Editor's Note: *This essay was written before the recent South Asian nuclear tests. Due to post-test U.S. Department of Energy guidelines, it has not been possible for the authors to update it. However, the essay's findings have become even more relevant after these tests.*

VIEWPOINT: COMMERCIAL SATELLITE IMAGERY AND THE CTBT VERIFICATION PROCESS

by Vipin Gupta & Frank Pabian

Satellite imagery has a long history of monitoring nuclear test activity. During the 1960s, the U.S. CORONA satellites were used to track Soviet and Chinese nuclear test programs.[1] In the 1970s, U.S. and Soviet intelligence satellites were reportedly used to observe South Africa's clandestine preparations for an underground nuclear test in the Kalahari Desert.[2] More recently, commercial imaging satellites were used to monitor underground nuclear testing at the U.S., Russian, and Chinese test sites.[3] These satellites were also used to investigate the December 1995 allegations of Indian nuclear test preparations in the Rajasthan Desert.[4]

The advent of commercial imaging satellites has added a new dimension to nuclear test monitoring from space. These satellites currently provide panchromatic and multispectral imagery at a resolution of five to 30 meters, and the next generation of commercial imaging satellites will provide such imagery at one to four meter resolution in near real time.Within the context of monitoring and verification for the Comprehensive Test Ban Treaty (CTBT), commercial imaging satellites offer a unique space-based capability that will likely be used to complement data collected by other sensors and collateral reporting. Sold on the open market at $1,000 to $5,000 per image, these commercial images provide states, organizations, and individuals with an additional means of remotely verifying compliance with the CTBT.

However, in contrast with seismic, radionuclide, hydroacoustic, and infrasound sensors, commercial satellite imaging is not embodied in the treaty as it is a fairly young technology. Unlike national technical means, the potential function of commercial imaging satellites in the verification process is not explicit.[5] The technology's role in CTBT verification remains undefined, and continues to be a subject for further discussion and evaluation.[6]

Consequently, it may be worthwhile considering exactly how this fairly young technology could affect CTBT verification. This essay examines this question by drawing on the experience of past nuclear test monitoring and trying to anticipate the opportunities and problems that are likely to arise with the emergence of more capable commercial imaging satellites.[7] It looks at how the different actors in the CTBT verification process could use commercial satellite imagery for either the benefit or detriment of the treaty. It concludes with some lessons on the use of commercial satellite imagery for addressing future CTBT compliance disputes.

COMMERCIAL SATELLITE IMAGERY AND CTBT VERIFICATION

There are four general groups that will have a formal or informal role in the verification of the CTBT: states, international organizations, non-governmental institutions, and individuals. Each group has a distinct role to play in the verification process, and its agenda may conflict with the others on how the treaty should be implemented, verified, and enforced. As a result, the verification role of commercial satellite imagery will depend not only on the information content of the images, but also the specific actor using the image information.

The Role of States in CTBT Verification

An overwhelming majority of states have signed the CTBT, although a small but significant minority have not.

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India, Pakistan, and North Korea have not yet signed the CTBT, and consequently the treaty cannot enter into force until they do.[8]

Both the states parties to the treaty and the non-signatories will probably use commercial satellite imagery for nuclear test monitoring—although for different political purposes. Among the states parties, commercial satellite imagery will most likely be used for four specific applications[9]:

- searching for human activity or surface disturbances near a seismically detected event;
- investigating allegations of a treaty violation (or intent to violate);
- justifying an on-site inspection request; and
- delineating the search area for an on-site inspection.

In principle, all states parties to the treaty will be able to collect and analyze commercial satellite images independently. Each state will be able to choose from a variety of image suppliers to obtain timely images of any region of its own choosing; states will not have to rely exclusively on the monitoring priorities of the CTBT Organization, the U.N. Security Council, or other states possessing their own national technical means. By combining commercial images with collected collateral information, states parties could make their own discoveries of clandestine efforts to violate or break out of the treaty. Conversely, states parties could reassure themselves that specific countries were complying with the terms of the agreement.

From the standpoint of day-to-day operations, commercial imaging satellites offer states parties several distinct capabilities. Since satellite imaging is a form of non-intrusive remote sensing, it can be done without the consent of the observed, and it can be used routinely without infringing the rights of the inspected party, as specified in the treaty. Furthermore, because satellite imaging can be used to detect "pre-test" as well as "post-test" activities, it is useful for watching nuclear test preparations—which are not prohibited under the CTBT—and making sure the observed state does not cross the threshold from allowed to illicit activity. If images reveal possible or probable nuclear test preparations, such a revelation could trigger intensified monitoring of the suspect site with the "post-test" technologies (e.g., seismic, radionuclide sensors) best suited for determining if and when the line of legality has been crossed.

In addition to triggering intensified monitoring of a suspect site, a state party could present its commercial imagery evidence to its allies and the state in question, asking for clarification on the purpose of the observed activity. For states parties with their own intelligence-gathering satellites, the sharing of commercial images would be a particularly attractive way of seeking an explanation without divulging classified sources and methods.[10]

Such direct state-to-state consultations are encouraged under the treaty.[11] If commercial satellite imagery were used as part of such a direct dialogue, suspect states would effectively be put on notice that they have aroused suspicions and may get caught if they proceed with their illicit plans. They would also retain the option of clarifying the purpose of the observed activity without raising the subject in the Executive Council of the CTBT. If cooperation were not forthcoming, the evidence provided by the commercial imagery could be used to request an on-site inspection.

If commercial satellite imagery were counted among the CTBT's approved evidentiary technologies and if a state party ultimately decided to request an on-site inspection, the commercial satellite images could be presented to the Executive Council to show probable cause. To get the necessary 30 (of 51) votes for approval, the imagery would have to provide enough reason for suspicion to justify the need for an on-site inspection. In addition, given that the Executive Council will comprise a mixture of states with conflicting national security and foreign policy interests, the image evidence would have to be robust enough to withstand politically motivated efforts to discredit its validity, content, and authenticity.

Through the prudent use and presentation of commercial satellite images, such efforts may be countered in several ways. If the ambiguity in the image information is used to cast doubt on the charges of illicit nuclear testing, the requesting state party could argue that it is this ambiguity that demonstrates the need for an on-site inspection. If the interpretation of the imagery is called into question, the requesting state party could ask other states parties to analyze the data independently and determine whether nuclear testing is a possible and plausible explanation for the observed activity. If some states parties claim that the image information has been doctored using digital special effects techniques, the requesting state party could present multiple images obtained from a variety of commercial sources outside of its direct and immediate control.[12] By describing the specific foreign commercial satellites and foreign ground stations

that were used to obtain the raw imagery, the requesting state party could challenge others to purchase the same images from the same commercial archives and digitally verify that the presented image evidence was indeed derived from the raw data.

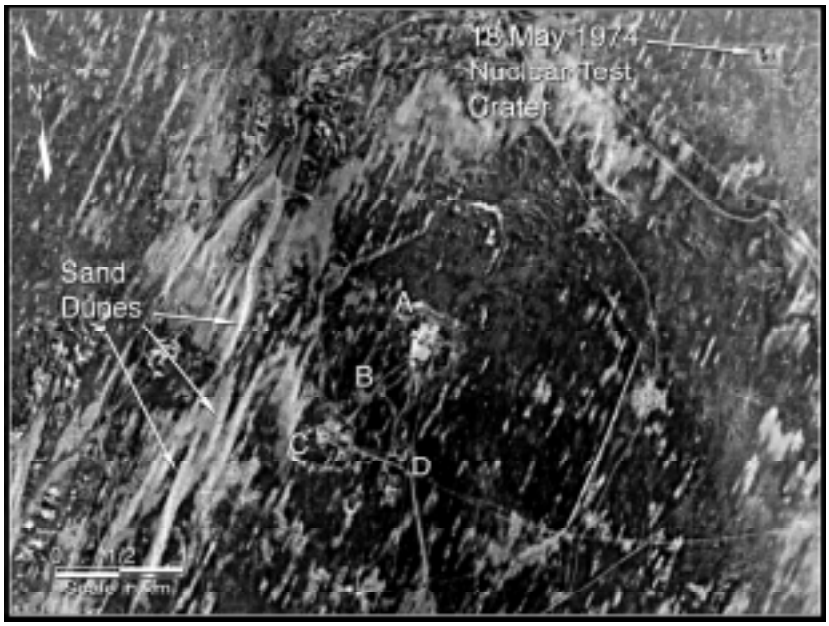

Plate 1: *March 25, 1995 SPOT image of the Indian test site. It was acquired nine months before the public allegations of Indian nuclear test preparations. The image shows basic infrastructure and the crater from India's May 18, 1974 nuclear test.*

Plates 1 and 2 illustrate how the authenticity of commercial satellite images can be verified within the context of a real nuclear testing controversy. In mid-December 1995, India was accused of preparing to conduct a nuclear weapons test—a charge that the Indian government vehemently denied.[13] Senior Indian defense officials stated categorically that no nuclear-related activity was happening at the Indian test site.[14] However, archived French SPOT satellite photos acquired nine months before and three months after the controversy erupted revealed that there was recent large-scale activity at the Indian test site, and that the activity was consistent with unconventional weapons testing—including nuclear weapons testing (see Plates 1 and 2).[15]

Hypothetically, if the authenticity of this image evidence was called into question, the image information could be verified through a repeated, independent analysis of the raw data residing in the SPOT image archives. The evidence could also be verified by obtaining imagery from other commercial imaging satellites, as illustrated in Plate 3.[16] This photo is an Indian IRS-1C satellite image of the Indian test site. Acquired one month after the SPOT image shown in Plate 2, the Indian satellite image shows the exact same surface changes in the French satellite image. Thus, in this case, it would be extremely difficult to argue that the imagery had been surreptitiously altered given that two different foreign commercial sources— including a source owned by the state in question—provided the same image information. Among the non-signatory states, commercial satellite imagery will probably be used to:

- search neighboring states for clandestine nuclear test activity;
- devise countermeasures to conceal their own nuclear test activity;
- monitor activities by the nuclear weapons states at their former test sites; and
- justify their position of refusing to sign the CTBT.

Although the non-signatories have various reasons against signing the CTBT, they also have a vested interest in having their neighboring states refrain from nuclear weapons testing. As a result, the non-signatory states are likely to join the CTBT states parties and use commercial satellite imaging for nuclear test monitoring. If one of the non-signatory states detected possible nuclear test activity, it would have the option of responding unilaterally, alerting others of the suspect activity, or doing both. If one of these states secretly notifies a CTBT state party or the CTBT Organization (CTBTO), it could, ironically, use the treaty regime to exert pressure on the suspect state. Such an alliance of convenience would be analogous to the 1977 Kalahari incident when the then Soviet Union reportedly alerted its rival, the United States, of South Africa's clandestine nuclear test preparations as part of an *ad hoc* campaign to stop South Africa from testing.[17]

Besides watching their regional neighbors, the non-signatory states may also carefully monitor the former test sites of the nuclear weapons states. If any of the non-signatories harbored plans to develop a nuclear testing capability, it could use the latest commercial satellite images to survey established test sites, learn more about how to conduct nuclear tests, and perhaps develop countermeasures to conceal its own nuclear test activity.

Additionally or alternatively, they may monitor former test sites to determine whether the nuclear weapons states were abiding by the spirit and letter of the treaty they signed. Given that the nuclear weapons states are the most capable at nuclear testing and have a continued need to maintain their stockpile, the non-signatory states may appoint themselves as the outside auditors of the CTBT with the primary mission of scrutinizing the nuclear activities of the nuclear weapons states.

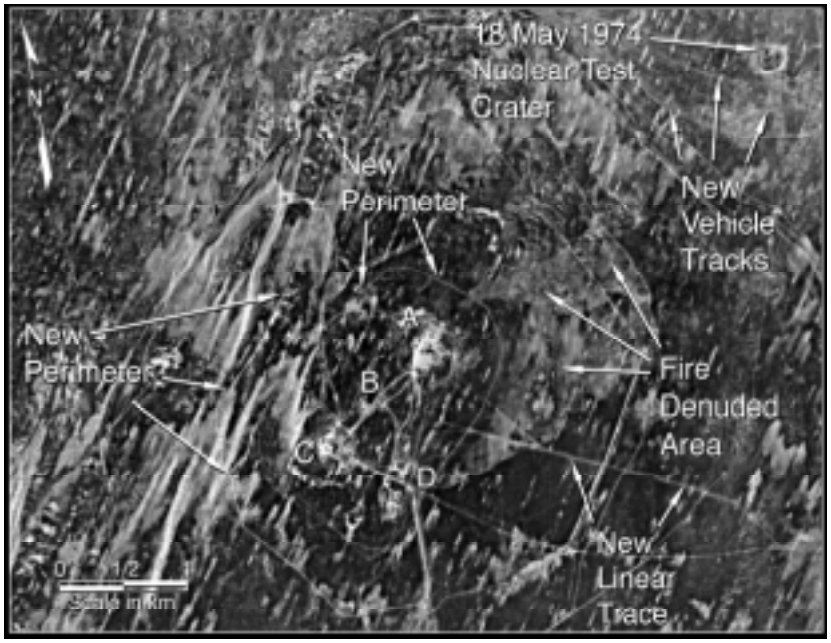

Plate 2: *March 2, 1996 SPOT image of the Indian test site. This photo was acquired three months after the public allegations of Indian nuclear test preparations. The image shows numerous changes since the March 25, 1995 SPOT image (see Plate 1). Brush fires denuded a large area of vegetation. New security perimeters were constructed. A branching linear trace was created. In addition, vehicle traffic around the 1974 crater noticeably increased as indicated by the presence of numerous tread marks.*

The non-signatories could go one step further with their own overhead observations. By highlighting the nuclear weapons states' on-going activities at their nuclear test sites, they could reinforce their argument that the CTBT is not comprehensive enough. By exploiting any ambiguities in the image information, they could further justify their need to retain a nuclear test option. Within the context of a specific compliance debate, they could pass on their image information to proxies on the Executive Council and thereby attempt to influence the debate in favor of their national security and foreign policy interests. In short, there are numerous, creative opportunities for non-signatory states to use commercial satellite imagery in the realm of nuclear test politics. The unanswered question is what cumulative impact the non-signatory states' use of commercial satellite imagery will have on the CTBT regime.

The Role of International Organizations in CTBT Verification

The CTBTO will be the principal international institution for the collection, processing, and dissemination of technical data as well as the management of on-site inspections, state-to-state consultations, and confidence-building measures.[18] The Conference of the State Parties and the U.N. Security Council will evaluate a suspect state's compliance with the CTBT and determine an appropriate international response.

The CTBTO will likely be the main international user of commercial satellite imagery for nuclear test monitoring. Along with the various technologies at the disposal of the CTBTO, commercial satellite imagery could be used to investigate suspicious events and allegations of treaty violations. In addition, at an investment of approximately $5 million per year for the collection, processing, and analysis of commercial satellite imagery,[19] the CTBTO could enhance its operational efficiency and decrease the overall cost of its large-scale monitoring tasks. These responsibilities include:

- preparing on-site inspectors for investigating suspected nuclear test sites;
- minimizing the intrusiveness of on-site inspections; and
- reducing the number of false alarms from "post-test" technologies and unreliable eyewitnesses.

Depending on the specific circumstances, the CTBTO may be called upon to conduct an on-site inspection of a suspect site. The international inspectors who are assigned the task of visiting and analyzing the site may have limited historical or topographical knowledge of the suspect site. In addition, these inspectors will probably have a short amount of preparation time given that the inspection may begin as soon as four days after the

formal submission of the on-site inspection request to the Executive Council.

To prepare for such contingencies, on-site inspectors could conduct routine training exercises using archived commercial satellite images of real nuclear test sites along with images of non-nuclear activities. Such exercises would enable the inspectors to build up experience in discriminating nuclear test activity from other activities as well as in detecting denial and deception efforts. When called upon to conduct a real inspection, the inspectors could use commercial satellite images of the suspect site to familiarize themselves with the basic and changed features, conduct simulated inspections of the site, and devise a strategy for the inspection.

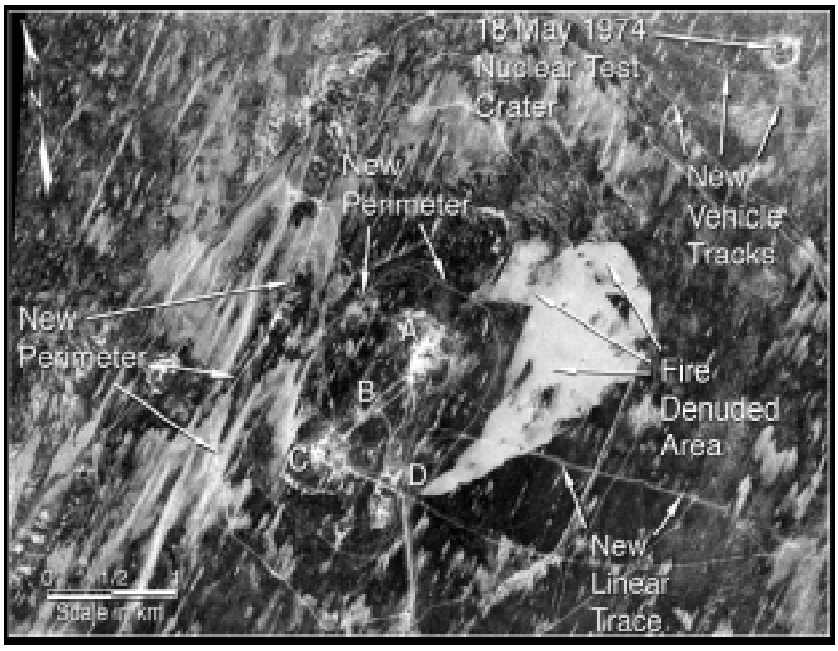

Plate 3: *April 4, 1996, IRS-1C image of the Indian test site. This Indian satellite photo shows the exact same surface changes as the French satellite photo in Plate 2. Thus, these changes are real and can be interpreted in the same way as the changes in the French satellite photo.*[20]

Under the terms of the CTBT, the inspection plan would have to minimize the intrusiveness of the on-site inspection (see Article II, Section A, Paragraph 6). Although the treaty allows the search area to cover up to 1,000 square kilometers (km) with a maximum linear dimension of 50 km, it would be logistically and politically preferable to make the inspection area substantially smaller. A series of empirical remote sensing studies indicate that change detection analysis of baseline and recent commercial satellite images can make such an area reduction possible[21]; the imagery could be used to identify unchanged features such as fields, forests, and infrastructure that would not require closer examination. By using satellite imagery in this way, the inspectors may allay any concerns of excessive intrusiveness by demonstrating their efforts to keep the size of the inspected areas to an absolute minimum.

In addition to supporting on-site inspections, commercial satellite imagery has a key role to play in systematically controlling false alarms generated by the four "post-test" technologies and eyewitnesses. Because the "post-test" technologies will be used to verify the smallest nuclear explosive events and because eyewitnesses can be unreliable, the international monitoring system may have to sift through thousands of suspect events each year. For the fraction of events that cannot be ruled out easily, commercial satellite images could be used to search for surface changes in the vicinity of the event that may be associated with nuclear testing.[22] If "before" and "after" images fail to show human activity or infrastructure near the event origin, the ambiguous event could be safely attributed to natural causes. By weeding out false alarms in this way, the CTBT verification regime can avoid unwarranted on-site inspections and assuage lingering doubts about the cause of suspicious events that brought a state's compliance record into disrepute.

The Role of Non-Governmental Organizations in CTBT Verification

There are two documented cases where non-governmental institutions used commercial satellite imagery to search for new nuclear test activity. In 1986, the Swedish company, Space Media Network, discovered several new "dots" in a SPOT satellite image of the then-Soviet test site in Kazakhstan that were interpreted as possible nuclear test preparations.[23] In 1992, a British non-governmental organization, the Verification Technology Information Centre, observed nuclear test activity in Landsat images of the Chinese test site near Lop Nor and fore-

cast (correctly) when and where China was likely to conduct their subsequent nuclear tests.[24]

These two cases demonstrate that companies, non-governmental organizations, and the news media could use overhead imagery to play a more proactive role in CTBT verification. Non-governmental institutions could use commercial satellite images to collect information on a suspect site that previously could only be learned from government sources. As a result, these institutions could initiate an investigation and conduct the information collection, analysis, and dissemination without relying primarily on information from official inquiries. With this newfound capability, non-governmental organizations could raise publicly a CTBT compliance issue independent of state-to-state consultations, Executive Council sessions, or deliberations within the Conference of the State Parties.

The increased influence commercial imaging satellites provide to non-governmental institutions has significant implications for the CTBT verification process. From the perspective of states that may be contemplating nuclear testing, it may make it more difficult to violate the treaty secretly or break out suddenly. These states would have to deal with not only the constant risk of discovery by several national intelligence agencies, but also the new concern of disclosure by one of many non-government entities that might be watching.

From the standpoint of the national and international bureaucracies responsible for CTBT verification, the increased monitoring and analytical capabilities of non-governmental institutions are a mixed blessing. While the established CTBT organizations may welcome new treaty-relevant information from non-government institutions, these organizations are likely to see the independent analysis of that information as problematic. If the independent assessments are done poorly or quickly by analysts who do not do such specialized work on a regular basis, the organizations responsible for CTBT monitoring will be left with the burden of correcting others' mistakes and explaining why their analysis differs from the reports of newspaper X, company Y, and non-governmental organization Z. Given that any non-governmental institution with a few thousand dollars will be able to acquire and analyze satellite images relating to a specific CTBT compliance issue, states and international organizations face the prospect of conducting their CTBT-related investigations in the same "noisy" environment that domestic law enforcement has had to endure for decades.

The Role of Individuals in CTBT Verification

Resourceful individuals have a track record of finding activities that academic, corporate, and government institutions did not know about. In network computing, a systems administrator Clifford Stoll at Lawrence Laboratory in Berkeley discovered and tracked down an elusive computer hacker that was on the payroll of the KGB.[25] In astronautics, satellite observer G.E. Perry deduced the functionality of then-Soviet satellites from the emitted radio signals.[26] In geophysics, seismologist Riley Geary routinely detected and identified unannounced nuclear explosive tests at the U.S. Nevada Test Site.[27] And in remote sensing, photo-interpreter Howard Hough used Russian MK-4 and KFA-1000 satellite imagery to describe Israel's alleged nuclear weapons infrastructure.[28]

With the increased availability of commercial satellite imagery at costs that are projected to decrease to a few hundred dollars per image, individuals have all of the necessary tools for information collection, processing, analysis, and dissemination. They can acquire images of any place in the world, process the imagery with affordable software packages and personal computers, analyze the data along with collateral information, and disseminate their analysis via the Internet.

With the capability to handle information from beginning to end, individuals can become citizen verifiers of the CTBT. Just as investigators rely on the public for tip-offs, individuals can act as watchful eyes for national governments, international organizations, and even non-governmental institutions. They can network with other individuals to form CTBT watch groups. Individuals could use image information within domestic political and legal processes to ensure their own country's compliance with the treaty. In regional or international circles, individuals could use image information to raise CTBT compliance issues that have not been addressed by anyone else.

Individuals using imagery to accuse or exonerate states of treaty violations is a new prospect. While it is not possible to forecast how often individual activists will use imagery to enter the CTBT verification process, it is reasonable to expect that such instances will occur in the future. Whether there will be an audience for such indi-

viduals will depend on their reputation, the quality of the analysis, and the specific circumstances. Whatever the outcome is for specific compliance cases, the new imaging powers wielded by individuals is likely to change the verification process from one that was secret and controlled by a few large and knowledgeable players to one that is more open to anyone with unique and useful information to offer.

CONCLUSIONS

The verification of the CTBT will be unlike any previous effort to evaluate compliance with a specific arms control treaty. Heavily reliant on remote monitoring technologies, the verification regime faces the daunting daily task of searching the Earth (and beyond) for nuclear explosions, filtering out extraneous signals, examining ambiguous events more closely, and determining whether any remaining suspect events represent a treaty violation. All of these tasks will be done using information acquired by a variety of advanced technologies within the multilateral mechanisms specified by the treaty.

The emergence of commercial imaging satellites as an additional, decentralized source of information will increase the transparency of outdoor activities worldwide as well as the number of actors involved in the CTBT verification process. These two general trends will affect potential CTBT violators and enforcers in parallel ways. With the deployment of 10 to 20 new commercial imaging satellites, states will have a more difficulty conducting illicit nuclear tests secretly. Similarly, the potential enforcers will have a more difficult time conducting their overhead investigations secretly given that more independent actors will be able to access and interpret the same image data. As a result, the states parties to the treaty risk being accused publicly of nuclear test activity, and the potential enforcers risk being mired in confusion due to conflicting interpretation of the image evidence by numerous organizations and individuals.

That commercial imaging satellites will increase noise in the CTBT verification process is inevitable. Noise is a side effect that comes with greater transparency and the increased direct involvement of different groups. The trick will be to devise analytical strategies that extract the facts out of the collected, noisy information and present a clear, coherent explanation of a disputed event.

The experience of past nuclear test monitoring clearly indicates that satellite imagery alone is insufficient; it must be combined with collateral technical data (e.g., seismic, radionuclide, and meteorological) and non-technical literature (e.g., media reports, government statements, and eyewitness accounts) to reveal the cause of a mysterious event or purpose of observed suspicious activity. This same experience demonstrates that satellite imagery is a critical and unique informational component that is needed for compiling the full factual story.

Past efforts at nuclear test monitoring reveal three key lessons on the use of commercial satellite imagery for CTBT verification. First, image analysts need to be sufficiently competent to detect efforts at deception. Given the increased transparency provided by commercial imaging satellites, states will likely be more inclined to disguise their nuclear test activities rather than attempt complete concealment. If the previously clandestine nuclear test programs of Brazil, India, and South Africa are indicators, analysts should specifically look for nuclear test activities co-located or adjacent to conventional military sites.[29] Such sites can offer the security, personnel, and basic infrastructure for conducting nuclear tests as well as a credible cover story for denying an on-site inspection request in the event the illicit activity is detected remotely.

Second, as commercial satellite imaging becomes more commonplace, the nuclear weapons and nuclear capable states will likely be subjected to an unprecedented amount of overhead observation by all groups with an interest in the CTBT. With this increased transparency, these states will be compelled to avoid non-nuclear activities that could easily be misconstrued as nuclear test activity—especially activities in sensitive areas such as former nuclear test sites. Failure to do so could inadvertently trigger unwarranted on-site inspection requests that could gradually erode confidence in the treaty. Thus, besides complying with the CTBT treaty provisions, states parties will have the *de facto* obligation to conduct their sensitive, non-nuclear activities in observably, unambiguous ways.[30]

Finally, in contrast with the verification of past nuclear test limitations, CTBT verification will be done in accordance with multilateral rules involving actors who have not only different political agendas, but also varying levels of technical experience in this specific application of remote sensing. As a result, it is critically important for the experienced to train the inexperienced in a systematic, sustained fashion. Such training can help miti-

gate noise and confusion caused by incorrect technical interpretation of the imagery.

The use of satellite imagery for nuclear test monitoring is entering a new phase. New commercial imaging satellites will be used to verify a new treaty. As the treaty ratification process continues and as the CTBTO develops over the next few years, the various groups involved with CTBT implementation will have a unique window of opportunity to prepare for the use of this new technology before the treaty comes into effect. If these groups take advantage of this window, they can prepare not only for the technical use of commercial satellite imagery, but also for the consequences that will follow. Whether they will be ready on both counts will ultimately determine the value of commercial satellite imagery as a tool for CTBT verification.

[1] Declassified Special National Intelligence Estimate 13-4-64, "The Chances of an Imminent Communist Chinese Nuclear Explosion," Central Intelligence Agency, August 26, 1964; R.A. McDonald, "CORONA: Success for Space Reconnaissance, A Look into the Cold War, and a Revolution for Intelligence," *Photogrammetric Engineering and Remote Sensing*, No. 6 (June 1995), pp. 689-720; Vipin Gupta and Don Rich, "Locating the Detonation Point of China's First Nuclear Explosive Test on 16 October 1964," *International Journal of Remote Sensing* 17 (July 10, 1996), pp. 1969-1974.

[2] Murray Marder and Don Oberdorfer, "How West, Soviets Acted to Defuse S. African A-Test: Keeping S. Africa Out of the Nuclear Armaments Club," *Washington Post*, August 28, 1977, p. A1; Bhupendra Jasani, "The Possible Prevention of a South African Nuclear Test," in *SIPRI Yearbook 1978: World Armaments and Disarmament* (London: Taylor and Francis Ltd, 1978), pp. 70-79; Frank Pabian, "South Africa's Nuclear Weapon Program: Lessons for U.S. Nonproliferation Policy," *The Nonproliferation Review* 3 (Fall 1995), pp. 1-19.

[3] For remote sensing studies on U.S. underground nuclear tests , see Bhupendra Jasani, "Civil Observation Satellites and Arms Control Verification," Preliminary Report, Department of War Studies, King's College London, August 1992, pp. 65-69; Peter Zimmerman, "Study of the Nevada Test Site using Landsat Satellite," CSIS Report, 1993, pp. 1-9; Bhupendra Jasani, "Could Civil Satellites Monitor Nuclear Tests," *Space Policy* 11 (February 1995), pp. 31-40.

For remote sensing studies on former Soviet underground nuclear tests, see Ulf Ekblad and Hans-Ake Olsson, "Satellite Imagery Detection of Preparations for Underground Nuclear Explosions," FOA Report C 30560-9.4, Swedish Defense Research Establishment, January 1990, pp. 1-18; William Leith and David Simpson, "Monitoring Underground Nuclear Tests," in Michael Krepon, Peter Zimmerman, Leonard Spector, and Mary Umberger, *Commercial Observation Satellites and International Security* (New York: St. Martin's Press, 1990), pp. 115-124; Johnny Skorve and John Skogan, "The NUPI Satellite Study of the Northern Underground Nuclear Test Area on Novaya Zemlya," *NUPI Report*, no. 164, December 1992, pp. 1-51; Lynn Sykes, Jishu Deng, and Paul Lyubomirskiy, "Accurate Location of Nuclear Explosions at Azgir, Kazakhstan, from Satellite Images and Seismic Data: Implications for Monitoring Decoupled Explosions," *Geophysical Research Letters* 20 (September 15, 1993), pp. 1919-1922; C.H. Thurber, H.R. Quin, and P.G. Richards, "Accurate Locations of Nuclear Explosions in Balapan, Kazakhstan, 1987 to 1989," *Geophysical Research Letters* 20 (March 5, 1993), pp. 399-402; C.H. Thurber, H.R. Quin, and R. Saleh, "Catalog of Locations of Nuclear Explosions at Balapan, Kazakhstan, 1965 to 1985," *Bulletin of the Seismological Society of America* 84 (April 1994), pp. 458-461; Johnny Skorve, "Epicentre Location and Cratering in the Novaya Zemlya Underground Nuclear Test Site," NORSAR Semiannual Technical Summary, Scientific Report No. 1-94/95, January 1995.

For remote sensing studies on Chinese underground nuclear tests, see Vipin Gupta, "Future Chinese Nuclear Tests on the Horizon," *Trust & Verify* (July/August 1992), pp. 2-3; Jasani, "Civil Observation Satellites and Arms Control Verification," pp. 73-74; Vipin Gupta, "Assessment of the Chinese Nuclear Test Site near Lop Nor," *Jane's Intelligence Review* 5 (August 1993), pp. 378-381; Vipin Gupta and Philip McNab, "Sleuthing from Home," *The Bulletin of the Atomic Scientists* 49 (December 1993), pp. 44-47; Vipin Gupta, "The Status of Chinese Nuclear Weapons Testing," *Jane's Intelligence Review* 6 (January 1994), pp. 31-35; Vipin Gupta, "Locating Nuclear Explosions at the Chinese Test Site near Lop Nor," *Science and Global Security* 5 (Winter 1995), pp. 205-244; Vipin Gupta, "A Remote Sensing and Photogrammetric Study of the Chinese Nuclear Test Site," (Ph.D. diss., University of London, 1996);

[4] Vipin Gupta and Frank Pabian, "Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert: A CTB Verification Exercise Using Commercial Satellite Imagery," *Science and Global Security* 6 (Winter 1997), pp. 101-188.

[5] For states that have traditionally lacked national technical means of verification, there may be a way to incorporate commercial imaging satellites into the treaty without amendment or consensus; these states could credibly argue that commercial imaging satellites are their national technical means (NTMs) for the verification of the CTBT, and thus deserve all of the rights and privileges of NTMs as specified in the treaty.

[6] According to Article IV, Section A, Paragraph 11 of the Comprehensive Test Ban Treaty, new monitoring technologies—including "satellite monitoring"—can be incorporated into the treaty by amending the verification provisions in accordance with Article VII or updating the operational manuals in accordance with Article II, Paragraph 44.

[7] Karen Plumb, Ray Harris, Debbie Needham, "Commercial Activities in High Resolution Imaging from Space," Reference Paper for BNSC Seminar 'From Space to Database', February 1997, pp. 1-37; Vipin Gupta, "New Satellite Images for Sale," *International Security* 20 (Summer 1995), pp. 94-125.

[8] If the CTBT has not entered into force "three years after the date of the anniversary of its opening for signature (24 September 1996)," a conference of those states that have ratified it may be held to decide what measures may be taken to accelerate the ratification process and facilitate the treaty's entry into force (see Article XIV of the CTBT. Information, Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization, Provisional Technical Secretariat, Vienna, Austria, PTS/INFO/1/Rev.2, 20 October 1997, p. 4.

[9] Empirical research had demonstrated that commercial satellite imagery can be used effectively for all four of the enumerated applications. See references cited in endnote 3.

[10] In the United States, the publication, *Soviet Military Power*, set the precedent for the government use of commercial satellite imagery to discuss intelligence subjects openly. *Soviet Military Power* (Washington, D.C: U.S. Government Printing Office, 1987), pp. 49, 68, 115; *Soviet Military Power* (Washington, D.C: U.S. Government Printing Office, 1988), pp. 35, 40, 52, 60. For a commentary on the utility of imagery as a public policy tool, see Peter Usowski, "Photo Intelligence and Public Persuasion," *Studies in Intelligence* (Spring 1990), pp. 7-9.

[11] See Article IV, Section C, Paragraph 29.

[12] In addition, image interpreters could carefully analyze the images for evidence of digital alteration. See Dino Brugioni, "Spotting Photo Fakery," *Studies in Intelligence* (Summer 1979), pp. 57-67.

[13] Tim Weiner, "India Suspected of Preparing for A-Bomb Test," *The New York Times*, December 15, 1995, p. A6; Tim Weiner, "US Suspects India Prepares to Conduct Nuclear Test," *The New York Times*, Late Edition, December 15, 1995, p. A9; John Burns, "India Denies Atom-Test Plan But Then Turns Ambiguous," *The New York Times*, December 16, 1995, p. 4; Srinivas Laxman, "NYT Report of N-test a Big Lie: Ramanna," *The Times of India*, December 17, 1995, p. 9; Lisa Vaughan, "India Says Not Planning Nuclear Weapon Test," *Reuters*, December 19, 1995.

[14] M.D. Nalapat, "Defense Officials Upset over Report on N-test," *The Times of India*, December 18, 1995, p. 1; "Using a Pretext of the Nuclear Test," *Jansatta*, December 19, 1995, p. 6.

[15] Gupta and Pabian, "Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert: A CTB Verification Exercise Using Commercial Satellite Imagery," pp. 132-148.

[16] If the feature of interest is movable or mobile, it would be critical to obtain images from other commercial imaging satellites that were acquired around the same time as the image in question.

[17] Marder and Oberdorfer, "How West, Soviets Acted to Defuse S. African A-Test: Keeping S. Africa Out of the Nuclear Armaments Club," p. A1.

[18] Before the CTBTO was mandated, the IAEA had to bear the occasional burden of investigating past nuclear test activity within the context of a state's safeguards and NPT obligations. In Iraq, the UNSC 687 Action Team within the IAEA uncovered Iraqi documentation describing plans to establish a nuclear test site in southwestern Iraq. In South Africa, following that country's accession to the NPT, the IAEA supervised the backfilling of two vertical test shafts at the clandestine nuclear test site in the Kalahari Desert.

[19] For an itemized breakdown of the cost estimates, see *Scientific and Technical Aspects of the Verification of a Comprehensive Test Ban Treaty* (London: VERTIC, 1990), pp. 3.62-3.68.

[20] Gupta and Pabian, "Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert: A CTB Verification Exercise Using Commercial Satellite Imagery," pp. 146-147. The fire denuded area in the April 4, 1996 IRS-1C image appears lighter than the same area shown in the SPOT image acquired one month earlier. This can be attributed to the natural dispersal of the killed vegetation, exposing the light, sandy soil.

[21] Jasani, "Civil Observation Satellites and Arms Control Verification," pp. 65-69; Jasani, "Could Civil Satellites Monitor Nuclear Tests," pp. 31-40; Ekblad and Olsson, "Satellite Imagery Detection of Preparations for Underground Nuclear Explosions," pp. 1-18; Skorve and Skogan, "The NUPI Satellite Study of the Northern Underground Nuclear Test Area on Novaya Zemlya," pp. 1-51; Sykes, Deng, and Lyubomirskiy, "Accurate Location of Nuclear Explosions at Azgir, Kazakhstan, from Satellite Images and Seismic Data: Implications for Monitoring Decoupled Explosions," pp. 1919-1922; Thurber, Quin, and Richards, "Accurate Locations of Nuclear Explosions in Balapan, Kazakhstan, 1987 to 1989," pp. 399-402; Thurber, Quin, and Saleh, "Catalog of Locations of Nuclear Explosions at Balapan, Kazakhstan, 1965 to 1985," pp. 458-461; Gupta, "Future Chinese Nuclear Tests on the Horizon," pp. 2-3; Gupta and McNab, "Sleuthing from Home," pp. 44-47; Gupta, "The Status of Chinese Nuclear Weapons Testing," pp. 31-35; Gupta, "Locating Nuclear Explosions at the Chinese Test Site near Lop Nor," pp. 205-244; Gupta, "A Remote Sensing and Photogrammetric Study of the Chinese Nuclear Test Site," pp. 1-264.

[22] Two recent seismic events illustrate the importance of visually searching for nearby nuclear test activity. On January 13, 1996 and August 16, 1997, weak seismic events were detected and located near the Russian nuclear test site at Novaya Zemlya. Occurring in close proximity to a functional test site, the events triggered more in-depth investigation to determine whether the cause was nuclear. These investigations could utilize commercial satellite images of the area to shed more light on the events in question. See Bill Gertz, "US Officials Suspect Russia Staged Nuclear Test This Year," *The Washington Times*, March 7, 1996, p. A3; Greg van der Vink and Terry Wallace, "The Political Sensitivity of Earthquake Locations," *IRIS Newletter*, vol XV, no 3, pp. 20-23; John Diamond, "CIA Now Says August Tremor Was Not Caused by Nuclear Test," *Associated Press Washington*, November 5, 1997.

[23] William Broad, "Photos Said to Show New Activity at Main Soviet Nuclear Test Site," *The New York Times*, August 4, 1986, p. 13. In a similar case that same year, a Brazilian newspaper, *Fôlha de São Paulo*, disclosed the existence of a clandestine nuclear test site deep in the Amazon jungle. See "Further Reportage of Alleged Nuclear Test Site," *Fôlha de São Paulo*, August 8, 1986, translated in FBIS-Latin America, August 12, 1986, p. D-1.

[24] Gupta, "Future Chinese Nuclear Tests on the Horizon," pp. 2-3; Gupta and McNab, pp. 44-47.

[25] Clifford Stoll, *The Cuckoo's Egg: Tracking a Spy Through a Maze of Computer Espionage* (London: Pan Books, 1991).

[26] G.E. Perry and S. Grahn, "Recovery Beacon Signals from Cosmos Satellites," *Spaceflight*, April 1968, pp. 142-143; Geoff Perry and Cliff Ranft, "Soviet Satellite Longevity," *Aviation Week and Space Technology*, October 20, 1986, p. 160; P. Daly and G.E. Perry, "Recent Developments with the Soviet Union's VHF Satellite Navigation System," *Space Communication and Broadcasting* 4 (1986), pp. 51-61; "Stored Imagery from Cosmos 1869," *Kettering Group Technical Memo GP8706*, September 9, 1987.

[27] Riley Geary, "Nevada Test Site's Dirty Little Secrets," *Bulletin of the Atomic Scientists*, April 1989, pp. 35-38.

[28] Harold Hough, "Israel's Nuclear Infrastructure," *Jane's Intelligence Review*, November 1994, pp. 508-511. In a more recent analysis of commercial satellite imagery, Hough claims to have identified a Jericho-2 missile TEL , nuclear weapon bunkers, and underground tunnels for missile storage. However, close examination of the published photos indicates that many of these identified features are not visually evident. Consequently, there is large uncertainty associated with these identifications. See Harold Hough, "Could Israel's Nuclear Assets Survive a First Strike," *Jane's Intelligence Review*, September 1997, pp. 407-410.

[29] "Further Reportage of Alleged Nuclear Test Site," p. D-1; Gupta and Pabian, "Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert: A CTB Verification Exercise Using Commercial Satellite Imagery," pp. 149-150; Pabian, "South Africa's Nuclear Weapon Program: Lessons for US Nonproliferation Policy," p. 9.

[30] Gupta and Pabian, "Investigating the Allegations of Indian Nuclear Test Preparations in the Rajasthan Desert: A CTB Verification Exercise Using Commercial Satellite Imagery," p. 150.