus of national attention. Then, the problems associated with diversion and theft by authorized insiders was recognized and the appropriate measures to counter this were discussed.

By 1975, the INMM had four major activities: national material accounting, national physical protection, international material accounting and international containment and surveillance. Many of those involved in the development of IAEA safeguards in other countries attended and participated in our national meetings. We had a number of members in other countries, and chapters were formed in Vienna and in Japan. The Institute was now an international professional organization. A substantial fraction of the U.S. membership were involved in improving national material control and accounting, and physical protection systems and techniques. Most of our foreign members were primarily interested in IAEA safeguards. Through our participation in the development of standards, the U.S. section became involved with waste management and transportation of nuclear and radioactive materials. Then, with the end of the Cold War, many of our members became involved in arms control and nonproliferation activities.

These new activities led to the recent adoption of six division to complement and extend the previous action committees:

- International Safeguards
- Waste Management
- Transportation
- Nonproliferation and Arms Control
- National Material Control and Accounting
- National Physical Protection

As this issue illustrates, all of the divisions are active and most of them are taking on an international flavor. Hopefully, more of our non-U.S. members will take an interest in national MC&A and physical protection, since each state depends on other states to protect their sensitive nuclear materials and to prevent sabotage of their nuclear power reactors.

William Higinbotham, Ph.D.
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Upton, New York, U.S.A.

Divisions: MC&A

INMM sponsored the second workshop on long-term special nuclear material (SNM) storage on May 3–5 in Oak Ridge, Tenn. About 70 people representing more than 30 orgzanizations attended the workshop, which focused on improving the effectiveness and efficiency of long-term storage through safety, safeguards and operational interactions.

The first session of the workshop consisted of presentations on various long-term storage issues. For the afternoon session, U.S. Department of Energy personnel with interests in long-term SNM storage presented a panel discussion. Panel members represented the offices of Defense Programs, Nuclear Material Disposition Project, International Safeguards, and Safeguards and Security. Following the panel discussion were discussions of storage systems and storage concepts used at the Oak Ridge DOE facilities and throughout the DOE complex.

On the second afternoon of the workshop, the attendees divided into assessment teams to apply long-term storage concepts to a variety of storage facilities in Oak Ridge. These facilities ranged from Category I vaults for storage of highly enriched uranium metal through Category IV storage areas for irradiated materials. Some of these facilities are being converted from active to passive storage applications. Each assessment team was assigned one storage configuration to evaluate, and team went on a facility tour to view its assigned storage system and other storage systems in the area. The storage issues identified by the teams were combined to develop recommendations toward resolution of the issues.

Bruce Moran
Martin Marietta Energy Systems Inc.
Oak Ridge, Tennessee, U.S.A.

Chapters: Central

The INMM Central Region chapter sponsored a day-long technical session at the WATTec Conference and Exposition, on Feb. 21–25 in Knoxville, Tenn.

The session focused on technology transfer from the U.S. Department of Energy facilities to the commercial sector. Session Chair Francis Kovac, Martin Marietta Energy Systems, gave the opening remarks. Approximately 50 people attended the session during most of the day.

During the WATTec Conference awards luncheon, Bruce Moran received the INMM Central Region Chapter Distinguished Service Award for his contributions as a chapter officer and as a technical chair of the INMM's WATTec session and the chapter's past annual meetings. (See picture below.)

Central Region member John Wachter was the vice chair of the conference; James Saling represented the INMM on WATTec's Sponsors Committee.

In other chapter news, the Central Region Executive Committee spring meeting was held March 28 in Lexington, Ky. The meeting focused on plans for the next annual meeting and the next chapter election. The next chapter meeting will be Oct. 27–28, 1994, in Lexington.

Bruce Moran, Chapter Secretary
Martin Marietta Energy Systems Inc.
Oak Ridge, Tennesses, U.S.A.

Francis Kovac
Oak Ridge National Laboratory
Oak Ridge, Tennessee, U.S.A.

Francis Kovac, WATTec '94 Technical Program Sponsor, awards Bruce Moran the INMM Central Region Chapter Distinguished Service Award in recognition of "the many years of commitment, dedication and service to the INMM Central Region Chapter."

Chapters: Vienna

At a special session of the March 14 -18 Safeguards Symposium at the International Atomic Energy Agency (IAEA) in Vienna, Italy, the five men who have headed the Agency's Department of Safeguards since 1969 reflected on their terms of office and gave their thoughts on the direction safeguards should take in view of the events of the '90s. The session was followed by a reception for all symposium participants, hosted by INMM headquarters, and the Japan and Vienna chapters.

The five men were Rudolf Rometsch, who headed the Department from 1969 to 1978; Hans Gruemm, 1978 to 1983; Peter Tempus, 1983 to 1987; Jon Jennekens, 1987 to 1993; and Bruno Pellaud, the current department head. The first department head, Alan McKnight from Australia, held the post from 1964 to 1969, which was the time when the first Safeguards System (INFCIRC /66) was formulated. He died a few years ago.

Following is a synopsis of the department heads' remarks.

Rudolf Rometsch

The biggest single event in this term of office was the drafting of the safeguards agreement subject to the Nonproliferation Treaty (NPT), today known as INFCIRC/153 or simply *the blue book.* This was drafted in 1970-71 in a period of eleven months, with meetings interrupted by only two brief holiday breaks. For political reasons, all Agency Member States had to have access to these sessions, so the drafting took place in what was known as the Committee of the Whole. About 55 delegations attended these meetings, some with as many as 20 delegates, so about 300 people attended the drafting sessions. As the head of the Safeguards Department (at that time he was known as Inspector General), Rometsch was scientific secretary of this committee.

There were two important points in this agreement that have a great deal of relevance today. The first was that the safeguards system be nondiscriminatory and objective for all Member States under NPT. This led to inspectors going to each safeguarded state and gathering pieces of information that were fit together back in headquarters, like the pieces of a puzzle. The result was that the inspection effort devoted to each state was in proportion to the size of the state's nuclear industry, and hence a few states got the biggest part of the agency's safeguarding effort, quite independent of whether or not they represent the greatest diversion risk.

This situation has been the subject of discussions right up to the present day, and Rometsch volunteered a solution: each national nuclear industry under safeguards should be subject to a sort of peer group review, with a group of experts posing questions with the object of determining the overall extent of each national program.

The second point in the agreement was that Agency inspectors could not look for undeclared facilities, "so it should be no surprise that a system not designed to detect undeclared facilities, when the time came, did indeed fail to detect one," Rometsch said.

He ended by noting the importance that the NPT safeguards system be kept under review and adapted to changing conditions. The inspection work of the agency may by no means become petrified.

Hans Gruemm

When Hans Gruemm took over as head of the department in September 1978, he felt that with the NPT agreement in place, his work would be more or less routine. He quickly found out that was not so.

With the coming of EURATOM (Ispra, Italy) and Japanese facilities under NPT safeguards, an enormous staff increase was needed and he was


Five deputy directors general of the IAEA Department of Safeguards — four former and one current — address the Vienna Safeguards Symposium in March. From left to right: Rudolf Rometsch, Hans Gruemm, Peter Tempus, Jon Jennekens and current director Bruno Pellaud.

faced with convincing the Member States to increase the department's staff from 200 to 400 over a five-year period.

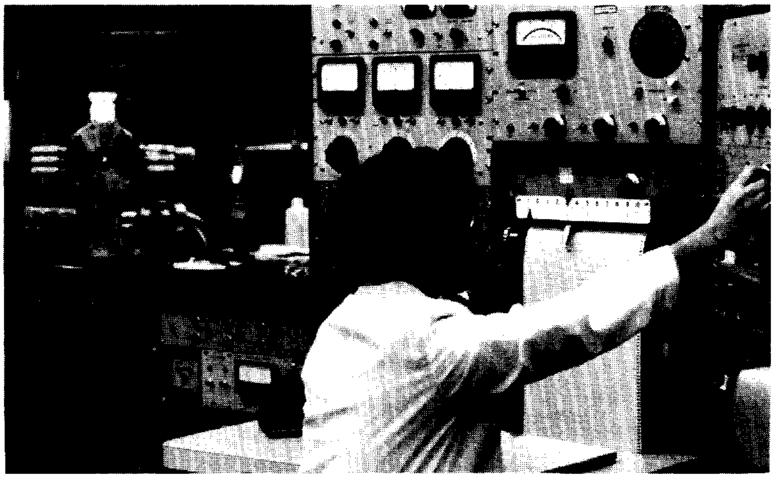
At the same, time verification activities were strengthened through an increase in training facilities, an improvement in instruments and the introduction of computers. A most important step was the replacement of *detection* goals by *inspection* goals, the latter being something that was technically feasible to attain. However, the Member States remained adamant that Agency safeguards were not to be concerned with undeclared facilities or material despite the fact that the department managed to include the two terms in the 1980 *Safeguard's Glossary.*

When Israel attacked a French-supplied research reactor in Iraq on June 7, 1981, the Agency was under a storm of political and media criticism. Finally, both the Board of Governors and the UN General Assembly sided with the Agency, but the media criticism remained. It was heartening when, in the aftermath of the Gulf War, it was learned that no material under our safeguards had been diverted into Iraq's clandestine nuclear weapons program.

The Israeli attack was not the only crisis during Gruemm's tenure. The irradiation by Pakistan of indigenous fuel in its Canadian-supplied reactor led to another flurry of political activity.

Looking to the future, Gruemm has two concerns. First, there should continue to be adequate financing of the department's activities. Financing is always a problem, even though safeguard's annual budget is about the price of one rather modest military aircraft, and the cost of safeguards, if passed on to the consumers of nuclear generated electricity, would increase the cost by about 0.04 mills per kilowatt-hour. His second concern is the prospect for the extension of NPT at the 1995 review conference, which he is fairly sure will happen.

In closing, Gruemm said: "Safeguards was the first institution in the history of our restless species to be



entrusted, in the interests of global peace, to inspect sensitive facilities using foreign nationals. I am convinced that the department will continue to live up to this noble responsibility, also in the years to come."

Peter Tempus

Peter Tempus arrived after years of stormy development in the department of safeguards, after the conclusion of the NPT agreement, after huge increases in staff, and after the negotiation of agreements, subsidiary arrangements and facility attachments. What was needed was consolidation. " I had the feeling when I came that I had inherited not a Safeguards Department but a federation of safeguards divisions," he said. Fortunately for this period of consolidation there were no major problems while he was department head. Indeed, his was the only term of office that did not have a crisis of some sort.

Some of the measures he implemented were not welcome at first, such as a computerized inspection report. He also insisted that firm rules, as spelled out in the Safeguards Manual, should be followed. In retrospect, he feels this was perhaps the end of the classical period of INFCIRC/153. "At that time [it] was a sort of bible and while knowing about certain flaws and difficulties, nobody really questioned this document."

It was exasperation with the board's budget committee and the questions of the Member States about the cost of safeguards, what are good safeguards and how much safeguards are enough that caused Tempus to institute safeguards criteria. He recalls the many department discussions that led to their formulation and again there was a heated debate whether undeclared material and undeclared facilities should be mentioned. "It was pointed out to me that Member States are honest states and such things have no place in the criteria," Gruemm said. Nevertheless, the criteria was approved, although they did not lead to any relaxation of budget constraints, which was the initial reason for their formulation.

Looking to the near future of safeguards after the events in North Korea and Iraq and the breakup of the Soviet Union, he reminded the audience that safeguards is as much a business of politics as it is of technology. It should not be assumed that there is agreement just because there is a consensus in the Board of Governors. This may merely signify that diplomats do not have the courage to say no even when no political agreement exists.

Of considerable concern to Tempus is the continual eroding of safeguards salaries and the conditions of employment for inspectors. This was already underway during his term of office and it continues. It has now reached the point that salaries are no longer sufficient to attract candidates from many nations and these in general are the ones with well-developed nuclear programs. While salaries are still attractive to candidates from the former Soviet Union, in time this could result in an overall imbalance in the composition of the inspectorate.

In closing, Tempus wished the department well with the difficult work ahead. " I wish to encourage ... (you) ... to really stand up and make your opinions clear so that those, mainly on the political and financial side, know what way you are thinking."

Jon Jennekens

Jon Jennekens first paid tribute to the other former department heads —

he had worked with all of them, as a member of the early Safeguards Consultants Group and later as a member and then Chairman of SAGSI (Standing Advisory Group on Safeguards Implementation) — and went on to say, "For me and I think for most realists, the Agency's human resources continue to be the most important single contributor to the successful implementation of all Agency programs. And if the Agency is to … cope … with the challenges of the future, and we all know that they are many and very great, Member States must ensure that all of the candidates who are put forward for appointment to P staff and GS staff positions must have exemplary personal attributes and demonstrated expertise. Without that, the probability of the Agency continuing to be as successful as it has been will diminish very rapidly."

Referring to the safeguards criteria initiated before him by Peter Tempus, Jennekens noted that he continued to encounter resistance and lack of acceptance. Equally negative was the early reaction by some to the introduction of a more cooperative, efficient and effective set of arrangements with States' systems of accounting and control, both for individual and multi-State systems.

With the 1991-95 criteria, it took even longer to achieve the degree of acceptance that was required and this did not happen until 1992. Finally, however, " the acceptance of those unified planning, implementation and evaluation criteria was a major factor in reaching agreement on revised safeguards approaches … and these in turn represent a major factor in the reduction of our person-days of inspection effort."

Jennekens shares Tempus' concern that events could lead to a departure from the Agency's statute concerning peaceful uses, and, further, "the intervention of third parties between the Agency Secretariat acting on behalf of Member States and individual States or groups of States is something I believe … has not been carefully examined."

And, finally, he said, "now I think it's time for our political masters, hopefully with our prompting, to begin to think in a larger context, a more universal regime for arms control, reduction and eventual elimination."

Bruno Pellaud

As the incumbent department head, Bruno Pellaud added some thoughts of his own. The events in Iraq and South Africa caused people to say that safeguards is at a crossroads. There is a new wave. Everyone is talking about strengthening and streamlining. What is the reaction of this new department head, who arrived at the beginning of this wave without too much previous experience in safeguards?

He likened the present safeguards system to a kind of cathedral, one that was 25 years in the building. As such, it represented a great deal of effort and thought and this should not be destroyed in the name of change. If the cathedral did not meet all the requirements then it may be necessary to build a few other churches around it. However, we should not, in order to discharge some additional responsibilities given to us, destroy this solid basis, this cohesive safeguards system that is established.

Ed Kerr
INMM Vienna Chapter

Three books offer differing, original visions of the new world order

Daniel Patrick Moynihan, *Pandaemonium: Ethnicity in International Politics* (Oxford University Press, Oxford, New York, 1993)

Francis Fukuyama, *The End of History and the Last Man* (Free Press, New York, 1992)

Henry Kissinger, *Diplomacy* (Simon and Schuster, New York, 1994)

As one who witnessed many of the momentous events of the brilliant but terrible 20th century and participated in some of them, this reviewer often asks himself the fundamental questions, "How did we get here? Where are we heading? And where are we anyway?" These questions have become even more immediate in view of the events of the last five years: the collapse of the Soviet Union and with it, most other Marxist regimes throughout the world.

During the last several years it has become popular for political leaders to describe future and even current international relations in terms of the *new world order.*

A great deal of thought and comment address the shape of the world to come. Of the many commentaries that appeared, there are three that are particularly impressive for their originality and depth. Each was produced by a distinguished scholar and, interestingly, each bears little resemblance to the others in either content or philosophy.

These are: *Pandaemonium: Ethnicity in International Politics*, by U.S. Sen. Daniel Patrick Moynihan; *The End of History and The Last Man*, by Francis Fukuyama; and *Diplomacy*, by Henry Kissinger.

Pandaemonium: Ethnicity in International Politics is unlike the others, which range over many topics, because it focuses on a particular problem, the most troubling in today's world: the tragic ethnic conflicts, driven by ancient hatreds and conflicting territorial claims, that have erupted in many areas after colonial regimes or strong central governments have vanished, such as in the Balkans, Africa and the former Soviet Union.

Living in America, where many immigrants with diverse backgrounds are assimilated into what is essentially a common culture (although this, clearly, is becoming less so), or viewing populous, essentially homogeneous societies such as those of Japan and China, it requires a conceptual leap to realize that other areas of the world consist of a patchwork quilt of ethnic splinters, each ranging in population from several million down to no more than about two hundred thousand. In some instances, these individual groups differ radically among themselves in racial origins, language and culture, and in other instances, such as former Yugoslavia or Northern Ireland, they are almost identical racially, linguistically and culturally, but view as essential their perceived differences based on religion and political history.

Moynihan first addressed the concept of ethnicity, pointing out that there is no generally accepted definition, for the purpose of conferring nationhood, of what constitutes a distinct ethnic group. We learn that some nations perceived to be homogeneous are in fact a mosaic. For example, Albania is actually populated by two distinct tribes, the Gogs and Tosks. When Iraq was carved out of the Ottoman Empire and converted into a European colony, it was populated by both Sunni and Shiite Muslims, Jews in Baghdad, Assyrians (Nestorian Christians), and Kurds in the north. In a few years both the Jewish and Assyrian communities were destroyed (their members now live, largely, in Israel and Chicago, respectively), the Kurds have been under repeated attacks by the Iraqi army, and the Sunni and Shiite Muslims are often at each others' throats. By contrast, under the Ottomans, these same groups lived in relative tranquility and harmony over centuries.

The origins of the principle of self-determination, which provides the legal basis for the claims and aspirations of most ethnic groups throughout the world, are discussed at some length. In a certain logical sense, the collapse of empires and colonial regimes worldwide, and hence the present chaos, stem directly from the application of this principle. To view this in a negative sense, however, and to hearken back to an era when these regimes provided law and order and even a measure of civility, is to ignore the negative side of colonialism, i.e. the fact that it involved the rapacious seizure and exploitation of the resources of subject people, discrimination and sometimes outright racism, and often the unwitting or even deliberate practice of cultural genocide. For these and other reasons, such regimes are no longer viable in the modern world, and we have inherited the problems inherent in their dissolution.

The key question in the application of the self-determination principle is that of establishing the demographic and geographical criteria which define a "nation" to which the principle should apply.

Moynihan, with his customary eloquence and wit, provides an interesting and provocative discussion of the origins and nature of the problem of ethnic conflicts in today's world. Although he discusses at some length the basis in international law for nationhood and self-determination, he does not, in the end, offer solutions for the problems we face. Perhaps this is to say that the best minds of our generation have yet to devise solutions. In a real sense, it is ironic that the major powers, with their overwhelming military might, who were capable of reacting with the utmost vigor to the threat of a disruption of the flow of petroleum from the Middle East, cannot muster the political will to apply the principle of collective security to regional conflicts. Meanwhile, we all bear silent witness to the spectacle of mass genocide occurring repeatedly throughout the world.

Francis Fukuyama's book, *The End of History and The Last Man*, is so wide-ranging that it is difficult to describe its scope in a few lines. In essence, it is an attempt to describe and interpret the development and evolution of political institutions in terms of human psychology, culture and sociology. The main thrust of the work is the underlying thesis that worldwide, the evolution of political institutions is unidirectional, not random, with liberal democracy as its inevitable end point. If this thesis turns out to be correct in the next few years, it will have profound significance for the new world order, since, as Fukuyama points out, in today's world it is almost unthinkable for two genuinely democratic governments to engage in war with each other.

The most interesting sections of *The End of History and the Last Man* deal with the major events of the last several decades and Fukuyama's interpretation of them, most important, the collapse of the Soviet empire, and, during those same years, the quiet replacement of authoritarian regimes in many of the world's democratic governments. The reasons for the collapse of the Soviet Union and other Marxist governments are well-known, namely that a country with a command economy, in competition with free-market economies, will fall short in the areas of innovation, production costs, and, in general, fulfilling the essential needs of its population.

While events in the Soviet Union have held our attention in recent years, the quiet democratic revolution that has been taking place in many countries the past two decades may well turn out to be equally significant. Not only have communist regimes toppled in the satellite nations of Eastern Europe, but democratic governments replaced authoritarian ones in Spain, Portugal, South Korea, the Philippines, practically all of South America and other areas. In fact, the number of genuinely democratic governments in the world doubled between 1975 and 1990. Fukuyama points out that the transition from an authoritarian to a democratic form of government is an almost inevitable consequence of economic development, i.e., to provide either military technology or economic growth, a government must promote education and technology, which inevitably lead to a more mobile, sophisticated and urbanized population, with consequent changes in social institutions.

The recent political changes in South America are particularly encouraging, in that along with the transition to democratic government, free-market economic policies replaced the traditional mercantile policy of maintaining complex, bureaucratic state controls that stunted economic growth throughout the region for generations, and an era of vigorous economic growth is now under way.

The reader may find the 23rd chapter, "The Unreality of Realism," particularly interesting in that it squarely challenges the prevailing, pessimistic foreign policy doctrine of realism, most prominently promulgated by Henry Kissinger. In brief, this doctrine rests on the assumption that the nations of the world, as sovereign states, are inevitably in competition with one another, that there can be no guarantee regarding the future nature of their governments, and, consequently, of the actions they may resort to in pursuing their interests, up to and including aggressive warfare.

The relative validity of the realism doctrine versus the more optimistic views of political thinkers such as Fukuyama, that a strong and irreversible trend exists toward a more benign, peaceful and cooperative behavior on the part of democratic governments, is probably the most important foreign policy question of our time. During the next several decades only history will decide which of these two concepts most nearly describes the real world.

Henry Kissinger's *Diplomacy* also defies description in a few mere lines. In its 31 chapters and 835 pages it covers the major events in diplomatic history, from the rise of the modern nation state in France under Richelieu and the origination of the balance of power concept by William of Orange, to the end of the Cold War and the demise of the Soviet Union.

The End of History and The Last Man, while providing a deep insight into the origins and nature of many recent world events, nevertheless can be viewed as originating from an academic and theoretical point of view. *Diplomacy*, on the other hand, clearly represents the pragmatic approach of a battle-wise veteran of the diplomatic wars. Approximately half of the book is devoted to events up to and including World War II, and half covers the beginning of the Cold War to the present, an era during which Kissinger was an active participant in much of the diplomatic history he describes. The first and last chapters are particularly interesting since they sum up

Kissinger's philosophy, perception of events and ideas on what our course of action should be over the next few decades.

The second chapter, "The Hinge: Theodore Roosevelt or Woodrow Wilson," is particularly significant because Kissinger compares the two basic foreign policy approaches our country has followed during most of the century: the traditional, pragmatic approach followed by Roosevelt, in which a nation pursues its own interest, and forms alliances where necessary (the balance of power) to preserve stability in the relative power of individual states, and the basically idealistic policy of Wilson, founded upon the principle of self-determination and reliance upon collective security and international organizations rather than individual alliances and the employment of military power on an individual basis.

While Kissinger leaves no doubt about which of these policies he favors, the issue is probably not as simple as it is presented. It is true, as he points out, that the traditional policy worked well for centuries in Europe, and those based on Wilson's idealistic policy often foundered. But it is also true in today's world that policies adopted by a democratic country must be acceptable to the public. The policies adopted by our government during most of this century usually contained a strong element of idealism, and liberal internationalism has gained wide acceptance in other countries as well. In the final analysis, future foreign policy approaches will probably incorporate a synthesis of these two philosophies.

Summing up *The End of History and the Last Man* and *Diplomacy*, Fukuyama's constitutes a vision of the world as it might be and may well become, while Kissinger's is a view of the world as it has been and may well remain so.

The important message of all three books is their presentation of the challenges we face and the courses of action we should follow in meeting these challenges, which are:

- We now exist in a multipolar world with six major or potential power centers: the United States, Europe, Russia, Japan, China and, at least potentially, India.
- The United States is no longer economically dominant. Europe and Japan overtook us decades ago and China is fast emerging as an economic colossus. We now have a truly international economy where even very small nations with virtually no resources can compete effectively and achieve high living standards if they provide an environment that is conducive to economic growth. In the sphere of economic activity, we are practically, at this point, living in a world without borders.
- Threats to peace and stability such as overpopulation, degradation of the environment and nuclear proliferation, will exist for the foreseeable future.
- The terrible spectacle of ethnic conflicts will continue to exist until the major powers devise effective means for defusing and resolving these conflicts.

The first thing to realize in dealing with these challenges is that there are limits to our power. While we still possess overwhelming military might, it will be of little use in many situations, and in the economic sphere we will be dealing with other players as powerful as we are. In contrast to our traditional experience in relations with Europe, several of the emerging power centers represent cultures and a world view far different from our own. In dealing with other centers of power we must define our interests realistically and bring them into balance with our resources. It should be realized that the creation of a stable, and hopefully better, world order is a task that may extend well into the next century.

In the words of Kissinger, "The fulfillment of American ideals will have to be sought in the patient accumulation of partial successes." Traditionally, in international relations, the American public has been more disposed to engage in crusades of limited duration rather than in the patient pursuit of goals stretching over decades or even centuries, as has been the case of other world powers. One part of the task ahead will be creating the political will necessary for its fulfillment.

In many respects, the twentieth century fulfills the ancient Chinese curse, "May you live in interesting times!" On the other hand, it is not so bad to have lived through a half-century during which our nation remained steadfast in a confrontation between superpowers while avoiding a catastrophic world war. We now must deal with a new, difficult and complex set of problems during the next decades. If we manage to succeed in creating the brave new world that is envisioned, it will be a fitting legacy for our descendants.

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Three Views from the Nonproliferation and Arms Control Seminar

On April 6 and 7, 1994, the first INMM-sponsored seminar of the Nonproliferation and Arms Control Technical Division was held in Washington, D.C. Sixteen papers were presented in three main areas: SNM production cutoff, U.S. fissile materials initiatives, and nuclear materials management technical programs with republics of the former Soviet Union.

*Dr. Wolfgang Panofsky gave the keynote presentation, a summary of a paper on disposition of our excess plutonium prepared by a panel of the National Academy of Scientists (*The Management and Disposition of Excess Weapons Plutonium, *National Academy Press, 1994). The three papers on the following pages were among those given at the seminar. Others are planned for future issues of the* Journal.

The topics covered in these and future papers from the seminar are extremely timely and promise to challenge our abilities in nuclear materials management.

C. Ruth Kempf, Chair
INMM Nonproliferation and Arms Control Technical Division

Status of the Highly Enriched Uranium (HEU) Purchase Agreements and HEU Transparency Implementation

By Jim Staggs

Abstract

In August 1992, the United States and Russia tentatively agreed that the United States would purchase 500 metric tons of highly enriched uranium (HEU), which Russia was withdrawing from its nuclear weapons program. This paper lists the many details that have been agreed upon by the two parties regarding the price, where the HEU is to be blended down to reactor enrichment (Russia) and on transparency agreements so that the United States may be assured that the HEU comes from the weapons program and Russia may be assured that disposition of the low enriched uranium is consistent with the United States' commitments. The four most significant documents are summarized: the Umbrella Agreement, signed in February 1993; the Memorandum of Understanding, signed in September 1993; the Implementing Contract, signed in January 1994; and the further Arrangements Protocol, signed in March 1994.

Roles Within the Department of Energy

Within the Department of Energy, two organizations are actively involved in the HEU purchase: the Office of Arms Control and Nonproliferation and the Office of Uranium Programs.

The Office of Arms Control and Nonproliferation is responsible for the development and coordination of all policies and agreements related to transparency activities required under the HEU purchase agreement. Since November 1993, Anthony Czajkowski, the principal deputy in the Office of Arms Control, has served as the U.S. Head of Delegation and Chief Negotiator for visits and discussions related to HEU transparency.

In November 1994, the Office of Nuclear Energy was designated by the Secretary of Energy to be responsible for all activities related to the implementation of HEU transparency. Within the Office of Nuclear Energy, the Office of Uranium Programs, headed by Norton Haberman, was assigned the role of coordinating the HEU transparency implementation. These activities include conducting monitoring activities at Russian facilities processing HEU subject to the HEU purchase agreements, recruiting and training personnel to serve as monitors and contract representatives, procuring equipment and supplies required for conducting special monitoring visits and contract representative offices, developing inspection procedures and guidelines, establishing a permanent contract representative office at the Ural Electrochemical Integrated Plant (UEIP), providing assistance for Russian monitoring activities in the United States, establishing budgets, obtaining funding, and providing support for the development of HEU transparency-related policies and agreements.

In performing the above functions, the Office of Uranium Programs draws upon the technical expert resources located at the department's national laboratories as well as other federal agencies.

History of HEU Purchase Agreements

Since 1992, there have been numerous meetings, protocols and agreements with the Russian Federation pertaining to the purchase of HEU derived from Russian nuclear weapons. A brief summary of the significant events to date is given below.

- On August 28, 1992, the United States and Russia initialed an agreement allowing for the purchase of 500 metric tons of Russian HEU from dismantled weapons. Also included was a provision requiring that transparency measures be established.
- During November 1992, the Russians stated a desire to convert the HEU into low enriched uranium (LEU) product in Russia and agreed to put into place verification procedures to guarantee that the LEU was coming from HEU derived from nuclear weapons.
- On January 16, 1993, a protocol was signed containing an outline of the main provisions to be included in a contract for the purchase of the LEU derived from the Russian HEU.
- On February 2, 1993, the Russians stated that transparency measures would also have to apply to the United States to ensure that the LEU derived from the HEU is used for fuel in commercial nuclear power plants and not used for the production of weapons.
- On February 18, 1993, the Umbrella Agreement was signed providing for the purchase of 500 metric tons of HEU derived from Russian weapons. This was the final document resulting from the August 28, 1992, initialed agreement.
- During March 1993, the United States held the first HEU transparency discussions with Russia.
- On May 3, 1993, an agreement was signed outlining the basic principles of the HEU purchase contract.
- On May 12, 1993, a U.S. delegation visited the UEIP. The visit included a tour of the oxidation, fluorination, LEU transfer facilities, the analytical laboratory and the centrifuge enrichment plant.
- On June 4, 1993, a protocol relating to a draft text for a Memorandum of Understanding (MOU) on transparency was signed.
- On June 21-25, 1993, a Russian delegation visited the Portsmouth Enrichment Plant and the Westinghouse Fuel Fabrication Plant.
- On September 1, 1993, the MOU on Transparency was signed, with some modifications from the draft of June 4, 1993.
- On September 21, 1993, the United States was informed that in order to remove plutonium from the HEU, the metal would be converted to oxide using a wet chemical process at Mayak and Tomsk. The oxide would be shipped to UEIP for further processing and blending.
- On January 1, 1994, the Implementing Contract was signed during President Clinton's visit to Moscow.
- On February 10, 1994, a draft joint U.S./Russian Further Arrangements Protocol text was prepared highlighting differences.
- On March 18, 1994, the differences contained in the draft joint Further Arrangements Protocol were resolved, and the Protocol was signed.
- During April 1994, a U.S. delegation of experts paid a second visit to the UEIP. The Head of Delegation was allowed to see the blending facility. During the visit, the Russians requested a visit in June 1994 to the Portsmouth Enrichment Plant and the General Electric Fabrication Facility.

From this sequence of events, the four most significant documents that emerged are the Umbrella Agreement signed in February 1993, the Memorandum of Understanding signed in September 1993, the Implementing Contract signed in January 1994, and the Further Arrangements Protocol signed in March 1994. Each of these documents represents a significant milestone required to allow deliveries to the United States to begin.

Umbrella Agreement

The February 1993 Umbrella Agreement, which is also referred to at times as the Government-to-Government Agreement or the Agreement, contained three objectives: to convert as soon as practicable 500 metric tons of HEU into LEU for use as fuel in commercial nuclear powerplants; permit the possible transfer of Russian conversion technology to the United States for conversion of HEU derived from U.S. weapons into LEU; and fulfill the nonproliferation, physical protection, material control and accountability (MC&A) and environmental objectives of both countries.

Among the many provisions contained in the Agreement, the most significant was a commitment to seek to enter into an implementing contract for no less than 10 metric tons of HEU per year for the first five years and 30 metric tons of HEU annually thereafter. The LEU product to be derived from the conversion process is required to meet product specifications for use in commercial reactors. The Agreement also permits an equivalent amount of HEU to be substituted for LEU if mutually agreed. To satisfy physical protection and nonproliferation concerns, the Agreement also requires that prior to conclusion of any implementing contract, the establishment of transparency measures, including MC&A and access arrangements, from the time that HEU is made available for conversion until converted to LEU.

Memorandum of Understanding

The September 1993, the Memorandum of Understanding (MOU) called for both sides to provide assurances that the objectives of the Umbrella Agreement were being met. Both parties agreed to commit to implement transparency and access measures that avoid hampering the economic and technological development of either party as well as avoid any undue interference in either party's nuclear activities and operation of facilities.

The main provisions of the MOU include providing for monitors, a general list of monitor rights and the obligation to provide the other party with various reports. The MOU also defines U.S. activities in Russia and Russian activities in the United States. Information received as a result of transparency activities is required to be treated confidentially unless otherwise agreed. Restrictions are also included limiting the United States' right to adjust the uranium-235 content of the Russian material at the Portsmouth Enrichment Plant. The MOU also requires that the Parties seek further arrangements regarding transparency prior to first delivery of converted LEU to the United States.

Implementing Contract

The January 1994 Implementing Contract was signed in Moscow by the United States Enrichment Corporation (USEC), acting as the agent for the U.S. government, and by Techsnabexport Co., Ltd. (TENEX), acting as agent for the Government of the Russian Federation. The contract calls for the delivery over 20 years of LEU blended down from at least 500 metric tons of Russian HEU. The contract cumulatively has a potential value of about $12 billion.

Deliveries under the contract were contingent upon an acceptable proceed-sharing arrangement between the Russian Federation and Ukraine, Kazakhstan and Belarus. Deliveries were also subject to establishing transparency measures. Both of these conditions were met through subsequent actions and agreements and no longer pose an obstacle to deliveries under the contract.

However, a request by the Russians to modify the specifications to allow for higher levels of uranium-232, uranium-234, uranium-236 and transuranic alpha activity than is currently allowed for LEU product in the United States has caused a delay in USEC issuing delivery orders under the contract. USEC is working with TENEX to resolve this problem. Under the contract, delivery is made six months after the issuing of a delivery order. It is unlikely that a delivery order will be issued until the product specification issue is solved.

Further Arrangements Protocol

The main objectives of the March 1994 Further Arrangements Protocol were to guarantee access to all facilities where material subject to the Agreement will be processed, permit a permanent monitoring presence at the key processing facility in each country, provide a mechanism to resolve problems and allow deliveries to begin as soon as practicable.

The most significant provision of the Protocol is the establishment of a Transparency Review Committee (TRC). The purpose of the TRC is to provide a forum for raising and resolving issues, answering questions, addressing the effectiveness of existing transparency measures and obtaining agreement on additional or improved measures. The Protocol also provides a mechanism for stopping deliveries if the parties fail to resolve issues in a timely manner through the TRC.

Additionally, the Protocol defines facility-specific access locations and activities. The Protocol also allows for special monitoring visits, permanent contract representative offices stationed at each country's key processing facility and familiarization visits. The Protocol requires that detailed procedures governing transparency activities be developed through the TRC and attached as annexes. The Protocol also contains a clause that allows deliveries to begin upon signing.

Next Steps

During the remaining months of 1994, a great deal of work needs to be accomplished before transparency activities can be put into place at either the Russian or the U.S. facilities where material subject to the Agreement will be processed. One significant task is the establishment of guidelines and rules under which TRC meetings can occur. The first few TRC meetings will be dedicated to the development of the detailed annexes that are required to allow special monitoring visits and contract representative offices to function.

Transparency implementation efforts are proceeding aunder the assumption that the first contract representatives and the initial special monitoring visits will occur by late summer or early fall of 1994. To meet this schedule, monitors and contract representatives must be selected and trained. To date, more than 100 individuals submitted applications to serve as U.S. monitors and contract representatives. The first group of individuals to serve in these roles are scheduled to be trained in a two-week training course to be held at the Portsmouth Enrichment Plant in late July or early August.

Assuming that the product specification problem can be resolved by USEC and TENEX during May 1994, initial delivery of LEU product converted from Russian HEU should begin by the end of 1994.

Conclusion

Over the past two years, the U.S. government aggressively pursued the purchase of Russian HEU. By the end of 1994, deliveries of LEU product derived from Russian HEU, regular special monitoring visits, functioning contract representative offices and ongoing working meetings of the TRC should all be evidence that the objectives of the February 18, 1993, Umbrella Agreement are becoming a reality.

National Laboratory Technical Exchanges with Institutes and Laboratories in the Newly Independent States of the Former Soviet Union

Alan M. Preszler, Ph.D., Office of Arms Control

Abstract

In March, 1992, the Department of Energy and the State Department established guidelines to encourage and direct laboratory-to-laboratory (lab-to-lab) cooperation with institutes in the newly independent states (NIS) of the former Soviet Union. As a nonproliferation effort, the cooperative activities focus on the need to prevent emigration of weapons scientists to potentially proliferant states and organizations. The objective is to encourage joint projects/contracts in non-weapons-related areas in order to provide meaningful work, commensurate with scientific capabilities, that will reduce economic pressures for emigration and assist in the development of a market economy. In addition, by encouraging Western science's philosophy of openness, peer reviews and publishing, the cooperative projects improve the transparency of weapons laboratories in the former Soviet Union.

Technical collaborations are rapidly increasing in number and are fostering U.S. industrial participation. Since the initial technical exchanges in October of 1992, lab-to-lab interactions resulted in more than 200 contracts, totaling more than $5 million, and involving more than 40 institutes in Russia, Ukraine, Kazakhstan and Belarus. The many lab-to-lab projects established professional and technical relationships that provided the foundation for establishing a Laboratory/Institute Partnering Program in April 1994 directed toward applying technologies to commerical use in the newly independent states. In addition, lab-to-lab partnering is involved in many of the projects funded by the International Science and Technology Center in Moscow.

Laboratory-to-Laboratory Projects

The Department of Energy National Laboratory's contracting with institutes of the former Soviet Union proved effective in redirecting weapons scientists towards open research with commercial goals. Direct contracting for goods and services, while preserving professional integrity of the former weapons scientists, engineers and technicians, provides experience functioning in market economics through negotiation of deliverables and schedule requirements.

A broad range of outstanding talent is employed in many technical areas such as energy, materials, computer sciences, reactor safety, laser technologies, environmental sciences, fusion research, medical technologies and basic scientific research. Unique capabilities of the institutes of the former Soviet Union have competitive application in international as well as domestic commercial markets. For example, large crystals of potassium dihydrogen phosphate are required for advanced fusion lasers. The crystals boost the frequency of light in the laser beams that greatly increase efficiencies for imploding fusion capsules. The Institute for Single Crystals at Kharkov in the Ukraine has the unique capability to rapidly (days versus months) produce crystals that are large and ultra-pure. Their crystal production capabilities far exceed Western capabilities. Commercialization of their methods is proceeding in partnership with U.S. industry. In addition, unique porous metal structures, having high strength-to-weight ratios as formed through gas-eutectic reactions, are progressing towards commercialization through a U.S. industrial Specialty Metals Consortium.

Overall, the institutes of the former Soviet Union are performing well on the various project contracts. They are providing outstanding talent, at a minimum cost, to help accomplish National Laboratory projects. Firm relationships are being established between scientists in the United States and the newly independent states that are helping all make the transition away from military research.

International Science and Technology Center

The International Science and Technology Center (ISTC) in Moscow was authorized under Nunn-Lugar funding in joint sponsorship with Japan and the European Community to develop, finance and monitor projects primarily within the Russian Federation. The Center is chartered to provide employment for former weapons scientists as a nonproliferation measure. The projects of the Center intend to provide impetus and support to participating scientists and engineers in developing long-term career opportunities, which will strengthen the scientific research and development capacity of their countries in nonmilitary areas. In March 1994, $11.6 million was committed to start 23 projects and additional projects will be selected in June 1994. Additional member countries recently admitted to the ISTC include Armenia, Belarus, Canada, Finland, Georgia, Kazakhstan and Sweden.

The Center primarily supports and funds projects within the Russian Federation. It encourages expanding cooperation for peaceful purposes between the Russian technical community and counterparts in other member countries, as well as for industrial concerns by offering support for travel for technical data exchanges and project management.

The Department of Energy is supporting the Center by assigning one representative to the Board of Governors, two senior technical advisors in Moscow and one scientific advisory committee member. In addition, the National Laboratories of the Department of Energy are cooperating with Russian institutes on many projects in environmental monitoring, computer modeling of ecological and meteorological phenomena, medical imaging methods, microelectronics, laser fusion research, nuclear material safeguards and radioactive waste disposal research.

In addition to the Moscow International Science and Technology Center, efforts are underway to establish centers in Ukraine and Kazakhstan. Funding for the Ukraine center was provided by the United States, Canada and Sweden. To date, Ukraine appointed the Ministry of Space to be the Center's lead agency, and work is in progress to define organizational and operational requirements of the Center.

Laboratory/Industrial Partnering

The Foreign Operations Appropriations Act provided $35 million to initiate a program for stabilization of scientific and engineering institutes in the newly independent states by fostering commercialization of NIS technologies. The cooperative program between Department of Energy National Laboratories, NIS institutes and United States industry commenced in April 1994, with the objective of laying the foundation for lasting scientific and commercial relationships among all participants.

Ten national laboratories are developing direct laboratory-to-institute projects as technological opportunities for industrial commercialization. Building upon existing National Laboratory relationships with NIS institutes and U.S. industry, the National Laboratories are responsible for coordinating, reviewing and initiating joint applications research projects. From these initial and subsequent projects, a U.S. industrial consortium will identify, plan and develop cost-sharing projects to commercialize promising technologies. Commercialization of existing technical knowledge through risk-sharing agreements will ensure careful and cost-effective development of technologies that will expand international markets for both U.S. and NIS goods and services.

In addition to the goal of promoting market growth, these partnerships will encourage the emergence of western-style political and economic institutions within the newly independent states. In support of this goal, U.S. academic institutions will conduct a business training program and establish a telecommunications infrastructure in support of project commercialization activities.

Conclusion

Direct laboratory-to-laboratory interactions are employing and training thousands of weapons scientists within the former Soviet Union in nonmilitary areas. The impact, through individual education and employment, is significant in converting a military-product-oriented scientific community into a commercial/peaceful research and development community. Large-scale government-to-government programs effectively address the needs and requirements of the moment. However, enduring change and progress comes from the personal and professional relationships established between partners working toward a common goal. To that end, the direct laboratory-to-laboratory interaction process fostered by the Department of Energy is a success.

Overview of Joint Statement on Reciprocal Inspection of Fissile Material Removed From Nuclear Weapons

C. Mark Percival
Timothy H. Ingle

Abstract

Transparency in nuclear disarmament and the continuing control of the fissile material from nuclear weapons has been a goal since end of the Cold War and the beginning of reductions in nuclear stockpiles. The United States and Russia took a bold step in nuclear disarmament by announcing their intentions to host reciprocal inspections of fissile materials removed from nuclear weapons. While important questions must be answered, the sides are taking a step-by-step approach toward confirming fissile material inventories from nuclear disarmament. This paper reviews the events leading to this statement and discusses U.S. views on how it should be implemented.

Background

Progress toward the transparency of nuclear stockpiles is quickening.

- *December 1993*: During the Gore-Chernomyrdin exchanges, the United States and Russia agreed to improve transparency measures at U.S. and Russian dismantlement and fissile material storage facilities.
- *January 1994*: Presidents Clinton and Yeltsin agreed to establish a joint working group to consider steps to ensure the transparency and irreversibility of the process of reduction of nuclear weapons.
- *March 16, 1994*: Secretary of Energy Hazel O'Leary and Minister of Atomic Energy of the Russian Federation Victor Mikhialov signed a joint statement of intent to host reciprocal inspections of facilities containing plutonium removed from nuclear weapons. Included were:
  - A statement describing these inspections as an important first step in the process of establishing a world-wide control regime for fissile materials.
  - Milestones including discussions on inspection procedures within two months and inspections by the end of 1994.
  - An announcement of intent to conclude an agreement on the means of confirming the plutonium and highly enriched uranium from nuclear disarmament.

Overview of Storage of Fissile Material Removed Nuclear Weapons

United States Plutonium Storage Facilities. Plutonium removed from U.S. nuclear weapons is stored at a number of facilities: Pantex, outside Amarillo, Texas; the Rocky Flats Plant outside Golden, Colorado; Los Alamos National Laboratory, Los Alamos, New Mexico; and the Savannah River Plant outside Aiken, South Carolina.

The plutonium is stored in the form of a nuclear weapon component known as a pit. Because nuclear weapons are assembled and disassembled at the Pantex Plant, the large majority of pits removed from nuclear weapons is stored there. The pits are stored in earth-covered ammunition magazines that lack utilities of any sort. At other sites, pits may be stored along with other plutonium forms such as bulk metal and oxide. At all plutonium storage facilities, radiation exposure is high, and the pits might have to be removed from the vaults for inspection to avoid adverse health effects and to minimize measurement interference.

United States Highly Enriched Uranium Storage Facilities. Most highly enriched uranium (HEU) removed from nuclear weapons is stored at a single site, the Y-12 Plant in Oak Ridge, Tenn. At this plant, the HEU weapon parts no longer needed for nuclear weapons are typically broken down and recast into hollow right circular cylinders. These cylinders are then stored in specially designed storage facilities referred to as tube vaults. The radiation hazard of inspecting HEU is very low compared to plutonium.

Russian Dismantlement and Fissile Material Storage Facilities. Russia publicly released some information about facilities that are involved in these activities. Dismantlement takes place at four sites: Nizhnaya Tura, Yuryuzan, Penza and Arzamas. It is assumed that there are fissile material storage facilities at these sites. Additionally, Russia stores pits at the Tomsk site, but this facility is not known to be involved in nuclear weapon dismantlement.

As part of the U.S. program of assistance to Russia's facilitating the safe, secure dismantlement of nuclear weapons, the United States is providing up to 40,000 pit storage containers, which are very similar to those used by the United States. The United States is also assisting in the design and construction of a facility for storing fissile materials. Presumably, fissile materials removed from nuclear weapons will eventually be stored at these facilities.

Technical Challenges of Inspecting Fissile Material Removed from Weapons

The United States hopes to achieve two goals. The first is to achieve some confidence that nuclear weapons are being dismantled. Assuring the continued safeguarding of the fissile materials is the second goal. Much of the information that could be gained from an intrusive inspection regime geared toward meeting these goals continues to be closely protected, however, even from a highly advanced nuclear weapons state. Important technical challenges must be overcome to assure protection of sensitive information and mitigate radiation exposure during inspections.

Because the United States lacks the capability at this time to reduce pits to bulk form, plutonium inspections under this regime should focus on pits. Each of these pits is stored in a stainless steel container designed to keep the pits in a critically safe configuration and protect them from adverse environments, such as fire. Typically, the pit containers are welded closed and can only be opened in a controlled environment in facilities other than those in which they are stored. Visual inspection of pits could reveal nuclear weapon design information in violation of the Atomic Energy Act.

While HEU weapon components are reduced to bulk form, doing so makes it difficult to confirm that it came from a weapon. Inspection of HEU before it is recast into cylinders is a potential scenario, although revealing weapon design information is again a concern.

For these reasons, inspection of fissile weapon components would benefit from the use of nondestructive inspection technologies and other procedures that do not require physical access to components and do not reveal weapon design information. These inspections may be able to utilize existing radiation measurement technologies, possibly in conjunction with nonradiation measurements, such as heat generation. However, the traditional arms control intrusiveness versus confidence trade-off applies here as well. High-resolution germanium gamma-ray detectors with full spectrum resolution could give high confidence of the presence of plutonium but could also reveal information about the mass and shape of the components. This could provide weapon design information to proliferants and would violate the Atomic Energy Act.

The Department of Energy and its national laboratories are evaluating existing measurement technologies that provide the highest level of confidence within legal and technical constraints. These techniques will be discussed with Russia at an appropriate point in negotiations.

Negotiation Approach

The fundamental purpose of initial inspections under the joint statement is to establish proof-of-principle that transparency measures can be established at nuclear weapon dismantlement facilities. The United States hopes that measures agreed for initial inspections will provide the foundation for a more comprehensive regime of dismantlement transparency.

The United States views declarations as providing basic information for an inspection regime. Initial declarations could include locations of past and present dismantlement sites and facilities storing fissile material removed from nuclear weapons. Inspections and site visits under the joint statement could then be developed to confirm these declarations. If the sides engage in developing a broader regime to confirm fissile material inventories from nuclear dismantlement, more detailed declarations, such as specific quantities of fissile material, could be included.

An important U.S. objective is reciprocity. Russia has stated that its nuclear weapons are dismantled at four sites. Because the United States dismantles at only one facility, one key Russian dismantlement facility should be targeted for initial site visits. If Russia does not accept this position and offers a pit storage-only site (e.g., Tomsk), then the United States could offer in return a pit storage-only facility such as Rocky Flats. However, the United States does desire to establish initial inspections at dismantlement sites.

The United States believes that initial familiarization visits to facilities such as Pantex could include:

- visual tours of areas in the facility related to the dismantlement process,
- access to a typical storage site for plutonium removed from dismantled nuclear weapons, and
- demonstration of the presence of a plutonium weapon component in its storage container.

It is important to note that each side would illustrate its own procedures for demonstrating the presence of plutonium removed from a nuclear weapon. The U.S. strategy is to avoid protracted negotiation of inspection procedures and technologies by building agreed procedures from these initial demonstrations.

Summary

While the details of inspections of fissile material removed from nuclear weapons are yet to be agreed upon, the United States established its objectives for the regime. It should both provide confidence of nuclear weapon dismantlement and demonstrate safeguarding of the fissile materials removed. The United States views relevant declarations and confirmatory inspections as vital to meeting these goals. While flexible on the specifics of declarations and inspections, reciprocity is paramount. The United States hopes that execution of this joint statement will lead to a broader agreement on confirming fissile material stockpiles from nuclear dismantlement that eventually will form part of a worldwide regime of control of fissile materials.

Four Discussions on Transparency from the INMM International Safeguards Division Meeting

On March 18, 1994, INMM's International Safeguards Division (ISD) met at the Vienna International Center in Vienna, Austria, the site of the 1994 IAEA Safeguards Symposium. Fifty-three members of the International Safeguards Community participated in the meeting, including the IAEA, CEC/EURATOM, CEC/JRC-Ispra, Australia, Canada, China, Czech Republic, Finland, France, Germany, Japan, Netherlands, Russia, South Africa, Sweden, Ukraine, United Kingdom and United States.

The ISD meeting opened on the broad subject of transparency and focused on the discussion papers prepared by Andre Petit, Paul Ek, John McManus and Frank Houck, all of which are reprinted on the following pages. The discussion papers were prepared to stimulate discussion; the material represents only the views of the specific individuals and possibly their colleagues.

As usual, several interesting discussions occurred during the meeting. First and foremost — as with much of the preceding IAEA Safeguards Symposium — it was clear that major events and changes in the world in the last few years will certainly lead to changes in international safeguards as the IAEA now administers them. The IAEA's access to additional information may be one of the most fundamental changes. However, it will not be easy to include very meaningful qualitative information if the conventional way of doing things is maintained. We will have to find new approaches to meaningful information, and it will be some time before a consensus is reached on definitions of openness and transparency — words that mean different things to different people. Perhaps one of the reasons a consensus is difficult is that it is related to the issue of drawing conclusions from qualitative information.

Cecil S. Sonnier, Chair
Paul I. Ek, Vice Chair
INMM International Safeguards Division

Openness, Transparency and Enhanced Safeguards

This paper was generated by staff of the Atomic Energy Control Board of Canada at the request of INMM. It does not necessarily reflect the policy of the Atomic Energy Control Board.

Much confusion exists regarding the use of the terms openness and transparency in the context of improved International Atomic Energy Agency (IAEA) safeguards pursuant to the Nuclear Nonproliferation Treaty (NPT). While the two are often used interchangeably, they are quite different aspects of the overall NPT safeguards approach.

To clarify the terms, Standing Advisory Group on Safeguards Implementation (SAGSI) describes transparency as a glass house with an interior that can be viewed from a distance, and openness as a brick house that one can enter. While this analogy is helpful, it is not entirely satisfactory.

Transparency is not a synonym for openness; it is a function or a result of openness. There can be no transparency without openness first, thus the issue of improved openness should be a prime consideration in ongoing international efforts to strengthen the current NPT safeguards system.

The safeguards system administered by the IAEA pursuant to the NPT works because the treaty's signatories have a common committment to nuclear nonproliferation and have agreed to common guidelines to verify compliance with this committment. Nevertheless, a need to improve existing safeguards was expressed at the 1990 NPT Review Conference. Following the Iraq experience, the concern that present safeguards arrangements do not reflect full implementation of the spirit of Article 2 of INFCIRC/153 and thus should be improved, particularly in the area of undeclared activities, has been under discussion.

This perceived weakness in the NPT safeguards system may be rooted in the lack of a common definition among Member States as to what constitutes openness. In this context, the issue of openness could have ramifications not only for the effectiveness of the international community's nuclear nonproliferation efforts but also for the activities of the IAEA in terms of the resources required for the effective administration of the current NPT safeguards system. Some adjustment of the IAEA's NPT safeguards activities should occur in the form of a redirection of current efforts, an augmentation of current resources, or both.

One approach to the ongoing discussions concerning enhanced NPT safeguards is to view the question as a relationship between quantitative verification of the absence of diversion from declared inventories and qualitative assessment of a nation's nuclear activities and intentions. The issue of openness is closely related to the latter. Agreement among the Member States on qualitative guidelines for openness at the state level would supplement other quantitative analyses, thus not only building confidence and enhancing international nuclear nonproliferation efforts through a strengthening of the NPT safeguards system but also assisting the IAEA in streamlining its implementation of the system.

The effectiveness of enhanced NPT safeguards can be viewed as a function of the combination of the provision by a state of useful and relevant information in a form and quantity the IAEA can handle, and physical access to verify the correctness and completeness of that information. This is particularly so if access to the state and within the state is free from arbitrary restrictions arising from narrow interpretations of legal agreements. Thus, openness at the state level is logically the most important aspect in the process insofar as the state, and only the state, can influence these criteria. Consequently, the openness of the state is a critical, if not necessary, consideration in the pursuit of greater transparency within the NPT safeguards system.

In this approach, government policies and actions are important indicators of openness. First, a state's intentions as an international player must be clear. (What are a nation's security concerns? What would be a nation's motivation for acquiring nuclear weapons?) Openness could be demonstrated through a state's willingness to liberally interpret ambiguous aspects of international agreements or by its interaction with regional neighbors. Second, the internal policy-making process within the government of a state should be open to scrutiny and debate. (How do interdepartmental or interagency discussions take place? What are the checks and balances?) Third, it would be in the state's interest to be as open and honest as possible with its own citizenry in the provision of information and the explanation of the intent of its policies. A government's secrecy with its own population bodes ill for international efforts to obtain information adequate for safeguards and could negatively affect relationships with the IAEA or with regional neighbors.

The nature of the state's society is an equally significant factor in this approach. A society that encourages free exchange of information, open debate and criticism, easy access to facilities, and cooperation rather than confrontation could be considered critical to efficient and effective safeguards efforts. For example, the ability of resident IAEA inspectors to function effectively in the local environment is an important indication of that country's commitment to the safeguards process.

The issue of openness can also be examined as a function of the effectiveness of a nation's own State System of Accounting and Control (SSAC). The role of the SSAC within an open state environment can make a significant contribution to enhanced and more efficient safeguards. An SSAC with confidence in its own capacity to investigate, its powers of sanction, its input into the plans and policies of the government, and its legislative authority encourages openness within the state and the society. This in turn might benefit the SSAC's interaction with the IAEA and SSACs in other countries, thus enhancing the transparency framework to the degree required for greater confidence building at reasonable cost to the IAEA. For example, such an SSAC may undertake some IAEA tasks if specifically asked to do so. In other words, that which gives the national SSAC confidence would by extension give confidence to the IAEA, resulting in improved two-way communication, cooperation, and openness at the state–IAEA level. When an SSAC has extensive access to information and activities and the IAEA is provided with the same level of access the overall goal of greater transparency within the system is acheived.

A concern has been expressed that the current NPT safeguards system as administered by the IAEA devotes a disproportionate amount of time and energy to a handful of nations with societies and governments among the most open. Calls for both an increase in IAEA resources and a shift in existing resources toward monitoring those states of greater nuclear proliferation concern may not address either the root cause of suspicion and mistrust or the desire for enhanced, cost-effective NPT safeguards. Greater efforts to encourage all nations to accept certain standards of openness against which their performances can be judged might not only improve transparency and enhance existing safeguards but also produce more efficient use of existing resources. A greater common effort to increase openness could have the synergistic effect of creating, through the resulting positive reinforcement, even greater openness in the future.

Transparency, Openness and Cooperation with the State System of Accounting and Control of Nuclear Material

Paul Ek, SKI

Background

During its meeting in November 1993, the Standing Advisory Group on Safeguards Implementation (SAGSI) concentrated on the re-examination of safeguards implementation. This re-examination took note of both the discussion at the June 1993 Board of Governors meeting on SAGSI's April 1993 Report to the Director General and the resolution at the General Conference requesting the director general to continue and intensify his efforts to achieve a more effective and cost-efficient safeguards system.

This paper focuses on relevant aspects of transparency in relation to the State System of Accounting and Control of Nuclear Material (SSAC) and to Operators. Some views expressed by SAGSI are included.

Transparency and Openness

Transparency and *openness* are two complementary concepts used in relation to different aspects of safeguards implementation. Transparency is primarily related to providing information, while openness refers to providing access. Access allows the IAEA control of the information received. These concepts are a basis for enhancing the efficiency and effectiveness of the IAEA's safeguards system, which might lead to a decrease of certain IAEA activities.

Increased transparency and openness should build confidence between the IAEA and States, as well as between States. In many cases, such confidence was built over the years, while for others this confidence still needs to be improved. This might put extra demands on the latter group of States.

Transparency and openness are being considered at the level of:

- States and their nuclear programs. At this level, the concepts are intended to increase the confidence in States' nonproliferation commitments.
- SSACs. At this level, the concepts are intended to enable the Agency to make a fuller use of them.
- The operator. At this level, the concepts are intended to permit more cost-effective safeguards approaches at the individual facilities.
- The IAEA Board of Governors. At this level, the concepts are intended to serve as a guarantee for nondiscrimination.

States subject to IAEA safeguards already provide substantial amounts of information under their safeguards agreements or other arrangements. Increased transparency and openness might be achieved in different degrees in different States, thus leading to different alternative approaches. From a State in which safeguards should be conducted in a different or alternative way, the additional information required includes information on:

- Nuclear activities that involve nuclear material and its ore concentrates or are aimed at the production or processing of nuclear material (including R&D and nonnuclear activities that involve nuclear material),
- Education and training institutes that are relevant for the nuclear sector,
- Planned future activities in the nuclear or nuclear-related area,
- All nuclear or nonnuclear activities at or in the immediate vicinity of safeguarded facilities,
- Export, import and production of nuclear material and the export of specified equipment and nonnuclear material,
- All relevant SSAC activities, both in advance and in real time, and
- The high transparency of facility operation, involving a large increase in the information and data made available to the IAEA as and when necessary.

How the availability of all information listed above, verified as necessary, could lead to a reduced Agency safeguards effort requires further analysis and field tests. The availability of other sources of information is clearly an important factor. Publicly available government information (for example, information provided to parliament) is one source; a free press (independent press organs not owned or controlled by the government, with free access for foreign journalists) is another. These factors would have to be weighed when delegating activities (but not responsibilities) to an SSAC or when determining IAEA verification requirements of SSAC activities.

Because the principle of unpredictability is already widely used in fields other than safeguards, unpredictability could have an important role to play in checking the additional information. Unpredictability could reduce costs and/or improve effectiveness by introducing an element of surprise as to whether and when the IAEA will inspect a particular site. Unpredictability could be applied to timing, location and scope of inspection activities.

Cooperation with SSAC

Three different ways the SSAC would further the objectives of the IAEA are apparent.

First, the SSAC would ensure that the IAEA inspection activities could be conducted with minimum difficulty and maximum efficiency. The SSAC would have *an enabling role* (*not* a role in which the SSAC conducts activities that are required by the safeguards system and performed by the IAEA). An effective SSAC can be a source of economies for the IAEA. For instance, the duration of inspections may be reduced if the IAEA inspectors have at their disposal correct accounting documents in a standardized format and the SSAC already checked that the accounting procedures and arrangements are being operated correctly. Additional examples include SSAC activities that facilitate Agency use of modern technology, integrated systems of surveillance, Non Destructive Assay (NDA) and integration of such systems with SSAC (operator) instrumentation.

Second, in appropriate circumstances, the SSAC could give additional help *working alongside* the IAEA inspector with the IAEA unpredictably asking the SSAC inspector to conduct tasks on its behalf and under its supervision. Examples of cooperation include sharing instruments and analytical capabilities. The essential requirement for this case is that the activities carried out by the SSAC inspectors be done under conditions such that confidence can be maintained that the SSAC results have not been falsified. The nature of the SSAC and the unpredictable manner and conditions under which tasks are allocated to the SSAC would be some of the qualifying requirements. In all cases, however, the IAEA must retain its right to conduct all activities, including those carried out by SSAC inspectors.

Third, the IAEA would *use results of SSAC inspection activities* in place of some IAEA inspection activities, with the intent to reduce the extent of inspections while maintaining effectiveness, thereby meeting the requirement that the IAEA reach independent conclusions. The environment under which this greater use of the SSAC can be introduced includes fulfillment of such conditions as:

- The IAEA must retain all its rights regarding activities to fulfill its obligations and draw independent conclusions; set safeguards inspection goal criteria and establish safeguards requirements; to verify independently or authenticate data and exercise that right to the extent necessary; satisfy itself that the SSAC has the capability to meet the quality assurance requirements set by the IAEA; and have fuller access to information and data of the SSAC.
- The SSAC must have the adequate independence, capability and experience to perform the agreed-upon tasks; satisfy all agreed-upon reporting requirements; communicate schedules for agreed-upon activities sufficiently in advance to enable the IAEA to meet its verification requirements; complete documentation and make it available to the IAEA; and document criteria and procedures compatible with IAEA criteria for tasks to be performed.

However, the SSAC would have a capability at least equal to that of the IAEA to measure and carry out relevant verification activities. The results should be authenticatable. The IAEA would retain the right to verify all data supplied by the SSAC from its delegated activities.

An SSAC can be a single- or multi-State system. For both types of systems, there are common conditions that are relevant to determine the degree of cooperation. However, in the context of a multi-State system only, there is also the possibility of taking into account the multinational character of such a multi-State system by considering the results of the system's independent verifications to contribute to international assurance of nondiversion, e.g., an agreed-upon arrangement for the IAEA to base its conclusion on the combination of its independent verification results and the unverified results of inspection (verification) activities of the SSAC.

Adoption of such an arrangement and the specific nontechnical characteristics (e.g., number of States involved in the system and their political, military or economic relationships) to be taken into account is largely, if not entirely, political and will have to be judged by a political body (e.g., the Board of Governors).

Suggestion

If a State is prepared to make a legally binding undertaking to the IAEA that will provide additional information as outlined above, give extended access to IAEA inspectors, have its SSAC meet criteria established by the IAEA, offer its SSAC services to the IAEA, and allow greater use of the unpredictability principle in verifications, this could be the basis for a shift in the safeguards approach from the currently used quantitative approach to an approach that places more emphasis on qualitative judgment.

On the basis of this greater transparency of the State's nuclear activities and greater flexibility for the IAEA to choose among verification activities, the IAEA should, under certain conditions, be able to offer to the State a significant reduction in the number of inspections.

Transparency at the Level of Safeguards Implementation

Andre Petit, consultant

Safeguards approaches that include higher degrees of transparency at the level of facilities and at the level of the state also need a higher degree of transparency at the level of IAEA safeguards implementation.

Confidentiality or Transparency in the Present Approach

Anonymity is a basic principle for the safeguards implementation reporting by the IAEA Secretariat to the Board of Governors. The Safeguards Implementation Report (SIR) describes technical safeguards achievements in different countries and facilities, without disclosing by name any country or facility. However, this anonymity is theoretical; specialists are easily able to identify most of the cases, even though anonymity is an imperative consequence of the principle of safeguards confidentiality.

This principle of anonymity was developed in the early days of international safeguards implementation, when nuclear activities, even purely peaceful ones, were considered confidential in most countries. This principle was consistent with a safeguards approach that considered implementation to be gathering clear and timely information about a possible diversion of one significant quantity of nuclear materials anywhere. It was sufficient to report that the procedures necessary to produce such information had been implemented everywhere.

The present reality is quite different. In most countries, the public has requested and received a very high degree of transparency for all nonmilitary nuclear activities. There is no reason for the IAEA to protect information that operators and governments disclose. In addition, experience showed that such clear and timely information (*yes* or *no* answers) was often impossible to achieve, especially in complex and highly developed nuclear fuel cycles. A significant quantity was impossible to define operationally at the level of a Member State. Moreover, nonachievement of inspection goals was sometimes the result of a lack of inspection effort by the IAEA, giving the potentially false impression of a likely diversion.

Thus the SIRs have based their conclusions about the reasonable assurance of nondiversion on increasingly qualitative reasonings. For example, that a facility could have been inspected at short notice was considered as sufficient to give such reasonable assurance, even if the facility was not inspected.

The rule of anonymity in reporting to the Board should be reconsidered. Because the reasonings behind the conclusions are more qualitative than in the past, the members of the Board should be provided with the information necessary to understand these qualitative reasonings. Such information is necessarily specific to each fuel cycle and providing it to the Board would be equivalent to designating countries by name.

Thus there are good arguments for designating countries by name in the SIRs, even with the present safeguards approach. However, the change in the principle could not be imposed suddenly and may not be considered absolutely necessary.

Transparency in the Alternative Safeguards Approach

The problem is different with the suggested alternative safeguards approach under study in the framework of the Standing Advisory Group on Safeguards Implementation (SAGSI). The alternative approach will improve safeguards effectiveness and efficiency, thanks to a greater cooperation of the states. Countries that volunteer to participate in this approach would achieve a much higher degree of transparency at both facility and state levels. Such greater transparency cannot be defined or dictated in a uniform way for all countries concerned; each state and each operator will determine the degree of transparency it is willing to offer the IAEA. The independent verifications performed by the IAEA to achieve the necessary assurance must be closely related to the specific commitments made by the state. Thus the actual commitments must be known by the Board for it to be able to understand the independent verification, performed by the IAEA to support its conclusions.

When independent verifications are performed in an identical way in all similar facilities in all countries, there is no need for the IAEA to describe such performance in detail, except when a deviation occurs. However, when the basic principle is that independent verifications, in order to achieve the highest level of effectiveness, are unpredictable and tailored to each national fuel cycle and to the specific commitments made to achieve transparency, detailed reporting by country becomes necessary. The detailed reporting to the Board about the specific commitments made by each country opting for the alternative approach and the way the IAEA performed its independent verifications as a consequence of these commitments is also required for the Board to verify that the fundamental principle of nondiscrimination is respected.

Practical Suggestions

Future SIRs could be divided in to two parts. The first part, similar to the present SIR, would apply to all countries opting for the traditional safeguards approach. The second part would apply to countries opting for the alternative safeguards approach.

This second part would include one section for each such country. Each section would include two subsections. The first subsection would summarize the additional commitments made by the state and/or the operators to achieve greater transparency and to give the IAEA increased verification rights. This subsection would describe:

- Any additional access granted,
- Any abandonment of state's rights that previously limited IAEA actions,
- A copy of the declarations made by the state about its nuclear research programs and industrial investments,
- A list of containment/surveillance devices and surveillance procedures agreed upon, and
- Any and all other commitments made by the state to increase transparency.

(Such information could be fully described in the first year only and thereafter included by reference and updated as necessary.)

The second subsection would summarize the independent verifications performed by the IAEA. This subsection would describe:

- The number, nature, predictability and location of inspections performed;
- Their results;
- The nature of additional inspections triggered or other remedies implemented as a result of anomalies possibly detected;
- The overall conclusion of the IAEA about the likelihood of possible diversions; and
- The moves considered for the following year, if necessary, to improve such conclusions.

Transparency — Some Observations

F. Houck, US ACDA

The increasingly popular term *transparency* has been used throughout the IAEA Safeguards Symposium to mean many things to many people. It has rather little utility as a catch-all term or buzz word. A precise definition of transparency is in order.

In this paper, *transparency* is the provision to the IAEA of additional information for which the IAEA has an identified use and includes any associated increased IAEA access to use the information. In 1993, the IAEA Board endorsed very specific proposals for provision to the IAEA of additional information on international nuclear transfers. It also made specific decisions on verification in the context of its earlier confirmation of the very sweeping access rights for special inspections outlined by the director general. Examples of transparency were recently identified . Both the IAEA Secretariat and South Africa spoke of the value of the additional information and associated increased access for the IAEA in that country.

In this and other examples where transparency was found valuable to IAEA safeguards, a clear need and use was recognized for the additional information, and the additional access utilized by the IAEA had a clear connection to the additional information. These two points are significant.

The need for objectivity and clear logical connections between information and safeguards conclusions should not be confused with the completely different issue of quantitative versus qualitative measures. Additional useful information could be quantitative or qualitative; it is neither necessary nor useful to restrict it to one or the other. What is necessary is that any new item of information has a clear use to the IAEA in reaching its safeguards conclusions. These could include new forms of conclusions as well as current conclusions.

Increased access rights have practical utility only if the IAEA also has information that can direct the application of that access right, i.e., that can indicate where in a country the IAEA inspectors should go. Without such information, the right of access has little, if any, practical value. An exercised or partially exercised right of informed access provides a basis for IAEA safeguards conclusions, whereas an unexercised right of access does not. Increased access per se has not been shown to contribute to safeguards conclusions, effectiveness or efficiency.

Access to an unsafeguarded site, without either information directing the IAEA's attention or other explicit need for the access, is unlikely to contribute to safeguards. It is questionable whether inspections of unsafeguarded locations selected on a random basis would be an efficient or effective use of IAEA resources, would contribute to a capability for detecting undeclared nuclear activities, or would have any significant deterrent effect. In general, an approach that is much more practical than the notion of "anytime, anywhere access" would be arrangements for increased access when and where it is needed while protecting legitimate rights of Member States. The Chemical Weapons Convention is a good example of this approach.

Additional information to the IAEA has two potential practical uses. First, it could help identify inconsistencies within the entirety of the information available to the IAEA, including information from inspections. These inconsistencies could be an indication of some violation of safeguards undertakings. Second, a declaration of the Member State could facilitate IAEA interpretation of analyses of other information or facilitate resolution of ambiguities. In these respects, additional information is not different from currently used information.

Any increase in the information provided to the IAEA involves an increased cost. Nothing is free. It costs the Member State to collect, compile and transmit the information, and it costs the IAEA to input, process, evaluate and store the information. The cost of analysis and evaluation, particularly when performed by experienced staff, can be substantial. Without meaningful analysis and evaluation, the information contributes nothing or, even worse, detracts by overwhelming the safeguards system, thus losing or masking useful information. A pragmatic approach involves the regular provision of carefully defined information for which a clear and meaningful use has been established, with additional information provided upon IAEA request to clarify or follow up any ambiguities or questions regarding the base information.

When considering seeking specific additional information, the IAEA must balance the potential contribution of the information and its expected costs. While some reasonable estimates might be made of the costs, there seems little prospect for quantifying the potential contribution. Nonetheless, the IAEA must make qualitative judgments about relative contributions, in the context of all information available to the IAEA, and establish priorities for seeking additional information, considering the cost of the information. How far down the priority list to go can only be a matter of judgment and debate.

The time has come to shift the debate about transparency from generalities and speculation to specific items of additional information, specific expected contributions to IAEA safeguards conclusions, likely costs, and specific additional access expected to be needed to make use of the information.

Comparison of Shuffler and Differential Die-Away Technique Instruments for the Assay of Fissile Materials in 55-Gallon Waste Drums

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Abstract

We compare the features of a ^{252}Cf shuffler and a differential die-away technique (DDT) instrument for the assay of 208-L (55-gal.) waste drums and the experimental results obtained using drums with 20 different simulated waste matrices. Active assays of uranium and plutonium were made, along with passive assays of plutonium.

The major potential sources of inaccuracy for most wastes are self-shielding and nonuniform distribution of the fissile material throughout a drum's volume. We examined the distribution problem by placing small samples of plutonium and uranium at 15 representative locations within each test matrix. The combined responses from all these locations simulated the case of a uniform distribution. Inaccuracies can grow as the density of moderator or absorber in a matrix is increased, so a wide range of absorber and moderator densities was used in the test drums.

Self-shielding and effects due to high-neutron backgrounds were also examined. The instruments' minimum detectable masses for uniform distributions of uranium and plutonium were calculated for the various matrices.

Introduction

A comparison of the shuffler and the differential die-away technique (DDT) instrument for 208-L (55-gal.) waste drums was completed. Data were taken with small uranium and plutonium samples at representative positions within drums containing various simulated waste matrices. These data were used to study problems associated with assaying drums with localized distributions of fissile materials. The data were also combined to simulate uniform distributions.

This paper reviews the highlights of the comparison. Other reports[1-4] give many more details on the measurements, including data obtained for individual drums, made with each instrument.

Table I summarizes some of the major features of the DDT instrument and shuffler used for this comparison; other versions of these instruments may differ in some of these details.

Active assays are done in fundamentally different ways by these two instruments. The DDT instrument's graphite

TABLE I. Characteristics of the Shuffler and DDT Instrument

	DDT	Shuffler
Passive counting efficiency	12%	17.8%
Active counting efficiency	2.8%	17.8%
Total active assay time; signal count time (for this comparison)	40 s; 6.4 s	1000 s; 240 s
Passive count time (for this comparison)	400 s	400 s
Coincidence gate length for passive counts	250 µs	128 µs
Interrogation source; interrogating neutron energy spectrum	Pulsed Zetatron;* thermal neutrons only	^{252}Cf; fast to thermal: neutrons moderated by the cavity walls and the waste matrix; thermal component reduced by Cadmium liner.
Interrogation source intensity	Typically 10^8 neutrons/s	Typically 10^9 neutrons/s
Effective fission cross section	^{239}Pu, 750 b ^{235}U, 585 b	Less than DDT for fast neutron interrogation; similar to DDT for thermal neutron interrogation
Available neutrons per fission for detection	^{239}Pu, 2.87 (prompt) ^{235}U, 2.43 (prompt)	^{239}Pu, 0.006 (delayed) ^{235}U, 0.016 (delayed)
Average energy of emitted neutrons being detected	About 1.5 MeV (prompt)	About 0.5 Mev (delayed)

*Zetatron tubes are manufactured by G. E. Aerospace, now Martin Marietta, Largo, Florida.

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*Work supported by the U.S. Department of Energy, Office of Safeguards and Security, and by the U.S. Department of Energy, Office of Arms Control and Nonproliferation, International Safeguards Division. The DDT instrument used in this study was part of a mobile system provided for our use by the DOE/WPSO. The shuffler used was funded by and is now installed in the Martin Marietta Energy Systems Portsmouth Plant.

and polyethylene walls, and possibly the waste matrix in the drum, rapidly thermalize the 14-MeV neutrons from a D-T generator. Active assays are based on the prompt neutrons released after fissions that are induced solely by the thermal neutrons as they "die away" with time after the neutron generator pulse.

In contrast, the shuffler's interrogating neutrons have relatively high energies. The average energy of neutrons from ^{252}Cf is initially 2.14 MeV but is reduced by scattering within the waste drum and the polyethylene walls of the assay chamber, so fissions generally are induced by neutrons with a broad spectrum of energies with an average energy in the range of 1 keV in lightly moderating matrices. The fraction of thermal neutrons in the shuffler's spectrum is generally low because a cadmium liner on the inner wall of the shuffler's assay chamber prevents neutrons thermalized in the wall from returning to the drum; however, thermal neutrons may be present in the drum due to moderating matrices or if a moderating sleeve is placed around the drum. Delayed neutrons are counted after the ^{252}Cf source has been retracted into a shield.

The passive-neutron assays of plutonium with the two instruments also differ somewhat. The shuffler has bare detector tubes behind a thin wall of polyethylene, achieves a higher counting efficiency than the DDT instrument and uses shift-register electronics. The DDT instrument described here has both cadmium-shielded and bare detectors located behind thick walls of graphite and uses a conventional first-neutron-gated coincidence unit.

Table II summarizes the types of detectors used to determine matrix correction factors in the two instruments being compared here; more details can be found in References 1-6. Again, remember that other shufflers and DDT instruments may obtain matrix correction factors differently.

TABLE II. Matrix Correction Basis of the Shuffler and DDT Instrument

	DDT	Shuffler
Active, Uranium	Cavity/barrel flux monitor ratio (absorber correction)	Cadmium shielded/bare flux monitor ratio
Active, Plutonium	Cavity/barrel flux monitor ratio and, if count rate precision is adequate, shielded/totals counting detector ratio from passive measurement (otherwise, no second correction)	Cadmium shielded/bare flux monitor ratio
Passive, Coincidence	Cavity/barrel flux monitor ratio and, if count rate precision is adequate, shielded/totals counting detector ratio from passive measurement (otherwise, no second correction)	Cadmium shielded/ bare flux monitor ratio and, if reals/totals[a] emission ratio is known and count rate precision is adequate, reals/totals count ratio

[a] "Reals" is an abbreviation for "real coincidence counts," which excludes accidental coincidence counts. "Totals" implies all neutron counts beyond background counts.

Test Matrices and Fissile Samples

We used both instruments to measure uranium, plutonium or both in the 20 matrices (plus an empty drum) described in Table III.

TABLE III. Selected Characteristics of the Matrices

	Matrix[a]	Matrix Weight (kg)	Density (g/cm^3)	
			Hydrogen	Boron
1.	Empty	0.0	0.0	0.0
	Low- and Medium-Density Moderators			
2.	Vermiculite	34.0	0.0008	0.0
3.	Vermiculite in liner[b]	34.9	0.0047	0.0
4.	Simulated junk[c]	38.6	d	0.0
5.	Polyethylene shavings	11.8	0.0086	0.0
6.	Iron and polyethylene chunks	d	0.014	0.0
7.	Vermiculite and 29.5 kg of polyethylene beads	49.0	0.021	0.0
	High-Density Moderators			
8.	Vermiculite and 59 kg of polyethylene beads	78.5	0.042	0.0
9.	Vermiculite and 68 kg of polyethylene beads	87.5	0.049	0.0
10.	Polyethylene chunks	91.2	0.066	0.0
11.	Polyethylene beads	120.2	0.086	0.0
	Absorbers			
12.	Iron chunks[e]	210.9	0.0	0.0
13.	Vermiculite and 0.3 kg of borax	34.3	0.00083	0.00017
14.	Vermiculite and 0.6 kg of borax	34.6	0.00087	0.00034
15.	Vermiculite and 0.9 kg of borax	34.9	0.00091	0.00052
16.	Vermiculite and 1.2 kg of borax	35.2	0.00095	0.00069
17.	Vermiculite and 1.8 kg of borax	35.8	0.0010	0.0010
	Moderators and Absorbers			
18.	Alumina with 28% water (by weight)[f]	237.7	0.038	0.0
19.	Vermiculite, 68 kg of polyethylene beads, 0.42 kg of borax	88.5	0.049	0.00024
20.	Matrix 19, top; vermiculite, bottom[g]	48.5	0.025	0.00013
21.	Vermiculite, top; matrix 19, bottom[h]	50.6	0.025	0.00013

[a] These matrices are considered homogeneous: 2, 3, 5, 7 through 9, 11, and 13 through 19.

[b] The liner was 5.4 kg of plastic.

[c] This matrix included scrap gloves, aluminum, and iron (loosely packed).

[d] Not known.

[e] Iron is an absorber of the DDT instrument's thermal neutrons but a slight moderator (through inelastic collisions) in the shuffler. However, the drum was only about two-thirds full of iron and thus many measurement positions near the top were outside the iron.

[f] This absorbed water fraction is unusually high. In routine use it is usually below 10% (by weight), greatly reducing the ability to moderate neutrons.

[g] The drum was half filled with vermiculite and then the top half was filled with matrix 19.

[h] The drum was half filled with matrix 19 and then the top half was filled with vermiculite.

Three hollow tubes penetrated the matrices vertically at different radii so that small samples of uranium and plutonium could be placed at 15 representative positions throughout the drums.[1,3] (Fewer positions were used in some shuffler measurements.) These positions were the centroids of equal-volume regions. The drums rotated continuously during assays.

Borax was a convenient material to use while exploring the effects of a thermal-neutron absorber (boron, in this case). Other elements can also be effective absorbers of thermal and epithermal neutrons depending on their concentrations. Such elements include hydrogen, iron and chlorine.

The uranium sample had 4.95 g of 94.5% enriched uranium distributed on alumina pellets within a 2-cm-diameter and 10-cm-long capsule. This sample was measured with an active technique using the shuffler for all the matrices. No DDT instrument measurements with this uranium source are used in this report. A 29.75-g cylinder of plutonium metal with 93.81% ^{239}Pu and 5.81% ^{240}Pu (or 1.75 g of ^{240}Pu$_{\text{eff}}$[7] for passive coincidence counting) was measured with an active technique in almost all of the matrices with the shuffler and all the matrices with the DDT instrument; the cylinder's diameter and height were both 1.339 cm. The same plutonium sample was used for all the passive measurements in both instruments. Neutron multiplication in this large source was significant for the passive assays but was accounted for in the data analyses.

For purposes of discussion, the 20 matrices in Table III are grouped into four categories, based on their gross moderator and absorber properties. The break between the drums classified as having low- and medium-density moderators and the drums classified as having high-density moderators is somewhat arbitrary. This is also the case for the other break points used. In fact, all drums contain materials that moderate and absorb neutrons to some extent, and the amount of moderation or absorption will also depend on the interrogating neutron energies, which are different for the two instruments being compared here. The categories used are primarily based on how much hydrogen (a good moderator) and how much boron (a good thermal neutron absorber) were contained in the drum.

Active Assay Results and Discussion

The accuracies of the active assays are dependent upon the characteristics of the assay instrument and can be greatly affected by the composition and homogeneity of the waste matrix, the uniformity of the fissile distribution in the matrix, and the degree of shielding of the interrogating flux caused by neutron-absorbing lumps of fissile material ("self-shielding"). The intrinsic sensitivity of the measurement depends on the characteristics of the particular instrument but is also affected by the background neutron intensity. These effects on the shuffler and DDT instrument assays are discussed in this section.

Assay Variability For Localized Fissile Distributions

If the fissile material is restricted to only a portion of a drum's volume, the assay result can depend strongly on the location of that volume, especially in matrices that are highly moderating or absorbing or both. Heterogeneities in the matrix can compound the effect.

The DDT instrument's active data analysis for plutonium assays includes a moderator correction factor,[1,2,5] deduced from the passive assay analysis that effectively provides some correction for the position of the neutron source. The precision of the moderator correction factor depends on the passive signal strength, which diminishes as the emission rate of spontaneous fission neutrons decreases; below about 0.5 g of low-burnup plutonium, the precision is so poor that the moderator correction factor is not useful. Of course, for uranium assays, there is no passive signal, so it is not possible to obtain a moderator correction factor, regardless of the amount of uranium present. The shuffler's data for active assays currently are not corrected for position, but data taken as part of this study point to a possible technique for both uranium and plutonium samples;[3] the shuffler too will face precision problems with weak signals from small amounts of uranium or plutonium.

With the shuffler, a polyethylene sleeve can be placed over a drum to lower the average energy of interrogating neutrons. This is effective when the matrix in a drum is not a strong moderator itself. Results presented below are for the shuffler without the sleeve in place; results with the sleeve are in References 3 and 4.

A comparison of the shuffler and DDT instruments' responses for localized distributions of fissile materials is shown in Table IV. The average relative standard deviations (RSD) were obtained by first finding the RSD for the 15 assay values for the point source in each drum and then averaging these values for the drums in each grouping. Thus, these values can be interpreted as showing the average degree of assay variability associated with localized sources randomly distributed in the drums. In the ideal assay system, results for localized sources of the same mass would not vary with position.

TABLE IV. Average Relative Standard Deviations for Active Assays with Localized Fissile Materials

	Average Relative Standard Deviations for Localized Fissile Materials			
	Uranium		Plutonium	
Matrix Type (by Table III numbers)	DDT[a]	Shuffler[b]	DDT[c]	Shuffler[c]
Low- and medium-density moderators (2-7)	0.130	0.276	0.142	0.177
High-density moderator (8-11)	0.324	0.333	0.367	0.414[d]
Absorbers (12-17)	0.206	0.074	0.209	0.195
Moderators and absorbers (18-21)	0.436	0.501	0.362	0.351
All (2-21)	0.253	0.272	0.252	0.257

[a] Calculated from measurements on the 30-g sample of plutonium without applying the moderator correction factor and using known nuclear properties of uranium and plutonium.

[b] Measured with the 5-g sample of uranium.

[c] Measured with the 30-g sample of plutonium.

[d] No data were taken with matrix 8.

For the average of all matrices, the DDT instrument and shuffler provide comparable results, with RSDs of about 0.25 for both uranium and plutonium. However, closer examination reveals differences for specific categories. The best results for the DDT instrument are for the drums containing low and medium amounts of moderators (drums 2-7), while the shuffler gave best results with drums containing absorbers with minimal moderator (drums 12-17). These results are not surprising. In the case of the DDT instrument, the interrogating neutrons are always at thermal energies; thus, their energies are not changed by the moderators, but they are particularly susceptible to absorbers (which usually have their highest absorption cross sections at thermal energies). Conversely, the shuffler's interrogating neutrons are reduced in energy by moderators (particularly hydrogen), but the nonthermal component of the spectrum is relatively unaffected by the absorbers.

In the drums where both moderators and absorbers are present in significant quantities, (drums 18-21) both instruments have large RSDs. This is also the case for drums with high amounts of moderators (drums 8-11), which have so much hydrogen that there is significant absorption even though hydrogen has a relatively low thermal capture cross section. Thus, for both instruments, the interrogating flux intensity can vary significantly with position in the drum, and the delayed and prompt fission neutrons from plutonium and uranium can be affected differently as they exit from various locations in the drum. The combination of these two factors produces widely varying responses from different locations in these sets of drums for both instruments. Additionally, for drums 20 and 21, the marked heterogeneous nature of these matrices results in further spatial variations in response.

Overall, the DDT instrument's moderator correction factor did not improve plutonium results (i.e., decrease the RSDs) over the uranium results in these tests involving localized sources. The moderating sleeve did not markedly improve the shuffler's RSD for the low and medium-density moderators (where its use is appropriate), and the sleeve worsened the RSD for matrices that were already highly moderating.

Accuracy For Uniform Fissile Distributions

A uniform distribution of fissile material was simulated by using 15 positions throughout each drum. A simple average of the measurement results from the 15 positions were used to simulate a homogeneous distribution for the shuffler. However, because of the position-correction feature in the DDT instrument's software, the average uncorrected measurement results and the average correction factors are multiplied to simulate the results for a uniform fissile distribution for that instrument.

For each matrix category, we computed the average assay result and the RSD of the results for the drums in that grouping; these results were then divided by the assay value obtained for the empty drum. Thus, the RSDs shown are a measure of the variations of the assay results from the mean for each grouping and not necessarily a measure of the variation of the assay values from the true value. These averages and RSDs are shown in Table V. Assays with perfect accuracies would have an average ratio of unity and an RSD of zero.

It can be seen that overall the absolute assay accuracies and RSDs obtained for the DDT instrument and shuffler are comparable for both uranium and plutonium; the RSDs are about 0.25. For the DDT instrument, overall assay results (as opposed to RSDs) are better for plutonium than uranium, while the converse is true for the shuffler. The DDT uranium assay values were calculated from measurements on plutonium but without the moderator correction factor (obtained from passive counts) applied; the plutonium values were thus generally better than those of uranium, especially for drums with high-moderator content (drums 8-11).

In general, the shuffler gave better assay results for uranium than plutonium. The role, if any, that self-shielding in the 30-g plutonium source played in the shuffler results was not determined. If a plutonium source with minimal self-shielding had been used for the shuffler measurements, somewhat different results might have been obtained, perhaps reducing the differences observed between plutonium and uranium.

The smallest RSDs for the shuffler were obtained for the drums categorized as absorbers (drums 12-17), which is also the case for the DDT instrument. The latter observation may be contrasted with the findings for localized sources described in the previous section, where the smallest RSDs for the DDT instrument were associated with low- and medium-density moderators. The low standard deviations here result from averaging the individual localized responses in the drum and using a DDT-instrument absorption correction factor that was based on average responses; the absorber correction factor is based on the average absorption characteristics of the matrix and has no positional correction associated with it. The shuffler gave the largest standard deviations for drums with high-density moderators (8-11), while the DDT had its highest standard deviations for drums containing substantial quantities of both moderators and absorbers (18-21). The two drums in this category with the grossly inhomogeneous (worst case) matrices were a major factor for the large standard deviations of the DDT instrument.

The assay accuracies reported in Table V for both the shuffler and DDT instruments are somewhat better than would be expected in practice because most of the matrix drums listed in the table were the same drums used to establish the matrix and absorber correction factors.

Self-Shielding Effects

The fissile material near the surface of a particle or lump can capture enough interrogating neutrons to greatly reduce the fission rate in the particle's interior. Self-shielding becomes more important as the particle size and density grows and the neutrons' energies diminish. Fission rates become proportional to the particle's surface area rather than its mass.

The thermal neutrons of the DDT instrument experience the maximum self-shielding effect. The largest effects of self-shielding on the shuffler are limited to those neutrons that are thermalized before reaching the fissile material in a drum. Some of the shuffler's interrogating neutrons are low in energy because they scatter in the polyethylene walls and in a drum's matrix. The shuffler's assay chamber has a cadmium liner to prevent the lowest-energy neutrons from returning from the walls into a drum, but thermalization in the matrix cannot be prevented. Of course, if the sleeve is used with the shuffler, a substantial fraction of the interrogating neutrons will be thermalized, increasing the self-shielding.

Table VI demonstrates the effect of self-shielding on four uranium materials. All of these values are deduced from Monte Carlo calculations.

Self-shielding by a 10-mg sphere of metallic uranium[8] is such that the fission rate in the DDT instrument is reduced to about 35% of the rate that would have occurred had there been no self-shielding. The neutrons in the shuffler have a much higher average energy and consequently the self-shielding is less; the fission rate is 86% of the unshielded value with the cadmium liner and 53% without the cadmium liner. The latter case, involving removal of the cadmium liner, simulates (approximately) the effect of adding the moderating sleeve to the shuffler, or having a matrix with substantial amounts of moderators in it.

Self-shielding in the instruments was further explored by performing calculations using uranium masses much larger than that of a small particle. Two uranium oxide spheres, with ^{235}U masses of 100 g and 200 g and a simulated air filter with a ^{235}U mass of 200 g gave unshielded rates of 9% to 28% and 52% to 85% of the non-self-shielded response, respectively, for the DDT instrument and shuffler in nonmoderating circumstances. Without the cadmium liner, the self-shielding is much larger in the shuffler (and is now similar in size to the DDT instrument values), primarily because the average neutron energy is lower, with a substantial thermal energy component.

TABLE V. Active Assay Accuracy with Uniform Fissile Distributions

	Assay Result/Expected Result (RSD)			
	Uranium		Plutonium	
Matrix Type (by Table III numbers)	DDT[a]	Shuffler[b]	DDT[c]	Shuffler[c]
Low- and medium-density moderators (2-7)	0.99 (0.13)	1.09 (0.26)	0.94 (0.16)	1.32 (0.20)
High-density moderator (8-11)	0.68 (0.29)	0.98 (0.38)	0.96 (0.18)	1.01 (0.28)
Absorbers (12-17)	1.03 (0.09)	1.02 (0.02)	1.04 (0.09)	1.02 (0.06)
Moderators and absorbers (18-21)	0.91 (0.48)	0.87 (0.17)	1.04 (0.52)	1.05 (0.25)
All (2-21)	0.92 (0.27)	1.00 (0.23)	1.00 (0.25)	1.11 (0.22)

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[a] Calculated from measurements on the 30-g sample of plutonium without applying the moderator correction factor and using known nuclear properties of uranium and plutonium.

[b] Measured with the 5-g sample of uranium.

[c] Measured with the 30-g sample of plutonium.

TABLE VI. Calculated Self-Shielding Effects on Active Assays

	Lumped/Dispersed Assay Ratio[a]		
		Shuffler	
Uranium Material	DDT[b] (%)	Moderated[c] (%)	Not Moderated[d] (%)
10-mg metal sphere (93% ^{235}U)	35	53	86
Sphere of U_3O_8 with 100 g of ^{235}U (93% enr.)	11	12	58
Sphere of U_3O_8 with 200 g of ^{235}U (93% enr.)	9	10	52
U_3O_8 with 200 g of ^{235}U (93% enr.) in a filter (6 in. diameter, 1 in. high)	28	40	85

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[a] The "lumped" assay means that self-shielding had an effect because the uranium was concentrated in a compact mass. The "dispersed" assay results from distributing the uranium uniformly throughout the entire volume of a 55-gallon drum. (For the three cases involving spheres, five spheres were placed at widely separated positions within the drum to improve the precision of the calculation and to lead to a self-shielding averaged throughout the drum.)

[b] Thermal neutrons were used in these calculations.

[c] This was calculated by "removing" the cadmium liner from the assay chamber, allowing neutrons that are thermalized in the walls to return to the uranium. (If a drum is not empty, the matrix may also moderate the neutrons regardless of the cadmium liner.) The ^{252}Cf fission spectrum was used for the initial neutron energies.

[d] The cadmium liner surrounded the assay chamber, preventing the lowest-energy neutrons from reaching the uranium. The ^{252}Cf fission spectrum was used for the initial neutron energies.

Minimum Detectable Masses for Active Assays

The minimum detectable masses are presented here for drums with uniform distributions of the fissile material. With localized distributions, the minimum detectable mass is the same function of position discussed earlier for the assay variability; for individual locations in some matrices, detection limits may be much larger than indicated in the table.

The minimum detectable mass is defined here as the smallest fissile mass that produces a net signal three times its precision. Precision is the standard deviation of a large number of repeat assays on the same drum. Table VII shows minimum detectable masses for the two instruments in the active mode.

The DDT instrument's minimum detectable masses of ^{235}U and ^{239}Pu for active assays are lower than those of the shuffler's because of the much higher count rates obtained with the DDT's thermal neutron interrogation and prompt neutron detection. For the 20 matrices studied here, the DDT instrument's average minimum detectable masses were 14 mg of ^{235}U and 9.6 mg of ^{239}Pu for 40-s active interrogations. With the shuffler, the minimum detectable masses were 209 mg of ^{235}U and 677 mg of ^{239}Pu for 1000-s measurements (including a 270-s background count) with interrogation by fast neutrons. The use of the shuffler's moderating sleeve around drums with low- and medium-density moderators reduces the minimum detectable mass of ^{235}U by about a factor of 3; the sleeve should not be used on matrices with high densities of moderator because it increases the minimum detectable masses.

The shuffler's minimum detectable mass for ^{235}U is better than that for ^{239}Pu because spontaneous fissions of even isotopes of plutonium create an interferring neutron background in addition to other factors involving relative delayed-neutron yields. The DDT instrument has better sensitivity for plutonium than uranium because of higher fission cross sections and neutron yields in plutonium.

Table VIII shows the calculated minimum detectable ^{235}U masses when interfering neutron backgrounds are present, such as those due to (α,n) reactions in the waste matrix or the presence of spontaneous emitters such as ^{252}Cf. These results are an average for all 20 drums; similar trends hold for the drums individually and for other fissile materials. It is readily apparent that the DDT system is less affected by neutron backgrounds in the active mode than the shuffler. From the lowest to highest backgrounds considered in the table, the minimum detectable masses increase by a factor of 6.7 for the DDT instrument and about 28 for the shuffler. The differences in sensitivity between the two instruments are related to an intrinsically higher signal-to-background ratio in the DDT method, different counting efficiencies and count times, and other factors; additional data and more details are contained in References 1 and 3.

TABLE VII. Minimum Detectable Masses for Active Assays

	Active Assay Minimum Detectable Masses (mg)[a]			
	^{235}U		^{239}Pu	
Matrix Type (by Table III numbers)	DDT[b]	Shuffler[c]	DDT[d]	Shuffler[e]
Low- and medium-density moderators (2-7)	8.3	153	5.5	456
High-density moderator (8-11)	22	74	15	196
Absorbers (12-17)	12	432	8.1	1487
Moderators and absorbers (18-21)	20	92	14	248
All (2-21)	14	209	9.6	677

[a] Natural background rates were those at the Los Alamos elevation (2220 m above sea level): 44 counts/s for the DDT instrument and 22 counts/s for the shuffler.

[b] Calculated from measurements with the 30-g plutonium sample using known differences between uranium and plutonium because few measurements with uranium were made.

[c] Calculated from measurements with the 5-g uranium sample.

[d] Calculated from measurements with the 30-g plutonium sample.

[e] Calculated from measurements with the 5-g uranium sample using known differences between uranium and plutonium because measurements with the 30-g plutonium sample have self-shielding and could not be extrapolated to minimum detectable masses accurately.

TABLE VIII. Calculated Effect of Background Rate on Minimum Detectable ^{235}U Masses for Active Assays

	Minimum Detectable ^{235}U Mass (mg)[a]	
Background Source Rate (neutrons/s)[b]	DDT	Shuffler
Natural	14	209
Natural + 100ε	15	279
Natural + 1 000ε	17	622
Natural + 10 000ε	33	1860
Natural + 100 000ε	94	5842

[a] These masses are averages over all the 21 matrices of Table I.

[b] Each background source rate is the sum of the natural background rate and the rate from spontaneous fissions in the plutonium. The natural background rates are 44 and 22 counts/s for the DDT instrument and the shuffler, respectively, at the Los Alamos elevation (2220 m above sea level); the shuffler's rate includes 12 counts/s from a 500 μg ^{252}Cf source and the use of cosmic-ray burst rejection. The detection efficiencies ε are 0.028 and 0.178 for the DDT instrument and the shuffler, respectively. The shuffler's efficiency was measured using a ^{252}Cf source but was designed to be a maximum at the lower energies of delayed neutrons.

Passive Assay Results and Discussion

Only passive assays based on coincidence counting will be discussed here. They have more applications in facilities than assays from total neutron counting because real coincidence counts are relatively immune to changes in the neutron background from facility activities and are rarely biased by (α, n) reactions within a drum. Coincidence counting is also relatively insensitive to neutron absorbers in the matrix. However, minimum detectable masses can often be improved with total neutron counting, if that technique can be applied properly and the interfering neutron sources are small.

The DDT instrument has a moderator correction factor based on ratios of passive neutron counts in detectors with a cadmium shield to the sum of counts in shielded and unshielded detectors (the shielded/totals ratio). This factor primarily depends on the amount of moderator the neutrons must traverse to escape the drum. (The passive correction factor is referred to as the 250-μ correction factor in previous publications[1, 5] but will simply be called the moderator correction factor here.) The precision of this factor decreases as the count rate decreases; the factor is generally too imprecise to use with low-burnup plutonium masses below approximately 0.5 g (30 mg ^{240}Pu). The correction can generally be used for counts obtained from low-burnup plutonium masses of this size or greater; however, severe moderation in the matrix will substantially reduce the count rate, correspondingly increasing the minimum mass required to use the moderation correction factor (or requiring that the count time be increased). For this reason, results for the DDT instrument are presented with (corrected) and without (uncorrected) this factor.

Monte Carlo calculations[9] for an instrument similar to the DDT instrument used here have shown that the moderator correction factor (for use with both active and passive assays) is generally applicable to mixtures of fission-neutron emitters and (α,n) sources. Errors in the measured shielded-to-totals ratio caused by relatively different energies of the (α,n) neutrons were shown to be minor, except for some extreme mixtures of fission neutrons and very low-energy (α,n) neutrons. However, operators of DDT instruments should perform measurements using varying intensity and energy (α,n) neutron sources appropriate to their waste streams to confirm that this calculational finding also holds for their particular instrument.

The shuffler may operate with a moderator correction factor based on the ratio of the real coincidence counts to the totals counts. This ratio is proportional to the effective detection efficiency for neutrons emitted from the drums, and thus it can be used to correct for moderation and absorption. The use of this ratio is limited to cases when the (α,n) yield of the standards closely matches that of the unknowns; a fractional error in the value of a leads to an error in the mass of about the same fraction. The results in Tables IX and X are presented with and without this correction factor.

Assay Variability for Localized Fissile Distributions

The results for localized sources for each group of drums are shown in Table IX. These RSDs were calculated in the same way and have the same interpretation as the active values in Table IV. It is clear for both instruments that the largest positional variations are associated with large amounts of moderator in the waste matrix. Absorbers have little, if any, effect on the passive coincidence results. The uncorrected results for the DDT instrument have overall RSDs that are about 0.8 of the shuffler's. It is not obvious what factors are responsible for this difference or how statistically significant it is. However, it is clear that application of the correction factors significantly improves the overall RSDs. All of the shuffler's RSDs are improved except for the high-density moderators. All drum categories for the DDT instrument are improved, except for the drums with absorbers only (drums 12-17), which have a moderator correction factor of unity.

TABLE IX. Average RSDs for Passive Assays with Localized Plutonium

	Average RSDs for Localized Plutonium			
	DDT[a,b]		Shuffler[a,c]	
Matrix Type (by Table III numbers)	Uncorrected	Corrected	Uncorrected	Corrected
Low- and medium-density moderators (2-7)	0.107	0.066	0.116	0.055
High-density moderator (8-11)	0.538	0.347	0.660	0.708[d]
Absorbers (12-17)	0.036	0.036	0.084	0.049[e]
Moderators and absorbers (18-21)	0.280	0.151	0.216	0.098
All (2-21)	0.206	0.130	0.256	0.170[d,e]

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[a] Calculated from measurements with the 30-g plutonium sample.

[b] The position-dependent moderator correction factor may be applied by the DDT instrument for low-burnup plutonium masses more than about half a gram.

[c] The position-dependent reals-to-totals ratio correction factor may be applied by the shuffler for low-burnup plutonium masses more than about half a gram and when the reals-to-totals emission ratio is known.

[d] No data were taken with matrix 8.

[e] No data were taken with matrix 16.

TABLE X. Passive Assay Accuracy with Uniform Plutonium Distributions

	Assay Result/Expected Result (RSD)			
	No Corr. Factors[a,b]		With Corr. Factors[b,c]	
Matrix Type (by Table III numbers)	DDT	Shuffler	DDT	Shuffler
Low- and medium-density moderators (2-7)	0.77 (0.31)	0.84 (0.23)	0.94 (0.16)	1.01 (0.02)
High-density moderator (8-11)	0.24 (0.33)	0.26 (0.50)	0.88 (0.16)	0.98 (0.07)
Absorbers (12-17)	1.00 (0.03)	1.01 (0.05)	0.99 (0.03)	1.00 (0.06)
Moderators and absorbers (18-21)	0.51 (0.41)	0.51 (0.55)	0.93 (0.11)	1.06 (0.07)
All (2-21)	0.68 (0.49)	0.73 (0.44)	0.94 (0.12)	1.00 (0.07)

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[a] Normal corrections are applied, such as background subtraction, but a matrix correction unique to the DDT instrument and a reals-to-totals correction for the shuffler have not been applied at this point.

[b] Calculated from measurements with the 30-g sample of plutonium.

[c] The DDT-instrument matrix and the shuffler's reals-to-totals corrections have been applied in computing these results.

Accuracy For Uniform Plutonium Distributions

Table X contains a summary of passive results for uniform distributions of plutonium. These results were calculated in the same manner as the active results of Table V and have the same interpretation. The matrices with large amounts of moderators give rise to the largest RSDs. Overall, RSDs without the correction factors are almost double the 0.25 obtained for active assays of uniform fissile distributions (Table V).

When the moderator correction factor is applied to the DDT instrument data, a large improvement in both the assay values and standard deviations is apparent; the overall RSD is reduced to 0.12. As discussed previously, this correction factor is valid for counting situations in which the counting precision is adequate (usually with 0.5 g or more of low-burnup plutonium). For those cases for which the shuffler's correction factor can be applied, even more improvement is obtained in both the assay values and the standard deviations; the overall RSD is now only 0.07. However, the cases for which the shuffler's correction factor can be applied are limited to those waste drums where the ratio of (α,n) to fission neutrons is known *a priori;* this may be a very limited number of applications and generally excludes samples with high (α,n) rates. It should be noted that a correction factor similar to the shuffler's could be applied to the DDT instrument (with poorer statistical precision), but that was not done here. Another caveat which should be applied to Table X for both instruments is that the correction factors used here were applied to some of the same matrices from which they were devised, so that the accuracies shown here are somewhat better than should be expected when the calibration and unknown matrices are different.

With the application of the correction factors, the passive standard deviations are now considerably better than the active results shown in Table VI. The differences in passive counting accuracies between the two instruments can be attributed mainly to the use of different moderation correction techniques and differences in the designs of the assay chamber walls, whose compositions and thicknesses were optimized for the active assay aspects of the instruments.

Minimum Detectable Masses for Passive Assays

The minimum detectable masses given here are for uniform distributions of plutonium and are governed by the assumption that there is no interference from other neutron emitters in the waste. If such interferences are present, the minimum detectable masses will increase. The minimum detectable mass for a passive assay of a localized source demonstrates position dependence similar to the assay responses and may be higher or lower than that obtained for a uniform distribution.

Table XI summarizes the minimum detectable masses for the two instruments averaged over each group of matrices.

The shuffler has smaller minimum detectable masses for passive counting than the DDT instrument, mainly because the shuffler has a higher counting efficiency and a shorter gate width. Also, the shuffler calculations assume the use of a cosmic-ray rejection technique that reduces the background coincidence rate by about one-half from the observed rate; the DDT instrument does not have this feature. For both instruments, it is assumed that there is no systematic change in the true cosmic-ray background level present during the measurement; this implies that the background is measured for a long time relative to the assumed assay time of 400 s and does not change beyond statistical expectations. Further, it is implicitly assumed that the waste matrix does not contain enough high-Z material to increase the cosmic-ray background significantly. If actual conditions are different than this, detection limits would be larger than given here.

TABLE XI. Minimum Detectable Masses for Passive Assays with 400-s Coincidence Counting

Matrix type (by Table III numbers)	Minimum Detectable Masses[a] (mg $^{240}Pu_{eff}$)[b]	
	DDT[c]	Shuffler[c]
Low- and medium-density moderators (2-7)	32	15
High-density moderator (8-11)	117	59
Absorbers (12-17)	22	12
Moderators and absorbers (18-21)	53	30
All (2-21)	47	24

[a] Coincidence background rates at the *Los Alamos elevation* (2220 m above sea level) were 1.2 counts/s with the DDT instrument and 1.37 counts/s with the shuffler using a cosmic-ray-burst rejection technique. Without that technique, the shuffler's background rate was 2.48 counts/s. The shuffler's minimum detectable masses given here are with the background rate of 1.37 counts/s.

[b] For low-burnup fuel, the mass of the total plutonium is about 17 times the mass of $^{240}Pu_{eff}$; for high-burnup fuel, the total plutonium mass is about 3 times the mass of $^{240}Pu_{eff}$.

[c] Calculated from measurements with the 30-g plutonium sample.

Minimum detectable masses for shufflers at the Los Alamos elevation (2,220 m), where the cosmic-ray background is relative high, averaged 24 mg of $^{240}Pu_{eff}$ for all the matrices studied; for the matrices that most represent those found in many facilities, the minimum detectable masses averaged about 15 mg of $^{240}Pu_{eff}$. The average minimum detectable mass with the DDT instrument was 47 mg of $^{240}Pu_{eff}$; for the more common waste matrices, the minimum detectable masses were about 32 mg of $^{240}Pu_{eff}$. For low-burnup and high-burnup plutonium (about 6% and 24% ^{240}Pu, respectively), 1 mg of $^{240}Pu_{eff}$ corresponds to about 17 mg and 3 mg of total plutonium, respectively.

At elevations close to sea level, the background rates are smaller, and the calculated minimum detectable masses are improved by more than a factor of two for both instruments. Longer count times would also improve sensitivity.

Summary And Conclusions

This comparison study used versions of the DDT and shuffler instruments that are now installed or are similar to versions now installed in DOE facilities. Improving and extending these instruments is an on-going effort and some of the problems described in this paper are already being addressed. This study should be viewed as a snapshot of the status of the instruments that were available for this study.

We can provide some generalizations about the relative strengths and weaknesses of the shuffler and DDT instrument. The shuffler is larger because of the storage block for the ^{252}Cf source, but the D-T generator in the DDT instrument requires more maintenance than the isotopic neutron source in the shuffler. Both neutron sources require periodic replacement, perhaps at intervals of three to six years; the interval is more predictable with the shuffler than the DDT instrument. The DDT instrument requires a warm-up time of 5 to 10 minutes in the active mode, while the shuffler does not require any. The shuffler has a typical active assay time for uranium of 16 minutes, including a 270-s background count; passive assays of plutonium are typically done in 400 s. The DDT instrument's assay time is 40 s in the active mode, plus 400 s in the passive mode (plutonium only), for total assay times of 40 s for uranium and 7.3 minutes for plutonium.

The active assay techniques differ dramatically for the two instruments. The shuffler used in this study interrogates with a broad spectrum of neutron energies and typically minimizes thermal neutron interrogation as much as possible, while the DDT instrument interrogates only with thermal neutrons. (The shuffler's neutron energies can be lowered, when it is advantageous, by removing a cadmium liner or applying a moderating sleeve around the drum.) This difference results in more induced fissions per unit fluence for the DDT instrument and thus greater sensitivity but with a greater susceptibility to thermal neutron "poisons" and self-shielding than with the shuffler, especially in nonmoderating waste matrices.

Conversely, the shuffler in the active mode is more affected by the presence of hydrogenous moderators in the waste matrix. These characteristics result in generally greater accuracy for the DDT instrument in hydrogenous matrices and better accuracy for the shuffler in absorbing matrices. When both moderators and absorbers are present in significant quantities, both instruments are subject to large errors in the active mode. The DDT instrument detects prompt-fission neutrons during a small fraction of the interrogating cycle, while the shuffler detects delayed neutrons during a larger fraction of the interrogating cycle. Even though the DDT instrument has a smaller detection efficiency than the shuffler in the active mode, these differences result in the DDT instrument having a higher count rate.

In the passive counting mode, both instruments detect total and coincident neutrons, but usually the coincidence rate is a more reliable indicator of plutonium content because it is less affected by (α,n) reactions in the waste and by background neutrons. The shuffler has a higher detection efficiency and a lower limit of detection than the DDT instrument in the passive mode.

Based on our study with test matrices and fissile sources, we offer the following specific comparisons of the shuffler and DDT instruments we used:

1. The DDT instrument has smaller minimum detectable masses in the active mode than does the shuffler. The overall minimum detectable mass of ^{235}U with the DDT instrument is about 0.067 that of the shuffler. The overall minimum detectable mass of ^{239}Pu with the DDT instrument in the active mode is about 0.014 that of the shuffler. (The minimum detectable masses from the shuffler with drums of low- and medium-density moderators are reduced by about a factor of 3 if the moderating sleeve is placed around the drums. Using the sleeve on drums with high-density moderators raises the minimum detectable masses and is thus inappropriate.)

2. The shuffler has smaller minimum detectable masses in the passive mode than does the DDT instrument. Generally, the shuffler has half the minimum detectable mass of the DDT instrument. The shuffler normally assays plutonium in the passive mode because of the improved minimum detectable mass and the improved accuracy, relative to its active mode.

3. For active assays of localized distributions of fissile material, the shuffler and the DDT instrument have comparable overall positional variations, with RSDs of about 0.25. For passive coincidence measurements of such distributions, the RSDs for the DDT instrument and the shuffler are comparable, ranging from 0.21 to 0.26 (uncorrected) and 0.13 to 0.17 (corrected).

Note that all assay values (passive as well as active) were obtained using one wide-range calibration curve for each instrument. Better accuracy could have been obtained for individual categories of drums by using calibrations specific to each category, as might be done in practice; however that procedure would not have improved the RSDs.

4. For active assays of uniform distributions of fissile material, the accuracies for the DDT and shuffler without the sleeve are roughly comparable and both have average RSDs of about 0.25. For passive assays of uniform distributions of plutonium, results are similar for uncorrected assays; both instruments give assay values that are low and have overall RSDs near 0.46. If moderator correction factors can be applied to the data, results are improved; for the DDT instrument and shuffler, respectively, the overall RSDs become 0.12 and 0.07. The moderator correction can be used for the DDT instrument data when enough plutonium is present (at least 0.5 g), and the shuffler's correction can be used when the emission ratio of random to coincident neutrons is known and enough plutonium is present (at least 0.5 g, again). These results were obtained with 30 g of plutonium and 5 g of ^{235}U; with small quantities (0.5 g or less) of the fissile materials, the worsening of the counting statistics will increase the RSDs.

5. In the active mode, the DDT instrument can more readily perform assays in the presence of high-neutron-background rates than the shuffler. For added neutron emission rates of 1000/s, the DDT minimum detectable mass for uranium increases by a factor of 1.2, while the shuffler's value increases by a factor of 3.

6. In the active mode, the DDT instrument is more susceptible to neutron poisons than is the shuffler. Conversely, the shuffler is more affected by the presence of moderators in the waste matrix.

7. In the active mode, the shuffler has a smaller self-shielding problem than does the DDT instrument. For example, the DDT instrument's assay result will be 11% of the true value for a sphere of 93% enriched uranium oxide containing 100 g of ^{235}U, while the shuffler's assay of the same material is 58% of the true value in nonmoderating matrices but decreases as moderation increases.

In considering use of the shuffler or DDT instrument for a particular application, reference to the information provided in this paper and the more detailed publications[1-6] can aid in the selection process. It is apparent that for some particular applications, one of these instruments may be the clear choice, while for other applications it may not be easy to decide which instrument will provide generally better results.

Not all of the conclusions reached above will necessarily apply to other DDT instrument and shuffler designs, which may have different features than those used for this study. Some differences may be minor and be of little, if any, importance; but others may be quite significant. For example, some DDT instruments built outside the US use an additional isotopic neutron source to obtain matrix corrections.[10] Also, some recent, commercially built DDT instruments have a higher active-detection efficiency, but do not have bare passive detectors to obtain the moderator correction for plutonium assays used in this study; provision for position-sensitive assays using a different technique has been described.[11] We are currently developing a DDT-type system called the combined thermal epithermal neutron (CTEN) instrument, which will be able to interrogate waste drums sequentially with epithermal and thermal neutrons[12] and will provide additional information about matrix and fissile distributions. A list-mode neutron multiplicity module is also being incorporated.[13]

Shuffler development is aimed at improving corrections for matrix effects, reducing the position effect, making use of the cadmium liner more flexible by removing it from the assay chamber wall and allowing its optional placement around a drum, using combinations of assays with and without the cadmium liner and with and without the moderating sleeve, and using more effective shielding to reduce the background rate caused by the ^{252}Cf source.

The mass of ^{252}Cf could be increased to improve the active detectability limits by an order of magnitude and to give the shuffler a higher signal-to-background ratio for high-background drums. Shufflers have been used for plutonium assays in high gamma-ray (10^5 R/h) backgrounds and high neutron backgrounds from curium by using 2 mg or 3 mg of ^{252}Cf rather than the 0.525 mg of ^{252}Cf of this study.[14, 15] Using such sources for waste drum shufflers would require the use of another 15 cm of polyethylene shielding or shielding materials that are more effective than polyethylene and that have recently become commercially available.

The ^{252}Cf add-a-source technique[16] can be included in the passive assays of plutonium. In a set of drums selected from those described here, with uniform distributions of plutonium in homogeneous and most heterogeneous matrices, this matrix correction method, without any reals-to-totals correction, has significantly improved the accuracy over that reported here.

The shuffler's active assay data from this study have been analyzed using the alternating conditional expectation (ACE) technique[17,18] for matrix corrections. The resulting RSD of the accuracy averaged over 28 matrices (the 21 of Table III plus seven others) was reduced from 23% to 13%.

Such changes in design or characteristics should be considered in the decision-making process when choosing an instrument. Discussions with instrument developers can clarify the current status of the instruments or lead to a design optimized for a particular situation.

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